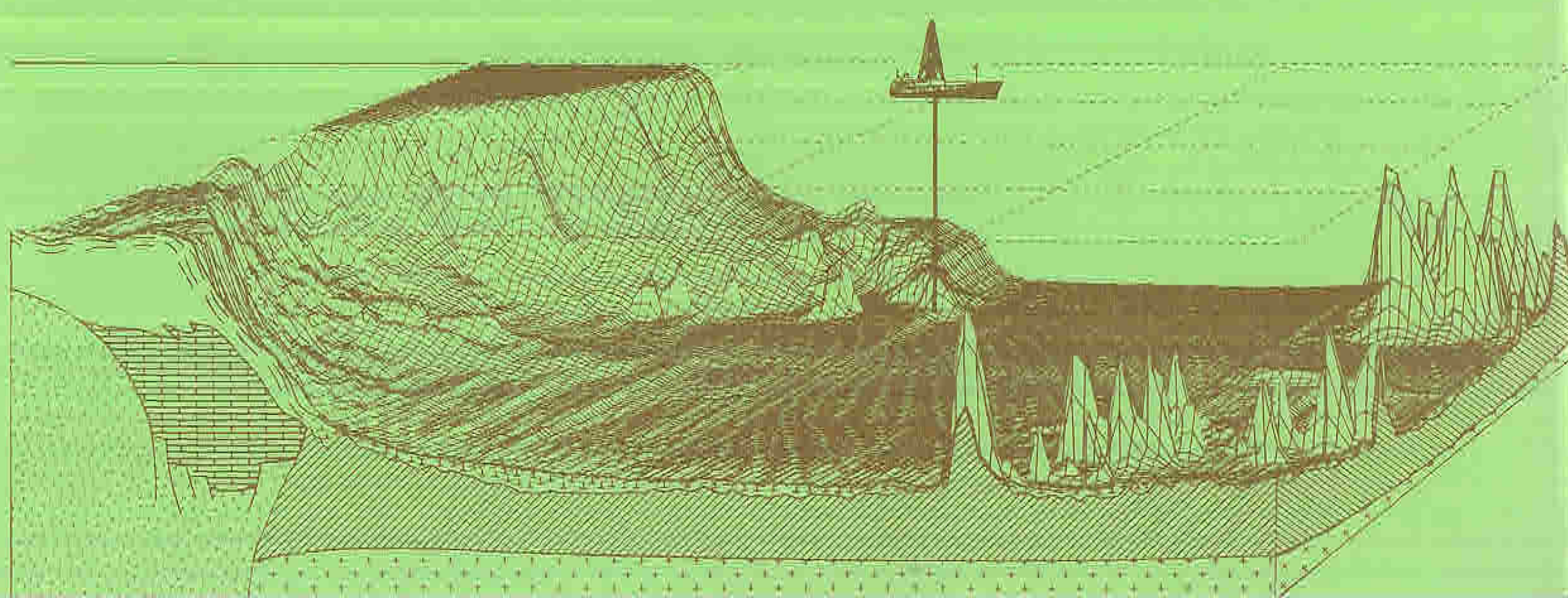
WORLD DATA CENTER A
for
Marine Geology and Geophysics

REPORT MGG-1

SEDIMENTOLOGY, PHYSICAL PROPERTIES, AND GEOCHEMISTRY IN THE INITIAL REPORTS OF THE DEEP SEA DRILLING PROJECT VOLUMES 1-44: AN OVERVIEW

JUNE 1984



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FOREWORD

The National Geophysical Data Center is pleased to release this, the first in a series of scientific data and information reports, which it intends to publish for World Data Center A - Marine Geology and Geophysics. It is expected that this series of reports will serve the marine geoscience community as other World Data Center report series have served other branches of the earth, atmospheric, and space sciences - as a medium through which science, data, and information of broad interest are widely disseminated through the Data Center advertising and distribution network. Suggestions regarding how this new report series may better serve its ultimate benefactors - marine geoscientists - are warmly solicited.

Michael A. Chinnery
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DESCRIPTION OF WORLD DATA CENTERS

World Data Centers conduct international exchange of geophysical observations in accordance with the principles set forth by the International Council of Scientific Unions (ICSU). They were established in 1957 by the International Geophysical Year Committee (CSAGI) as part of the fundamental international planning for the IGY program to collect data from the numerous and widespread IGY observational programs and to make such data readily accessible to interested scientists and scholars for an indefinite period of time. WDC-A was established in the U.S.A.; WDC-B in the U.S.S.R.; and WDC-C in Western Europe, Australia, and Japan. This new system for exchanging geophysical data was found to be very effective, and the operations of the World Data Centers were extended by ICSU on a continuing basis to other international programs; the WDC's were under the supervision of the Comite International de Geophysique (CIG) for the period 1960 to 1967 and are now supervised by the ICSU Panel on World Data Centres.

The current plans for continued international exchange of geophysical data through the World Data Centers are set forth in the *Fourth Consolidated Guide to International Data Exchange through the World Data Centres,* issued by the ICSU Panel on World Data Centres. These plans are broadly similar to those adopted under ICSU auspices for the IGY and subsequent international programs.

Functions and Responsibilities of WDC's

The World Data Centers collect data and publications for the following disciplines: Meteorology; Oceanography; Rockets and Satellites; Solar-Terrestrial Physics disciplines (Solar and Interplanetary Phenomena, Ionospheric Phenomena, Flare-Associated Events, Geomagnetic Phenomena, Aurora, Cosmic Rays, Airglow); Solid Earth Geophysics disciplines (Seismology, Tsunamis, Gravimetry, Earth Tides, Recent Movements of the Earth's Crust, Rotation of the Earth, Magnetic Measurements, Paleomagnetism and Archemagnetism, Volcanology, Geothermics), and Marine Geology and Geophysics. In planning for the various scientific programs, decisions on data exchange were made by the scientific community through the international scientific unions and committees. In each discipline, the specialists themselves determined the nature and form of data exchange, based on their needs as research workers. Thus, the type and amount of data in the WDC's differ from discipline to discipline.

The objects of establishing several World Data Centers for collecting observational data were: (1) to insure against loss of data by the catastrophic destruction of a single center, (2) to meet the geographical convenience of, and provide easy communication for workers in different parts of the world. Each WDC is responsible for: (1) endeavoring to collect a complete set of data in the field or discipline for which it is responsible, (2) safe-keeping of the incoming data, (3) correct copying and reproduction of data, maintaining adequate standards of clarity and durability, (4) supplying copies to other WDC's of data not received directly, (5) preparation of catalogs of all data in its charge, and (6) making data in the WDC's available to the scientific community. The WDC's conduct their operation at no expense to ICSU or to the ICSU family of unions and committees.

World Data Center A

World Data Center A, for which the National Academy of Sciences through the Geophysics Research Board and its Committee on Data Interchange and Data Centers has overall responsibility, consists of the WDC-A Coordination Office and seven subcenters at scientific institutions in various parts of the United States. The GRB periodically reviews the activities of WDC-A and has conducted several studies on the effectiveness of the WDC system. As a result of these reviews and studies, some of the subcenters of WDC-A have been relocated so that they could more effectively serve the scientific community. The addresses of the WDC-A subcenters and Coordination Office are given inside the front cover.

The data received by WDC-A have been made available to the scientific community in various ways: (1) reports containing data and results of experiments have been compiled, published, and widely distributed; (2) synoptic-type data on cards, microfilm, or tables are available for use at the subcenters and for loan to scientists; (3) copies of data and reports are provided upon request.

Data Reports

This report is the first in a series of science, data, and information publications issued by World Data Center A for Marine Geology and Geophysics. Future issues will be printed and distributed at irregular intervals as a means of disseminating scientific and technical reports, data sets, and reference materials which are deemed to be of broad interest to the marine geoscience community. The World Data Center has endeavored to support, with publication services and data-exchange activities, international programs in geoscience from its inception in the International Geophysical Year 1957-58. World Data Center A for Marine Geology and Geophysics is operated by the National Geophysical Data Center of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. Potential contributors are invited to submit manuscripts. Inquiries or suggestions should be addressed to: Director, World Data Center A for Marine Geology and Geophysics, National Geophysical Data Center (E-GC 3), 325 Broadway, Boulder, CO 80303; Telephone: (303) 497-6489.

Cover illustrations are derived from available data depicting the western North Atlantic continental margin at 40 degrees to 45 degrees north latitude. Bathymetry is from the SYNBAPS (Synthetic Bathymetric Profiling System) data base. The geologic cross section is an adaptation from C.A. Burk and C.L. Drake, eds., 1974, *The Geology of Continental Margins* (New York, Springer-Verlag, p. 397, fig. 6). The ship's position corresponds to site 384, leg 43 of the Deep Sea Drilling Project. The stratigraphic section on the back cover is from *Initial Core Descriptions of the DSDP,* leg 43, p. 44. The seismic section from the J Anomaly Ridge is from *Initial Reports of the DSDP,* vol. 43, p. 110. fig. 3.

PREFACE

In late 1975, the JOIDES Advisory Panel for Sedimentary Petrology and Physical Properties became concerned about the difficulty of locating information on various aspects of sedimentology in the growing mass of *Initial Reports of the Deep Sea Drilling Project*. The problem of tracing the methodologies of the various types of analyses was perceived as a particularly serious defect in the documentation of DSDP results.

To pull the methodological information together and provide potential users of the *Initial Reports* with a succinct annotated "menu," the Panel decided to sponsor a *JOIDES Technical Manual*. The transition from the national DSDP to the international IPOD program provided a logical end point for the material to be covered by the *Manual*, which was planned to address only Legs 1 through 44. The Panel compiled a list of 29 possible topics for review; of these, 20 are addressed in this publication.

Of the remaining 9 topics, several (dealing with thin sections of sedimentary rocks and early neutron activation studies, for example) were omitted because they appear in too few *Initial Reports*, one on core recovery was addressed in Moore and Heath (1978), one on igneous rocks was superseded by DSDP's compilations of major, minor, and trace element analyses (available from the Data Handling Group at DSDP), as well as DSDP's compilations of thin-section descriptions, and paleomagnetic data (the latter is in preparation). The remainder, dealing with underway geophysics, core disturbance, and consolidation testing, have been omitted because authors were unable to meet our publication schedule. Fortunately, a good review of core disturbance has been prepared by Kidd (1978).

Since the Panel's decision to proceed with the *Manual*, the project has suffered delays due to the late publication of the Leg 43 *Initial Report* (which did not appear until mid-1979) and to financial problems at DSDP (which received JOIDES Planning and Executive Committee approval to publish this manual, but no additional funds to do so). Fortunately, the value of the material assembled here is not time dependent. Thus the *Manual* should be as useful to a potential user of the *Initial Reports* now as it would have been two years ago.

The completion of an undertaking of this magnitude would have been impossible without the assistance of many people. I am particularly grateful to Yves Lancelot and Lillian Musich, who finally turned on the light at the end of the tunnel, and to all the contributors to the *Manual* who have maintained their interest and sense of humor during this inordinately protracted exercise.

G. Ross Heath
Corvallis, Oregon
January 1983

REFERENCES

Kidd, R. B., 1978. Core-discing and other drilling effects in DSDP Leg 42A Mediterranean sediment cores. *I.R. DSDP*, 42A:1143–1149.

Moore, T. C., Jr., and Heath, G. R., 1978. Sea-floor sampling techniques. *In* Riley, J. P., and Chester, R. (Eds.), *Chemical Oceanography* (2nd ed., Vol. 7): New York (Academic Press), pp. 75–126.

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PART I. SEDIMENTOLOGY

1. SEDIMENT NOMENCLATURE AND CLASSIFICATION

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BRIEF HISTORICAL REVIEW

When the Deep Sea Drilling Project (DSDP) began in the summer of 1968, a large number of deep-sea sediment cores already had been studied and described as a result of the Challenger Expedition of 1872-1876, and an inventory of deep-sea sediment types had been identified. Before DSDP, no single scientist had been confronted with so much material or found himself obligated to describe and categorize so wide a variety of sediment types for the common good rather than for his own research. Consequently, descriptive schemes had been rather individual, adapted to the tastes and objectives of the specific investigator. Sedimentologists, geochemists, and micropaleontologists had used the terminologies best suited for their own purposes. With the initiation of the Deep Sea Drilling Project, this situation changed drastically. The amount of material to be described by each team of sedimentologists increased enormously, and the range of sediment types broadened with the inclusion of the earliest deposits of young ocean basins, of sediments from high latitudes, and of deposits from continental margins. Most importantly, the objectives of the core description shifted from specialized research to the construction of a catalog easily accessible to a great variety of investigators, many of whom were not specialists in oceanic sedimentology. Finally, given the much longer time interval covered by DSDP cores, oceanic sediments that had been found rarely now were encountered frequently and had to be treated in the same way as more conventional ones such as red clays, biogenic oozes, and hemipelagic muds and sands.

During the preparatory phase of the DSDP, the requirement for a standard and comprehensive sediment classification had not been fully realized. The first core describers found themselves essentially on their own in this respect, so it is not surprising that the earliest descriptive schemes were perfunctory and poorly defined. In fact, from the first dozen legs, no less than seven do not state explicitly the principles of their sediment descriptions at all, or simply enumerate commonly used sediment names. Leg 5 was the first Initial Report that presented a sharply defined and quantitative classification system. Several other classifications evolved subsequently and were widely used until they were replaced by the current officially adopted system (on Leg 38 in the summer of 1974). Several Initial Reports, for example those of Legs 8, 9, 11, and 12, are based on rather specialized schemes, well designed for the sediment encountered on those legs, but not easily correlated with others. Another system, defined primarily by Olausson (1960) for cores obtained by the Swedish Deep-Sea Expedition and well suited to the equatorial region of high biological productivity, was used rather widely on legs in the equatorial Atlantic and Pacific because of the common background of the participating sedimentologists.

When the Glomar Challenger left the productive equatorial waters for a while (Leg 18, summer 1971), the limitations of this classification became obvious, and a comprehensive scheme developed by the DSDP staff (Weser, 1973) was adopted for most Initial Reports

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

from Legs 18 to 37, with minor modifications as experience was gained.

In June 1973, the JOIDES Advisory Panel on Sedimentary Petrology and Physical Properties, aware of the unsatisfactory state of the core description and sediment classification, formed a group to devise a standard system for the classification of DSDP sediments and sedimentary rocks. This group -- consisting of Tj. H. van Andel, E. L. Winterer, and J. Duncan, assisted by several members of the DSDP staff -- developed a new classification scheme that was adopted by DSDP in the spring of 1974 and was put into effect on Leg 38 after trials on Leg 33. The new system differed from the then-current Weser (1973) classification mainly in the elimination of genetic implications in several categories and in shifts of class boundaries to conform better to common usage. With the exception of Leg 41, which reverted to an older classification, the new scheme has been used consistently on the remaining legs of Phase III and continues to be the standard for the International Phase of Ocean Drilling (IPOD).

The classification schemes used on Legs 1 through 44 are summarized in Table 1 and will be discussed in more detail in later sections of this paper. It is apparent from Table 1 that comparison of sediment descriptions from leg to leg is made difficult by the wide variety of classifications. These difficulties are not diminished by the lack of adequate definitions of the terms used in several Initial Reports, and by the occasional omission (by accident, one hopes) of a legend to the graphic core logs. Fortunately, the basic descriptive data generally have been recorded and have recently been transcribed on to magnetic tapes by DSDP. A computer search and screening program has been developed (Davies et al., 1977) that permits the classification of the descriptive data into many different quantitative schemes. A reclassification of the older core descriptions in terms of the present standard system is thus conveniently available.

CRITERIA FOR A DSDP SEDIMENT CLASSIFICATION

The Initial Reports, although containing much original research, are first and foremost intended as a reasoned and detailed catalog of the geological materials and data that have been obtained on the leg. They may be used, therefore, for a broad variety of research purposes by investigators who did not participate on the cruise. This objective implies the following criteria for the description and classification of the sediment cores:

1) The classification should summarize highly detailed descriptive material into a general form that is suitable for graphic representation in log form and that facilitates comparisons from core to core, site to site, and leg to leg.

2) The nomenclature should adhere, as much as possible, to conventional sediment names to facilitate access to the catalog by nonspecialists in the field of oceanic sedimentology. The category boundaries should remain within the limits of existing definitions.

3) The nomenclature should avoid, as much as possible, genetic implications that are based on significant interpretation about and beyond the descriptive data because such implications are dependent on the views and experience of a wide range of personnel aboard ship and on the personal interpretation of the user of the catalog.

4) Boundary definitions in the classification should be as quantitative as possible within the limitations of the prime descriptive data to permit computer storage, retrieval, and screening.

5) The classification should cover the sediment types routinely encountered in

Table 1. Classifications of sediments used in initial reports for Legs 1 through 44.

Leg	None	Simple	Olausson (1960)	Weser (1973)	JOIDES	Special
1	x					
2	x					
3	x					
4	x					
5						x
6	x					
7			x			
8		x				
9						x
10	x					
11		x				
12						x
13	x					
14			x			
15			x			
16			x			
17			x			
18				x		
19				x		
20	x					
21				x		
22				x		
23				x		
24				x		
25				x		
26				x		
27				x		
28				x		
29				x		
30				x		
31				x		
32						x
33					x	
34				x		
35				x		
36				x		
37				x		
38					x	
39					x	
40					x	
41				x		
42					x	
43					x	
44					x	

Note: None = simple enumeration of types or no discussion at all; Simple = as above with some semiquantitative boundaries.

deep-sea drilling, but does not need to be totally comprehensive, allowing special names and definitions at the discretion of the shipboard staff for rare and unusual sediment types.

6) Because the results of shore-laboratory analyses are commonly available too late for incorporation in the core description sheets, the classification should be based only on shipboard descriptive parameters.

7) The classification, with allowance for Item 5 listed previously, should be mandatory on all legs; modifications and additions of a descriptive or interpretive nature, although optional to the staff, should supplement but not replace the basic classification.

Because of the long learning time involved in a project of the magnitude of DSDP, and because of the great range in background and interests of the shipboard staff, many of these criteria were not explicitly stated until late in the project. Consequently, most of the early classifications fall short on one or the other of these points.

AVAILABLE DESCRIPTIVE PARAMETERS

Composition and texture are the most important criteria for a general sediment classification. Compositional factors, both biogenic and abiogenic, are the most essential in pelagic sediments, whereas textural criteria play a primary role in hemipelagic and shallow-water deposits.

Only a few sediment properties can be determined reliably for large numbers of samples on board and are routinely and consistently available. These -- although subject to severe limitations in quality, precision, and resolution -- form the basis of all the adopted sediment classifications. In addition, a broad variety of other parameters have been measured in shore laboratories, either routinely and systematically (such as X-ray diffraction studies of the mineral composition and grain-size determinations) or occasionally (such as a wide range of petrologic and geochemical analyses). Almost without exception, the results of the shore studies have been available too late or have been too specialized for incorporation into the basic core description. Thus, the core description and sediment classification rest almost exclusively in all Initial Reports on the following descriptive parameters.

1) Composition -- Biogenic and mineral components have been estimated from macroscopic (or hand lens) inspection or microscopic examination of smear studies either in percent or semiquantitatively according to a scale of the type abundant (common-rare). No study has ever been made of the precision of estimates of composition by these techniques by the usual wide range of operators, but it is obvious that only a very few class limits can be based on quantitative estimates that inevitably must have large errors of estimate.

2) Calcium Carbonate Content -- During earlier DSDP cruises, the $CaCO_3$ content was usually estimated in smear slides, while a more precise determination, generally averaging about one sample per core section, was deferred for shore-laboratory study. Before Leg 23, with few exceptions, the carbonate analyses became available too late for incorporation into the core descriptions. The carbonate content estimates used for classification in Initial Reports 1 through 34 are, therefore, generally of low reliability, although the laboratory data may have been listed simultaneously. On Leg 35 a convenient shipboard carbonate determinator (the "Karbonate Bomb" of Müller and Gastner, 1971) was introduced. This apparatus allows rapid shipboard determinations with an approximate precision of $\pm 2\%$ at 50% $CaCO_3$ and $\pm 1\%$ at 100% $CaCO_3$. Determinations below 20% are somewhat less precise. On subsequent legs, the carbonate bomb was used routinely for estimate checks, often as frequently as once per core section. On a few legs,

however, virtually no carbonate data were obtained.

Note: The content of biogenic opal is a variable of equal importance to the carbonate content in the classification of pelagic sediments. This component cannot be adequately estimated from smear slides because a significant, sometimes dominant, fraction of the opal occurs in the finest grain size. Unfortunately, no practical technique exists for the routine analysis of large numbers of opal-bearing sediments, especially if they are older than a few million years. Only recently, good quality opal analyses have become available for several sites in the equatorial Pacific and for a few in the circum-Antarctic region.

3) Texture -- This is based on a visual estimation from smear slides. Sand-silt-clay ratios determined in the laboratory have not usually been incorporated in the sediment descriptions.

4) Induration -- The determination of induration has generally been subjective, but field geological experience shows that a useful partitioning into a small number of categories is possible. The most common terminology in calcareous sediments was defined by Moberly and Heath (1971) as: soft (ooze having little strength and being readily deformed under the finger or with the broad side of a spatula); firm (readily deformed by fingernail or sharp edge of spatula); and hard (not deformed by simple means). Chalks are the principal example of the last two categories, while the term limestone usually has been reserved for cemented calcareous rocks. Noncalcareous rocks have generally been grouped into two categories: nonindurated sand, mud, and so forth (if the core can be split easily with a wire), and sandstone, mudstone, and so forth (if splitting requires a saw).

5) Drilling Disturbance -- This is also a subjective criterion noted in a variety of ways, of which the sequence of terms slightly deformed, moderately deformed (extreme bending of bedding contacts), very deformed (completely disturbed bedding leaving only small domains of relatively undisturbed sediment), and soupy (all original structure lost, much uptake of water) is representative.

6) Sedimentary Structures -- This property has received very uneven treatment ranging from almost complete neglect in many Initial Reports to the use of very refined and sophisticated description and classification schemes in a few (for example, Leg 30, Klein, 1975). The distinction between primary sedimentary structure and drilling disturbance is often difficult or impossible.

Note: In Legs 1 through 7, X-ray radiographs of the unopened cores were obtained for the determination of sedimentary structure and drilling disturbance. The data usually were not incorporated in the core descriptions and the practice was abandoned beginning with Leg 8.

7) Color -- Sediment color has been routinely determined with the standard Munsell or Geological Society of America color charts.

The display of the core description has generally consisted of four basic elements: a graphic summary of the entire hole with biostratigraphy; individual graphic logs with adjacent verbal, and, as far as available, numerical descriptions, and analyses; graphs of physical properties such as GRAPE data; and core photographs by section. Legends for the graphic summary and core logs vary widely (in a few volumes symbols have not been identified). The core sheets usually contain some form of semiquantitative notes on fossil preservation but not the full biostratigraphic data that are presented in separate chapters with different degrees of coverage and completeness.

SEDIMENT TYPE LISTINGS AND SIMPLE CLASSIFICATIONS

Sediment classifications in this group consist of little more than a listing of names. Occasional attempts at providing a slight definition ("if the ooze contains a significant amount of clay, it has been called marl ooze") do not assist in recognizing or understanding the basis of the nomenclature. The sediment names frequently derive from the common literature, but references to basic definitions usually are not given. In general, the sediment names are purely descriptive, but occasionally (for instance, on Legs 1 and 10) there are strong interpretive elements (turbidites, laminites) given without any criteria for the interpretation.

Although at first sight the variety appears confusing, there is a strong general similarity illustrated by Table 2. Classifications similar to those shown in Table 2 were presumably used on Legs 3, 4, and 20, but the Initial Reports provide no specific information on these classifications.

On Leg 8, a simple but quantitative classification was introduced for the very limited suite of lithologies that consisted exclusively of pelagic biogenic sediments. The Leg 8 classification is as follows:

Nannofossil ooze	Dominantly calcareous nannofossils; $CaCO_3$ content above 80%
Radiolarian nannofossil ooze	Dominantly calcareous nannofossils ($CaCO_3$ above 50%); radiolarians subordinate; generally more than 20%
Nannofossil radiolarian ooze	Radiolarians dominant; nannofossils subordinate ($CaCO_3$ 20-50%)
Radiolarian ooze	Radiolarians dominant; $CaCO_3$ less than 20%

Note: Foraminifers and diatoms as important constituents are indicated by adjectival prefixes ("foraminiferal nannofossil ooze").

CLASSIFICATIONS BASED ON OLAUSSON

Modified (often only slightly) versions of the classification devised by Olausson (1960) for unconsolidated oceanic sediments obtained by the Swedish Deep-Sea Expedition were adopted for Initial Report Volumes 7 and 14 through 17 (see Table 3). In most of these, the conventional term red clay was replaced by brown pelagic clay, but otherwise the principal boundaries between categories at 10, 30, and 60% of a few designated main constituents ($CaCO_3$, siliceous skeletal remains, terrigenous clay) and the sense of the terminology were retained. In Volume 15 of the Initial Reports, slight additions to the boundaries and names modify the basic system as follows:

Percent $CaCO_3$	Term
0-10	Clay
10-30	Calcareous-rich clay
30-60	Marl ooze
60-90	Clay-rich chalk ooze
90-100	Chalk ooze

Textural classifications, based on the Wentworth (1922) scale of grain size, were adopted by Initial Report Volumes 7, 15, 16, and 17. Volume 15 applies this grain-size scale to the Shepard (1954) textural classification (Fig. 1).

Terminology for consolidated carbonate rocks in all cases adheres to that described under "Induration" in a previous section of this paper. For cherts, all volumes that explicitly discuss the subject follow in principle the descriptive scheme of Volume 7 that distinguishes cherts from porcellanites. Porcellanites are waxy and dull in luster and commonly show abundant pores

Table 2. Typical sample classifications and nomenclatures.

Leg 1	Leg 2	Leg 6	Leg 10	Legs 11 and 13
		Biogenic Pelagic Sediments		
Nanno-, foram chalks, marls, and oozes Radiolarian oozes, mudstones, and cherts Diatom and spicule clays Organogenic turbidites		Foram or nanno chalk ooze Marl ooze Limestone Diatom, radiol., spicule siliceous ooze	Nannoplankton ooze and chalk Radiolarian chert Deep-water limestones (calcilutites and calcarenites)	Foram or nanno oozes (chalks and limestones when indurated) Marl oozes (marls) Clayey ooze (Leg 11)
		Deep-Sea Clays		
Red and brown clays				Zeolitic clay (Leg 11)
		Volcanogenic Sediments		
Volcanogenic sediment	Palygorskite-sepiolite clays Montmorillonite clays Ash and altered tuff Cristobalite sediment	Volcanic ash (clay or silt size) Clay with ash	Volcanic ash and bentonites	Tephra, ash
		Terrigenous Sediments		
Terrigenous turbidite Pebbly muds Paraglacial terr. muds	Kaolinite clays Silty clays and sands Channel sands Silic., quartz sand	Clay, silty clay, silt, sand	Abyssal turbidites, laminites Clay-mud laminites Pebbly mudstones	Clay (shale when indurated) Sand, silt Hemipelagic mud (Leg 11)
		Miscellaneous		
	Authigenic carbonates		Shallow-water limestones/dolomites	

Table 3. Olausson (1960) sediment classification used in I.R. DSDP, 7 and 15 through 17.

1. $CaCO_3$ above 60%

   a. Recognizable calcareous fossil skeletal remains less than 30%: chalk ooze

   b. Recognizable calcareous fossil skeletal remains above 30%: add name of fossil group or groups: nannofossil chalk ooze, foraminiferal chalk ooze, foraminiferal-nannofossil chalk ooze, etc.

2. $CaCO_3$ between 30 and 60%

   a. Recognizable calcareous fossil skeletal remains less than 30%: marl ooze

   b. Recognizable calcareous fossil skeletal remains above 30%: add name of group: nannofossil marl ooze, etc.

3. $CaCO_3$ between 10 and 30%

   a. The adjective calcareous is added to the name: calcareous diatom ooze, etc.

4. Siliceous skeletal remains above 30%

   a. Named for the recognizable fossil skeletal remains: radiolarian ooze, diatom ooze, radiolarian marl ooze, etc.

5. Siliceous skeletal remains between 10 and 30%

   a. The adjective siliceous is added to the name: siliceous pelagic brown clay, etc.

6. $CaCO_3$ and siliceous skeletal remains less than 30%

   a. Brown pelagic clay ("Red Clay")

7. Pyroclastic grains (shards) above 10%

   a. The adjective ashy is added to the name: ashy chalk ooze, etc.

Note: Consolidated rocks (cherts, limestones), turbidites, pyroclastic sediments, etc. are classified separately and differently in different Initial Reports.

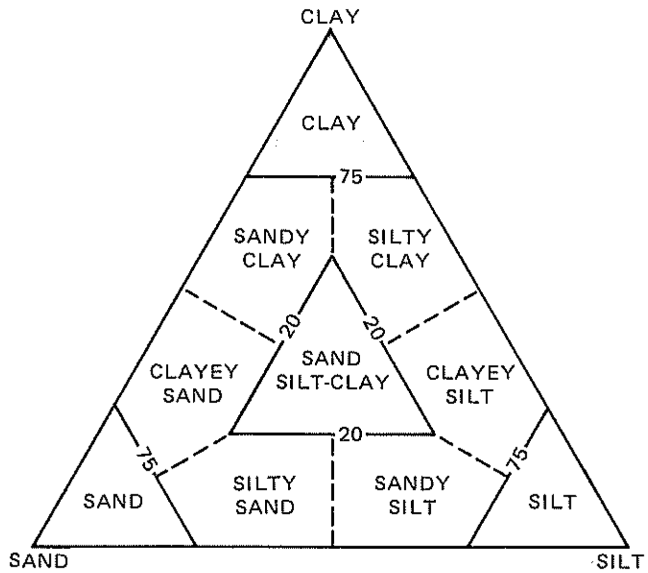


Figure 1. Textural classification of sediments based on the sand, silt, and clay boundaries of Wentworth, after Shepard (1954), as used in Volume 15. Sand: 2000 to 62.5 micrometers (μm); silt: 62.5 to 3.91 μm; clay: less than 3.91 μm.

under a hand lens. The silica in porcellanites is opal and cristobalite with large admixtures of montmorillonite and other minerals. The name chert is restricted to dense glassy rocks that are markedly purer than porcellanite and contain silica as chalcedony or microcrystalline quartz.

On Leg 14, a more detailed classification was used for the terrigenous deposits, which are given little attention in the Olausson scheme. The amplification rests on an initial decision whether to call a sediment pelagic or terrigenous, for which no clear and specific criteria are cited. The additional terminology, which supplements that of Table 3, is given in Table 4.

Many of the elements of the Olausson classification, in particular, the boundaries in major component categories, have been incorporated later in the standard classification adopted beginning with Leg 38.

In summary, the Olausson system is a sediment classification that uses quantitative parameters only to the extent necessary to separate the categories. It adopts the simplest possible sediment names to achieve the classification; uses no more quantitative boundaries than can be justified by the error limits of the data; and, in its original form, contains no genetic implications. The extension created for Volume 14 of the Initial Reports (Berger and Von Rad, 1972), in order to achieve a necessary enlargement to include nonpelagic sediments, contributes a genetic element. This element, although poorly defined, is inevitable.

LEG 18 CLASSIFICATION (WESER)

The Leg 18 classification, used in most subsequent Initial Reports through Volume 37, proceeds from a philosophy fundamentally different from the Olausson classification. It can be characterized best as a sediment description, endeavoring to use the maximum number of descriptive parameters available and to reflect as much as practical the entire nature of the sediment in its name. To do so it defines a large number of quantitative boundaries, arbitrarily set. It also contains a strong genetic element, namely, the distinction between sediment particles deposited in situ from the overlying water mass (authigenic and biogenic constituents, certain volcanics) and displaced detrital material. This distinction, although frequently difficult or risky, is as essential to the classification as is the distinction between pelagic and nonpelagic sediments in the Berger and Von Rad (Leg 14, 1972) extension of the Olausson classification.

The first version of the Weser classification appeared in I.R. DSDP, 18 (Weser, 1973); minor revisions are documented in subsequent Initial Reports. The basic description of the system is given in the form of a set of fairly complicated ground rules, for instance, in I.R. DSDP, 23. A condensed and somewhat more easily accessible summary derived from I.R. DSDP, 24 is as follows.

Table 4. Additions to the Olausson classification in the area of terrigenous sediments used in I.R. DSDP, 15.

I. Pelagic Deposits

A. Oozes

B. Red clay

These categories are identical with those of Table 3

II. Terrigenous Deposits

A. Organic muds: $CaCO_3$ or siliceous skeletal remains above 30%

1. $CaCO_3$ above 30%

a. skeletal remains of pelagic forams or pteropods less than 30%

(i) $CaCO_3$ 30-60%: marl mud or sand
(ii) $CaCO_3$ above 60%: chalk mud or sand

b. skeletal remains of pelagic forms or pteropods above 30%

(i) $CaCO_3$ 30-60%: foraminiferal (pteropod) marl mud
(ii) $CaCO_3$ above 60%: foraminiferal (pteropod) chalk mud

2. $CaCO_3$ less than 30%; siliceous skeletal remains above 30%

a. diatom mud

b. radiolarian mud

B. Inorganic muds: skeletal remains and $CaCO_3$ below 30%

1. Clayey muds; mean diameter less than 5 μm

Black (blue, green, etc.) mud

2. Silty or sandy muds or sand: average diameter above 5 μm

Black, etc. silty mud

Black, etc. sandy mud

Black, etc. sand

1) Major Constituents -- Sediments take the name of those constituents present in major amounts, defined as in excess of 25% in smear slides. If more than one major constituent is present, the principal components are listed from left to right in order of increasing abundance.

2) Class limits -- Class limits for two or more major constituents are: 0-25, 25-50, 50-75, and 75-100 percent. An example is the resulting set of major names for a series of sediments consisting of zeolites and nannofossils:

% 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

3) Minor constituents -- Those present in amounts from 10 to 25 percent are prefixed to the name only if very diagnostic and then with the suffix -rich. If present in amounts from 2 to 10 percent, and very diagnostic, they precede the sediment with the suffix -bearing. Examples: zeolite-rich rad nanno ooze (50% nannofossils, 30% radiolarians, 20% zeolites); zeolite-bearing rad nanno ooze (50% nannofossils, 40% radiolarians, 10% zeolites). Trace constituents, present in amounts below 2% may follow the sediment name accompanied by trace if so desired.

4) Biogenic constituents -- Nannofossil (discoasters, coccoliths, etc.) and foram (foraminiferal) are calcareous constituent terms; rad (radiolarian), diatom, spicule (sponge), silicoflagellate, are siliceous constituent terms. The terms calcareous and siliceous are applied where no attempt is made to distinguish fossil groups or where this is impossible.

5) Induration terms -- The term ooze is appropriate for unconsolidated biogenic sediments. The term chalk is used for consolidated calcareous ooze only (the term marl is not used). Consolidated siliceous ooze is called radiolarite or diatomite. For nonbiogenic sediments, the suffix -stone is used to indicate consolidation.

6) Volcanic constituents -- Pyroclastics are given textural designations: volcanic breccia (above 32 mm), volcanic lapilli (32-4 mm), volcanic ash (under 4 mm).

7) Authigenic constituents -- Authigenic minerals enter the sediment name in a manner similar to that under "major constituents" and are not given a textural designation. The terms ooze and chalk apply to all carbonate minerals, whether identifiably biogenic or not. Ferruginous is a sediment containing microscopically translucent iron oxide minerals.

8) Detrital constituents -- When detrital grains are the sole constituent, a simple detrital term (textural term) suffices, e.g., sand, silty clay, clay, preceded by a mineralogical term if warranted.

If authigenic minerals or a fossil assemblage occur with detrital components, only the detrital component (recalculated on a 100% basis) is given a textural name; it also now requires a compositional term, usually the word detrital.

9) Redeposited biogenic components -- These become a detrital component carrying the appropriate compositional and textural terms. However, since the distinction between redeposited and in situ biogenic components is difficult, their classification and textural naming is only justified in the face of obvious and significant evidence. Similar considerations apply to volcanic

components. The distinction between redeposited (detrital) and nondetrital biogenic sediments is illustrated in Fig. 2 for the calcareous sediments.

10) Unidentified carbonate -- Fine-grained carbonates exist that cannot be identified as to biogenic, authigenic, diagenetic, detrital, or nondetrital origin. These are identified with the prefix micarb and the terms ooze and chalk are to be used as appropriate.

The Weser classification leads to complicated sediment names that, however, provide a quite comprehensive description of the sediment. The distinction between detrital and nondetrital, subjective as it is, occurs at a primary level in the hierarchy. Inspection of various Initial Reports shows that the criterion has been applied unevenly and that nondetrital biogenic sediment categories (implying no reworking) are probably overrepresented.

JOIDES CLASSIFICATION

The JOIDES classification was prepared by a subcommittee of the JOIDES Advisory Panel on Sedimentary Petrology and Physical Properties and, after having been recommended to the Deep-Sea Drilling Project by JOIDES, was formally introduced as the official classification beginning with I.R. DSDP, 38 and is still in use. A test of this classification during Leg 33 resulted in a modified version used in I.R. DSDP, 33; some of the modifications have been incorporated in the current version.

The JOIDES classification is, in one sense, a compromise between the Weser scheme and the Olausson classification with modifications by Berger and Von Rad (1982). Unlike the Weser scheme that focuses on the most comprehensive descriptive name for each sediment type, the JOIDES classification emphasizes the processes of ordering and

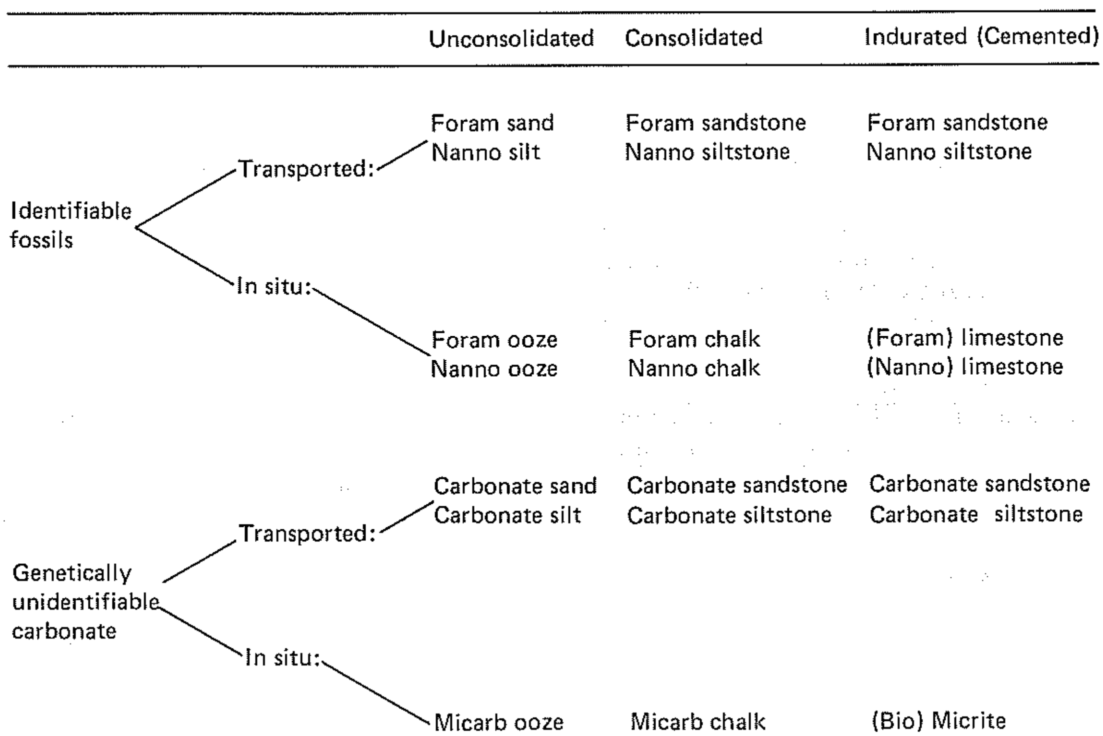


Figure 2. The carbonate portion of the Weser (1973) classification illustrates the basic hierarchy of this classification including the important role of the distinction between reworked and in situ components. The sediment class names used are the simplest forms; for sediments containing siliceous, detrital, volcanic, or authigenic components, the names would become longer. (From I.R. DSDP, 24:13.)

simplification. It was designed with the following points in mind: (1) to simplify the sediment names and adhere as much as possible to common usage; (2) to reduce the number of quantitative boundaries and thereby decrease the possible deleterious effect of errors of estimate; (3) to eliminate as far as possible genetic and hence subjective criteria; (4) to achieve an organic subdivision of marine sediments into three principal categories -- pelagic biogenic, pelagic nonbiogenic, and hemipelagic and terrestrial deposits, and their transitions. It avoids a common problem of many classifications -- that of overdefinition to accommodate all possible rock types including the rarest ones -- by allowing a category of special rock types to be defined by the shipboard staff at their option. The possible occurrence of exotic rock types, common in the early stages of young ocean basins, for example, is generally anticipated and countered by the appointment of appropriate specialists on the shipboard staff. These specialists can define the proper criteria and systems of classification.

The JOIDES classification scheme rests entirely on the descriptive parameters listed earlier in this chapter and accepts the stated boundaries and definitions. It scales the degree of detail of the various categories to the limitations of the printed graphic hole and core summaries and provides for a series of mandatory elements: (1) a mandatory graphic lithology column with standard symbols except for the "special rocks" category; (2) an optional graphic column if the shipboard staff judges that additional information is useful; (3) a mandatory sediment disturbance column; (4) an optional column for sedimentary structure and texture; (5) a lithologic description column that contains macroscopic and smear-slide descriptions, $CaCO_3$ and grain size data, and other elements judged useful (Fig. 3).

1) Compositional class boundaries -- $CaCO_3$ content determined by carbonate bomb is sufficiently precise to permit boundaries of 30 and 60% that reasonably reflect the natural frequency distribution of carbonate contents in oceanic sediments. The biogenic opal abundance, based on percent siliceous skeletal material in smear slides, may seriously underestimate the total opal abundance. Boundaries have been set accordingly at 10, 30, and 50%. Authigenic components and other indicators of very slow sedimentation (fish debris, for example) are used to define pelagic clay; they are conspicuous in smear slides, but even a small influx of diluents such as calcareous, siliceous, or terrigenous material will reduce them to insignificance. The upper boundary is 10%.

2) Qualifiers -- Numerous qualifiers are possible, but components of less than 5% should be used only exceptionally. The most important component should be the last qualifier and no more than two qualifiers should be used.

3) Sediment categories -- The following sediment categories have been defined; other types can be defined as desired under Special Rock Types.

A. Pelagic clay: authigenic pelagic deposits accumulating very slowly; often named brown or red clay. Boundary with terrigenous sediments set at 10% authigenic components (zeolites, Fe/Mn nodules) and fish debris, etc. Boundary with siliceous biogenic sediments at less tha 30% skeletal siliceous remains. Note: metal-rich muds, often occurring in association with calcareous biogenic sediments, should not be confused with pelagic clay but separately described and named. Transitions between pelagic clay and calcareous biogenic sediments are rare in nature.

B. Siliceous biogenic sediments: contain more than 30% skeletal sili-

SITE HOLE CORE CORED INTERVAL:

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS	LITHOLOGY	SED. DISTURBANCE	SED. STRUCTURES	LITHO. SAMPLE	SILTY CLAY / SILT / VERY FINE SAND / FINE SAND / MEDIUM SAND / COARSE SAND	LITHOLOGIC DESCRIPTION (Suggested Format Below. Please PRINT using BLACK Ink.)
						0							If "0" Section exists, please complete description.
						1							
						2							
						3							
						4							
						5							
						6							
						CORE CATCHER							

Slight — — ; Moderate ——— ; Very Deformed ⁀ ; Soupy O O O O

COLOR SYMBOLS (Munsell and GSA) MAY BE PUT ALONG THIS EDGE!

GENERAL LITHOLOGIC DESCRIPTION OF CORE

Detail at the discretion of sedimentologist for particular Site (Hole).

SMEAR SLIDE DESCRIPTIONS (Separate into Major and Minor lithologies include Nomenclature)

Major Lithologies Minor Lithologies

Data to be added when received from shorebased labs.

X-RAY MINERALOGY
Calc - M
Quar - TR
Plag - TR
Mica - TR
CARBON-CARBONATE
2-59 (% Total, % Organic, % $CaCO_3$)
2-75 (% Total, % Organic, % $CaCO_3$)
GRAIN SIZE
2-61 (% Sand, % Silt, % Clay)
2-82 (% Sand, % Silt, % Clay)

Figure 3. Core description log sheet for JOIDES classification.

ceous material and less than 30% carbonate.

1. Pelagic siliceous biogenic sediments:

soft: siliceous (radiolarian, diatomaceous, etc.) ooze
hard: radiolarite, diatomite (distinguishable components)
porcellanite, chert (no distinguishable fossil components)

Qualifiers: indeterminate carbonate: calcareous
nannofossils: nannofossil
foraminifers: foraminiferal (nannofossil-foraminiferal, etc.)

2. Transitional biogenic siliceous sediments: more than 30% clay.

Diatoms below 50%: diatomaceous mud (soft) diatomaceous mudstone (hard)

Diatoms above 50%: muddy diatom ooze (soft) muddy diatomite (hard)

Radiolarian equivalents are rare and can be specially described.

C. Calcareous biogenic sediments: contain more than 30% carbonate.

1. Pelagic calcareous biogenic sediments:

soft: calcareous ooze
firm: chalk
hard: indurated chalk

Limestone should be restricted to cemented rocks.

Qualifiers: nannofossils and foraminifers.

Foraminifers %	Name
below 10	nannofossil ooze, chalk, limestone
10-25	foraminiferal nannofossil ooze
25-50	nannofossil-foraminiferal ooze
above 50	foraminiferal ooze

Sediments with more than 10-20% siliceous skeletal material carry the qualifier "radiolarian," "diatomaceous," etc.

2. Transitional calcareous biogenic sediments

(a) $CaCO_3$ 30-60%: marly calcareous biogenic

soft: marly ooze
firm: marly chalk
hard: marly limestone

qualifiers as above

(b) $CaCO_3$ above 60%: as category 1

Note: sediments with less than 30% $CaCO_3$ fall in other categories but may be designated calcareous.

D. Terrigenous sediments: have more than 30% terrigenous and volcanic material and are subdivided on textural grounds using the sand, silt, and clay ratios (see Fig. 4). Rocks coarser than sand are treated as special rock types: clay, mud, silt, etc. (from Fig. 4) are used for soft sediments; indurated sediments have the suffix -stone (or are called shale if fissile).

Qualifiers are mainly compositional (glauconitic, feldspathic, etc.). Divisions such as arkose, graywacke, are acceptable for sandstones, if the classification criteria are identified. If $CaCO_3$ is 10-30%, the terrigenous rocks shall be called calcareous.

E. Volcanogenic sediments:

1. Pyroclastic rocks are described according to the scheme of Wentworth and Williams (1932). Textural groups are:

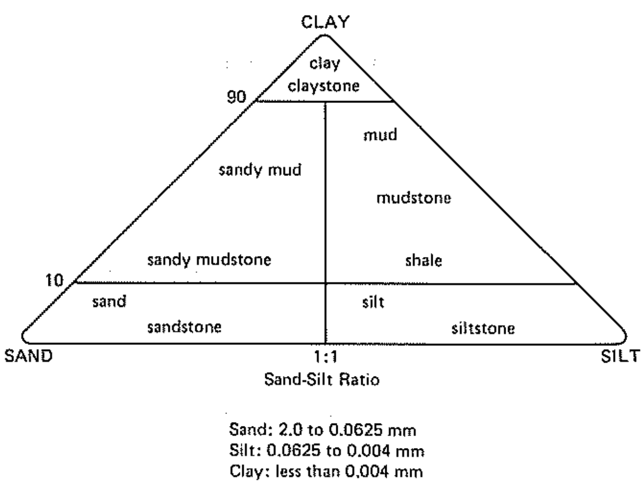


Figure 4. Classification of terrigenous sediments on the basis of texture. Use Wentworth (1922) grain-size scale if a subdivision of categories is desired.

volcanic breccia: above 32 mm
volcanic lapilli: below 32 mm
volcanic ash: below 4 mm (tuff, if indurated)

Compositionally, these rocks are described as vitric, crystal, or lithic.

2. Detrital sediments of volcanic provenance are described in the same manner as terrigenous sediments, noting composition of volcanic grains.

F. Special rock types: can be described and classified as desired, provided categories are defined, and include: igneous rocks, evaporites, shallow-water limestones (coquina, biostromal, and biohermal types), gravels, etc., concretions, coal and black shale, metal-rich brown clays, and so forth.

A summary of the JOIDES classification, based on the quantitative proportions of major components and omitting qualifiers, is given in Fig. 5.

MISCELLANEOUS CLASSIFICATIONS

Four Initial Reports (5, 9, 12, and 32) use description and quantitative classification schemes that are quite different from the systems discussed previously. They are summarized as follows:

Leg 5

This classification is the first quantitative system to appear in the Initial Reports. The system is based on six compositional end-members; uses class limits derived from Shepard's (1954) classification of terrigenous shallow marine sediments (the same class limits appear in other classifications, e.g., Weser's, 1973); and can accommodate three constituents present in amounts above 25%. The dominant constituent appears on the right. Qualifiers are

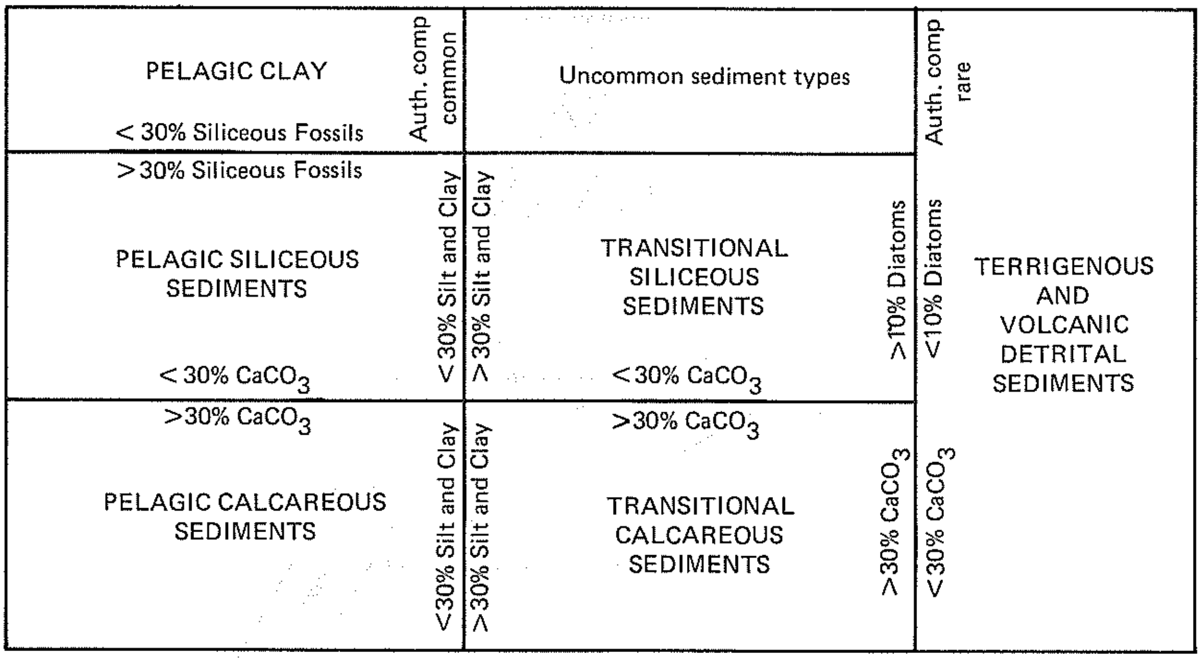


Figure 5. Summary diagram of the JOIDES sediment classification. For sediment types not included in the diagram, special rock types may be defined by the observer. Available qualifiers are discussed in the text.

possible, and fossil group names are used if justified. The sediment terminology, a bit exotic in appearance, is based on abbreviations. Indurated sediments are indicated with the term -stone, and in the case of biogenic siliceous and calcareous rocks, with the qualifier siliceous or calcareous. Red clay is retained even though this sediment is seldom truly red. Table 5 summarizes the classification by end-member pairs.

Leg 9

On Leg 9 a limited suite of rocks was encountered, consisting mainly of oozes and chalks, which were accommodated by a three-end-member classification with class boundaries of 10, 50, and 90% (Fig. 6). Increasing induration is indicated by the qualitative suite of terms ooze, chalk ooze, ooze chalk, and chalk. Color is the first qualifier in the name; then minor constituents not included in the name (e.g., foraminiferal, radiolarian), and finally the name.

Leg 12

This is an empirical system based purely on the sediments of Leg 12. The classification avoids genetic implications. Chalk is used as an induration term; claystone, indurated clay, and so forth are interchangeable. Class limits are close to those of the Olausson and JOIDES classifications, and sediment names are a combination of textural and compositional terms except for the calcareous biogenic sediments. The nomenclature should be reasonably interchangeable with the appropriate portions of the Olausson and JOIDES system. The classification scheme is shown in Fig. 7.

Leg 32

The sediment suite encountered on Leg 32 was rather limited and consisted, with the exception of some shallow-water sediments, of pelagic and volcanic deposits. For this reason, a simplified system of common names is used that is closely related to those mostly

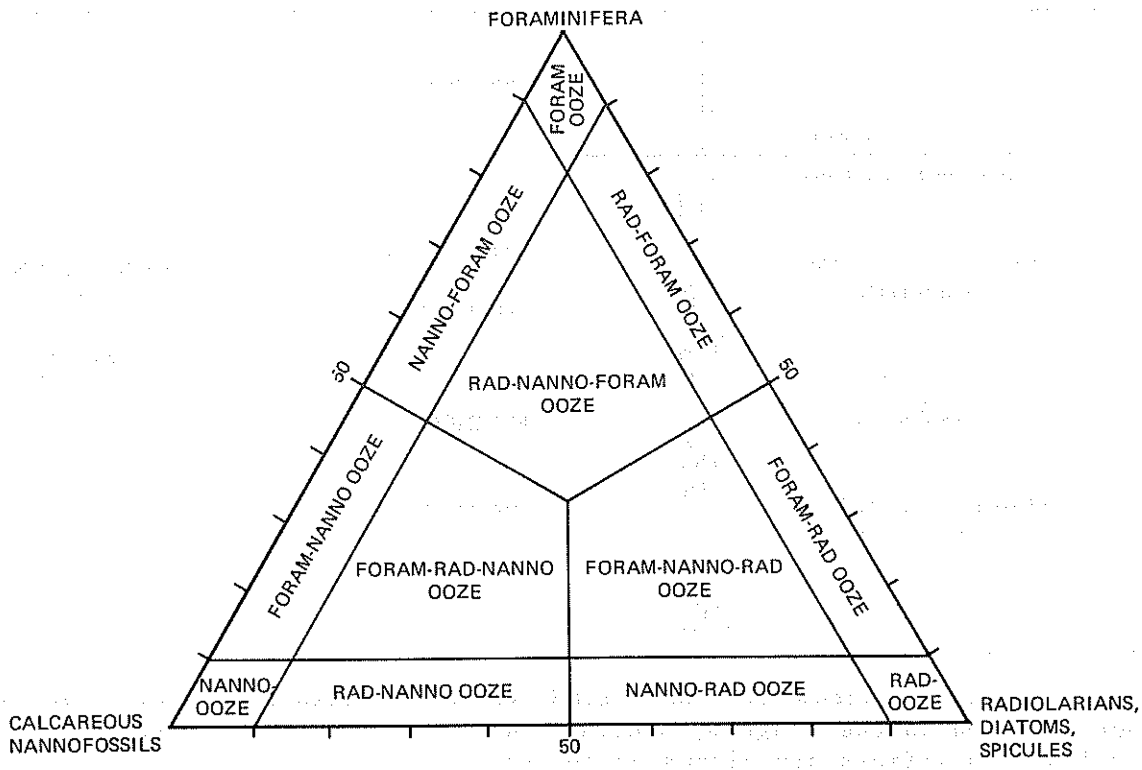


Figure 6. Sediment classification scheme used in I.R. DSDP, 9:6.

used on other legs: for a constituent present at 5-25%, a modifier followed by the suffix -bearing is added, between 25 and 75% the constituent is used as a qualifier, and constituents above 75% determine the basic name (for example, foram-bearing radiolarian nanno ooze). Pelagic clay when indurated is called pelagic claystone, indurated calcareous sediments are called chalks, and the term limestone is reserved for recrystallized carbonates. Cherts are distinguished from porcellanites (see I.R. DSDP, 7). Volcanic sediments are classified by texture into volcanic clay, silt, and sand; volcanic mud is a mixture of clay and silt. Volcanic ash shows shard structure. Genetic modifiers (pyroclastic, epiclastic, hyaloclastic) are used for fragmental volcanic rocks where possible.

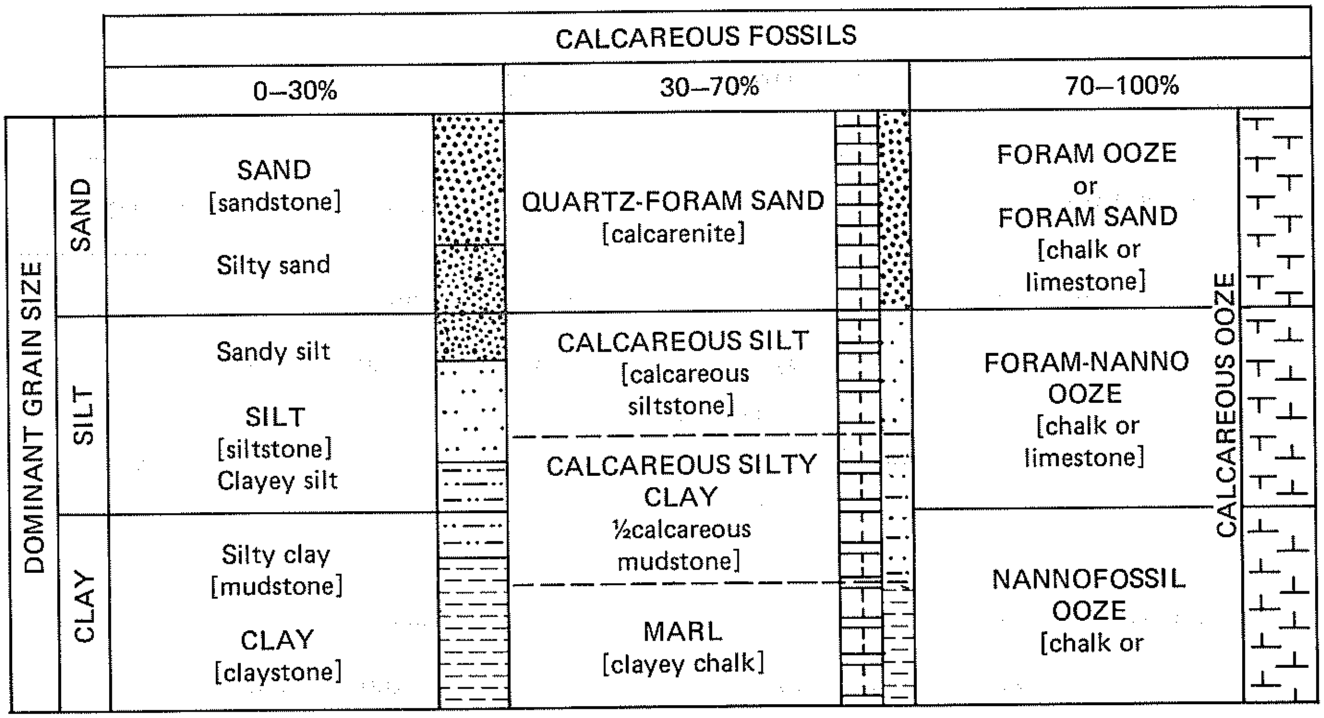
COMPUTERIZED CLASSIFICATION SYSTEM FOR DSDP SEDIMENT CORES

It is evident that the great variety of terms and classification schemes in the first 44 volumes of the Initial Reports seriously handicaps their use as an inventory of sediment samples and as a source of lithologic data for regional and stratigraphic studies. The situation is complicated further by the wide range in quality of the descriptive data and by the varying skills and interests of the members of the shipboard staffs. Short of a complete redescription of samples, there is little that can be done about the latter, but the basic descriptive techniques and parameters have remained much more constant throughout the history of the DSDP than their use in naming and classifying sediments.

This uniformity in the prime descriptive data permits the use of computer programs to screen, classify, and standardize sediment descriptive names. A program for this purpose has been designed by the DSDP staff (Davies et al., 1977) that permits the application of a variety of quantitative

Table 5. Classification of sediments in I.R. DSDP, 5:11-12.

Composition %		Terminology	Composition %		Terminology
Zeolite	Red Clay		Zeolite	Mud	
0-25	75-100	"red" clay	0-25	75-100	mud
25-50	50-75	zeolitic red clay	25-50	50-75	zeolitic mud
50-75	25-50	red clay zeolitite	50-75	25-50	mud zeolitite
75-100	0-25	zeolitite	75-100	0-25	zeolitite
Sil.Foss.	Red Clay		Sil.Foss.	Mud	
0-25	75-100	"red" clay	0-25	75-100	mud
25-50	50-75	sil foss red clay	25-50	50-75	sil foss mud
50-75	25-50	red clay sil foss ooze	50-75	25-50	mud sil foss ooze
75-100	0-25	sil foss ooze	75-100	0-25	sil foss ooze
Sil.Foss.	Nannos		Nannos	Mud	
0-25	75-100	nanno ooze	0-25	75-100	mud
25-50	50-75	sil foss nanno ooze	25-50	50-75	nanno mud
50-75	25-50	nanno sil foss ooze	50-75	25-50	mud nanno ooze
75-100	0-25	sil foss ooze	75-100	0-25	nanno ooze
Nannos	Red Clay		Forams	Nannos	
0-25	75-100	"red" clay	0-25	75-100	nanno ooze
25-50	50-75	nanno red clay	25-50	50-75	foram nanno ooze
50-75	25-50	red clay nanno ooze	50-75	25-50	nanno foram ooze
75-100	0-25	nanno ooze	75-100	0-25	foram ooze



[ ] = Indurated equivalents. (Note: Limestone is highly indurated equivalent of chalk.)

If siliceous fossils are conspicuous then the adjective SILICEOUS is added.
Any of these names can be modified by the addition of more adjectives.

Figure 7. Classification scheme used in I.R. DSDP, 12:19.

classification schemes to the prime descriptive data that have been recorded on magnetic tape. A summary of the system with an application to the JOIDES classification follows. The procedure does not, of course, provide a remedy for poor quality or lack of prime descriptive data (a condition that is, unfortunately, not at all uncommon), but it does yield a satisfactory standard reclassification for inter- (and sometimes intra-) leg comparisons that has proved to be very useful in practice. Moreover, it uses quantitative $CaCO_3$ data rather than smear-slide estimates.

The system is designed to accommodate classification schemes that adhere to the principles stated for the JOIDES classification and provides a lithologic summary classification. It is fairly comprehensive for common sediment types, but utilizes the observer's terminology for special rock types. The categories are based on shipboard data and on-shore laboratory analyses when the latter are available and thus permits considerable refinement in many cases. The classification scheme incorporated in the program is the JOIDES classification modified for computer logic as shown in Fig. 8. In addition, the terrigenous and volcanogenic sediment categories are subdivided further on the basis of texture using the Wentworth (1922) and Wentworth and Williams (1932) schemes. Induration terms used are those of the JOIDES classification.

The encoded prime descriptive data consist of laboratory grain-size and carbonate determinations, visual core descriptions, and smear-slide observations. The last two categories are subdivided into nine parameters: lithologic name, color, structures, deformation, unusual occurrences, minerals, paleontological data, other observations, and hardness. A new set of descriptions is prepared for each sediment layer and for each core section, regardless of changes in lithology. Mixed lithologies and very fine layering are not treated separately.

The program includes the following steps: (1) gather data from resource files; (2) convert abundances to standard classes; (3) check for inconsistencies between samples from the same interval and select most representative sample; (4) evaluate according to classification scheme and assign basic lithologic name; (5) evaluate individual component abundances and assign qualifiers. When inadequate data are available, the program displays the available data for inspection and decision by the user. The most common fatal deficiencies are: (1) absence of a smear-slide record (which contains the only information on siliceous components), (2) incomplete smear-slide data, and (3) conflicts in class assignments to the siliceous and

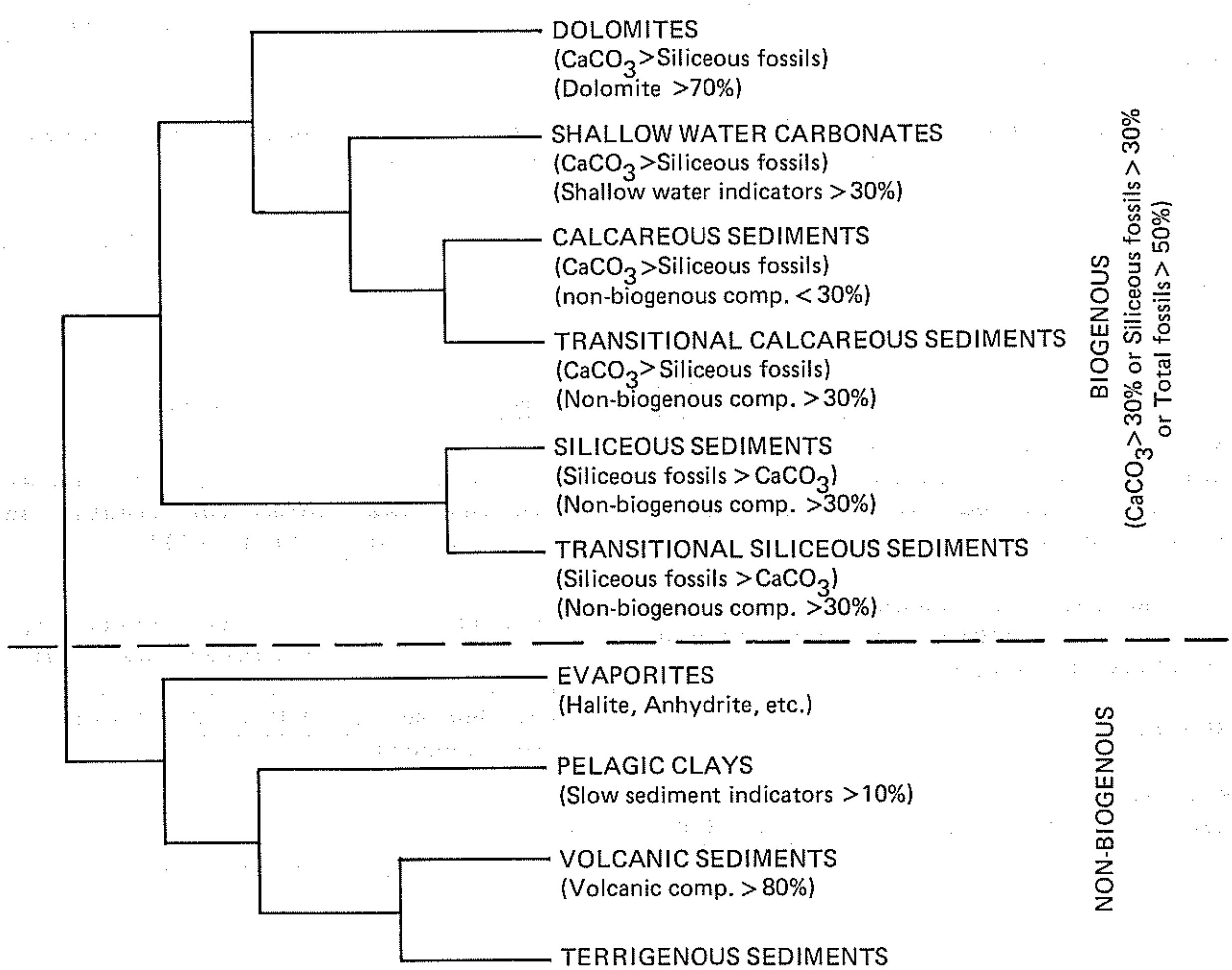


Figure 8. JOIDES sediment classification (Fig. 5) modified for computer logic and use with the JOIDESSCREEN program (Davies et al., 1977).

calcareous material totals. In such cases, no name can be assigned, and the shipboard name is substituted and flagged.

The application of the system greatly increases the consistency of the nomenclature and reduces the number of lithologic names as illustrated in Tables 6 and 7. Much of the reduction is due to interobserver variation. Table 7 also illustrates the disturbing number of cases where no rigorous naming of the samples was possible, mostly as a result of the lack of smear-slide data. Thus, significant portions of the sedimentary column have been classified and named on insufficient grounds -- a fact that can be easily explained by the commonly stressed shipboard conditions but that should be borne in mind by users of the data.

The system, named JOIDESSCREEN, has been extremely useful in several regional studies. Its output is readily available from DSDP.

ACKNOWLEDGMENTS

This compilation of DSDP sediment classification procedures was begun as part of a series of regional studies of the depositional history of the Pacific and Atlantic oceans. Preparation of this paper was supported by Grant OCE76-22151 of the National Science Foundation. I thank T. A. Davies, John Usher, and Peter B. Woodbury for their assistance in fighting my way through this particular jungle.

REFERENCES

Berger, W. H., and Von Rad, U., 1972. Sediment classification. I.R. DSDP, 14:11-13.

Davies, T. A., Musich, L. F., and Woodbury, P. B., 1977. Automated classification of deep-sea sediments. J. Sediment. Petrol., 47:650-656.

Klein, G. deV., 1975. Depositional facies of Leg 30, Deep Sea Drilling Project. I.R. DSDP, 30:423-442.

Moberly, J. R., and Heath, G. R., 1971. Carbonate sedimentary rocks from the Western Pacific, Leg 7. I.R. DSDP, 7:977-986.

Müller, G., and Gastner, M., 1971. The "Karbonat-Bombe," a simple device for the determination of the carbonate content in sediments, soils, and other materials. Neues Jahrb. Mineral., 10:466-469.

Olausson, E., 1960. Description of sediment cores from the Central and Western Pacific with adjacent Indonesian region. Rept. Swedish Deep-sea Exped. 1947-1948, 6:161.

Shepard, F. P., 1954. Nomenclature based on sand-silt-clay ratios. J. Sediment. Petrol., 24:151-158.

Wentworth, C. K., 1922. A scale of grade and class terms for clastic sediments. J. Geol., 30:377-392.

Wentworth, C. K., and Williams, H., 1932. The classification and terminology of the pyroclastic rocks. Rept. Comm. Sediment. 1930-1932, National Research Council.

Weser, O. E., 1973. Sediment classification. I.R. DSDP, 18:9-12.

Table 6. Examples of the application of JOIDESSCREEN to individual samples (after Davies et al., 1977).

Observed Composition (%)	Observer's Name	JOIDESSCREEN
Nannofossils 90, forams 10	Foram nanno chalk ooze	Nannofossil chalk
Clay mins. 6, glass 2, nannofossils 88, forams 3, rads 1, sponge spicules 1	Clay-bearing nanno ooze	Nannofossil chalk
Nannofossils 84, forams 10, rads 3, sponge spicules 3	Nanno ooze	Nannofossil chalk
Glass 2, nannofossils 90, forams 5, rads 1, sponge spicules 1	Glass shard and foram-bearing nanno ooze	Nannofossil ooze
Glass 4, nannofossils 70, forams 24, rads 1, sponge spicules 1	Glass shard and foram-bearing nanno ooze	Foram-rich nanno-fossil ooze
Quartz 10, feldspar 5, amphibole 2, nannofossils 2, forams 10, sponge spicules 1, indet. carbonate 68	Glauconite-bearing siltstone or fine-grained sandstone	Indurated carbonate chalk

Table 7. Results of JOIDESSCREEN application on Legs 3, 4, and 21 (after Davies, et al., 1977).

	Leg 3	Leg 4	Leg 21
Number of lithologic units	163	232	1059
Original number of terms used	29	64	338
Number of lithologic names assigned by JOIDESSCREEN	12	23	23
% success	79	56	46

2. SEDIMENTARY STRUCTURES

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INTRODUCTION

Studies about the origin and nature of sedimentary structures go far back in time and comprise some of the earliest observations of the pioneers of geology. Interest in studies of sedimentary structures accelerated during the period following World War II, and their use for interpreting the origin and environment of deposition of sedimentary rocks is now fairly well-established in outcrop and subsurface studies.

Studies of deep-sea sedimentary structures have lagged behind those on land, however, because until very recently bottom photography and television surveys provided limited observation of bedforms on the seafloor. Studies of structures in cores have been limited by core diameter, core disturbance, core storage procedures, and core handling. Only with the advent of high-resolution seismic profiling, deep-tow surveys and mapping, and hydraulic piston coring has our understanding of deep-sea sedimentary structures improved.

Drilling by the Deep Sea Drilling Project (DSDP) has provided new material for analysis of sedimentary structures. However, studies of sedimentary structures in DSDP cores have lagged behind studies of downhole mineralogy, petrology, dissolution, geochemistry, and paleoceanography. Yet these cores provide a unique opportunity ot deduce the dynamics of sedimentation in deep ocean environments and to pinpoint changes in processes and depositional history from an analysis of the vertical distribution of structures in relation to grain size and biogenic structure changes.

The purpose of this paper is to review the development of DSDP studies (Legs 1-44) of sedimentary structures and to assess what now is known about them. An identical review will be incorporated dealing with sedimentary sequences of structures, lithology, and grain-size change as an aid in understanding deep-sea depositional systems.

SEDIMENTARY STRUCTURES

Sedimentary structures are the three-dimensional discontinuities and primary aspects of sediments and sedimentary rocks. Their origin is normally related to the dynamic and physical history of deposition; therefore an understanding of sedimentary structures permits one to determine how a sedimentary rock or sediment was originally put together. In rare instances, it is even possible to estimate the hydraulic intensity, the bed state, and the paleoflow velocity of the agent of deposition from certain physical characteristics of a particular structure.

Classification

Classification of sedimentary structures has been a fairly fluid topic, and prior to 1964 very few were proposed. Pettijohn and Potter (1964, pp. 3-9) proposed a relatively simple classification using bedding as a departure point. It is used most commonly today by sedimentologists and is most effective when dealing with outcrops or trenches through Holocene sedimentary deposits.

Because of the limitations of core diameter, a slight revision of the Pettijohn and Potter (1964) classification

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

is proposed in Table 1 to accommodate the description of DSDP cores; and because most observations made of DSDP sediment cores are two dimensional, bedding plane discontinuities are observed only in two dimensions at right angle to bedding. Rarely are bedding planes preserved; only if cores are broken along a primary lithologic contact does one observe such features. Consequently, Class II of Pettijohn and Potter (1964) dealing with bedding plane features must be referred to as "bedding contact features." Identification of certain sole marks and bedforms requires a three-dimensional view and, consequently, recognition of certain strutures requires added two-dimensional information. Undulose or wavy bedding contacts could be ripples or scalloped scours. The presence of micro-cross-laminae immediately below such an undulose contact would assist in identifying the boundary or contact as a true ripple. Table 1 summarizes their usage and the proposed usage for cores.

The origin of many of these structures has been debated for a long time. These arguments are reviewed in standard symposia volume, textbooks, reprint series, and monographs (e.g., Middleton, 1965, 1977; Klein, 1977b; Pettijohn et al., 1972; Pettijohn, 1975; Blatt et al., 1972; among others). This chapter will not review these arguments, but will emphasize the recognition and interpretation of deep-sea processes as deduced from structures recognized in DSDP cores.

Symbolic Coding of Sedimentary Structures

Prior to Leg 38, sedimentary structures were recorded by written descriptions during shipboard examination of cores. Starting with Leg 38, a system of symbols was suggested for recording sedimentary structures in a special column on the barrel summary sheets (Fig. 1). A minor modification adopted during Leg 44 is also shown.

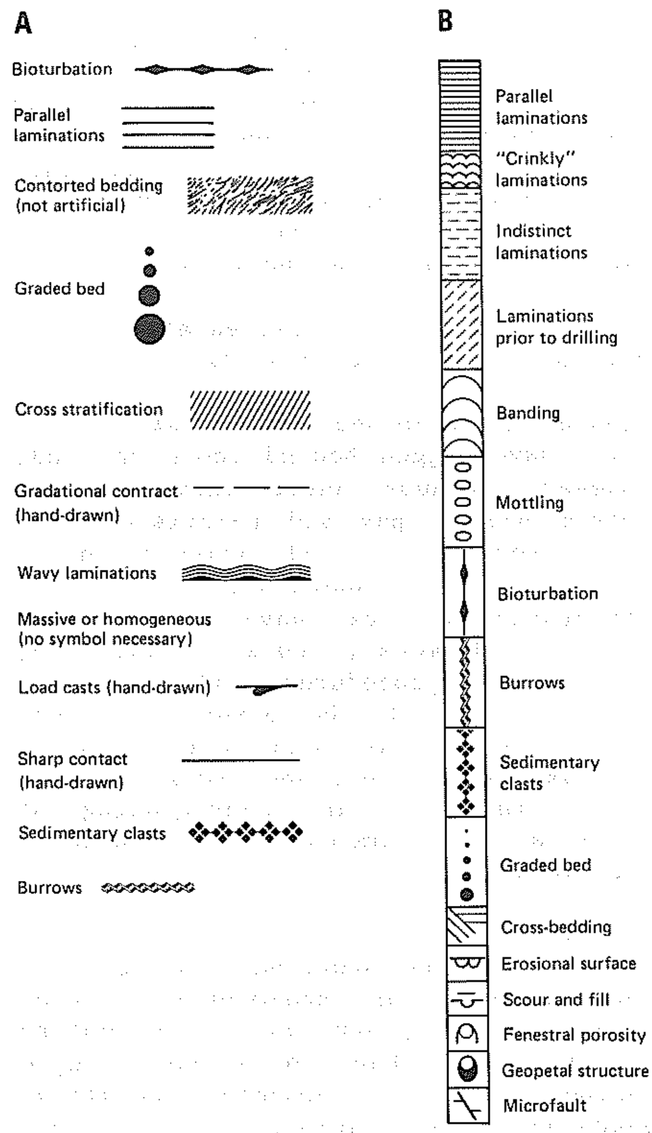

Figure 1. Symbols used in recording sedimentary structures during (A) Legs 38-43, and (B) Leg 44.

Table 1. Comparison of classification of sedimentary structures used by Pettijohn and Potter (1964) and Klein (this chapter).

Pettijohn and Potter (P&P), 1964	Klein, This Chapter
Group I: Bedding, external Form	Group I: Bedding, external Form (Rare to absent in DSDP cores)
Class A:	Class A: As in P&P
Class B: As in P&P, p. 5	Class B: As in P&P, p. 5
Class C: As in P&P, p. 5	Class C: As in P&P, p. 5
Class D: As in P&P, p. 5	Class D: As in P&P, p. 5
Group II: Bedding, internal organization and structure	Group II: Bedding, internal organization and structure
Class A: Massive	Class A: Massive
Class B: Laminated	Class B: Laminated
1. Horizontal laminae	1. Horizontal laminae
2. Cross-stratification	2. Cross-stratification
Class C: Graded	Class C: Graded
Class D: Imbricated, and other oriented internal fabrics	Class D: Imbricated, and other oriented internal fabrics
Class E: Growth structures	Class E: Growth structures
Group III: Bedding plane markings and irregularities	Group III: Bedding contact features
Class A: On base of bed	Class A: Basal contact
1. Load structures	1. Scour marks
2. Scour and toolmarks	2. Sharp contact
3. Organic markings	3. Gradational contact
Class B: Within the bed	Class B: Within the bed
	1. Wavy beds
	2. Lenticular bedding
	3. Flaser bedding
Class C: On top of bed	Class C: Upper contact
1. Ripple marks	1. Undulose bedding
2. Erosional markings	2. Casts
3. Pits and small impressions	3. Sharp contact
4. Casts -- mudcracks, salt casts	4. Gradation contact
5. Organic markings	
Group IV: Bedding, disturbed and deformed	Group IV: Bedding, disturbed and deformed
Class A: Founder and load structures	Class A: Founder and load structures
	1. Load casts
	2. Pseudonodules
	3. Water escape pipes
Class B: Convolute bedding	Class B: Convolute bedding
Class C: Slump structures	Class C: Slump structures
1. Folds	1. Folds
2. Faults	2. Faults
3. Breccias	3. Breccias
Class D: Injection structures	Class D: Injection structures
Class E: Organic structures	Class E: Organic structures
	Class F: Debris flow fabric

Recording of sedimentary structures on measured sections goes back to the work by Bouma (1962) who was perhaps the first to devise such a system. Since then, several other schemes have been proposed, including those of Selley (1970) and DeRaaf and Boersma (1971). The DeRaaf and Boersma (1971) symbols were expanded and incorporated later in a volume edited by Ginsburg (1975). These symbols were applicable in Holocene sedimentary sections or cores and in outcrops on land.

Because of their widespread usage, a special subcommittee of the Sedimentary Petrology and Physical Properties Panel was convened in 1977 to revise the symbols that originated in DSDP legs starting with Leg 38. Those symbols are presently used by DSDP (Fig. 2). These symbols recognize the diversity of structures recovered and described from the later DSDP cruises and permit an easier comparison of DSDP cores to land-based outcrops.

SEDIMENTARY SEQUENCES

In sedimentary facies analysis and sedimentological studies the vertical sequence (or distribution) of grain size, lithologies, primary sedimentary structures, and biogenic structures, taken together, are found to be more diagnostic of depositional processes, environments, and history than individual structures by themselves. The assumption inherent in analysis of sedimentary systems is that the vertical distribution of these features records a change in depositional process or subenvironment that is unique to a given mode of origin. In essence, the vertical sequence is an extension of Walther's Law of facies (Middleton, 1973) applied on a more detailed scale.

The earlier discussions of sequences were developed from meandering fluvial sediments by Nanz (1954), Bersier (1968), and Allen (1965); such sequences were observed to fine upward, although now it is known that such trends may coarsen upward or show no change

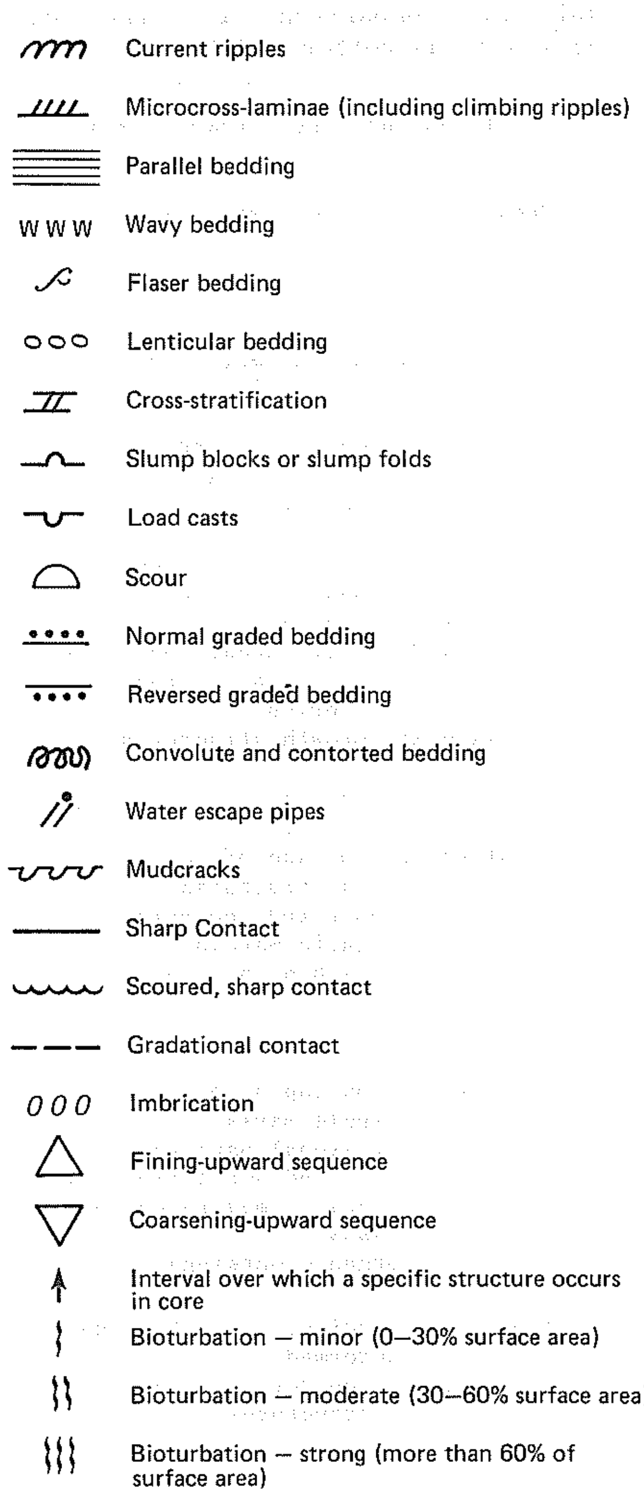

Figure 2. Symbols used for recording sedimentary structures recommended by the panel on Sedimentary Petrology and Physical Properties. This set of symbols was field-tested during Leg 58 and adopted aboard ship starting with Leg 65.

(Jackson, 1978). In deep-water sediments, Bouma (1962) first called attention to the vertical arrangement of grain-size changes in turbidites. He recognized that, ideally, turbidite beds were organized into a fivefold sequence commencing with a basal coarse to coarser grained sand overlying a sharp basal scour. This interval (termed A interval) is overlain by a parallel-laminated interval (B interval), which in turn grades up into an overlying interval of micro-cross-laminae and convolute bedding (C interval). This C interval may also contain climbing-ripple sedimentary structures. It is overlain by an interbedded siltstone and mudstone parallel-laminated zone (D interval). The entire sequence is capped by mudstone (E interval). Fig. 3 shows a sketch of such a sequence and a hydraulic interpretation of it. The hydraulic interpretation indicates that the sequence is deposited by a decelerating turbidity current, which undergoes a change in flow regime from supercritical (a,b interval) to subcritical (c,d interval) and passes through a hydraulic jump. Magnetic grain orientation indicates that perhaps the "A" interval is emplaced by debris flow that passes upward into a turbidity current (Taira and Scholle, 1979). An example of a complete Bouma sequence recovered from Site 313 is shown in Fig. 4.

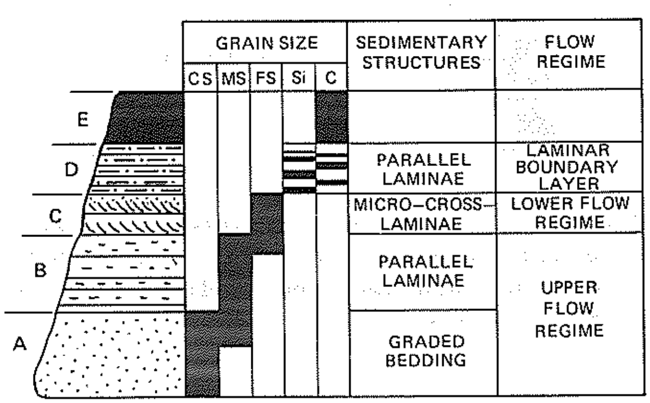

Figure 3. Vertical sequence of fining-upward Bouma (1962) sequence showing changes in sedimentary structures, grain size, and interpreted flow regime.

Other vertical sequences were recognized by Visher (1965) including the coarsening upward barrier island sequence (Bernard et al., 1962); the coarsening upward deltaic sequence (Coleman, 1976); and the fining upward paleotidal range sequence from tidal flats (Klein, 1971, 1977a). In deep-water realms, two additional sequences were recognized. One of these is the coarsening upward sequence produced by prograding submarine fans (Mutti and Ricci-Lucchi, 1972); here, coarsening upward sequences are developed by the progradation and growth of submarine fans as outlined by Normark (1969). This sequence is shown in Fig. 5. Although overall it does coarsen upward, it must be observed that individual sandstone units fine upward because of deposition from turbidity currents. Each successive layer shows progressively coarser content.

A second type of vertical sequence described from deep-water environments is the reworked pelagic, volcaniclastic sequence described by Klein (1975a, b) from site 288 on the Ontong-Java Plateau. Here, pelagic carbonate is reworked by deep-water currents, some with a possible tidal component, into a fining upward trend (Fig. 6).

PHASE I

With some exceptions, there were very little sedimentary structure data obtained during Phase I of the Deep Sea Drilling Project. No systematic way was devised to record such data. Thus, handwritten observations were made on the barrel summary sheets where the shipboard sedimentologists deemed it necessary. During Legs 1 and 2, each

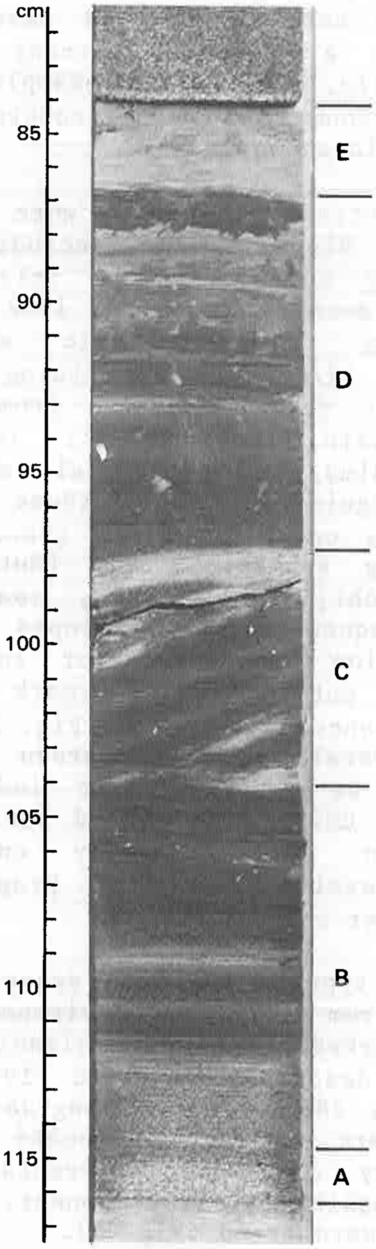

Figure 4. Complete Bouma (1962) sequence from Sample 313-38-3, 72-117 cm showing (A) graded bed, (B) parallel laminated interval, (C) micro-cross-laminae, (D) parallel laminae, and (E) pelagic interval. Site 313, northern edge, Mid-Pacific Mountains.

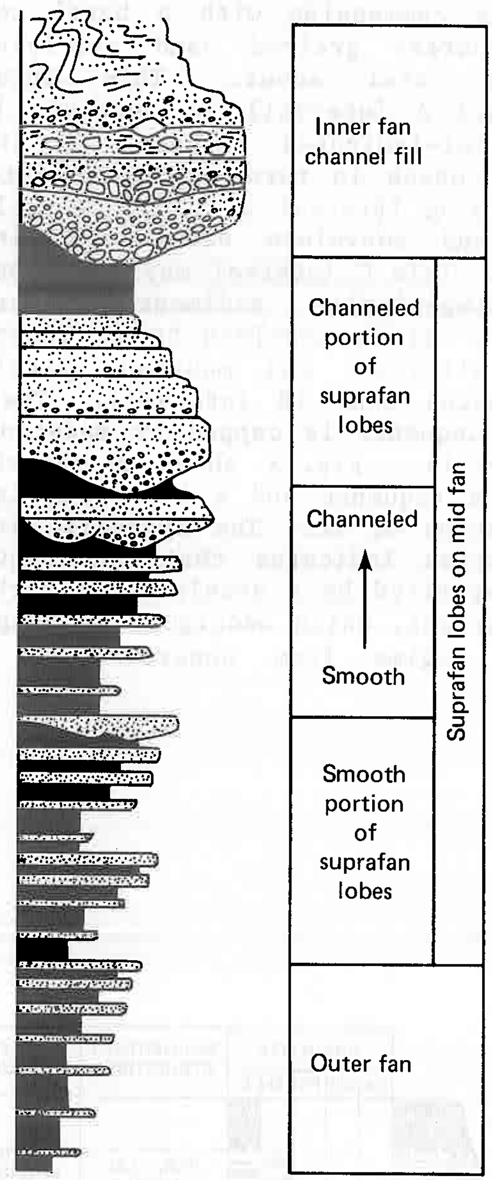

Figure 5. Vertical coarsening-upward sequence produced by prograding submarine fan (Redrawn and modified after Walker, 1978).

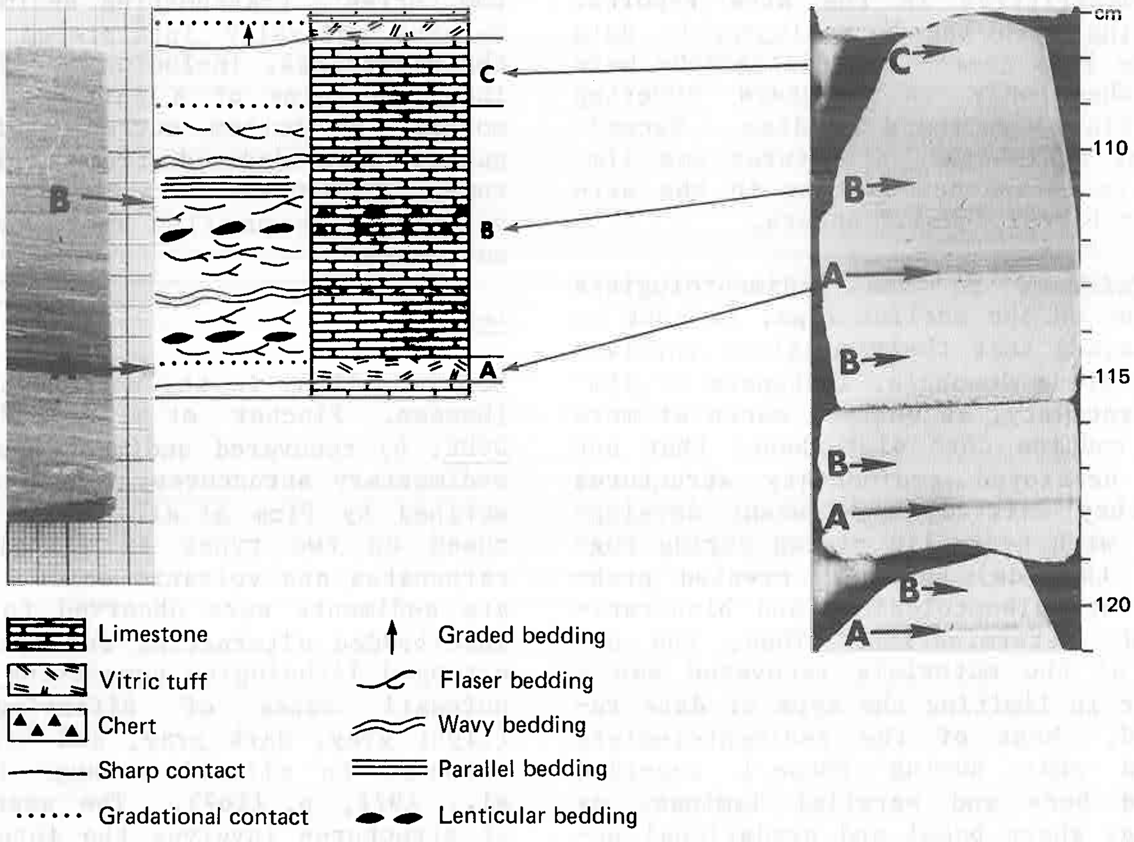

Figure 6. Left: Partial sequence of graded fresh vitric siltstone (interval "A") and resedimented biogenic limestone and altered vitric siltstones of interval "B," showing isolated and flat lenticular bedding and flaser bedding. Sample 288A-20-2, 37-44 cm. Scale in background in mm and cm.
Center: Sedimentary log of volcanic siltstone-pelagic carbonate sequence. Left column shows structures and center column shows lithologies. "A" interval consists of graded fresh vitric siltstone overlying basal scour. "B" interval consists of biogenic limestone and altered vitric siltstone arranged in flaser, lenticular, and wavy beds, and parallel laminae. "C" interval consists of lithographic nannofossil limestone.
Right: Complete volcanic siltstone-pelagic carbonate sequence from Sample 288A-20-4, 106-120 cm. Two partial sequences of intervals "A" and "B" immediately below complete sequence. Scale in cm. (from Klein, 1975a, b.)

core was radiographed aboard ship, and both the radiographs and the photographs of the core and the barrel summary data were published on a single page. Consequently, sedimentary structure data were recorded photographically and radiographically, but with minimal description in the site reports. Starting with Leg 3, radiographic data became less common and radiographs were published only in chapters covering specific shore-based studies. Recording of sedimentary structures was limited to occasional listing in the site report barrel summary sheets.

In fairness to the sedimentologists working on the earlier legs, it must be emphasized that their missions involved spot coring downhole, instances of limited recovery, as well as cases of more than routine core disturbance that not only destroyed sedimentary structures (if they existed, and recent developments with hydraulic piston coring suggests they do) but also created problems for paleontological and biostratigraphic determination. Thus, the nature of the materials recovered was a factor in limiting the type of data recorded. Most of the sedimentologists aboard ship during Phase I recorded graded beds and parallel laminae, as well as sharp basal and gradational upper contacts of turbidite beds and identified their origin accordingly. Phase I legs were drilled mostly in the deepest marine environments where pelagic processes were dominant. Consequently, limited preservation of sedimentary structures was to be expected. Nonetheless, possible resedimentation of pelagic sediments by physical current systems was overlooked and not recognized until later.

Leg 1

The sedimentology studies of Leg 1 (Beall and Fischer, 1969) reported several types of structures. Graded bedding and parallel laminae were observed and their origin was related to the Bouma sequence model. Beall and Fischer (1969) also incorporated considerable data on grain-size change in graded beds. Their study focused on reworking of sands and hemipelagic sediments by turbidity currents, on recording the presence of turbidites, and on tying in their presence to prior land-based studies of turbidite outcrops. Although raising the possibility of bottom currents transporting sediment, the authors generally interpreted most of the structures, including parallel laminae, in terms of a turbidity current model. No bottom currents of consequence were deduced from their findings, in contrast to what has been developed subsequently by several researchers.

Leg 6

Leg 6 drilling in the northwest Pacific (Heezen, Fischer et al., 1971, I.R. DSDP, 6) recovered sediments containing sedimentary structures. These were described by Pimm et al. (1971) and focused on two types of lithologies -- carbonates and volcanic sands. Carbonate sediments were observed to contain interbedded alternating and cyclically-arranged lithologies consisting of nannofossil oozes of differing color (light gray, dark gray, and brown) attributed to climatic change (Pimm et al., 1971, p. 1167). The second mode of structures involves the interbedding of carbontate nannoplankton oozes and chalks with volcanic ashes that are graded at the base and bioturbated at the top; these are overlain by carbonate oozes that are also bioturbated. The ashes were emplaced by turbidity currents whereas the oozes represent an interval of pelagic deposition.

Intervals in which volcanic ash is dominant also contain graded bedding and comprise graded cycles (Pimm et al., 1971, p. 1219). The cycles consist of ash beds that show graded and parallel laminae, with grain sizes changing from a basal fine-sand size to silt-size at the top. These alternate cyclicly with nannoplankton ooze that is bioturbated. In a restudy of some of these cores, micro-cross-laminae and partial Bouma sequences were also observed (Castle, 1978), indicating that ash deposition included a history of resedimentation by turbidity currents.

Leg 9

Cook (1972) summarized the stratigraphy and sedimentation of cores recovered from the equatorial Pacific during Leg 9. Cook emphasized the stratigraphic nomenclature and the establishment of units and their correlation. Sedimentary structures were recorded and comprised part of the identification of the formations Cook (1972) and the Leg 9 scientific staff (Tracy, Sutton et al., 1971, I.R. DSDP, 9) had proposed. Parallel laminae, color banding, and mineralogically-defined laminae were recognized in chalks and oozes (Cook, 1972, p. 934) as were cyclic alternating lithologies (Cook, 1972, pp. 940-941).

The Leg 9 site reports, particularly for Site 76, refer to resedimented "allodapic" carbonates that were characterized by a history of resedimentation by turbidity currents. These were identified only from the presence of graded, biogenic carbonate constituents.

Leg 10

Leg 10 drilling in the Gulf of Mexico (Worzell, Bryant et al., 1973, I.R. DSDP, 10) recovered both carbonate pelagic sediments and terrigenous clastics of turbidite origin. The site reports (Sites 85 through 97) record the occurrences of textural grading, parallel laminae, and, in some instances (Site 90), micro-cross-laminae. The descriptions of these structures, particularly at Site 90, imply the presence of a Bouma sequence. Although this sequence has been known since 1962 (Bouma, 1962), no mention of its existence was recorded either in the site reports or in the sedimentological synthesis chapter by Beall et al. (1973). The terrigenous sediments were considered to comprise an association of "Abyssal Plain Turbidities and Laminates" (Beall et al., 1973). The turbidite origin was attributed to textural grading, for which a great deal of grain-size data was incorporated.

PHASE II

Studies of sedimentary structures during DSDP Phase II showed some improvement over those during Phase I, partly because of the quality and enhanced recovery of the cores. Deeper drilling also permitted recovery of lithified materials that showed structures more clearly. Nevertheless, there was an unevenness in the treatment of sedimentary structures. Thus, certain site reports contained some of the best descriptions of structures and clearly used such data for interpreting oceanic history (e.g., Leg 13; Ryan, Hsü et al., 1973, I.R. DSDP, 13). Other legs reported such data in synthesis chapters on sedimentology (Leg 14; Berger and Von Rad). Others kept the level of data observed no better than Phase I.

Leg 11

Leg 11 dealt with the sedimentary history and evolution of the northwest and western Atlantic (Hollister, Ewing et al., 1972, I.R. DSDP, 11). Site reports recorded a variety of sedimentary structures including graded bedding, micro-cross-laminae, slump structures, parallel laminae, and flow rolls. These were examined in more detail by Lancelot et al., (1972) who not only reported these same structures but interpreted them in terms of lithologic units. Thus, they were the first to record the presence of physical sedimentary structures in DSDP cores such as parallel laminae, micro-cross-laminae, flow structures, and slump features from pelagic biogenic carbonates and from pelagic red clays. These structures indicated a history of resedimentation of such pelagic sediments by physical processes. However, they were unable to determine the volume of resedimentation, the proportion of resedimented versus pelagic materials, or the change in sedimentation rates of such sediments.

Leg 12

Leg 12 covered the northwest and north-cenral Atlantic (Laughton, Berggren et al., 1972, I.R. DSDP, 12). The presence of sedimentary structures in terrigenous turbidites, hyaloclastic sandstones, and resedimented biogenic pelagic oozes was recorded in the site reports. Graded beds, parallel laminae, convolute bedding, load casting, slump folds, slump structures, and micro-cross-laminae were observed.

Further details were presented by Davies and Laughton (1972). Criteria for turbidites that they identified in their cores included the recognition of sequences consisting of sharp bases with gradation tops, graded bedding, parallel laminae, and bioturbation. No mention was made of the Bouma (1962) sequence. The presence of shallow-water fossils in terrigenous turbidites, as well as a layered seismic stratigraphy, was recorded. The authors' synthesis is particularly noteworthy for its review of dynamic sedimentation processes in the North Atlantic, but somehow their excellent discussion of these processes did not tie in with their observations from cores.

Leg 13

Leg 13 drilled in the Mediterranean (Ryan, Hsü et al., 1973, I.R. DSDP, 13). In the opinion of this writer, very few legs will meet the sedimentological standards set by this leg. Those standards were set by the co-chiefs and the scientific staff, but it is only fair to say that with the nature of the materials that were recovered and the geological uniqueness of this sea, the scientific staff really could not miss. The lithologic descriptions in the site reports are among the best of the first three phases of the Deep Sea Drilling Project. With regard to sedimentary structures, the types of structures and the presence of complete or partial Bouma (1962) sequences were documented carefully, described and figured in the text, and recorded properly on the barrel summary sheets. Structures reported ranged from graded bedding, parallel laminae, micro-cross-laminae, bioturbation, graded foraminiferal sand laminae, flame structures, slump blocks, slump folds, nodular anhydrite, algal stromatolite laminae, mudcracks, and microfaulting. Bouma sequences were recorded from several sites and identified in terms of observed intervals as well as by intervals absent from an ideal succession.

Accompanying chapters by several onshore experts and shipboard participants were equally valuable. Friedman (1973) stressed the presence of nodular anhydrite, algal stromatolite, and flat-pebble conglomerates from a sabkha setting, which were represented in these sediments. The discussion of halite sedimentology by Hsü et al., (1973) stressed structures again, particularly desiccation features and micro-cross-laminae. Similarly, the chapter by Nesteroff (1973) on sapropels (see later discussion of paper by Kidd, Cita et al., 1978b, from Leg 42A) and the summary by Hsü et al. (1973) utilized sedimentary structures to interpret depositional processes and environments.

Leg 14

Leg 14 traversed the Central Atlantic (Hayes, Pimm et al., 1972, I.R. DSDP, 14). The lithologic summaries in the site reports were somewhat minimal and nothing was stated about structures. This minimal description, however, was complemented by an exhaustive study of the sediments by Berger and Von Rad (1972), which covered grain size, mineralogy, sedimentary structures, sedimentary facies, CCD fluctuations, and diagenesis. The discussion of sedimentary structures (Berger and Von Rad, 1972, pp. 822-824) focused on color banding, lithologically defined bedding, presence of allodapic carbonates (resedimented pelagic, biogenic carbonates deposited by turbidity currents), alternating sand-silt layers containing graded beds, sharp upper and lower boundaries, and lenticular bedding, and size grading of turbidities. Their descriptions were extremely detailed. The origin of these structures was covered in their section on facies, focusing primarily on turbidities and volcanogenic sandstones, where deposition by turbidity currents was recorded. Their emphasis focused only on detailed description by lithologic unit and by age distribution.

Leg 15

Leg 15 drilled in the Caribbean (Edgar, Saunders et al., 1973, I.R. DSDP, 15). The lithologies encountered were dominantly pelagic clays and oozes and chalks, some of which were bioturbated. Graded bedding was recorded from ash beds overlying basalts, but sedimentary structures were rarely preserved (see Edgar, Saunders et al., 1973, p. 408).

Maurasse (1973) recorded the presence of compositional and color-variable layering, parallel laminae, graded bedding in ashes, and microfaults.

Leg 17

Leg 17 focused on the geology of the western equatorial Pacific, a region dominated by pelagic carbonate and siliceous sediments and clays. Locally, however, turbidite clastics were deposited and these were derived from local guyots (Winterer, Ewing et al., 1973, I.R. DSDP, 17).

Although few observations were possible on sedimentary structures, Site 167 on the Magellan rise was characterized by cores containing sedimentary structures, particularly in intervals where limestone and volcaniclastic sandstones were interbedded. Among the structures reported and illustrated from Site 167 were parallel laminae, micro-cross-laminae, wavy bedding, lenticular bedding, graded bedding, and disturbed laminae (Fig. 7). All data point to a turbidite origin, a finding confirmed by the

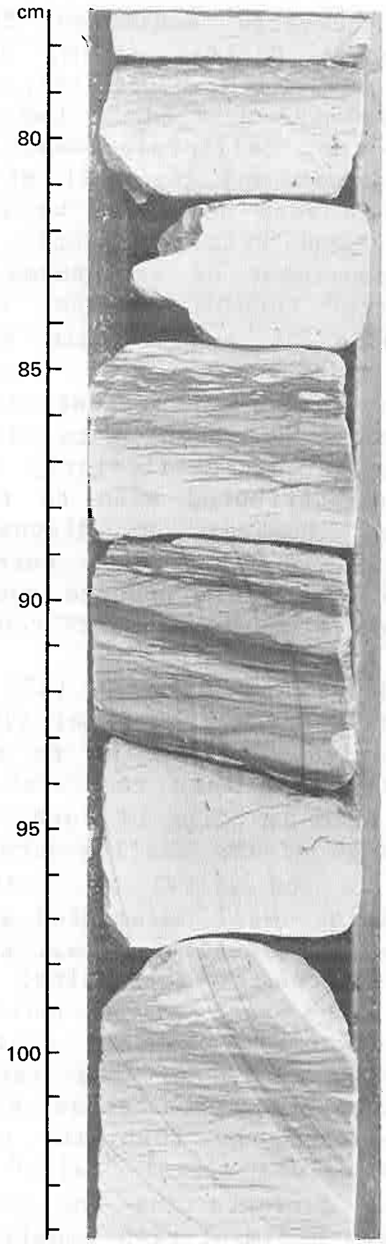

Figure 7. Lenticular bedding, flaser bedding, and flaser-bedded climbing-ripple sedimentary structure in limestone from Sample 167-64-3, 78-101 cm. Site 167, Magellan Rise.

presence of shallow-water displaced faunas, with perhaps some reworking by bottom currents.

Leg 18

Leg 18 recovered sediments from the northwestern Pacific (Kulm, Von Huene et al., 1973, I.R. DSDP, 18), although the cruise was devoted to two separate areas -- the California-Oregon continental margin and the Gulf of Alaska. Both areas were dominated by interbedded clay and silt sediments, and the usual assortment of structures associated with turbidites was reported. Most sands of such origin contained graded bedding, parallel lamination, and sharp bases and gradational tops. Cycles of sand grading into silty clay were recovered, particularly at Site 177, and attributed also to turbidity currents. However, no discussion of the details of turbidity current hydraulics that would produce such a sequence was given in the site reports.

The Gulf of Alaska sites (178 through 182) were discussed by Piper (1973) who paid particular attention to the silt turbidites that were recovered, interpreting them as being of turbidite origin because of the shallow-water microfossils in the silts; the presence of size grading (well documented with photometric size analysis data); the sharp basal contacts of the silts; and the overall high rate of accumulation of the sediments. Moreover, Piper documented that much of the interbedded clay associated with these silts was also deposited by turbidity currents. Both the dilute distal "tails" of such turbidity currents and the derivation of density sediment-rich underflows derived from glacial sources explained the finer grain size and the grading in these silts.

Leg 19

The North Pacific region was drilled during Leg 19 (Creager, Scholl et al., 1973, I.R. DSDP, 19) and because of its sub-Arctic location, most of the sediment recovered consisted of diatomaceous oozes and lithified equivalents. In addition, diatomaceous clays, hemipelagic clays, silts, and sands were recovered, some of which contained sedimentary structures. These were recorded in the lithologic descriptions and included such features as size grading of sands and silts, convolute laminae (Site 186, p. 221, fig. 5), slump blocks, and inclined bedding (comprising part of slump blocks). Slump fractures also were recorded in siltstones, some filled with clay (Fig. 8); these fractures were clearly oriented at near-right angles to bedding (see Site 189, p. 332, fig. 10). Additional details were given by Fullam et al., (1973).

Leg 21

Leg 21 drilled eight sites in the active margin zones of the southwest Pacific (Burns, Andrews et al., 1973, I.R. DSDP, 21). This cruise recovered cores with a great deal of sediment diversity, and, as a consequence, the shipboard sedimentologists were able to record a variety of sedimentary structures and vertical sequences. Within ash beds, volcanic sandstones, and conglomerates, a variety of sedimentary structures were reported including micro-cross-laminae, graded bedding, reverse graded bedding, contorted laminae, and dish structures (Fig. 9). Despite this variety of structures, the site reports did not specify the mechanics of deposition other than to suggest turbidites.

The site Report 210, however, contains a very detailed discussion and description of a series of graded cycles (sequences) from the Pliocene and Quaternary of the Coral Sea (Fig. 10). These sequences consist of a sharp base and a basal dark gray silt. Next above is an interval of silty clay and clayey silt, and the sequence is capped by a light-colored clay, sometimes containing nannofossils (see Burns, Andrews et al.,

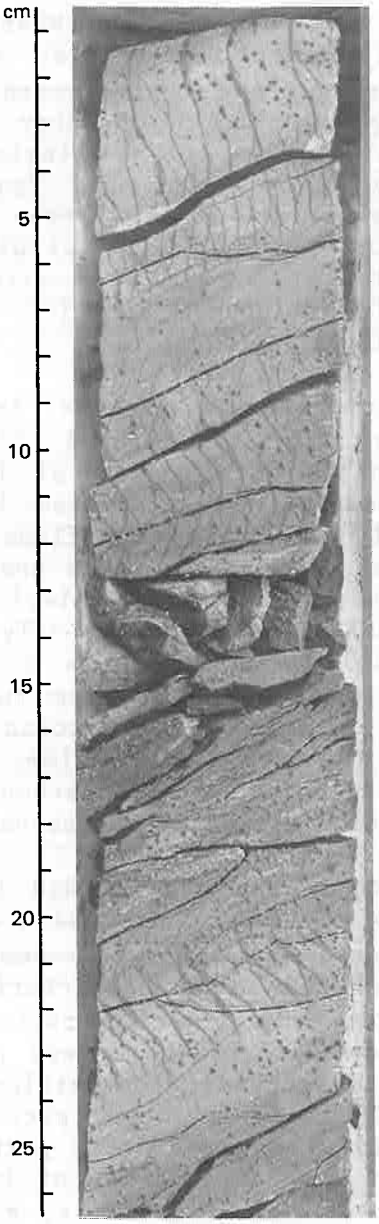

Figure 8. Vertical and folded slump fractures filled with clay in silty mudstone, Sample 189-13-3, 0-26 cm. Site 189, north flank of the Aleutian Ridge, Bering Sea.

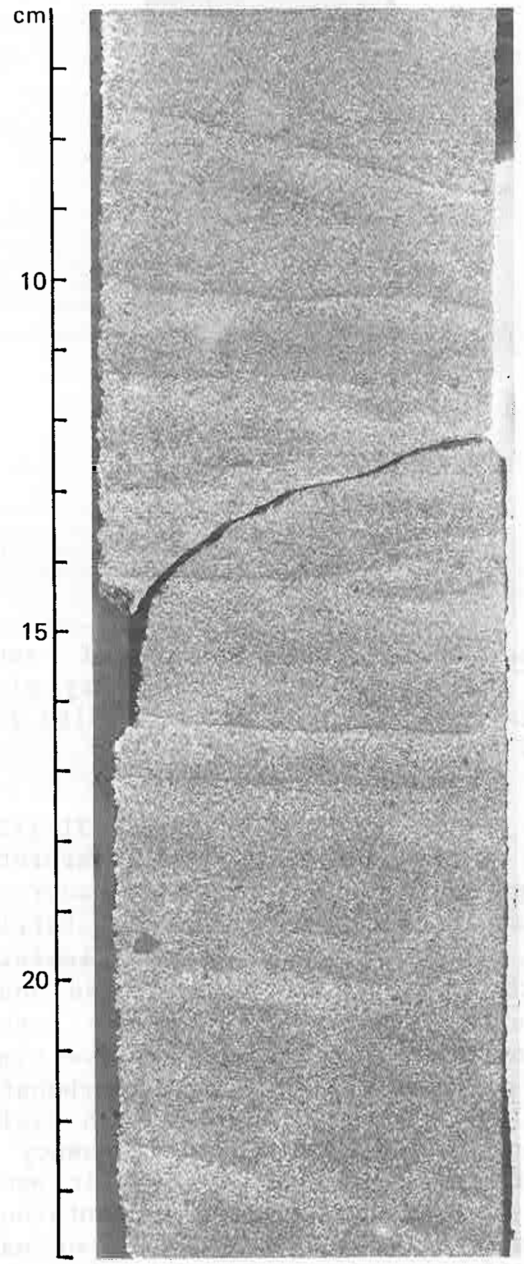

Figure 9. Dish structures, Sample 204-9-3, 6-24 cm. Site 204, Upper Trench Slope, Tonga-Kermadec Trench. (Photo courtesy of W. H. Busch.)

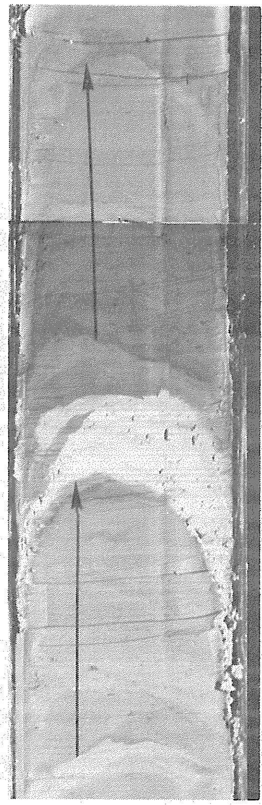

Figure 10. Graded cycle of sandy silt grading into silt and silty clay, Sample 287-6-4, 68-92 cm. Site 287, Coral Sea.

1973, I.R. DSDP, 21, pp. 371-372). These graded sequences are interpreted to be emplaced by turbidity currents because of the basal scour, the terrigenous origin of the component minerals, and the presence of resedimented shallow-water fossils. The organic carbon component of these cycles is five times that of underlying pelagic carbonates and clays. A total of 1900 such cycles is estimated, indicating a frequency of deposition of one turbidite cycle every 4000 years. These cycles are interbedded with an estimated 800 beds of nannofossil ooze, some of which also show evidence of resedimentation (containing shallow-water forms).

Interbedded with these clayey turbidite sequences is a series of silts and sands that is characterized by sharp bases and sharp tops and parallel lamination, indicating deposition from ocean bottom currents.

Leg 22

This leg drilled into the Wharton Basin, the Ninety East Ridge, and the Bengal Fan in the northeastern Indian Ocean (Von Der Borch, Sclater et al., 1974, I.R. DSDP, 22). Pelagic oozes and clays were recovered from most sites, although a few other exotic lithologies (such as lignite) also were recovered. The Bengal Fan site (218) recovered terrigenous clastics -- mostly turbidites.

Sedimentary structures were described from two sites only. At Site 212, graded chalks with horizontal laminae, micro-cross-laminae, contorted laminae, flute and load casts, and flame structures were recovered. These are interbedded and overlain by pelagic brown clay. These chalks were clearly resedimented below the CCD in a depth approximately 6000 m by either turbidity currents, or more likely, ocean bottom currents (Gartner, 1974; Pimm, 1974). Several instances of such carbonate resedimentation events were observed.

On the Bengal Fan both graded beds of silty sand and sandstones and a cyclicity of graded units were recovered. The graded beds were characterized by sharp upper and lower contacts, suggesting some erosional process had occurred after turbidity deposition (Site 218, p. 327). In the lower part of the hole, within the older basal portion of the Bengal Fan, a cyclicity of lithologies with a basal graded silt, a parallel-laminated and micro-cross-laminated silt and clayey silt, and an uppermost silt was common. Superimposed on these were dark clay-rich silt laminae spaced at 2-8 cm throughout the entire lower sequence. Deposition of these cycles was by turbidity currents that controlled the growth of the Bengal Fan.

The dark silty laminae spaced every 2 cm appear to have beem emplaced every 400 years (Pimm, 1974, p. 738).

Leg 23

Leg 23 drilling focused on two regions, -- the Arabian Sea (Sites 219-224) and the Red Sea (Sites 225-230) that was dominated by evaporites (Whitmarsh, Weser, Ross et al., 1974, I.R. DSDP, 23). The Arabian Sea sites included several parts of the Indus Cone as well as areas of pelagic carbonate sedimentation. The Indus Cone sites were dominantly sand and silt, silt, and nanno-rich clay. Graded bedding was common to the sands, whereas parallel laminae and micro-cross-laminae occurred commonly in either sands, silts, or clayey silts. Several types of graded beds were observed (Jipa and Kidd, 1974), including normal graded beds with sharp bases and gradational tops, normal graded beds with both sharp bases and sharp tops, and inverted graded bedding, where silty clay coarsens upward within a bed to a silt and then fines up toward the top of the bed. Parallel laminae and micro-cross-laminae occur within normal graded beds, as do climbing ripples and truncated foresets. These graded units were emplaced by turbidity currents, but Jipa and Kidd (1974, p. 480) make the distinction that the lower part of the graded beds were deposited only from suspension, whereas the upper part of the graded bed that is laminated or micro-cross-laminated involves combined suspension and traction deposition.

In addition to these graded layers in the Indus Cone sites, microfolding, slump folding, slump blocks (Fig. 11), and microfaults were observed in some of the nanno-rich clays of this region.

The Red Sea sites contained several sedimentary structures, including chicken-wire anhydrite, algal stromatolitic planar lamination and oncolites, color banding, lithologic banding of anhydrite and halite, fine lamination in silts, and graded bedding in

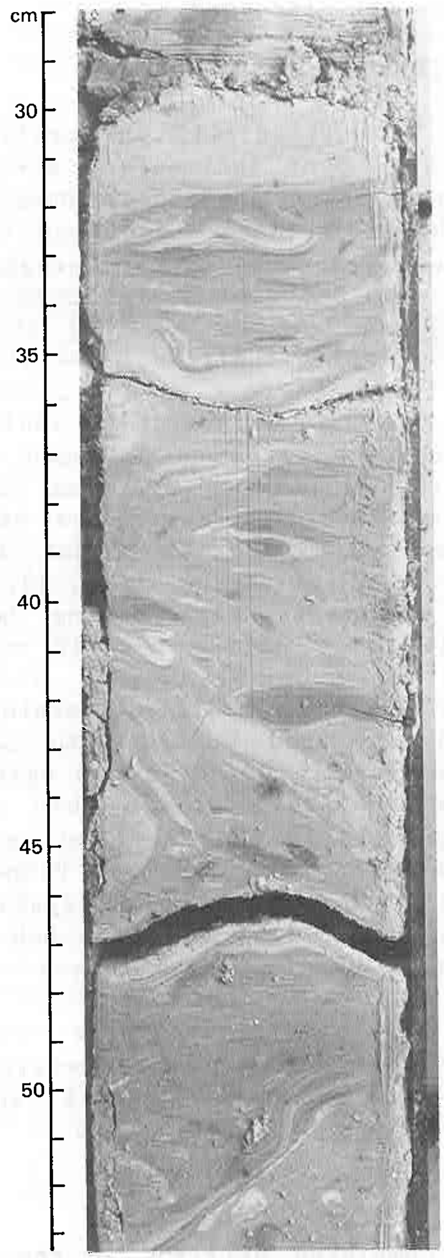

Figure 11. Slump blocks and slump folds, Sample 223-24-3, 29-53 cm. Site 223, west flank of Owen Ridge, northwest Arabian Sea.

terrigenous sands and lithified tuffs. The evaporites and stromatolitic limestones clearly point to a sabkha origin (Stoffers and Kuhn, 1974; Stoffers and Ross, 1974). The mechanics of deposition was not discussed.

PHASE III

During DSDP Phase III, the utilization and analysis of sedimentary structures and sedimentary sequences showed considerable improvement, and such studies were more frequent. This increased interest resulted from better core recovery, deeper penetration (and thus recovery of more lithified material), and more frequent continuous coring on site. The mode of recording sedimentary structures data was expanded starting with Leg 38 when a system of symbols for recording structures was introduced on a separate column on the barrel summary sheets (Fig. 1). Despite excellent usage during Leg 38, sporadic usage during Legs 39 and 40, and no usage during Legs 41, 42A, and 42B, a slightly modified version was adopted and used during both Legs 43 and 44. During Leg 58, a new system of symbols was field-tested; this system was developed by the Panel on Sedimentary Petrology and Physical Properties (Fig. 2). This new set of symbols is currently in use by the Deep Sea Drilling Project.

During Phase III, intervals of the Bouma (1962) sequence were recorded by letter code on the barrel summary sheets (Legs 30, 38, 42A, 43).

Leg 25

Leg 25 completed drilling in the western Indian Ocean in the Madagascar, Somali, and Mozambique basins (Simpson, Schlich et al., 1974, I.R. DSDP, 25). Within the sedimentary sections recovered from 11 sites, sedimentary structures were recorded from 9 and were confined mostly to terrigenous sands and silts, although some were observed also in nanno chalks. Structures were interpreted to have been emplaced by turbidity currents, including graded bedding with sharp bases and indistinct tops, lenticular bedding, parallel lamination, slump folds, and micro-cross-laminae. Within the chalks, graded bedding, micro-cross-laminae, and parallel laminae occur. A peculiar red-and-black-banded, parallel laminated claystone was described from Site 248.

Many of these features are illustrated in Moore (1974). He dealt with terrigenous sands and muds, provided a great deal more detail concerning the sedimentary structures, and reviewed the nature of depositional processes of these sediments. Moore concentrated on the terrigenous sediments that were found in slope and basin settings at Sites 239, 240, 241, 243, 244, 248, and 249. Four subdivisions were recognized -- graded bedded units, massive sands, flysch, and laminates. The graded beds, in addition to being size-graded, contained sand and displaced fauna and are associated with parallel laminae and micro-cross-laminae. Massive sands at Sites 240 and 248 range up to 1 m in thickness and show both displaced fauna and inverse grading. Flysch, present only at Site 244, consisted of calcareous sand, graded beds, and laminated claystone, with graded bedding, micro-cross-laminae, slump folds, convolute beds, and both partial and complete Bouma sequences.

The graded beds and flysch deposits clearly were emplaced by turbidity currents, mostly from terrigenous land sources down submarine canyons onto slope and basin settings. The massive sandstones were transported at least 750 km from source by a mass flow or grain flow deposit, but Moore believed additional work was needed to understand their origin. Subsequent work during Leg 30 (Klein, 1975a, c) and Leg 31 (Bouma and Pluenneke, 1975) suggested deposition of such sediments as sandy debris flow. The laminates were deposited by grain settling of clays or from nepheloid layers, presumably fed by sediment from turbidite input.

Leg 28

Leg 28 was the first of several DSDP legs that explored the Antarctic margin. Much of the sediment recovered consisted of diatomaceous oozes and clays, interbedded with glacial marine sediments and clays and minor sands. The site reports list a variety of sedimentary structures such as graded beds, parallel bedding, micro-cross-laminae, slump blocks, inclined bedding (due to slump), and microfaults. Barrel summary sheets record both the presence of structures and the exact position in the core where the structures occur.

The discussion of these structures is sketchy in the site reports, but Piper and Brisco (1975) describe them in far more detail. Supporting grain-size and mineralogical data and photographs of some of these features are included (Piper and Brisco, 1975, pp. 734-735). Most of the sands are graded. The major emphasis of the Piper-Brisco paper is on the origin of silty laminae, some of which are lenticular in nature. These laminae appear to be formed by contour bottom currents, rather than by turbidity currents, although Piper and Brisco (1975) admit the sedimentary criteria for these currents are not too clear and differ from those of Bouma and Hollister (1973). The Antarctic margin also is an area of turbidite sedimentation as indicated by the graded sands at Sites 268 and 274. Silty grading is present also.

None of the structures described from this region appear to be arranged in a sequence, and no comparison to sequences was mentioned.

Leg 30

Leg 30 (Andrews, Packham et al., 1975, I.R. DSDP, 30) drilled three back-arc basin (South Fiji, New Hebrides, and Coral Sea) sites and two sites on the Ontong-Java Plateau. The site reports described a variety of sedimentary structures and sequences (or cycles) both from turbidites and volcaniclastic sediments as well as from resedimented pelagic biogenic carbonates in the Ontong-Java Plateau. These were described and illustrated in greater detail by Klein (1975a; see, also, Klein 1975b, c).

At Sites 285 and 286, similar stratigraphies and sedimentology were observed. Basal turbidites contained parallel laminae, micro-cross-laminae, reverse graded bedding, normal bedding, flame structures (Fig. 12), in-phase waves, convolute laminae, dewatering pipes (Fig. 13), and sharp basal scours. In addition to being listed in the site reports, the individual barrel summary sheets contained a summary description of structures and sequences for each unit on the barrel sheet covering the first appearance of the unit containing such features. Sequences present in the turbidites at Site 285 and 286 were of two types (Andrews, Packham et al., 1975, Site Reports, I.R. DSDP, 30). At Site 285, the sequences in volcaniclastic sandstone consisted of an "a" interval with a basat scour and parallel-laminated sandstone with micro-cross-laminae, an overlying "b" interval which is finer grain and faintly laminated, and next above, a "c" interval of bioturbated mudstone (Andrews, Packham et al., 1975, p. 32). Their origin was left indeterminate in the Site Report, although in the chapter by Klein (1975a), graded bedding was also observed and he interpreted such cycles or sequences to be produced by turbidity currents (Fig. 14).

The sequences at Site 286 differ. Overlying a basal scour is an "a" interval of graded sandstone, grading up into a silty sandstone with parallel laminae and micro-cross-laminae ("b" interval), and in turn overlain by a bioturbated siltsone and capped by silty claystone (Andrews, Packham et

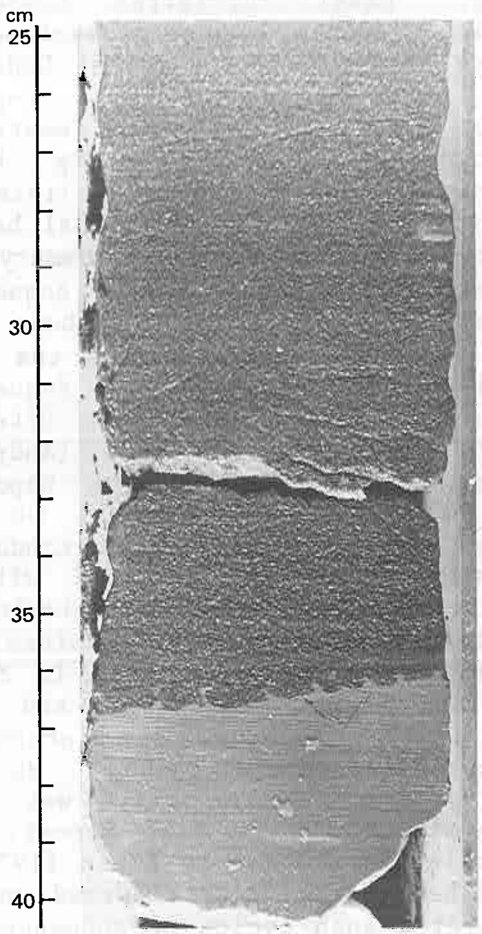

Figure 12. Coarse-tail graded bed with sharp scour and flame structures, Sample 286-29-2, 25-46 cm. Site 286, New Hebrides Basin.

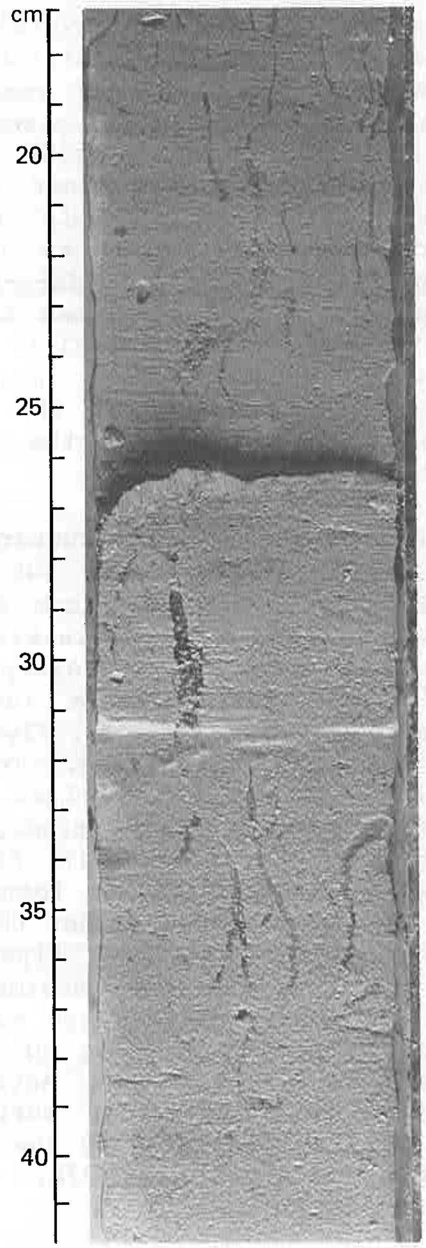

Figure 13. Water-escape structures in mudstone, Sample 286-27-2, 118-141 cm. Site 286, New Hebrides Basin.

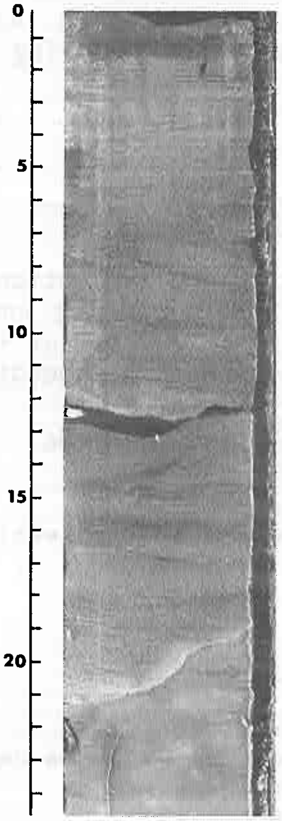

Figure 14. Partial vertical Bouma sequence showing sharp scour overlain by both graded and micro-cross-laminated sand and capped by parallel-laminated silty sand, Sample 285-6-3, 0-24 cm. Site 285, south Fiji Basin.

al., 1975, p. 99). These intervals are coded by letter on the barrel summary sheets. These sequences owe their origin to turbidity currents (Klein, 1975a, c).

At Site 287 the dominant motif of sedimentation, as at Site 210 (Burns, Andrews et al., 1973, I.R. DSDP, 21), is that of terrigenous turbidites organized into graded cycles with a basal scour, overlain by a sandy silt, a clayey silt, a silty clay, and capped by clay. These are also indicated on the barrel summary sheets (Fig. 10).

The Ontong-Java sites consist dominantly of biogenic carbonate sediment. Much of these show sedimentary structures, including dewatering pipes, slumped beds, interbedded graded volcanic ashes with mixed carbonate material, flaser, wavy, and lenticular bedding, and parallel lamination. The intervals where such structures occur are recorded on the barrel summary sheet. Cyclic color banding is also present.

Klein (1975a) described the sequences and each of the structures in detail. The graded sequences from Sites 285 and 286 are related to the Bouma (1962) sequence, reporting only four complete sequences recovered and several types of partial sequences. These sequences and structures are related to different aspects of turbidite deposition on submarine fans in these basins. Klein (1975a, b) also described the sequential arrangement of sedimentary structures and lithologies in the resedimented pelagic carbonates of the Ontong-Java Plateau, where admixing of volcanic ashes, which are also resedimented, brings out the structures more clearly. Essentially, these cycles, referred to as volcaniclastic-siltstone-pelagic-carbonate cycles (Fig. 6), consisted of a sharp basal scour overlain by a graded volcanic glass shard siltstone ("a" interval). This is overlain by a "b" interval of foraminiferal, silt-sized limestone with thin laminae of altered glass shards arranged as parallel laminae, flaser bedding, lenticular bedding, and wavy bedding. Micro-cross-laminae also occur in this interval. This sequence is capped by a "c" interval of pelagic biogenic carbonate. These sequences were interpreted to have been deposited by both turbidity currents (graded ash intervals) and reworking bottom currents, perhaps with a tidal component (see, also, Klein, 1977a) or with a longer-term alternation of a bedload and a suspension mode of deposition and transport. This style of resedimentation appears to have been more widespread (Fig. 7) as discovered in later drilling on the Daito Ridge (Klein, Kobayashi et al., 1980, I.R. DSDP, 58), and from a series of seismic surveys and box coring cruises by Berger and Johnson (1976), who demonstrated that on the Ontong-Java Plateau, extensive mass movement of biogenic carbonate sediment is triggered by dissolution along fracture zones and the edge of the plateau.

Leg 31

Leg 31 (Karig, Ingel et al., 1975, I.R. DSDP, 31) drilled in the Philippine Sea and Sea of Japan. Sedimentary structures were observed and recorded in the lithological descriptions of the Site Reports and on the barrel summary sheets. Structures reported included "vague" lamination, thin bedding, graded bedding, cut-and-fill structure, load casts, slump structures, and foreset bedding (synonym: micro-cross-laminae). Partial Bouma sequences representing T_{b-e} were recorded from Site 297 in the Shikoku Basin, where turbidites are well represented.

Excellent descriptive details and illustrations about sedimentary structures are provided in three shore-based chapters by Bouma (1975a, b) and Bouma and Pluenneke (1975). The emphasis was on description, classification, and association of structures with lithologies. Bouma (1975b) proposed and applied a new classification for his structures (Table 2) that fits moderately well with the general classification revised from Potter and Pettijohn (1964) given earlier (Table 1). Bouma (1975b) recognized three lithologic associations in Leg 31 sediment cores with associated structures. These were: (1) volcanic conglomerates and conglomeratic sandstone -- faint bedding, (2) tuffs and sandstone -- thick laminae, graded bedding, (3) chalks -- bedding lamination.

Sedimentary sequences of two kinds were reported from Leg 31 cores. Partial Bouma sequences were recorded from site 297 in the Shikoku Basin (see Karig, Ingle et al., 1975, p. 280). These sediments were interpreted to represent varying styles of turbidites. A second type of sequence was reported from the Toyama Submarine Fan (Bouma, 1975a, p. 494) consisting of six components with a gradational size change accompanied by a color change. The basal unit consists of clayey sand with laminae, grading up into sandy silt clay, silty clays (with silt content diminishing upward), and capped by clay. The basal clayey sand shows both parallel laminae and "micro-grading" (Bouma, 1975a, p. 494), but because the sediments were soft, most structures and laminae have been distorted. These cycles owe their origin to deposition as overbank interchannel fan deposition adjoining channel levees.

Lastly, faint, thin bedding and graded bedding were observed in debris flow conglomerates from the Philippine Sea (Bouma and Pluenneke, 1975).

Although these studies by Bouma (1975a, b) were excellent in terms of description, they provided less interpretation

Table 2. Classification of sedimentary structures used during Leg 31 by Bouma (1975b).

Primary Structures

1. Bedding and lamination
   a. Simple bedding and lamination, regular or irregular
   b. Composite bedding and lamination
   c. Foreset bedding
   d. Homogeneous
2. Graded bedding
3. Wedge-shaped and lenticular
4. Primary inclusions or nests
5. Erosional contacts

Secondary Structures

1. Bioturbation
2. Penecontemporaneous deformation
   a. Load casting
   b. Slumping
   c. Microfaulting
3. Mycelium

about the mechanics of sedimentation than some of the earlier as well as subsequent DSDP studies. Vague discussions about possible contourite versus turbidite deposition were included, however.

Leg 32

Leg 32 (Larson, Moberly et al., 1975, I.R. DSDP, 32) drilled in the northwestern Pacific. Sedimentary structures were recorded from only two sites (306 and 313). Faintly-laminated and parallel-laminated chalks occur at Site 306, whereas at Site 313 volcaniclastic and calcareous volcanic sandstones are interbedded with pelagic carbonates. They contain a diversity of structures, including "mud-supported" debris flow conglomerates, graded bedding, micro-cross-laminae, parallel laminae, penecontemporaneous folding, groove casts, load casts, ripples, and slump structures (Fig. 4). These are listed in the lithologic reports and on the barrel summary sheets. The thickness of turbidite layers is shown on the barrel summary sheets by large triangles where the base of the triangle represents the base, and the apex represents a finer-grained top of the turbidite bed.

Leg 33

Leg 33 (Schlanger, Jackson et al., 1976, I.R. DSDP, 33) drilled in the southern Line Islands and the Manihiki Plateau of the south central equatorial Pacific. The site reports and barrel summary sheets record sedimentary structures in both biogenic pelagic carbonates and in volcaniclastic sandstones. In the biogenic carbonates, graded foraminiferal oozes and chalks are common, associated with reefal debris and other shallow-water debris, and volcanic material. These are well illustrated by Cook et al. (1976). (The reader is warned, however, that all their photographs of structures are upside down.) Resedimentation by turbidity currents is inferred. In addition to these graded features, parallel laminae and micro-cross-laminae occur, as do both soft and hard deformation features such as slump folds (Fig. 15) and crinkled tops (see, also, Jenkyns, 1976).

Volcaniclastic sediments that are common to the basal portions of nearly all sites drilled during Leg 33 show the usual assortment of turbidite structures, including graded bedding, parallel laminae (Fig. 16), micro-cross-laminae, and sequential arrangements of structures. Although vertical sequences are not described in the site chapters or the chapters by Cook et al. (1976) or Jenkyns (1976), both partial and complete Bouma sequences are shown in the core photographs accompanying the site reports.

Leg 35

Leg 35 drilled four sites in the southeast Pacific on the Bellingshausen Abyssal Plain and Rise (Hollister, Craddock et al., 1976, I.R. DSDP, 35). Core recovery was poor, but discussion of sedimentary structures is incorporated in both the site reports and in Tucholke et al. (1976), which adds laboratory data on grain size and provides excellent illustrations.

The description and discussion of structures focused on the relative importance of turbidite deposition and sedimentation by normal ocean currents. Evidence for turbidite deposition included the presence of terrigenous sands, silts, and clays that are graded and organized into partial Bouma sequences with a sharp base, a graded bed, a parallel-laminated interval, and a convolute and disturbed bedded interval. Load casts, microfaults, and slump folds also occur. Turbidite sedimentation appears to be dominant on the Bellingshausen Rise, and distal turbidites are present in the Bellingshausen Abyssal Plain.

In addition, interbedded, well-sorted silt laminae and clay laminae are common, the silt layers showing both a sharp base and a sharp top. These were

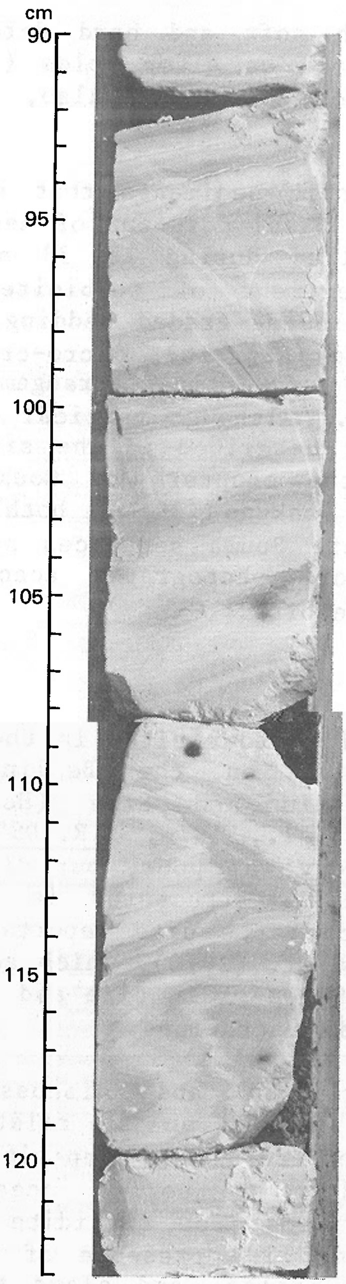

Figure 15. Slump microfaults in slump-folded limestone, Sample 318-16-2, 91-123 cm. Site 318, north side of Tuamoto Ridge.

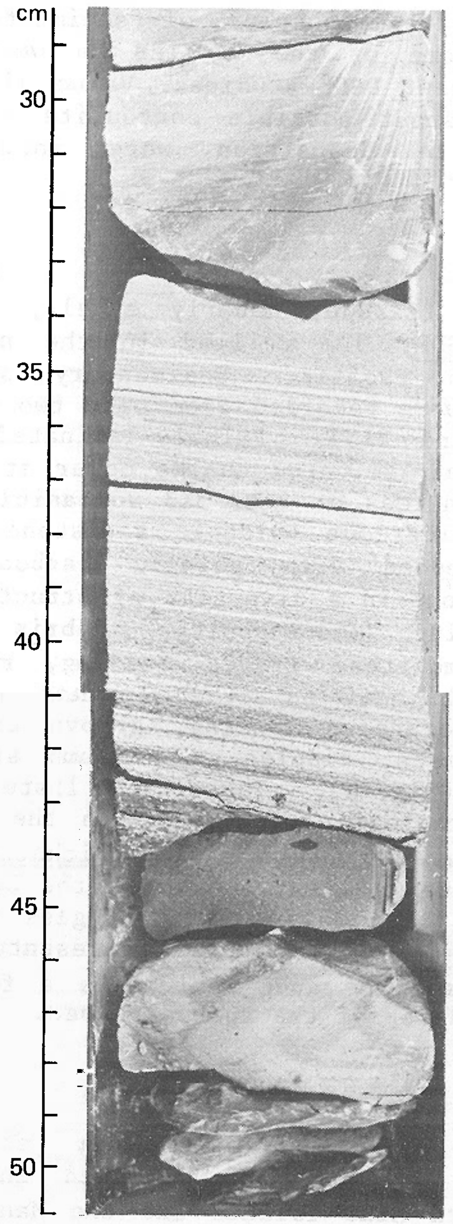

Figure 16. Parallel-laminated graded carbonate-volcaniclastic sandstone, Sample 318-28-1, 128-150 cm. Site 318, north side of Tuamoto Ridge.

considered to be of ocean current origin, but both in the site reports and the chapter by Tucholke et al. (1976) extreme caution is indicated about the true depositional process producing these structures. Although it is suggested that perhaps these silts are the result of turbidity current-fed sediment resedimented by ocean currents, it is stated that no clear-cut criteria for ocean bottom currents were present. These sediments containing such structures are sufficiently distinct from turbidites that such a mechanism seems most likely.

Leg 38

Leg 38 drilled 17 sites in the Norwegian and Greenland seas (Talwani, Udintsev et al., 1976, I.R. DSDP, 38).

This leg was the first in which sedimentary structure data were recorded on the barrel summary sheets using a special set of symbols (Fig. 1). Sedimentary structures were mentioned in the site reports and in the text of the barrel summary sheets. But it was observed that in many instances sedimentary structure symbols were recorded on the barrel summary sheets but not mentioned either in the site reports or in the descriptions of the barrel summary sheets; or structures were mentioned on the barrel summary sheets, but the structure symbols were missing. Both the site reports, the barrel summary sheets and the structures symbols were minimal compared to the data reported by Nilsen (1978).

Nilsen's (1978) description of sedimentary structures recovered from Leg 38 cores is among the most detailed reported in the Initial Reports. He identified and described massive bedding, graded bedding, reverse graded bedding, parallel lamination, cross-stratification, convolute lamination, disturbed and deformed beds, rip-up clasts, load clasts, dish structures, and slump folds. All these structures were related to the depositional mechanisms of turbidity currents, although very little was said by Nilsen about bottom currents or alternative processes. Thus, the site reports contain reference to "distal" turbidites, as does White's (1978) sedimentary synthesis, but Nilsen says little about them. Nilsen described varieties of Bouma sequences, which are common in these turbidites. Their relationshiip to sediment dispersal and basin geometry was not mentioned.

Leg 39

Leg 39 (Supko, Perch-Nielsen et al., 1976, I.R. DSDP, 39) drilled along the Brazilian continental margin, the Rio Grande Rise, and the Walvis Ridge. Sediments recovered contained a few sedimentary structures, such as slumped breccias (see, also Thiede, 1976), contortions, dark laminae, graded ash beds, graded foraminiferal sands, load casts, and microfaults. These were recorded also using the new symbols proposed on Leg 38 on the barrel summary sheets. However, some sheets show structures not mentioned in the site reports, and other barrel summary sheets recorded symbols that are not coded to any explanatory scheme listed anywhere in the volume. Thinly laminated silts were attributed to a distal turbidite origin in the site reports.

Thiede (1976) described and illustrated slump breccias, indicating extensive resedimentation by slumping from shallower water, a finding consistent with the occurrences of graded foraminiferal sands, and the presence of shallow-water fossils such as Inoceramus. McCoy and Zimmerman (1976) dealt with paleocirculation and facies distribution, where the facies are based only on grain size and composition, but the authors do not discuss sedimentary structures.

Leg 40

Leg 40 (Bolli, Ryan et al., 1978, I.R. DSDP, 40) took place in three rifted basins in the Atlantic continental margin off southwestern Africa. A variety of sedimentary structures were described and illustrated in the site reports, the accompanying barrel summary sheets, and two shore-based chapters by Kagami (1978) and Natland (1978). Kagami (1978) summarized the types of structures by sites rather well, with excellent descriptions, excellent illustrations, and a tabulation of occurrence of structures both by site and by lithologic unit and lithofacies. The structures were classified as per Bouma (1975b) and included bedding (thickness in excess of 1 cm), laminae (thickness less than 1 cm), color banding, groove casts, graded beds, foreset laminae (micro-cross-laminae), load casts, microfaulting, slump folds, lenticular beds, sandstone dikes, and concretions. Size analyses were reported for some of the graded beds.

Natland (1978) mentioned a few of these structures, as well as illustrating them both in the text and two plates. Although details are coordinated with Kagami's paper, Natland (1978) observed and illustrated a Bouma sequence, and related much of the sandstone deposition to turbidite deposition. However, some of the micro-cross-laminated intervals are neither graded nor in a sequential arrangement, but, instead, are characterized by "Placers" or coarser grains within cross-laminae, a criteria suggested by Hollister and Heezen (1972) as potentially distinctive of contourites. Such features are particularly characteristic of sands on the Walvis Ridge where other evidence indicates strong current activity.

Leg 41

Drilling on Leg 41 focused on the basins of the continental margin of West Africa (Lancelot, Seibold et al., 1978, I.R. DSDP, 41) and emphasized regional pelagic and hemipelagic deposition. Although a few structures are listed in the site reports, and the barrel summary sheets mention structures, or code so-called "turbidite sequences" at Site 367 with a triangular symbol, there is no basis for identifying such sequences as being of turbidite origin. However, Dean et al. (1978) pointed out that recognition of turbidites comes from the presence of terrigenous components in cyclic alternations of dark clays with sharp bases grading into light clays. Associated sand layers may contain load casts, graded beds, and laminae. Some slump deposits are present and can be observed in the core photographs. Other cycles in the recovered cores include a diagenetic, or redox cycle, and a pelagic cycle. Other structures, such as micro-cross-laminae and parallel laminae, are reported from Mesozoic rocks recovered by drilling and are discussed by Jansa et al. (1978). The mechanics of deposition and the basis for interpretations are not mentioned, but turbidites and contourites are identified.

Leg 42A

Leg 42A took place in the Mediterranean (Hsü, Montadert et al., 1978, I.R. DSDP, 42A). Descriptions of sedimentary structures were minimal in the site reports. The barrel summary sheets did not include a special column for structures and the official symbols adopted during Leg 38 were not used. Graded bedded intervals and fining-upward intervals were recorded with an arrow indicating the appropriate interval where such features are represented. Only Site Report 375/376 included more than routine mention of structures. What would appear as a minimal effort in recording structures in the site reports may well have come about because sedimentary structures were described in moderate to great detail by Kidd et al. (1978b) dealing with sapropels; by Garrison et al. (1978) dealing with the Messinian Evaporities; and by Kidd et al. (1978a) dealing with lithologies.

Within the sapropels, a great variety of structures were documented, following an earlier, briefer discussion by Nesteroff (1973) from Leg 13 (Ryan, Hsü et al., 1973, I.R. DSDP, 13). Structures are tabulated according to type and sapropel bedding contacts. The sapropels contain size grading, parallel laminae, graded bedding, micro-cross-laminae, and either sharp base-sharp tops, or a sharp basal contact and a gradational top. These organic-rich sediments are pelagic-type turbidite, although the micro-cross-laminated intervals possibly could be resedimented contourites (see, also, Nesteroff, 1973).

Garrison et al. (1978) provided an extremely detailed report on the nature and origin of sedimentary structures in the evaporite sediments recovered during Leg 42A. This chapter is perhaps the most detailed discussion of sedimentary structures in evaporites that has been published. Not only are the structures listed and described megascopically but they are discussed also on the basis of examination of thin sections with a polarizing microscope. The supporting microscopic study was a critical component of the interpretations of the origin and environment of deposition of these structures. Structures are described by site and subsequent lithofacies subdivision of evaporite rock type.

Essentially, structures present include parallel lamination in anhydrite, gypsum and halite, nodular anhydrite, laminated anyhdrite (replaced stromatolitic algal laminae), flaser bedding, micro-laminae, reverse graded laminae in gypsum, rip-up clasts, micro-cross-laminae, asymmetrical ripples, graded-bedded laminated gypsum, graded-bedded gyparenites and gyprudites, entrolithic folding, wavy laminae, and microfaulting. Selenite crystals and grains contain inclusions of eggs of brine shrimp and fecal pellets.

Some of the lithologies and structures are arranged in a preferred sedimentary sequence (Garrison et al., 1978). At Site 374, Garrison et al. (1978) observed a three-fold cycle with a basal "A" member consisting of dolomitic mudstone with brecciation, parallel laminae, and crinkled laminae, overlain by a "B" interval of brown and white gypsum, with parallel-laminae that are wafer thin, with alternating color contrasts of dark and light parallel laminae, reverse grading, micro-cross-laminae, and capped by a "C" interval of wavy bedded to nodular gypsum (Fig. 17). The "A" interval represents a subaqueous zone, the "B" interval a tidal flat to shallow subtidal zone, and the "C" interval clearly is a sabkha or exposed zone. The interpretation is shown in Fig. 17.

The origin of the structures is complicated not only by mechanical primary depositional modes of origin but by the continual solution and redeposition of evaporites, giving rise to brecciation, reverse grading and certain types of parallel laminae. The origin of some of the parallel-laminated gypsum by solution and redeposition and recrystallization is shown in Fig. 18.

A second cycle mentioned in the site reports is that reported from Site 376 involving terrigenous arenites and marlstones. Here the basal (A member) consists of terrigenous arenites with

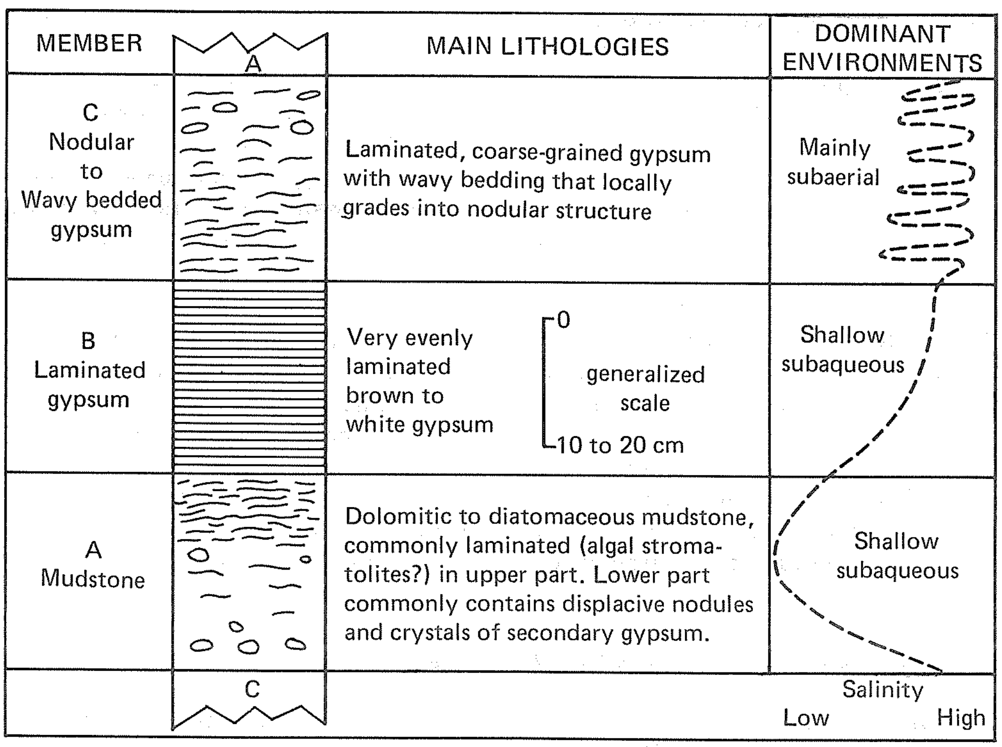

Figure 17. Schematic representation of gypsum-mudstone sequence at Site 374. The dotted line in column at right represents a generalized salinity curve (from Garrison et al., 1978, fig. 17).

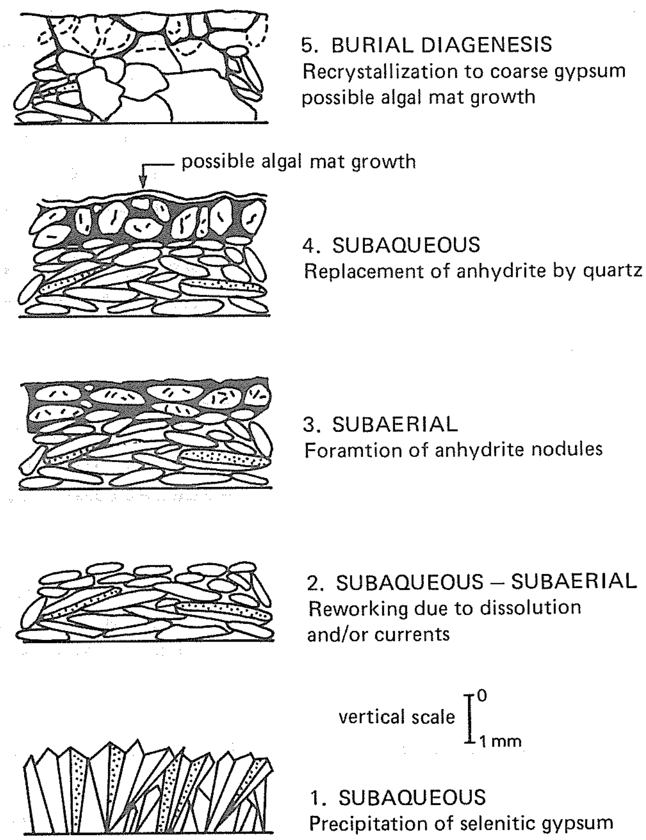

Figure 18. Schematic representation of interpreted sedimentological and diagenetic events during development of smaller cycles in uppermost member of gypsum-mudstone sequence at Site 374 (from Garrison et al., 1978, fig. 30).

sharp lower contacts, rare graded bedding, parallel laminae, and micro-cross-laminae, overlain by a "B" interval of structureless marl, overlain by ("C" interval) partly bioturbated marl. These presumably represent distal turbidites. Other instances of graded beds and partial or complete Bouma sequences were also mentioned by Kidd et al. (1978b) from the pre-evaporite beds encountered during drilling. These, again, represent turbidite deposition.

Researchers interested in sedimentary structures in DSDP cores should read Kidd's (1978) paper dealing with core-discing and other "structural" artifacts of drilling. Previously, it was mentioned that drilling disurbance obliterated any potentially preserved structures in soft sediments. Within intervals where alternating lithified and soft sediments occur, or where there are pronounced changes in lithology, it is not uncommon for the cores to be broken horizontally along such contacts and for individual pieces to rotate during coring. As a consequence, the upper parts of hard zones become convex, and the lower or under surface becomes concave. This process, or core-discing, can be confused with a cut-out or erosional contact without more critical examination. Kidd (1978) also mentioned that some microfaults observed in cores represent displacements induced by the drill string, particularly in semilithified materials. Thus, caution must be exercised when examining these structures.

Leg 42B

This leg drilled three sites in the Black Sea (Ross, Neprochnov et al., 1978, I.R. DSDP, 42B), where most of the recovered sediment represented deposition in a lake, rather than in an ocean. Sedimentary structures were recorded from all three sites and the descriptive information in the site reports is detailed. The accompanying barrel summary sheets however, minimized this detail, failed to record sedimentary structure symbols (although they appear in the introduction), and contained a minimal amount of data concerning structures (except for recording their presence in a few instances). The most common structures observed was graded bedding, parallel laminae, and micro-cross-laminae in terrigenous turbidites that were generally fine grained (fine sand, mostly silt and clay). Varved clays were common to two of the sites (380 and 381) and these consisted of couplets of silty clay grading into clay.

The most interesting and unusual lithology and sequence involved the so-called "seekreide" sediments representing a lacustrine carbonate deposit, very fine grained, similar to a deep-water ooze. These are arranged cyclically, consisting of a basal medium gray mud, grading into a burrowed mud zone, and capped by light gray calcareous ooze.

Breccias containing carbonate rocks with algal stromatolites also were recovered, suggesting derivation from a shoreline algal-matte type of desiccated flat that was remobilized into deeper lake waters. Extensive zones of slumped seekreides also occur and are tilted and folded.

Stoffers and Müller (1978) list these same structures and mention both turbidite and slump processes.

Leg 43

Leg 43 drilled in the western North Atlantic (Tucholke, Vogt et al., 1979, I.R. DSDP, 43) retracing the drilling performed during Legs 11 and 12. Volume 43 appears to be the first in which detailed attention was given to systematically recording sedimentary structures and sequences and symbols on the barrel summary sheets. The descriptions in the site reports also are of a high level, giving much detail about sedimentary structures and sequences.

Most of the sedimentary structures reported from Leg 43 occur in turbidites. Thus, most of the clastic components contain coarser beds that are characterized by sharp basal scours, graded bedding, parallel laminae, and, in some instances, micro-cross-laminae. Silts and siltstones are also laminated. Slump breccias are recorded from one site and debris flow volcaniclastic breccias from two other sites. The silts and siltstones also are graded, and although such grading was less apparent in visual descriptions aboard ship, such grading was confirmed by McCave (1979) using a Coulter Counter particle size analyzer.

The finer grained turbidites at Sites 386 and 387 are organized into a special vertical sequence that has much in common with the bouma sequence, but also some important differences (Fig. 19). It is subdivided into five components, labeled with Greek letters. The basal bed "alpha" is characterized by a sharp scour, and consists of graded sand and/or silt and is overlain by the "beta" interval of laminated claystone. Both "alpha" and "beta" correspond to the A and B interval of Bouma (McCave, 1979, p. 396). Next above is the "gamma" interval of homogeneous claystone and it is overlain by a "delta" interval of mottled claystone rich in carbonate. The entire sequence is

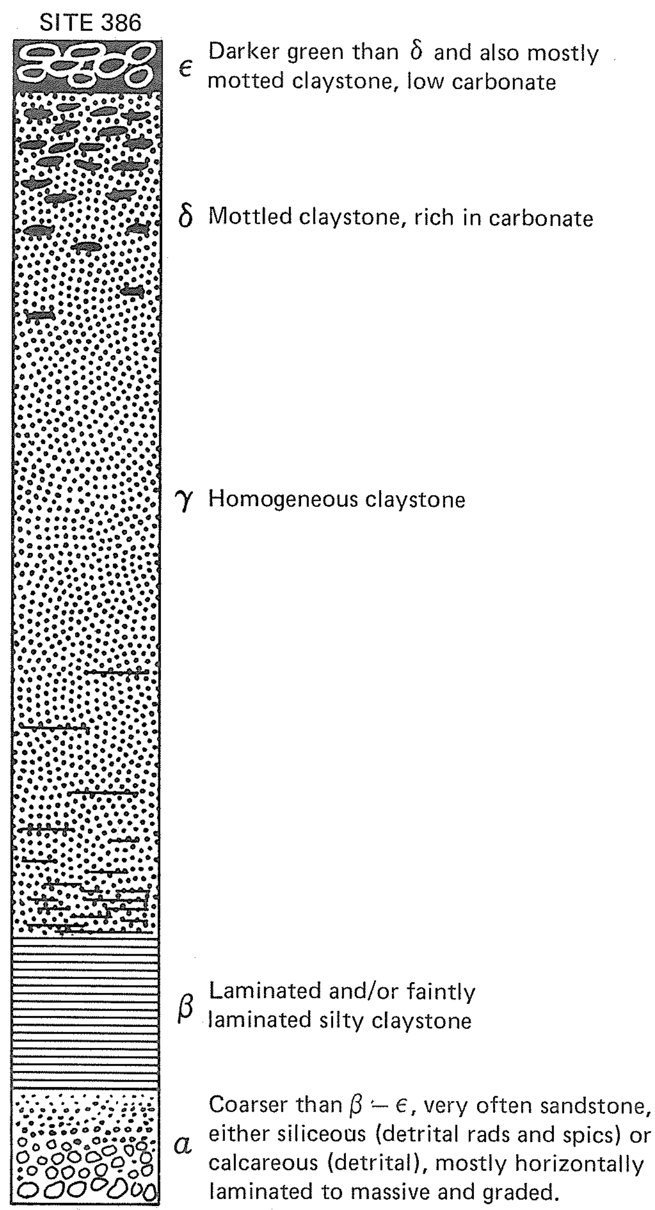

Figure 19. Idealized sequence of silty turbidites at Site 386 (from Tucholke, Vogt et al., fig. 8).

capped by an "epsilon" interval consisting of darker green claystone that is mottled and low in carbonate (Fig. 19). These sequences fine up, and as McCave (1979) showed, the fining-upward trend is confined to the basal three intervals (see, also, Table 3). These are dominantly silty fining-upward sequences and are of turbidite origin.

These sequences are coded by Greek letters in the barrel summary sheets in the site reports; this coding was accomplished by constricting the width of the lithologic symbols column.

Leg 44

Leg 44 drilled in the Blake Plateau and western Atlantic (Benson, Sheridan et

Table 3. Turbidites of Units 4A (Site 386) and 3A (Site 387) (from McCave, 1979, table 1).

Layer[a]	Characteristics	Interpretation	Sand	Silt[b]	Clay
α	Base of next unit				
ε	Dark green non-calcareous claystone	Pelagic interturbidite deposit below CCD			
δ	Light green calcareous silty claystone with dark green burrow mottles	Sediment burrowed down into calcareous material	0	30	70
γ	Light green calcareous silty claystones	Fine sediment bulk of current deposited rapidly	0	30	70
β	Laminated to faintly laminated silty claystone	Plane bed deposition in upper flow regime	1	44	55
α/β	Boundary-gradational		3	54	43
α	Massive to graded clayey siltstone to sandy siltstone	Rapid deposition in upper flow regime	13	67	20

[a] α and β are equivalent to Bouma's (1962) A and B divisions, γ and δ to his E division (less certainly), and ε to the F division of Van der Lingen (1969).

[b] Silt = 63 μm to 3.9 μm (4 to 8 ∅). Size data from the DSDP laboratory at Scripps Institution of Oceanography.

al., 1978, I.R. DSDP, 44). The barrel summary sheets utilized the sedimentary structure code and proposed some new symbols for unique lithologies germaine to that leg -- namely, the very shallow-water carbonates recovered at Site 392 (Fig. 2). During this leg, turbidites with grading and parallel laminae and partial Bouma sequences were encountered (see, also, Sheridan et al., 1978), but the most distinctive sedimentary structures features in limestone were reported by Enos and Freeman (1978) and Freeman and Enos (1978). Structures observed included interlayered coarse and fine-grained limestone, graded calcarenties, parallel laminae, wavy beds, mudcracks, birds-eye structure (fenestral pores), and laminated chalks. Clearly these structures, some of which include algal stromatolites, indicated coastal carbonate deposition in shallow subtidal and intertidal flats, not unlike in the present-day Bahamas. Supporting petrographic data confirmed the interpretation.

CONCLUDING REMARKS

This review has focused on observations of sedimentary structures by DSDP scientists during Phases I-III. The data and interpretations regarding deep-sea sediment transport and depositional processes have been highly variable. Nevertheless, certain topics stand out and are summarized here.

1) The sedimentary structures data reported in site reports range from listing sedimentary structures in the text or on the barrel summary sheets to detailed descriptions of sedimentary structures in both site report chapters and in chapters covering shore-based sedimentology. There appears to be no standard manner in which sedimentary structures observations were reported. Thus, in some legs (e.g., 35, 42A) sedimentary structures were barely mentioned in the text, yet the accompanying shore-based chapters included extremely detailed descriptions and interpretations of sedimentary structures. In other cases the reverse was true where detailed descriptions and interpretations of sedimentary structures were confined to the site report chapters (e.g., Legs 13, 43) and minimal discussion was presented in the shore-based chapters.

2) The nature of associated grain-size data was, again, highly variable. Some DSDP legs incorporated grain-size data of restricted graded intervals in shore-based studies (e.g., Legs 1, 18, 28, 43), whereas others did not mention them. In some instances, such grain-size data are incorporated in the chapters dealing with grain size, but cross-referencing to specific intervals of sedimentary structures is missing.

3) Recording of sedimentary structures with symbols or letter codes was undertaken on a minimal basis prior to Leg 38. Thus, some legs showed graded beds and graded intervals on barrel summary sheets with an arrow for the appropriate interval (e.g., Legs 13, 42A) or by a letter for the appropriate intervals in which certain portions of Bouma sequences are represented (e.g., Legs 13, 21, 30 43). Instead of using a letter code, some legs adopted a system of showing such graded sequences with a triangle, where the base of the triangle coincided with the base of the interval, and the top of the triangle indicated the top of the sequence and the fining-upward trend (e.g., Legs 32, 41).

4) Since Leg 38, formal symbols for recording sedimentary structures have been in use by the Deep Sea Drilling Project. These were used extensively during Legs 38 and 39, and sporadically during Leg 40. They were omitted during Legs 41, 42A, and 42B, but used again during Legs 43 and 44, and presumably in the subsequent IPOD phase. A new system for recording sedimentary structures was field-tested during Leg 58 and has been in operation since 1979. This new system (Fig. 2) was recommended by the Panel on Sedimentary Petrology and Physical Properties. These new symbols are expected to

foster comparison of Deep Sea Drilling sediment cores to land-based outcrops.

5) Recovery by the Deep Sea Drilling Project of graded sands with associated sedimentary structures organized into a systematic vertical sequence has confirmed many land-based interpretations of deposition of graded sands in deep-water environments by turbidity currents. These observations were confirmed with the observation of identical structures and the presence of reworked shallow-water microfossils in turbidites recovered by DSDP. Detailed analysis of sedimentary structures by Nesteroff (Leg 13), Moore (Leg 25), Klein (Leg 30), Bouma (Leg 31), Tucholke et al. (Leg 35), Kagami (Leg 40), among others, has established more firmly the turbidity current hypothesis in ocean basin analysis.

6) Analysis of sedimentary structures by DSDP sedimentologists has not solved the problem of establishing definitive criteria for recognizing sediments deposited by normal ocean botton currents and contour currents. Studies by Lancelot et al. (Leg 11), Piper (Leg 18), Piper and Briscoe (Leg 38), Tucholke et al. (Leg 35), and McCave (Leg 43), among others have skirted the problem. Criteria of recognition of such sediments suggested by Hollister and Heezen (1972) and Bouma and Hollister (1973) have neither been confirmed nor rejected. This problem has been obscured in part by recognition of distal turbidite beds that may show similarity to contourites, and by the suggestion that some contourites and other bottom current-deposited sediments may be fed by turbidity currents. Consequently, some inherited "turbidite" features, particularly size grading, may be common to sediments deposited by both mechanisms.

7) Examination of sedimentary structures occurring in pelagic biogenic carbonate sediments, sapropels, and laminated pelagic mudstone indicates that many sediments of pelagic origin experience a later history of resedimentation by physical processes, primarily turbidity currents. Such observations have been made periodically since Leg 9 (Cook, 1972) and are discussed extensively by Lancelot et al. (1972), Moore (1974), Klein (1975a, b), and Cook et al. (1976) for carbonate sediments recovered during Legs 11, 25, 30, and 33, respectively. Similarly, Nesteroff (1973) and Kidd et al. (1978a, b) devote considerable discussion to resedimentation of pelagic sapropels from the Mediterranean (Legs 13, 42A). These studies lack, however, a quantitative estimate of the volumes of resedimentation of biogenic carbonate sediments by physical processes and how these processes change concepts of deep-sea rates of sedimentation and of carbonate preservation and dissolution. In short, the phenomenon has been observed, but its quantitative significance has not been evaluated. A preliminary evaluation was undertaken with data from Leg 58 (White et al., 1980).

8) Only a few of the DSDP sedimentologists have attempted to tie their interpretations of sedimentary structures with larger-scale problems of deep-sea fan deposition, basin evolution, and sedimentary tectonics. Thus, Moore (1974) and Bouma (1975a) examined the nature of continental margin and back-arc basin deep-sea fans and demonstrated similarities between proposed models of fan-evolution suggested by Normark (1969) and Mutti and Ricci-Lucchi (1972). Data from the Delgada Fan (Leg 18), the Bengal Fan (Leg 22), and the Indus Cone (Leg 23) did not permit any further resolution of evaluating the validity of some of these concepts by direct drilling. An occurrence of repeated coarsening-upward cycles in a back-arc basin submarine fan recorded by Klein (1975a, c) from the New Hebrides Basin (Site 286) suggests that the fan facies models of Normark (1969) and Mutti and Ricci-Lucchi (1972) occur in the drill-hole record obtained by DSDP.

Recognition of depositional systems from analysis of sedimentary structures and sedimentary sequences recovered by drilling during the Deep Sea Drilling Project has permitted tying the timing of specific depositional events to certain stages of seafloor tectonics. Thus, Moore (1974) demonstrated that the submarine fans of the East African continental margin are associated with early rifting of the Indian Ocean; Klein (1975a, c) has proposed that submarine fan development in a back-arc basin is associated with an early history of basin rifting, followed by a phase of sedimentation when pelagic processes become more dominant when basin rifting has ceased. A somewhat similar scenario was developed from analysis of sediment data by Karig, Ingle et al. (1975, I.R. DSDP, 31) in the Philippine Sea and Sea of Japan. The Atlantic legs have demonstrated that certain sedimentary systems, such as black shales, are associated with restricted basin circulation (Hollister, Ewing et al., 1972; Davies and Laughton, 1972; Berger and Von Rad, 1973; Nilsen, 1978; McCoy and Zimmerman, 1976; Lancelot, Siebold et al., 1978; and Ryan, Bolli et al., 1978). Multi-colored limestones of a deep-water type were common in the earlier stages of marine circulation (Hollister, Ewing et al., 1972; Berger and Von Rad, 1973; among others), and so forth. These Atlantic studies on sedimentary tectonics have been more lithologically oriented than those mentioned by Moore (1974), Klein (1975a, b), and Bouma (1975a b).

9) In closing, it must be emphasized that although research on sedimentary structures and vertical sequences has lagged in the Deep Sea Drilling Project, this lag can be attributed to spot coring in the earlier legs, drilling in pelagic-dominated realms, minimal recovery, and drilling disturbance. This condition began to change starting with Phase III (Leg 25) when more attention was paid to recording structures and utilizing them to interpret oceanic processes and geologic history. With Phase III, drilling technology improved, permitting recovery of lithified material for analysis. The adoption of a symbolic code for recording structures during Leg 38 permitted more routine observations of structures to be made and seems to have further stimulated research in this area.

It is perhaps noteworthy that the evolution of sedimentary structures research by the Deep Sea Drilling Project has paralleled the evolution of sedimentological research on land. In the earlier days of land-based sedimentology, the research focused on studies of the vertical and lateral distribution of rock types, grain-size changes, and mineralogical changes. Research on sedimentary structures in outcrops became an active field in the period following World War II and now comprises a significant part of analysis facies and depositional systems. The sedimentology of deep-water sediments recovered by DSDP drilling has experienced a similar evolution, focusing in its earlier history on vertical and lateral distribution of grain size, mineralogy, and dissolution phenomena. Since Phase III started, analysis of sedimentary structures and associated facies and systems analysis has come more into its own. Thus, despite the unevenness of data and interpretation of DSDP sedimentary structures in the past, the future for such studies looks most promising.

REFERENCES

Allen, J. R. L., 1965. Fining-upward cycles in alluvial succession. Geol. J., 4:229-246.

Beall, A. O., and Fischer, A. G., 1969. Sedimentology. I.R. DSDP, 1:521-592.

Beall, A. O., Laury, R., Dickinson, K., and Pusey, W. C., III., 1973. Sedimentology. I.R. DSDP, 10:699-730.

Bernard, H. A., LeBlanc, R. J., and Major, C. F., Jr., 1962. Recent and Pleistocene geology of southeast

Texas. Geol. Gulf Coast Central Texas Guidebook of Excursions. Houston (Houston Geol. Soc.), pp. 175-225.

Bersier, A., 1958. Sequence detritique et divagations fluviales. Eclog. Geol. Helv., 51:854-893.

Berger, W. H., and Johnson, T. C., 1976. Deep-sea carbonates -- dissolution and mass wasting on Ontong-Java Plateau. Science, 192:785-787.

Berger, W. H., and Von Rad, U., 1972. Cretaceous and Cenozoic sediments from the Atlantic Ocean. I.R. DSDP, 14:707-954.

Blatt, H., Middleton, G. V., and Murray, R. C., 1972. Origin of Sedimentary Rocks: Englewood Cliffs, N.J. (Prentice-Hall).

Bouma, A. H., 1962. Sedimentology of Some Flysch Deposits: Amsterdam (Elsevier).

_______, 1975a, Deep-sea fan deposits from Toymama Trough, Sea of Japan. I.R. DSDP, 31:489-495.

_______, 1975b, Sedimentary structures of Philippine Sea and Sea of Japan sediments, DSDP Leg 31. I.R. DSDP, 31: 471-488.

Bouma, A. H., and Hollister, C. D., 1973. Deep ocean basin sedimentation. In Middleton, G. V., and Bouma, A. H. (Eds.), Turbidites and Deep-Water Sedimentation: Los Angeles, (Soc. Econ, Paleont. Mineral., Pacific Section Short Course), pp. 79-118.

Bouma, A. H., and Pluenneke, J. L., 1975. Structures and textural characteristics of debrites from the Philippine Sea. I.R. DSDP, 31:497-505.

Castle, J. W., 1978. Comparative sedimentology of modern and ancient oceanic trench deposits (Unpublished Ph.D. dissertation), Univ. of Illinois at Urbana-Champaign.

Coleman, J. M., 1976. Deltas: Processes of Deposition and Models for Exploration: Champaign (CEPCO).

Cook, H. E., 1972. Stratigraphy and sedimentology. I.R. DSDP, 9:933-944.

Cook, H. E., Jenkyns, H. C., and Kelts, K. R., 1976. Redeposited sediments along the Line Islands, Equatorial Pacific. I.R. DSDP, 33:837-847.

Davies, T. A., and Laughton, A. S., 1972. Sedimentary processes in the North Atlantic. I.R. DSDP, 12:905-934.

Dean, W. E., Gardner, J. V., Jansa, L. F., Čepek, P., and Seibold, E., 1978. Cyclic sedimentation along the continental margin of northwest Africa. I.R. DSDP, 41:965-989.

DeRaaf, J.F.M., and Boersma, J. R., 1971. Tidal deposits and their sedimentary structures. Geol. Mijnb., 50: 479-504.

Enos, P., and Freeman, T., 1978. Shallow-water limestones from the Balke Nose, Sites 390 and 397. I.R. DSDP, 44:413-461.

Freeman, T., and Enos, P., 1978. Petrology of Upper Jurassic-Lower Cretaceous limestone, DSDP Site 391. I.R. DSDP, 44:463-475.

Friedman, G. M., 1973. Petrographic data comments on the depositional environment of the Miocene sulphates and dolomites at Sites 124, 132 and 134, Western Mediterranean Sea. I.R. DSDP, 13:695-708.

Fullam, T. J., Supko, P. R., Boyce, R. E., and Stewart, R. W., 1973. Some aspects of the Cenozoic sedimentation in the Bering Sea and North Pacific Ocean. I.R. DSDP, 19:887-896.

Garrison, R. E., Schreiber, B. C., Bernoulli, D., Fabricius, F. H., Kidd, R. E., and Mélières, F., 1978. Sedimentary petrology and structures of

Messinian evaporitic sediments in the Mediterranean Sea, Leg 42A, Deep Sea Drilling Project. I.R. DSDP, 42A:571-611.

Gartner, S., 1974. Nannofossil biostratigraphy, Leg 22, Deep Sea Drilling Project. I.R. DSDP, 22:577-587.

Ginsburg, R. N., (Ed.), 1975. Tidal Deposits: New York (Springer-Verlag).

Hollister, C. D., and Heezen, B. C., 1972. The Face of the Deep: Oxford (Oxford Univ. Press).

Hsü, K. J., Ryan, W.B.F., and Schreiber, B. C., 1973. Petrography of a halite sample from Hole 134, Balearic Abyssal Plain. I.R. DSDP, 13:708-711.

Jackson, R. G., 1978. Preliminary evaluation of lithofacies models for meandering alluvial systems. In Miall, A. D. (Ed.), Fluvial Sedimentology: Can. Soc. Petrol. Geol. Mem., 5:543-576.

Jansa, L. F., Gardner, J. V., and Dean, W. E., 1978. Mesozoic sequences of the central north Atlantic. I.R. DSDP, 41: 991-1032.

Jenkyns, H. C., 1976. Sediments and sedimentary history of Manihiki Plateau, south Pacific Ocean. I.R. DSDP, 33:873-890.

Jipa, D., and Kidd, R. B., 1974. Sedimentation of coarser-grained interbed in the Arabian Sea and sedimentation processes on the Indus Cone. I.R. DSDP, 23:471-495.

Kagami, H., 1978. Sedimentary features of Cape Basin and Angola Basin sediments, DSDP Leg 40. I.R. DSDP, 40:525-540.

Kidd, R. B., 1978. Core-discing and other drilling effects in DSDP Leg 42A Mediterranean sediment cores. I.R. DSDP, 42A:1143-1149.

Kidd, R. B., Bernouilli, D., Garrison, R. E., Fabricius, F. H., and Mélières, F., 1978a. Lithologic findings of DSDP Leg 42A, Mediterranean Sea. I.R. DSDP, 42A:1079-1094.

Kidd, R. B., Cita, M. B., and Ryan, W. B. F., 1978b. Stratigraphy of eastern Mediterranean sapropel sequences recovered during DSDP Leg 42A and their paleoenvironmental significance. I.R. DSDP, 42A:421-443.

Klein, G. deV., 1971. A sedimentary model for determining paleotidal range. Geol. Soc. Am. Bull., 82:2585-2592.

________, 1975a. Depositional facies in Leg 30 deep-sea sediment cores. I.R. DSDP, 30:423-442.

________, 1975b. Resedimented pelagic carbonate and volcaniclastic sediments and sedimentary structures in Leg 30 DSDP cores from the western equatorial Pacific. Geology, 3:39-42.

________, 1975c. Sedimentary tectonics in southwest Pacific marginal basins based on Leg 30 Deep Sea Drilling Project cores from the South Fiji, Hebrides and Coral Sea Basin. Geol. Soc. Am. Bull., 86:1012-1018.

________, 1977a. Clastic tidal facies: Champaign, CEPCO, 148 p.

________, 1977b. (Ed.). Sedimentary processes: processes of detrital sedimentation. Soc. Econ. Paleontol. Mineral. Repr., Ser. 4.

Lancelot, Y., Hathaway, J. C., and Hollister, C. D., 1972. Lithology of sediments from the western North Atlantic, Leg XI, Deep Sea Drilling Project. I.R. DSDP, 12:901-950.

Maurasse, F., 1973. Sedimentary structures of Caribbean Leg 15 sediments. I.R. DSDP, 15:833-845.

McCave, I. N., 1979. Diagnosis of turbidites at Sites 386 and 387 by particle-counter size analysis of the silt (2-40 m) fraction. I.R. DSDP, 43:395-405.

McCoy, F. W., and Zimmerman, H. B., 1976. A history of sediment lithofacies in the south Atlantic Ocean. I.R. DSDP, 39:1047-1079.

Middleton, G. V., 1965. (Ed.). Primary sedimentary structures and their hydrodynamic interpretation -- a symposium. Soc. Econ. Paleontol. Mineral. Spec. Publ. 12.

_______, 1973. Johannes Walther's law of the correlation of facies. Geol. Soc. Am. Bull., 84:979-988.

_______, 1977. (Ed.), Sedimentary processes: sedimentary structures: Soc. Econ. Paleontol. Mineral. Repr., Ser. 3.

Moore, J. C., 1974. Turbidites and terrigenous muds. I.R. DSDP, 25:441- 470.

Mutti, E., and Ricci-Lucchi, F., 1972. Le torbiditi dell'Appennino settentrionale: introduzione all 'analisi di facies'. Mem. Soc. Geol. Ital., 11: 161-199.

Natland, J. H., 1978. Composition, provenance and diagenesis of Cretaceous clastic sediments drilled on the Atlantic continental rise off southern Africa, DSDP Site 361 -- implications for the early circulation of the south Atlantic. I.R. DSDP, 40:1025-1062.

Nanz, R. H., Jr., 1954. Genesis of Oligocene sandstone reservoir, Seeligson Field, Jim Wells and Kleberg Counties, Texas. Am. Assoc. Petrol. Geol. Bull., 51:2033-2043.

Nesteroff, V., 1973. Petrography and mineralogy of sapropels. I.R. DSDP, 13:713-720.

Nilsen, T. H., 1978. Turbidites, red beds, sedimentary structures, and trace fossils observed in DSDP Leg 38 cores and the sedimentary history of the Norwegian-Greenland Sea. I.R. DSDP, 38: 259-288.

Normark, W. R., 1969. Growth patterns of deep-sea fans. Am. Assoc. Petrol. Geol. Bull., 54:2170-2195.

Pettijohn, F. J., 1975. Sedimentary Rocks (3rd ed): New York (Harpers).

Pettijohn, F. J., and Potter, P. E., 1964. Atlas of Sedimentary Structures: New York (Springer-Verlag).

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972. Sand and Sandstone: New York (Springer-Verlag).

Pimm, A. C., 1974. Sedimentology and history of northern Indian Ocean from the Cretaceous to Recent. I.R. DSDP, 22:717-803.

Pimm, A. C., Garrison, R. E., and Boyce, R. E., 1971. Sedimentology synthesis: Lithology, chemistry and physical properties of sediments in the northwestern Pacific Ocean. I.R. DSDP, 6:1131-1152.

Piper, D.J.W., 1973. The sedimentology of silt turbidites from the Gulf of Alaska, I.R. DSDP, 18:847-863.

Piper, D.J.W., and Brisco, C. D., 1975. Deep-water continental margin sedimentation, DSDP Leg 28, Antarctica. I.R. DSDP, 28:727-755.

Selley, R. C., 1970. Ancient Sedimentary Environments: London (Chapman & Hall).

Sheridan, R. E., Enos, P., Gradstein, F., and Benson, W. E., 1978. Mesozoic and Cenozoic sedimentary environments of the western North Atlantic. I.R. DSDP, 44:971-979.

Stoffers, P., and Kuhn, R., 1974. Red Sea evaporite: A petrographic and geochemical study. I.R. DSDP, 24:821-847.

Stoffers, P., and Müller, G., 1978. Mineralogy and lithofacies of Black Sea sediments, Leg 42B, Deep Sea Drilling Project. I.R. DSDP, 42B:373-411.

Stoffers, P., and Ross, D. A., 1974. Sedimentary history of the Red Sea. I.R. DSDP, 23:849-859.

Taira, A., and Scholle, P. A., 1979. Deposition of resedimented sandstone beds in the Pico Formation, Ventura Basin, California, as interpreted from magnetic fabric measurements. Geol. Soc. Am. Bull., 90:952-962.

Thiede, J., 1976. Sedimentary structures in pelagic and hemipelagic sediments from the central and southern Atlantic Ocean (Deep Sea Drilling Project Leg 39). I.R. DSDP, 39:407-422.

Tucholke, B. E., Hollister, C. D., Weaver, F. M., and Vennum, W. R., 1976. Continental rise and abyssal plain sedimentation in the southeast Pacific Basin -- Leg 35, Deep Sea Drilling Project. I.R. DSDP, 35:359-400.

Van der Lingen, G. J., 1969. The Turbidite Problem: New England Jour. Geol. and Geophysics, 12:7-50.

Visher, G. S., 1965. Use of the vertical profile in environmental reconstruction. Am. Assoc. Petrol. Geol. Bull., 49:41-61.

Walker, R. G., 1978. Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. Am. Assoc. Petrol. Geol., 62:932-966.

White, S. M., 1978. Sediments of the Norwegian-Greenland Sea, DSDP Leg 38. I.R. DSDP, 38:193-257.

White, S. M., Chamley, H., Curtis, D. M., Klein, G. deV., and Mizuno, A., 1980. Sedimentological synthesis, Leg 58, Philippine Sea. I.R. DSDP, 58:963-1014.

3. SEDIMENT SMEAR SLIDES: PREPARATION AND HANDLING

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INTRODUCTION

The Deep Sea Drilling Project drilled 575 holes at 394 sites and recovered 52,583 m of sediment from August 1968 until the end of its third phase of drilling in November 1975. Along with other data, this resulted in approximately 30,000 smear slides and their descriptions to be archived and processed by DSDP. This chapter discusses smear-slide preparation, the evolution of their descriptions, and the subsequent processing and handling of these data from Legs 1 through 44.

DEFINITION AND PREPARATION

A smear slide is examined utilizing a petrographic microscope to determine sediment composition. A classification scheme (see van Andel, Chapter 1) is employed to determine the sediment name once the mineral and/or fossil composition is known.

There are four different types of slides prepared aboard ship: untreated sediment smear slides, coarse-fraction smear slides, acid-treated smear slides, and thin sections. Thin sections are "hard rock" equivalents of smear slides and are discussed elsewhere in this manual. Of the three types discussed here, the untreated slide is the most representative, hence the most commonly used to classify a sediment.

The slide is prepared by scraping a small portion of sediment from a split core section with a spatula or a toothpick. The material is distributed evenly (adding water as necessary) on a standard glass slide. Then the sediment is dried on a hot plate, imbedded in Caedex, sealed with a cover slip, and cured. This basic procedure has not varied since the Deep Sea Drilling Project began. A detailed description of this method can be found in the provisional edition (May 1968) of the DSDP Core Description Manual, "Part V: Shipboard Treatment of Cores."

A coarse-fraction slide is made up only of grains greater in size than 63 microns. These slides are prepared by sieving (through a 63-mm sieve) a portion of sediment that has been disaggreagated (using a chemical deflocculent or by mechanical agitation).

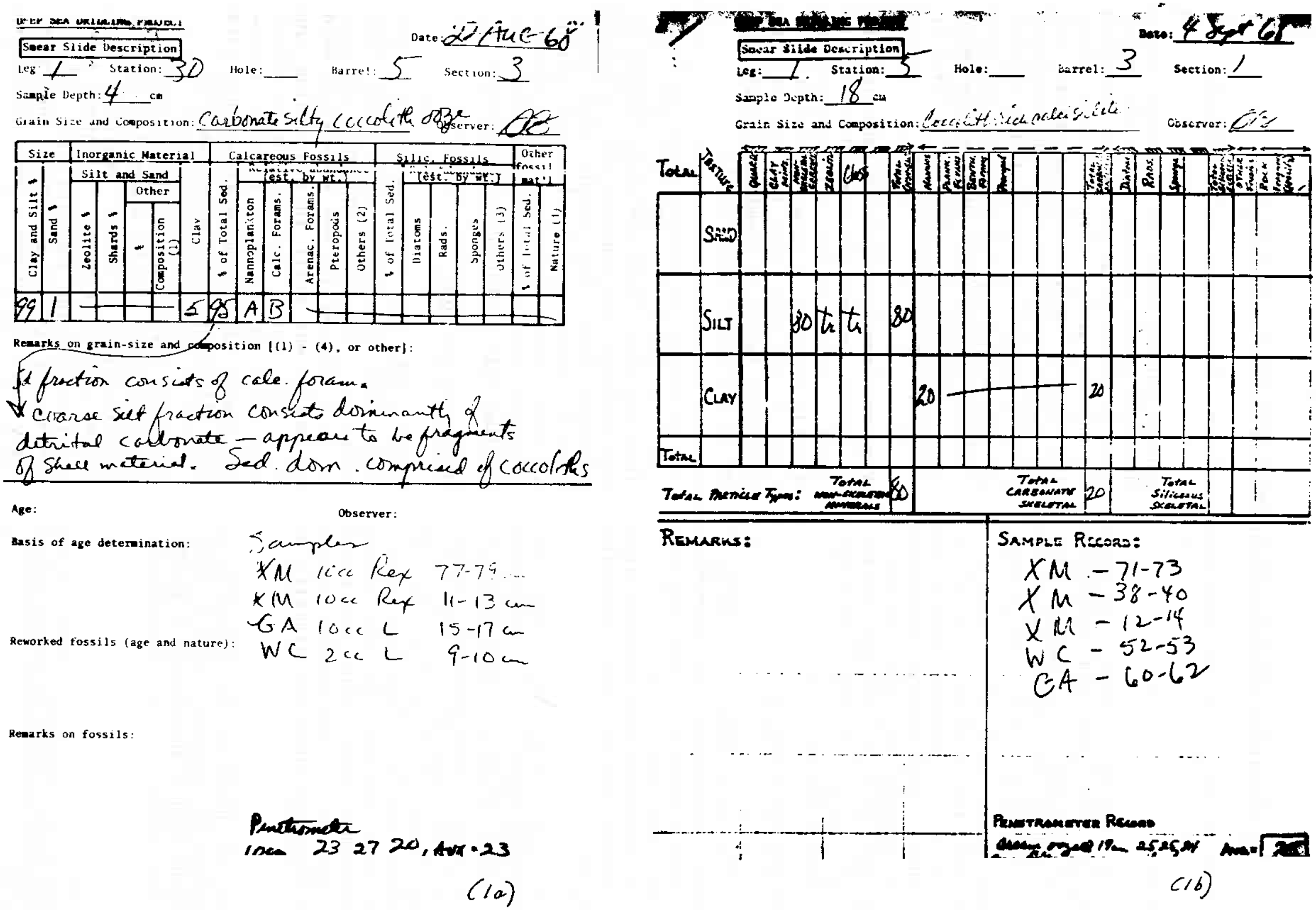
The acid-residue coarse fraction is a sample to which HCl has been added before sieving. This not only breaks up the sediment but removes all carbonate elements from the sample and (once sieved) leaves mainly detrital grains in the coarse fraction. The coarse-fraction and acid-residue slides are studied with a binocular microscope.

RECORDING THE DATA

Since 1968, six different formats have been used to record smear-slide data (Fig. 1). New forms appeared on Legs 1, 5, 7, 8, and 22; the form first used on Leg 22 was still in use during Leg 44. All forms include the standard DSDP label (Site, Core, Section, Interval sample in centimeters) so that data from different legs can be compared.

The form first used on Leg 1 (Fig 1A) provided very little space for mineral identification (only zeolites and shards were mentioned). Abundant space was provided for fossils, with all major fossil groups included; inadequate space was provided for describing

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.



DEEP SEA DRILLING PROJECT

Smear Slide Description

Date: 22 AUG 68

Leg: 1 Station: 3D Hole: ___ Barrel: 5 Section: 3

Sample Depth: 4 cm

Grain Size and Composition: Carbonate silty coccolith ooze Observer: OB

Size		Inorganic Material					Calcareous Fossils						Silic. Fossils					Other Fossil mat'l	
		Silt and Sand						Relative abundance (est. by wt.)						(est. by wt.)					
				Other															
Clay and Silt %	Sand %	Zeolite %	Shards %	%	Composition (1)	Clay	% of Total Sed.	Nannoplankton	Calc. Forams.	Arenac. Forams.	Pteropods	Others (2)	% of Total Sed.	Diatoms	Rads.	Sponges	Others (3)	% of Total Sed.	Nature (1)
99	1	—	—	—	—	5	95	A	B	—	—	—	—	—	—	—	—	—	—

Remarks on grain-size and composition [(1) - (4), or other]:

Sd fraction consists of calc. forams.
Coarse silt fraction consists dominantly of detrital carbonate — appears to be fragments of shell material. Sed. dom. comprised of coccoliths

Age:

Observer:

Basis of age determination:

Samples
XM 10cc Rep 77-79
XM 10cc Rep 11-13 cm
GA 10cc L 15-17 cm
WC 2cc L 9-10 cm

Reworked fossils (age and nature):

Remarks on fossils:

Penetrometer
10cm 23 27 20, Ave • 23

(1a)

DEEP SEA DRILLING PROJECT

Smear Slide Description

Date: 4 Sept 68

Leg: 1 Station: 5 Hole: ___ Barrel: 3 Section: 1

Sample Depth: 18 cm

Grain Size and Composition: Coccolith siliceous silt

Observer: OB

Total	Texture	Quartz	Clay minerals	Heavy minerals	Zeolite	Chert	Total minerals	Nannos	Plank. forams	Benth. forams	Pteropod			Total carbonate	Diatoms	Rads.	Sponge		Total siliceous	Shale fragments	Rock fragments	Fecal pellets
	Sand																					
	Silt		80	tr	tr		80															
	Clay							20						20								
Total																						

Total Particle Types: Total non-carbonate minerals 80; Total carbonate skeletal 20; Total siliceous skeletal

Remarks:

Sample Record:
XM - 71-73
XM - 38-40
XM - 12-14
WC - 52-53
GA - 60-62

Penetrometer Record
[illegible] 19cm 25,25,24 Ave = [illegible]

(1b)

Figure 1. Smear slide descriptions.

DEEP SEA DRILLING PROJECT

SMEAR SLIDE

CONTRACT	SITE	HOLE	CORE
	38	0	2

	SEC	Interval from top of section: Top	Bottom	CARD Cat	No	QUARTZ	CLAY MINERAL	NON SKEL CARBONATE	ZEOLITE	GLASS	OTHER MINERALS	TOTAL INORGANIC	NANOS	PLANKTON FORAMS	BENTH FORAMS	CALCAREOUS FORAMS	PTEROPODS	OTHER	TOTAL CARBONATE SKELETAL	DIATOM	RADS	SPONGE	OTHER	TOTAL SILICATE SKELETAL	CUMULATIVE TOTAL
SAND	3	412		35	1																				
SILT				35	2				25		5														
CLAY				35	3		70																		
TOTAL																									
LITHOLOGY				35	4	zeolite-bearing red clay																			
COMMENTS				35	5																				

	SEC	Interval from top of section: Top	Bottom	CARD Cat	No	QUAR	CLAY MIN.	N.SK CARB	ZEOL	GLASS	OTH. MIN.	TOT. INOR.	NANOS	PLAN. FORA.	BENTH FORA.	CALC. FORA.	PTER.	OTHER	TOT. CARB. SKEL.	DIAT.	RADS	SPON.	OTHER	TOT. SIL. SKEL.	CUM. TOT.
SAND	3	70		35	1																				
SILT				35	2				20		5														25
CLAY				35	3		75																		75
TOTAL																									100
LITHOLOGY				35	4	zeolite-bearing red clay																			
COMMENTS				35	5																				

(1c)

DEEP SEA DRILLING PROJECT
SMEAR SLIDE

LEG	SITE	HOLE	CORE	SEC	Interval from top of sec.: Top	Bottom
7	62	1	3	CC		

CARD Cat No	SAND	SILT	CLAY	QUARTZ	FELDSPAR	PYROXENE	CHLORITE	DK MICA	LT MICA	GLASS	PALAGONITE	GLAUCONITE	PHOSPHOR	PYRITE	AUTH. CARB.	BARITE	PHILLIPS	OTH. ZEOL.	MICRONOD	OTHER MINERALS	ABUND.	OTHER MINERAL	ABUND.	COMMENTS	REVISION
351	R	C	A	-	-	-	-	-	-	-	-	-	-	R	R	-	-	-	-	CLY	A			Y	

CARD Cat No	FORAM. (PLANK)	FORAM. (BENTH)	CALC. NANNOS.	PTEROPOD	OTHER CALCAREOUS FOSSILS	DIATOMS	RADIOLARIA	SPONGE SPICULES	SILICOFLAG.	PLANT DEBRIS	POLLEN & SPORES	FISH DEBRIS	OTHER FOSSILS	OTHER FOSSILS	COMMENTS	REVISION
352												R				

CARD Cat No	LITHOL/COMMENTS
353	NANNOPLANKTON MARL OOZE TO CALCILUTITE/ CLAY LUMPS

CARD Cat No	COMMENTS
3541	PARTLY SILICIFIED AND PERHAPS CALCITE CEMENTED.
3542	-
3543	

(1d)

Figure 1. Smear slide descriptions. (Cont.)

DEEP SEA DRILLING PROJECT
SMEAR SLIDE/COARSE FRACTION

LEG	SITE	HOLE	CORE	SEC	INTERVAL FROM TOP OF SEC. Top	Bottom
[illegible]	7[illegible]		11	2	130	

Smear Slide	Coarse Frac.	Acid Treat
✓		

CARD Cat No	SAND	SILT	CLAY	QUARTZ	FELDSPAR	PYROXENE	CHLORITE	DK MICA	LT MICA	DK GLASS	LT GLASS	PALAGONITE	GLAUCONITE	PHOSPHOR	PYRITE	AUTH. CARB.	BARITE	PHILLIPS	OTH. ZEOL.	MICRONOD	OTHER MINERALS	ABUND.	Estimated Carbonate %	Foram.	Calc. Nannos.	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	COMMENTS	DIVISION
351	Cl																	Tr					95		R							

CARD Cat No	LITHOL/COMMENTS
353	nanno ooze (tr phillipsite)
3541	
3542	
3543	

(1e)

DEEP SEA DRILLING PROJECT

Leg	Site	Hole	Core	Sec.	Interval
22	218	0	13	2	131

Smear Slide	Coarse Frac.	Acid Treat.	Thin Sec.
✓			

Dom. Lith.	Minor Lith.
✓	

Sediment Name: Clay ~~silt~~ Sand silt

PER CENT	TEXTURE	DATA CODE	SPECIFIC DATA
20	Sand		
75	Silt		
5	Clay		
	COMPOSITION		
7	Quartz		
75	Feldspar		
3	Mica		
7	Heavy Mins.		
	Total Detrital		
2	Clay		
	Volc. Glass		
	Palagonite		
2	Opaques		
	Glauconite		
	Pyrite		
	Micro Nodules		
	Dolo. Rhombs		
	Zeolite		
	Auth. Carb.		
Tr.	Foraminifera		
	Calc. Nannos		
	Diatoms		
	Radiolarians		
	Sponge Spic.		
	Silicoflag.		
	Fish Remains		
	Plant Debris		

PER CENT	DETAILED MINERALOGY
	amphibole
	Sericite
	Zircon
Tr.	RK Frag.

REMARKS:

Angular to subangular

DATA CODE LEGEND
C = Clastic
I = Index of refraction
S = Size range
F = Fossil preservation

G = good
M = moderate
P = poor

(1f)

Figure 1. Smear slide descriptions. (Cont.)

detrital sediments. The form was divided into two parts: the top portion was used for sediment classification and the bottom for age determination. This approach was abandoned almost immediately (Leg 1, Site 5) and a separate paleontology/biostratigraphy form was created. The new form (used through Leg 4) excluded the paleo/biostratigraphy information and included sample record information and penetrometer results. This form (Fig. 1B) also provided a greater share of space for mineral identification.

The first form prepared with the thought of keypunching smear-slide data (Fig. 1C) appeared on Leg 5. Aside from the keypunch-oriented format, this form was arranged so that components could be estimated for each grain-size category. This form was used for Legs 5 and 6.

The form used on Leg 7 (Fig. 1D) was also designed for keypunching. The division of components into grain-size categories was eliminated and the mineral and fossil name lists were greatly increased.

From Legs 8 to 22, DSDP used a form similar to that for Leg 7, except that the area for comments was expanded and a designation for slide type was added (Fig. 1E).

The form (Fig. 1F) used from Legs 22 to 44 was not arranged specifically for keypunching, but was easily adaptable for this purpose. The form included new categories for additional minerals and divisions into detrital and nondetrital groups. An area for detailed mineralogy was included, as were codes for additional information such as index of refraction, size range, and fossil preservation. The form also includes an area for designating whether the slide represents a dominant or minor lithology in the section.

Point counting is not used on smear slides to determine abundances of various components; instead, a visual estimate is made. These percentages are based on the area occupied by each grain on the slide (volume), not by the number of individual grains.

Ideally, smear slides are taken at 75 cm in each 150-cm section if the lithology appears visually homogeneous. If the core is not uniform, a sufficient number of smear slides are taken to adequately describe the lithologies present.

The abundance of a component is recorded either as a numerical percent or (most commonly) a relative abundance. The problem with relative abundances, however, is that sedimentologists neglected to record a legend of the numerical range that each letter represented. This makes it difficult to evaluate a slide, especially in cases where several components are said to be dominant.

QUALITY OF THE DATA

The quality of data is dependent upon scientific and mechanical technique. From a mechanical point of view, it is essential that the smear slide be representative of the sediment and that the slide be properly prepared. Scientifically, a describer familiar with marine sediments will obviously do a more reliable job than one who is not. Also to be taken into account is the individual's ability to visually estimate the percent of various components within a field.

When estimating components on a smear slide, accuracy for major constituents ranging from ±10 to 20% is considered very good, while accuracy for minor components is usually correct to within a few percent. Shipboard determination of the relative frequency of components appears to be most reliable in the case of biogenic pelagic sediments.

Of the three types of smear slides discussed in this paper, the untreated sediment slide should be representative of a lithology. This is not always true, especially with reference to coarse material. It has been found that in these cases the content of silt-size particles (such as nannofossils) is often overestimated because the sediment is too thinly distributed on the slide. This error was empirically demonstrated on Leg 29. A 5-cc sample of ooze was taken with a syringe (opening enlarged), then extruded into a 63-micron sieve where the < 63 micron material was removed. The remaining coarse fraction was then packed back into the syringe and measured on the graduated scale on the syringe. In many instances, smear slide and syringe estimates of foraminifer percentages differed by as much as 70% (Kennett et al., 1975). A solution to this would be to make a coarse-fraction slide to be studied along with a standard slide. It is almost impossible to optically identify the nature of clay-size detrital particles. This must be done by referring to the subsequent shore-based results of X-ray fractionation analyses.

IMPROVING THE DATA

Use of Postcruise Laboratory Evaluations

To improve the data for coarse-grained sediments or sediments with a large proportion of coarse-grained material, a scheme such as that illustrated in Fig. 2 can be used. This methodology involves separating the coarse fraction from the fine-grained portion of a sample of known volume, and separately studying the greater than 63-micron and less and 63-micron components. Material for coarse-fraction study often can be recovered from the residues left after grain-size analysis.

For fine-grain detrital material, the most reliable way to confirm the presence or absence of a mineral is by comparing shipboard results with shore-based X-ray laboratory results.

Grain-size distribution, calcium carbonate content, and X-ray data can be

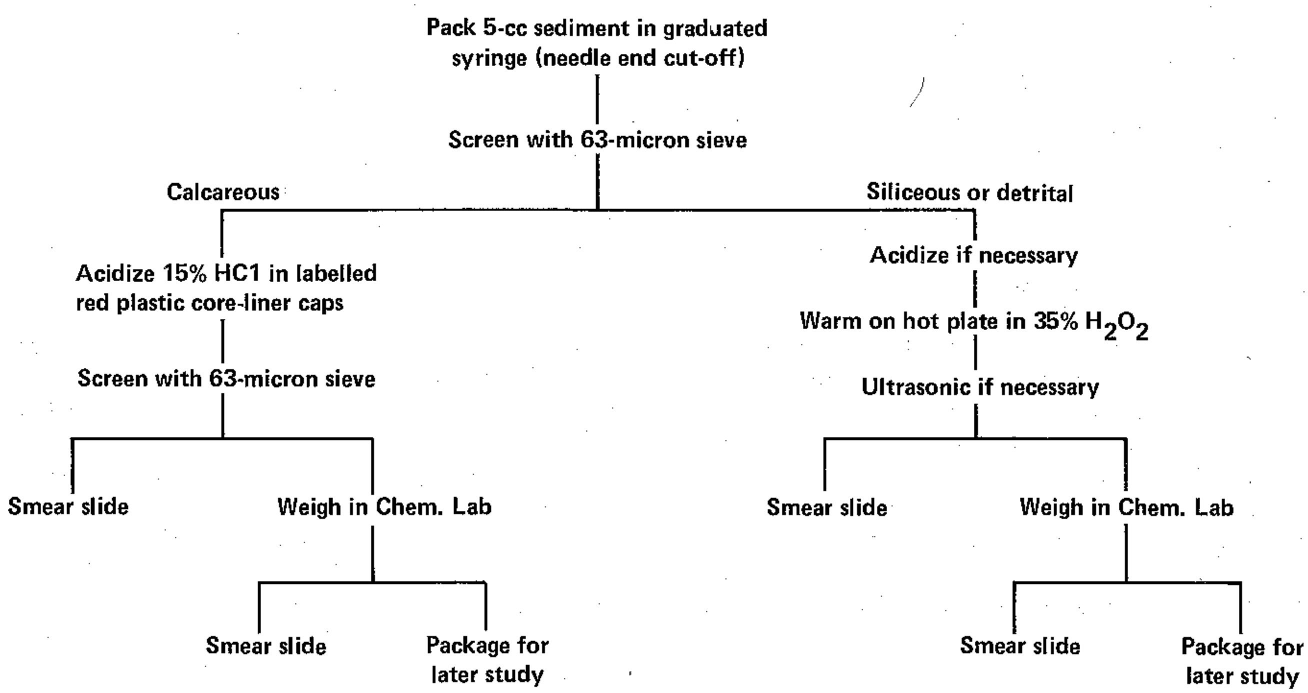


Figure 2. Diagrammatic procedure for sand-size insoluble residue (Kennett, Houtz et al., 1975).

obtained from the DSDP data handling group. X-ray data are available only through Leg 38.

Use of JOIDESCREEN

JOIDESCREEN is a computer program that analyzes smear-slide results that have been encoded, then reclassifies the slide using the sediment classification scheme developed by the Sedimentary Petrology Panel (van Andel et al., 1973). The scope of JOIDESCREEN is discussed elsewhere in this manual, but it should be emphasized that one of the peripheral results of processing smear-slide descriptions through this program is the facilitated identification of defects in these descriptions.

In evaluating coded smear-slide data, the computer may reach a point where it is impossible to classify a slide. Although there are numerous trouble areas the two main reasons for this difficulty are related directly to the smear slide preparation: (1) Incomplete or incorrect data recording at the time of initial description (i.e., percent of total components was recorded as being 80 or 120); (2) Incomplete sampling.

The computer's failure to classify a sediment layer because of incorrectly totaled data represents about 10% of the slide information that cannot be processed. These failures include slides having components that were originally measured in terms of relative abundance. These data, to be rendered usable to JOIDESCREEN, must be converted to numerical equivalents; unfortunately, the Initial Reports have not indicated a standard for these conversions. The conversion system we use is: D = >60%, A = 31 to 59%, C = 10 to 30%, R = 2 to 9%, and Tr = < 2%. These after-the-fact standards for determining numerical equivalents are often at variance with the unrecorded intention of the sedimentologist (such that a slide's components often total over 200% when converted). Some cases of computer classification failure are the result of the describer having noted the presence or absence of only an unusual mineral component rather than doing a complete description. This is particularly true in homogeneous sequences.

The greatest percent of failure (54%) is caused by lack of data. Because the 9-m cores are described in six sections (of 1.5 m each), we handle the data from each section as a distinctive layer. This is in keeping with original DSDP core description policy, which encouraged the preparation of at least one smear slide per 150-cm section. Most often in the case of apparently homogeneous sediment, a scientist will take only one smear slide per core; occasionally, in holes of homogeneous lithology (i.e., nannofossil ooze or gray clay), even fewer smear slides were taken. This frequently results in loss of data for two reasons: (1) subtle mineralogic changes are not observed, so that in a section that "grades" slowly from one lithology to another this gradation is overlooked; (2) "quick and dirty" core descriptions result when the section is not thoroughly studied and features such as burrows or other structures are completely missed. These features often are not visible in the standard core photos taken aboard ship. It appears that in taking smear slides, the sedimentologist is more conscientious in core examination instead of hurriedly using the descriptive shortcut, as has been done in homogeneous sediment, of noting SOS ("same ol' sediment").

We have attempted to solve these problems, in the first case, by normalizing components to 100% on the assumption that at least the relative proportions are correct. In the second instance, a lithology is inferred by comparing the name of the sediment above an unclassified one with the one below it. If the names match, the name is shared with the unclassified layer that lies between them. This method is obviously not ideal, but is more feasible than attempting to sample and describe these layers (a herculean undertaking far surpassing our level of staffing).

AVAILABILITY OF DATA

Presently, all smear slides from Sites 1 through 532 (75) have been encoded and are stored on magnetic tape. It is now possible to computer search the data for specific information such as mineral type, abundance, and distribution both downhole and laterally. Requests for additional information concerning this system should be addressed to the author.

Requests for prime shipboard data, now available on microfilm, should be addressed to:

Information Handling Group
Deep Sea Drilling Project A-031
Scripps Institution of Oceanography
La Jolla, California 92093

After completing studies for a particular cruise, scientists are requested to return their smear slides to the curator of the Deep Sea Drilling Project for storage. These slides become part of the archive material that other investigators may borrow for subsequent studies. Smear slides of the Atlantic, Mediterranean, Antarctic, Arctic, and Caribbean material are stored at the East Coast Repository at Lamont-Doherty Geological Observatory, and the West Coast Repository at Scripps Institution of Oceanography stores Pacific and Indian ocean material. All requests should be addressed to:

The Curator
Deep Sea Drilling Project A-031
Scripps Institution of Oceanography
La Jolla, California 92093

REFERENCES

Deep Sea Drilling Project, 1968. Part V: Shipboard Treatment of Cores in Deep Sea Drilling Project Core Description Manual. Unpublished JOIDES report.

Kennett, J. P., Houtz, R. E., Andrews, P. B., Edwards, A. R., Gostin, V. A., Hajós, M., Hampton, M., Jenkins, D. G., Margolis, S. V., Ovenshine, A. T., and Perch-Nielsen, K., 1975. I.R. DSDP, 29:3-16.

van Andel, Tj. H., Winterer, E. L., and Duncan, J., 1973. Report of Subcommittee on Sediment Classification of Advisory Panel on Sedimentary Petrology and Physical Properties. Unpublished JOIDES report.

4. X-RAY MINERALOGY STUDIES

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INTRODUCTION

The importance of X-ray mineralogy was recognized from the earliest days of the Deep Sea Drilling Project (DSDP). This resulted in part from the recognition that fine-grained, nonbiogenic pelagic sediments are difficult to characterize other than by X-ray diffraction (XRD) and in part from the development of techniques to obtain high-precision XRD data for sediments. The technique developed at the research laboratories of Chevron Oil Company formed the basis for mineralogy studies of samples from Legs 1 to 37. These studies were carried out at the DSDP laboratory in the Institute of Geophysics and Planetary Physics at the University of California at Riverside. The methodology used for most of these studies is described in the appendix.

PUBLISHED RESULTS

Table 1 summarizes the X-ray mineralogy work carried out as part of the sediment descriptions of Phases I to III (DSDP Legs 1 to 44). This table is an attempt to summarize the size fractions analyzed, the forms in which data are presented (tables, bar logs, columnar logs), a cross reference to the methodology, and a cross reference to the articles published in the Initial Reports.

On the positive side, the publication of 83 articles with an exclusive or major focus on X-ray mineralogy is an important contribution to our knowledge of deep-sea sediments. To the extent that the data are well characterized, these studies will be invaluable in the future.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

On the negative side, however, is the lack of documentation that makes a number of the studies essentially useless to later workers. It is distressing to study Table 1 and note that even the size fraction studied cannot be determined from some references. More commonly, the chemical treatment of samples prior to analysis is inadequately documented (Table 2), as is the protocol used to convert XRD peak intensities to absolute or relative concentrations.

Even where the methodology is spelled out, the value of much of the data is reduced by the use of unusual size fractions or by harsh chemical pretreatment of samples. Strong HCl, for example, destroys both chlorite and iron-magnesian smectite that is the dominant authigenic component of pelagic clays, yet this acid commonly was used to remove biogenic carbonate prior to XRD analysis.

The Riverside and compatible data sets (M1, 2, 5 in Table 1) offer a view of oceanic mineralogy that is internally consistent, precise, and well documented. Even in this case, however, the lack of internal standards severely limits the application of these data to more general geochemical problems.

LESSONS FROM THE XRD STUDIES

1. The editorial supervision of the Initial Reports should include a review of X-ray mineralogy chapters by an experienced XRD researcher (perhaps designated by the JOIDES Panel on Sedimentary Petrology and Physical Properties). This review should ensure that the sample treatment and data manipulations are described in sufficient detail to allow results to be compared and even integrated with earlier studies.

2. Every effort should be made to encourage XRD investigators to use internal standards. Deep-sea sediments commonly contain such a large fraction of nondiffracting material that lists of relative mineral abundances (for example, summing diffracting components to 100%) give a very misleading picture of the deposits.

3. XRD studies of sediments that are dominated by biogenic carbonate or opal are nonproductive and should be avoided. The early Riverside analyses of biogenic deposits from the equatorial Pacific yielded virtually nothing of scientific value, despite the effort expended. Such studies raised doubts as to the general value of XRD work that persisted for years afterward and that may well have contributed to the demise of the Riverside laboratory.

4. Some agreement needs to be reached on the treatment of clay mineral data. The papers summarized in Table 1 run the gamut from unquestioning use of Biscaye's (1965) factors to convert peak areas to abundances, to suggestions that any attempt to estimate clay mineral abundances is hopeless because mixed layering invalidates all conversion factors. A reasonable compromise might be to continue converting peak areas to abundances (which have considerable value in provenance and transport studies), while at the same time making the effort to determine from 003/005 characteristics the extent and nature of illite-smectite interlayering.

DATA AVAILABILITY

The magnetic tapes containing all the Riverside data are archived at DSDP. Inquiries should be directed to the Information Handling Group. Inasmuch as DSDP has not developed computer programs to manipulate XRD data, however, potential users should be prepared to reprocess the data themselves or to spend a considerable amount of time working with the DSDP group to develop appropriate reduction programs.

REFERENCES

1. Biscaye, P. E., 1965. Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans. Geol. Soc. Am. Bull., 76:803-832.

2. Chamley, H., and d'Argoud, G. G., 1978. Clay mineralogy in volcanogenic sediments. I.R. DSDP, 42A: 395-397.

3. Chamley, H., de Segonzac, G. D., and Mélières, F., 1978. Clay minerals in Messianian sediments of the Mediterranean area. I.R. DSDP, 42A:389-395.

4. Cook, H. E., Johnson, P. D., Matti, J. C., and Zemmels, I., 1975. Methods of sample preparation and X-ray diffraction data analysis, X-ray mineralogy laboratory, Deep Sea Drilling Project, University of California, Riverside. I.R. DSDP, 28:999-1007.

5. Cook, H. E., Rex, R. W., Eklund, W. A., and Murray, B., 1971. X-ray mineralogy studies, Leg 7. I.R. DSDP, 7(2):913-963.

6. Cook, H. E., and Zemmels, I., 1971. X-ray mineralogy studies -- Leg 8. I.R. DSDP, 8:901-950.

7. ________, 1972. X-ray mineralogy studies -- Leg 9. I.R. DSDP, 9: 707-777.

8. ________, 1973. X-ray mineralogy studies of Leg 10 cores in the Gulf of Mexico. I.R. DSDP, 10: 337-373.

9. ________, 1976. X-ray mineralogy data from the central Pacific, Leg 33 Deep Sea Drilling Project. I.R. DSDP, 33:539-555.

10. Cook, H. E., Zemmels, I., and Matti, J. C., 1974. X-ray mineralogy data, southern Indian

Ocean -- Leg 26 Deep Sea Drilling Project. I.R. DSDP, 26:573-592.

11. _______, 1974. X-ray mineralogy data, eastern Indian Ocean -- Leg 27, Deep Sea Drilling Project. I.R. DSDP, 27:535-548.

12. _______, 1975. X-ray mineralogy data, Austral-Antarctic region, Leg 28, Deep Sea Drilling Project. I.R. DSDP, 28:981-998.

13. _______, 1975. X-ray mineralogy data, Campbell Plateau and South Tasman Sea: Leg 29, DSDP. I.R. DSDP, 29:1173-1186.

14. _______, 1975. X-ray mineralogy data, far western Pacific, Leg 31 Deep Sea Drilling Project. I.R. DSDP, 31:883-895.

15. Couture, R., Miller, R. S., and Gieskes, J. M., 1978. Interstitial water and mineralogical studies, Leg 41. I.R. DSDP, 41:907-914.

16. de Segozac, G. D., and Hoffert, M., 1973. A preliminary investigation of the clay minerals in the Western Alboran Basin, Site 121. I.R. DSDP, 13(2):670-672.

17. Connelly, T. W., and Nalli, G., 1973. Mineralogy and chemistry of Caribbean sediments. I.R. DSDP, 15:929-961.

18. Drever, J. I., 1971. Chemical and mineralogical studies, Site 66. I.R. DSDP, 7(2):965-975.

19. _______, 1973. The preparation of oriented clay mineral specimens for X-ray diffraction analysis by a filter-membrane peel technique. Am. Mineralog., 58:553-554.

20. Emelyanov, E. M., Blazchishin, A. I., Kharin, G. S., Lozovaya, N. G., and Zangalis, K. P., 1979. Mineral and chemical composition of sediments of the Vøring Plateau, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):31-44.

21. Eslinger, E. V., and Savin, S. M., 1976. Mineralogy and O^{18}/O^{16} ratios of fine-grained quartz and clay from Site 323. I.R. DSDP, 35:489-496.

22. Fan, P. -F., and Rex, R. W., 1972. X-ray mineralogy studies -- Leg 14. I.R. DSDP, 14:677-725.

23. Fan, P. -F., and Rex, R. W., Cook, H. E., and Zemmels, I., 1973. X-ray mineralogy of the Caribbean Sea -- Leg 15. I.R. DSDP, 15:847-921.

24. Fan, P. -F., and Zemmels, I., 1972. X-ray mineralogy studies -- Leg 12. I.R. DSDP, 12:1127-1154.

25. Flood, R. D., 1978. X-ray mineralogy of DSDP Legs 44 and 44A, western North Atlantic: lower continental rise hills, Blake Nose, and Blake-Bahama Basin. I.R. DSDP, 44:515-521.

26. Gorbunova, Z. N., 1976. Clay-sized minerals from cores of the southeast Pacific Ocean, Deep Sea Drilling Project, Leg 35. I.R. DSDP, 35:479-488.

27. Gostin, V. A., and Moriarty, K. C., 1975. Investigations of tertiary clay mineral distributions around Tasmania, DSDP, Leg 29. I.R. DSDP, 29:1077-1082.

28. Greene-Kelly, R., 1953. Identification of montmorillonids. Soil Sci., 4:233-237.

29. Hayes, J. B., 1973. Clay petrology of mudstones, Leg 18 Deep Sea Drilling Project. I.R. DSDP, 18:903-914.

30. Jenkyns, H. C., and Hardy, R. G., 1976. Basal iron-titanium-rich

sediments from Hole 315A (Line Islands, central Pacific). I.R. DSDP, 33:833-836.

31. Johns, W. D., Grim, R. E., and Bradley, W. F., 1954. Quantitative estimations of clay minerals by diffraction methods. J. Sediment. Petrol. 24:242-251.

32. Kastner, M., 1976. Diagenesis of basal sediments and basalts of Sites 332 and 323, Leg 35, Bellingshausen Abyssal Plain. I.R. DSDP, 35:513-527.

33. Koch, R., and Rothe, P., 1979. X-ray mineralogy studies -- Leg 43. I.R. DSDP, 43:1019-1041.

34. Kossovskaya, A. G., and Drits, V. A., 1978. Mineralogy, geochemistry and petrography of sediments recovered at Site 345, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):45-54.

35. Lisitzin, A. P. et al., 1971. Geochemical, mineralogical and paleontological studies. I.R. DSDP, 6:829-960.

36. Marchig, V., and Vallier, T. L., 1974. Geochemical studies of sediment and interstitial water, Sites 248 and 249, Leg 25, Deep Sea Drilling Project. I.R. DSDP, 25:405-415.

37. Matsumoto, R., Utada, M., and Kagami, H., 1978. Sedimentary petrology of DSDP cores from Sites 362 and 363, the Walvis Ridge and Site 364, the Angola Basin, drilled on Leg 40. I.R. DSDP, 40:469-485.

38. Matti, J. C., Zemmels, I., and Cook, H. E., 1973. X-ray mineralogy of sediments from the far western Pacific, Leg 20, DSDP. I.R. DSDP, 20:323-334.

39. ________, 1973. Mineralogy and mineralogic trends in sediments from the Tasman and Coral Seas, Leg 21 Deep Sea Drilling Project. I.R. DSDP, 21:723-750.

40. ________, 1974. X-ray mineralogy data, northeastern part of the Indian Ocean, Leg 22, Deep Sea Drilling Project. I.R. DSDP, 22:693-710.

41. ________, 1974. Appendix III. X-ray mineralogy data, Arabian and Red Seas -- Leg 23 Deep Sea Drilling Project. I.R. DSDP, 23:1137-1156.

42. ________, 1974. X-ray mineralogy data, western Indian Ocean -- Leg 24 Deep Sea Drilling Project. I.R. DSDP, 24:811-825.

43. ________, 1974. Appendix IV. X-ray mineralogy data, western Indian Ocean -- Leg 25 Deep Sea Drilling Project. I.R. DSDP, 25:843-861.

44. McCoy, F., Zimmerman, H., and Krinsley, D., 1977. Zeolites in South Atlantic deep-sea sediments. I.R. DSDP, 34:423-443.

45. Mélières, F., 1978. X-ray mineralogy studies, Leg 41 Deep Sea Drilling Project, eastern North Atlantic Ocean. I.R. DSDP, 41:1065-1086.

46. ________, 1978. Detailed X-ray mineralogy of Core 9, Sections 1 and 2, Hole 372 (Balearic Rise), Deep Sea Drilling Project Leg 42A. I.R. DSDP, 42A:385-387.

47. ________, 1978. Bulk X-ray mineralogy data. I.R. DSDP, 42A:1157-1169.

48. Mélières, F., Chamley, H., Coumes, F., and Rouge, P., 1978. X-ray mineralogy studies, Leg 42A Deep Sea Drilling Project, Mediterranean Sea. I.R. DSDP, 42A:361-383.

49. Nesteroff, W. D., 1972. Distribution of the fine-grained sediment

component in the Mediterranean. I.R. DSDP, 12:666-670.

50. Okada, H., and Tomita, K., 1973. Clay mineralogy of deep-sea sediments in the northwestern Pacific, DSDP, Leg 20. I R. DSDP, 20:335-343.

51. Pastouret, L., Auffret, G. -A., and Chamley, H., 1978. Microfacies of some sediments from the western North Atlantic: paleoceanographic implications (Leg 44 DSDP). I.R. DSDP, 44:477-501.

52. Perry, E. A., Beckles, E. C., and Newton, R. M., 1976. Chemical and mineralogical studies, Sites 322 and 325. I.R. DSDP, 35:465-469.

53. Perry, E. A., Grady, S. J., and Kelly, W. M., 1979. Mineralogic studies of sediments from the Norwegian-Greenland Sea (Sites 336, 343, 344, 345, and 348). I.R. DSDP, 38 (Suppl.):135-139.

54. Rateev, M. A., Renngarten, N. V., Shutov, V. D., and Drits, V. A., 1979. Lithology and clay mineralogy of sediments from Hole 346. I.R. DSDP, 38 (suppl.):55-65.

55. Renngarten, N. V., Rateev, M. A., Shutov, V. D., and Drits, V. A., 1979. Lithology and clay mineralogy of sediments from Site 337, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):21-29.

56. Rex, R. W., 1969. X-ray mineralogy studies -- Leg 1. I.R. DSDP, 1:354-367.

57. ________, 1970. X-ray mineralogy studies -- Leg 2. I.R. DSDP, 2: 329-346.

58. ________, 1970. X-ray mineralogy studies -- Leg 3. I.R. DSDP, 3: 509-581.

59. Rex, R. W., Eklund, W. A., and Jamieson, I. M., 1971. X-ray mineralogy studies. I.R. DSDP, 6: 753-810.

60. Rex, R. W., and Murray, B., 1970. X-ray mineralogy studies -- Leg 4. I.R. DSDP, 4:325-369.

61. ________, 1970, X-ray mineralogy studies. I.R. DSDP, 5:441-483.

62. Roberson, H. E., 1973. Mixed-layer illite/montmorillonite clays from sites 146 and 149. I.R. DSDP, 15:923-927.

63. Siesser, W. G., and Bremner, J. M., 1978. X-ray mineralogy of cores from Leg 40 Deep Sea Drilling Project. I.R. DSDP, 40:541-548.

64. Stoffers, P., and Müller, G., 1978. Mineralogy and lithofacies of Black Sea sediments, Leg 42B Deep Sea Drilling Project. I.R. DSDP, 42B:373-411.

65. Supko, P. R., Stoffers, P., and Coplen, T. B., 1974. Petrography and geochemistry of Red Sea dolomite. I.R. DSDP, 23:867-878.

66. Timofeev, P. P., Eremeev, V. V., and Rateev, M. A., 1978. Palygorskite, sepiolite and other clay minerals in Leg 41 oceanic sediments: mineralogy, facies and genesis. I.R. DSDP, 41:1087-1101.

67. Timofeev, P. P., Renngarten, N. V., and Bogolyubova, L. J., 1979. Lithology and clay mineralogy of the sediments from Site 336, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):9-19.

68. Trimonis, E. S., Gorbunova, Z. N., Kozhevnikov, A. S., Serova, V. V., and Shevchenko, A. Y., 1978. X-ray mineralogy studies, Leg 42B. I.R. DSDP, 42B:451-468.

69. Varentsov, I. M., 1979. Lithologic-mineralogic studies of the sedimentary deposits from Hole

350, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):111-120.

70. Venkatarathnam, K., 1974. Mineralogical data from Sites 211, 212, 213, 214 and 215 of Deep-Sea Drilling Project Leg 22 and origin of noncarbonate sediments in the equatorial Indian Ocean. I.R. DSDP, 22:489-501.

71. von der Borch, C. C., and Trueman, N. A., 1974. Dolomitic basal sediments from northern end of Ninetyeast Ridge. I.R. DSDP, 22:477-483.

72. von Rad, U., and Rösch, H., 1972. Mineralogy and origin of clay minerals, silica and authigenic silicates in Leg 14 sediments. I.R. DSDP, 14:727-751.

73. White, S. M., 1976. X-ray mineralogy of sediments, DSDP Leg 38. I.R. DSDP, 38 (Suppl.):437-441.

74. Zemmels, I., 1973. X-ray mineralogy studies -- Leg 16. I.R. DSDP, 16:529-571.

75. Zemmels, I., and Cook, H. E., 1973. X-ray mineralogy studies of selected samples from the sea floor of the northeast Atlantic and Mediterranean Sea. I.R. DSDP, 13(2):605-665.

76. _______, 1973. X-ray mineralogy of sediments from the central Pacific Ocean. I.R. DSDP, 17:517-556.

77. _______, 1973. Appendix IV. X-ray mineralogy of sediments from the northwest Pacific and Gulf of Alaska -- Leg 18 Deep Sea Drilling Project. I.R. DSDP, 18:1015-1060.

78. _______, 1973. X-ray mineralogy of sediments from the northern Pacific and the Bering Sea -- Leg 19, Deep Sea Drilling Project. I.R. DSDP, 19:667-697.

79. _______, 1975. X-ray mineralogy data from the northwest Pacific, Leg 32, Deep Sea Drilling Project. I.R. DSDP, 32:547-557.

80. _______, 1976. X-ray mineralogy data from the Nazca Plate -- Leg 34 Deep Sea Drilling Project. I.R. DSDP, 34:589-600.

81. _______, 1976. X-ray mineralogy data from the southeast Pacific basin -- Leg 35 Deep Sea Drilling Project. I.R. DSDP, 35:747-754.

82. Zemmels, I., Cook, H. E., and Hathaway, J. C., 1972. X-ray mineralogy studies -- Leg 11. I.R. DSDP, 11:729-789.

83. Zemmels, I., Cook, H. E., and Matti, J. C., 1975. X-ray mineralogy data, Tasman Sea and far western Pacific, Leg 30 Deep Sea Drilling Project. I.R. DSDP, 30:603-616.

84. Zemmels, I., Harrold, P. J., and Cook, H. E., 1977. X-ray mineralogy data from the Argentine Basin -- Leg 36 Deep Sea Drilling Project. I.R. DSDP, 36:1017-1031.

85. _______, 1977. X-ray mineralogy data from the FAMOUS area of the Mid-Atlantic Ridge -- Leg 37 Deep Sea Drilling Project. I.R. DSDP, 37:895-905.

86. Zimmerman, H. B., 1977. Clay mineral stratigraphy and distribution in the South Atlantic Ocean. I.R. DSDP, 39:395-405.

Table 1. Summary of X-ray mineralogical studies reported in DSDP Volumes 1 to 44.

Leg (Sites)	Location	Size Fraction: Bulk	<2	2-20	Data: Tables	Bar Log	Col Log	Methodology (Table 2)	Ref. No. (from Ref. List)	Notes
1 (1-7)	Gulf of Mexico	X			X			M1	56	Brief definition of methodology at Riverside lab
2 (8-12)	North Atlantic	X			X			M1	57	
3 (13-22)	South Atlantic	X		X	X	X		M1	58	
4 (23-31)	Atlantic, Caribbean	X		X	X	X		M2	60	Riverside methodology in Appendix
5 (32-43)	Eastern North Pacific	X			X	X		M2	61	
6 (44-60)	Western North Pacific	X		X	X	X		M2	59	
			<1 μm		X			M3	35	
7 (61-67)	Western Pacific	X	X		X	X		M2	5	
			X	<2 μm		X		M4	18	Site 66 only
8 (68-75)	Eastern Pacific	X	X	X	X	X		M2	6	Semi-quantitative data for 2-20 μm
9 (76-84)	Eastern Pacific	X	X	X	X	X		M2	7	As Leg 8
10 (85-97)	Gulf of Mexico	X	X	X	X	X		M2	8	As Leg 8; lists revised peak intensity vs. concentration factors
11 (98-108)	Eastern North Atlantic	X	X	X	X	X		M2	82	As Leg 8; no data for Site 107; no methodology for Hathaway samples (bulk and <2 μm)[a]
12 (109-119)	Northern North Atlantic	X	X	X	X	X		M5	24	No data for Sites 109, 110; quantitative data for all fractions
13 (120-134)	Mediterranean	X	X	X	X	X		M5	75	Site 121 only[b]
			X				X	M6	16,49	
14 (135-144)	North Atlantic	X	X	X	X	X		M5	22	No data for Site 143; new factor for chlorite; no data for Sites 139, 142, 143
		X					X	M7	72	
15 (146-154)	Caribbean	X	X	X	X	X		M5	23	Sites 146, 149 only[c]
			X				X	M8	62,17	
16 (155-163)	Eastern North Pacific	X	X	X	X	X		M5	74	No data for Site 156
17 (164-171)	Central North Pacific	X	X	X	X	X		M5	76	

Table 1. Summary of X-ray mineralogical studies reported in DSDP Volumes 1 to 44. (Cont.)

Leg (Sites)	Location	Size Fraction: Bulk	Size Fraction: <2	Size Fraction: 2-20	Data: Tables	Data: Bar Log	Data: Col Log	Methodology (Table 2)	Ref. No. (from Ref. List)	Notes
18 (172-182)	Northeastern Pacific	X	X	X	X	X		M5	77	No data for Site 182
			X		X			M9	29	No data for Sites 172, 173, 177, 182
19 (183-193)	Bering Sea	X	X	X	X	X		M5	78	
20 (194-202)	Western North Pacific	X	X	X	X			M5	38	No data for Sites 197, 200, 201, 202
		?			X	X		M10	50	Size fraction not stated
21 (203-210)	Western South Pacific	X	X	X	X			M5	39	
22 (211-218)	Eastern Indian Ocean	X	X	X	X			M5	40	
		X			X			--	71	Site 217 only; semi-quantitative mineralogy of dolomites
		>20	X	X	X		X	M11	70	No data for Sites 216, 217, 218
23 (219-230)	Arabian and Red seas	X	X	X	X			M5	41	No data for Site 226
		X			X			--	65	Estimates of mole % $CaCO_3$ in dolomites by XRD
24 (231-238)	Western Indian Ocean	X	X	X	X			M5	42	
25 (239-249)	Western Indian Ocean	X	X	X	X			M5	43	No data for Sites 243, 244, 247
		X			X			--	36	Sites 248, 249 only; quantitative SiO_2 mineralogy; no methodology
26 (250-258)	Southern Indian Ocean	X	X	X	X			M5	10	
27 (259-263)	Eastern Indian Ocean	X	X	X	X			M5	11	
28 (264-274)	Southern Ocean	X	X	X	X			M5	4,12	Final Riverside methodology; see Appendix
29 (275-284)	South of Tasman Sea	X	X	X	X			M5	13	No data for Site 276
			X		X		X	M12	27	Sites 280, 281, 282, 283 only
30 (285-289)	Tasman and Coral seas	X	X	X	X			M5	83	
31 (290-302)	Far Western Pacific	X	X	X	X			M5	14	No data for Site 300
32 (303-313)	Western North Pacific	X	X	X	X			M5	79	No data for Sites 309, 312

Table 1. Summary of X-ray mineralogical studies reported in DSDP Volumes 1 to 44. (Cont.)

Leg (Sites)	Location	Size Fraction: Bulk	Size Fraction: <2	Size Fraction: 2-20	Data: Tables	Data: Bar Log	Data: Col Log	Methodology (Table 2)	Ref. No. (from Ref. List)	Notes
33 (314-318)	Central Pacific	X	X	X	X			M5	9	Site 315 only; boehmite internal standard; qualitative abundance estimates
		?			X			--	30	
34 (319-321)	Eastern South Pacific	X	X	X	X			M5	80	
35 (322-325)	Drake Passage	X	X	X	X			M5	81	
			<1 µm	>1 µm			X	M13	52	Sites 322, 325 only
			<1 µm		X		X	M11	26	Bulk also for 323
		X	<0.3, 0.3-0.7, >0.7 m		X			M14	21	Site 323 only
			X	>2	X		X	M15	32	Sites 322, 323 only
36 (326-331)	Western South Atlantic	X	X	X	X			M5	84	No data for Site 326
37 (332-335)	FAMOUS, North Atlantic	X	X	X	X			M5	85	
38 (336-352)	Norwegian Sea	<1, 1-10 µm			X			M16	67	Site 336 only
		<1, >10 µm			X			M16?	55	Site 337 only
		X			X		X	--	20	Sites 339, 340, 341, 342, 343; methodology[d]
		<1, 10? µm			X		X	M16?	34	Site 345 only[e]
		<1 <10 µm			X			M16?	54	Site 346 only[e]
			<1 µm		X			M16?	69	Site 350 only[e]
			<1 µm		X		X	M17	53	Sites 336, 343, 344, 345, 348 only
		X	X	<5	X			M18,19	73	No data for Sites 336, 337, 339, 342, 350, 351, 352
39 (353-359)	South Atlantic		<4 µm				X	M11	86	Intensity vs. concentration factors for non-clays not stated
		X			X			--	44	Qualitative abundances using M5 intensity factors
40 (360-365)	Eastern South Atlantic	X	X			X	X	M20	37	Sites 362, 363, 364 only
		X	X		X			M21	63	
41 (366-370)	Eastern North Atlantic	?			X			M22	15	Qualitative abundance estimates
		X			X	X		M23	45	
			<10 µm		X			--	66	Verbal listing of relative dominance; no methodology
42A (371-378)	Mediterranean	X	X		X		X	M23	47,48	Includes <2 µm data, despite the title
		X					X	M23	46	Site 372 only
			?				X	M23?	3	
			X		X			M23?	2	
42B (379-381)	Black Sea	X	X				X	--	64	No methodology; used WHOI program[a]
		X	X		X		X	M2,M24	68	

Table 1. Summary of X-ray mineralogical studies reported in DSDP Volumes 1 to 44. (Cont.)

Leg (Sites)	Location	Size Fraction Bulk	<2	2-20	Data Tables	Bar Log	Col Log	Methodology (Table 2)	Ref. No. (from Ref. List)	Notes
43 (382-387)	North Atlantic	X	X		X	X		M25	33	No data for Site 383
44 (388-394)	Western North Atlantic	X	X	20-63 μm	X			M26	51	Sites 388, 390, 391 only
		X			X			M5	25	No data for Sites 389, 393

[a]Refs. 64, 82. The Hathaway samples were analyzed at Woods Hole Oceanographic Institution. There is no information on sample preparation. Layer silicates are not differentiated in the bulk analyses. Clays (<2 μm) treated with ethylene glycol. Intensity vs. abundance factors not stated.

[b]Ref. 49. Nesteroff refers to X-ray mineralogy done at the University of Paris, but includes no methodology or data plots or listings. Composition ranges are reported in the text, but their origin (Riverside or Paris) is unclear.

[c]Ref. 17. No methodology or data listings given. Qualitative results discussed in text.

[d]Ref. 20. Carbonates, quartz, and feldspars determined for bulk sediment (using CaF_2 internal standard?).

[e]Refs. 34, 54, 55, 67, 69. None of the Leg 38 Russian mineralogy includes adequate methodology. All sites are assumed to have used M16 treatments.

Table 2. Synopsis of treatments for Legs 1-44 X-ray mineralogy samples (refers to Table 1).

M1	Ref. 56. Rex's initial paper summarizes the sample treatment, intensity to concentration conversion factors, and concept of data reduction used at Riverside. The Appendix (M5) is a direct descendant of M1.
M2	Rex reviews the data-processing scheme at Riverside. Includes filter description, intensity to concentration conversion factors, and interference corrections. The Appendix (M5) describes the Riverside procedure that eventually evolved from M2.
M3	Ref. 35. Grind to <1 μm (sic), add CaF_2 standard. Compare to standards for quartz and carbonate estimates. Stokes-separate <1 μm fraction, remove carbonate with 0.1N HCl, remove oxyhydroxides with dithionite-citrate-bicarbonate (DCB), saturate with 1N $MgCl_2$, expand with glycerine. Also use Li saturation (Greene-Kelly, 1953). Use Biscaye (1965) peak-area ratios (M11).
M4	Ref. 18. No information on sample treatment. M1 factors used for abundance estimates.
M5	Ref. 4. This is the "polished" Riverside Lab methodology (see Appendix).
M6	Ref. 16. Remove carbonate by 0.1N HCl, Stokes-separate (settle and centrifuge) <2 μm, Mg-saturate. Ethylene glycol solvate? Plots of peak character and montmorillonite/illite and chlorite/illite (4.7/5Å) peak ratios.
M7	Ref. 72. Bulk samples, formic-acid-treated fractions run if carbonate rich. Abundances estimated as "main," "abundant," "common," and "trace" (>40, 20-50, 10-20, 3-10%). Columnar logs with abundance symbols.
M8	Ref. 62. Wash out salt, disaggregate ultrasonically, Stokes-separate <2 μm by centrifuge, pipette on glass. Use "similar to" Johns, et al. (1954) abundance estimates.
M9	Ref. 29. Stokes-separate <2 μm (centrifuge), Mg-saturate, ethylene glycol solvate. Intensity to conversion ratios - mica/ montmorillomite:illite:chlorite = 1:3:3. Separate chlorite from vermiculite by 7Å/14Å ratio (2 to 0.2, respectively).
M10	Ref. 50. Air-dry aggregates on glass, expand with ethylene glycol. Intensity to conversion factors for montmorillonite:illite: kaolinite = 1/2.6:1:1/1.2 (based on matching standards to unknowns). Size fraction not stated, probably bulk.
M11	Ref. 70. Biscaye (1965) methodology and intensity to abundance factors. Sodium acetate (pH = 5) carbonate removal, DCB oxyhydroxide removal, sodium carbonate disaggregation, then size separate. Paste smear <2 μm fraction on glass, ethylene glycol solvate. Conversion factors - montmorillonite:illite:kaolinite: chlorite = 1:4:2:2. Ref. 26. Uses <1 μm, no DCB. Ref. 86. Uses <4 μm.
M12	Ref. 27. Carbonate removal by glacial acetic acid, Stokes-separate <2 μm fraction, NaOH remove opal, DCB remove oxyhydroxides, Mg saturate, glycerine solvate. Conversion factors - montmorillonite: illite:kaolinite:chlorite = 1:4:2:4. ALso uses CEC (Ba) to cross check montmorillonite.
M13	Ref. 52. Stokes-separate <1 μm, <1 μm, pipette on glass. Ethylene glycol solvate? Use relative peak intensities (no abundance conversion).

Table 2. Synopsis of treatments for Legs 1-44 X-ray mineralogy samples (refers to Table 1). (Cont.)

M14	Ref. 21. Stokes-separate <0.3, 0.3-0.7, and >0.7 µm. Ethylene glycol solvate. Illite/smectite:illite:kaolinite:chlorite abundances given by I/S 003/005-1/2 I 001:I 001:K 002:C 004.
M15	Ref. 32. Stokes-separate <2 µm, >2 µm. Use Drever's (1973) technique. Data shown as relative peak intensities (illite 10A:chlorite 7Å:illite/smectite 17Å).
M16	Refs. 34, 54, 44, 67, 69. Stokes-separate <1 and 1-10 µm. Other methodology not stated. Mentions glycerine saturation. Description and rough estimates of clay mineralogy.
M17	Ref. 53. Stokes-separate <1 µm, pipette on glass, ethylene glycol solvate. Use Biscaye (1965) intensity to concentration factors (M11).
M18	Ref. 73. Grind dry, then wet. Stokes-separate <5 µm. Ethylene glycol solvate. Use Biscaye (1965) factors (M11). Sites 338, 340, 341, 343, 344, 345.
M19	Ref. 73. Bulk: wash, dry crush, report as "present," "abundant," "major." Clays: Stokes-separate <2 µm, vacuum mount on tile, ethylene glycol solvate. Use Biscaye (1965) factors (M11). Sites 346 to 349.
M20	Ref. 37. Bulk: dry grind. No intensity to concentration conversion factors. Clays: <2 µm, ethylene glycol solvate, hydrazine hydrate expand kaolinite. Intensity to abundance conversion factors - smectite:mica:kaolinite:chlorite = 1:1.7:1:1.5.
M21	Ref. 63. Dialyse 24 hr. Bulk: dry, crush, press, tabulate peak intensities above background. Clays: remove carbonate with 25% acetic acid, Mg-saturate, pipette on glass (warm to dry), ethylene glycol solvate. Use Johns, et al. (1954) factors (kaolinite and chlorite undifferentiated).
M22	Ref. 15. Glass mount. Remove carbonate by pH = 5 acetate buffer, ethylene glycol solvate. Data listed as "present," "abundant," "dominant."
M23	Refs. 45, 46, 47, 48. Bulk samples. Use NaF internal standard, ethylene glycol solvate. Abundances estimated by comparison with standards. For clays, remove carbonate with 10% HCl, pipette on glass, ethylene glycol solvate. Montmorillonite:illite:kaolinite: chlorite = 1 (14Å):1 (10Å):1:1 (7Å divided by 003:006 ratio).
M24	Ref. 68. For clays, Stokes-separate <2 µm, remove carbonate with 1*N* HCl, Mg-saturate, glycerine solvate. Abundance from Biscaye (1965) factors (M11).
M25	Ref. 33. Bulk plus <2 µm. Carbonate removed from clays with 10% HCl, pipette on glass (checked against smear mount). Clay ratios from Biscaye (1965) factors (M11). Bulk results comparable to Hathaway's (see footnote a, Table 1).
M26	Ref. 51. No methodology or accessible reference. Qualitative data (abundant, common, present?) for 20-63 µm. Percentages (conversion factors not stated) for clay minerals.

APPENDIX[1]

METHODS OF SAMPLE PREPARATION AND X-RAY DIFFRACTION DATA ANALYSIS, X-RAY MINERALOGY LABORATORY, DEEP SEA DRILLING PROJECT, UNIVERSITY OF CALIFORNIA, RIVERSIDE[2]

H. E. Cook, P. D. Johnson, J. C. Matti, and I. Zemmels, University of California, Riverside

INTRODUCTION

This article describes the methods of sample preparation and X-ray diffraction data analysis of X-ray mineralogy (XM) samples submitted to the DSDP X-ray Mineralogy Laboratory at the University of California, Riverside. The sample preparation procedure, the method of diffraction data analysis, and the methods of data handling are designed to efficiently meet the most general needs of geologists in view of the large number and the wide variety of sediment samples submitted for X-ray diffraction analysis.

These methods are shown schematically in Figure 1 and are briefly summarized below. Three preparations of each sample are made for X-ray diffraction analysis: a bulk fraction and decalcified 2-20μ and <2μ fractions. The bulk and 2-20μ samples are ground to a uniform size. All preparations are treated with trihexylamine acetate to expand the smectites and are X-rayed as random powders.

Raw X-ray diffraction intensities are digitized and recorded on magnetic tape. Mathematically scaled and smoothed diffractograms are generated from the diffraction data on tape. A computer-analysis program is used to make preliminary identification of minerals by diffraction peak position, to measure peak heights, to correct for diffraction peak interferences, and to compute the mineral content by the method of mutual ratios. This computer-generated output is checked manually by geologists with the diffractograms for each sample fraction to confirm the presence of minerals identified by the program and to look for unreported minerals. The original output of the computer program is then updated by computer methods with corrected mineral data; this serves as the data base for computing the percent amorphous and generating mineral tables and histograms.

SAMPLE PREPARATION

The method of sample preparation is nondestructive (except for grinding) and the sediment fractions can be recovered for further testing or refinement. An exception to this is that calcite, aragonite and, to some extent, dolomite, gypsum, and anhydrite are dissolved in the decalcification process.

Typically, 25-g (10-cc) sediment samples are submitted for X-ray diffraction analysis. Approximately 1 g is kept as a reference, 5 g are taken for bulk sample preparations, and the remainder is used in preparation of decalcified, fractionated 2-20μ and <2μ samples.

Bulk Samples

Sediments for bulk sample preparation are disaggregated in Waring blenders with 250-ml hot, distilled water until no lumps of sediment are visible. The samples are centrifuged and the wash-water is decanted. This treatment is sufficient to reduce the seawater salt content below the detection level of X-ray diffraction and also removes some organic residue.

The washed samples are allowed to dry and are disaggregated manually with a mortar and pestle. Coarse-grained samples are reduced to silt size. The samples are then placed in Fisher automatic mortar and pestle grinders and are ground under butanol for 2 hours. The butanol serves to dissipate the heat generated by grinding and also provides a medium for suspending the finer grains. Two hours of grinding under these conditions optimizes the grain sizes of the crystallites for X-ray diffraction. After grinding, the butanol is evaporated under heat lamps.

The ground samples are treated with trihexylamine acetate to expand the smectite minerals (synthesis and application of trihexylamine acetate are modified from Rex and Bauer, 1965). The amined samples are permitted to dry for several days to achieve equilibrium with ambient humidity conditions. Trihexylamine acetate has a low vapor pressure and remains in the clay minerals for several weeks. When equilibrated, the amined powders are pressed into sample holders using a custom-built sample press (Rex and Chown, 1960). The crystallites in the mounted powders have a low degree of preferred orientation because of the very fine grain size of the crystallites and because the sample press administers the pressure from the back of the sample.

2-20μ and <2μ Fractions

Sediments to be fractionated into 2-20μ and <2μ fractions are first thoroughly disaggregated in Waring blenders and then are decalcified in a sodium-acetate-buffered acetic acid solution (pH = 4.5). Decalcification is performed in an ultrasonic bath which provides heat and agitation to speed the reaction. When decalcification is complete, the reaction products and excess acid are removed by repeated centrifuge washing until the insoluble residue begins to disperse. The residue is then completely dispersed with a 0.05% sodium hexametaphosphate solution.

These dispersed slurries are passed through a 20μ sieve with the aid of an ultrasonic probe. The >20μ fraction is stored for microscope examination. The slurries with <20μ particles are fractionated into 2-20μ and <2μ

[1] Reproduced from *I.R. DSDP*, 28.
[2] Institute of Geophysics and Planetary Physics, University of California, Riverside, Contribution No. 74-5.

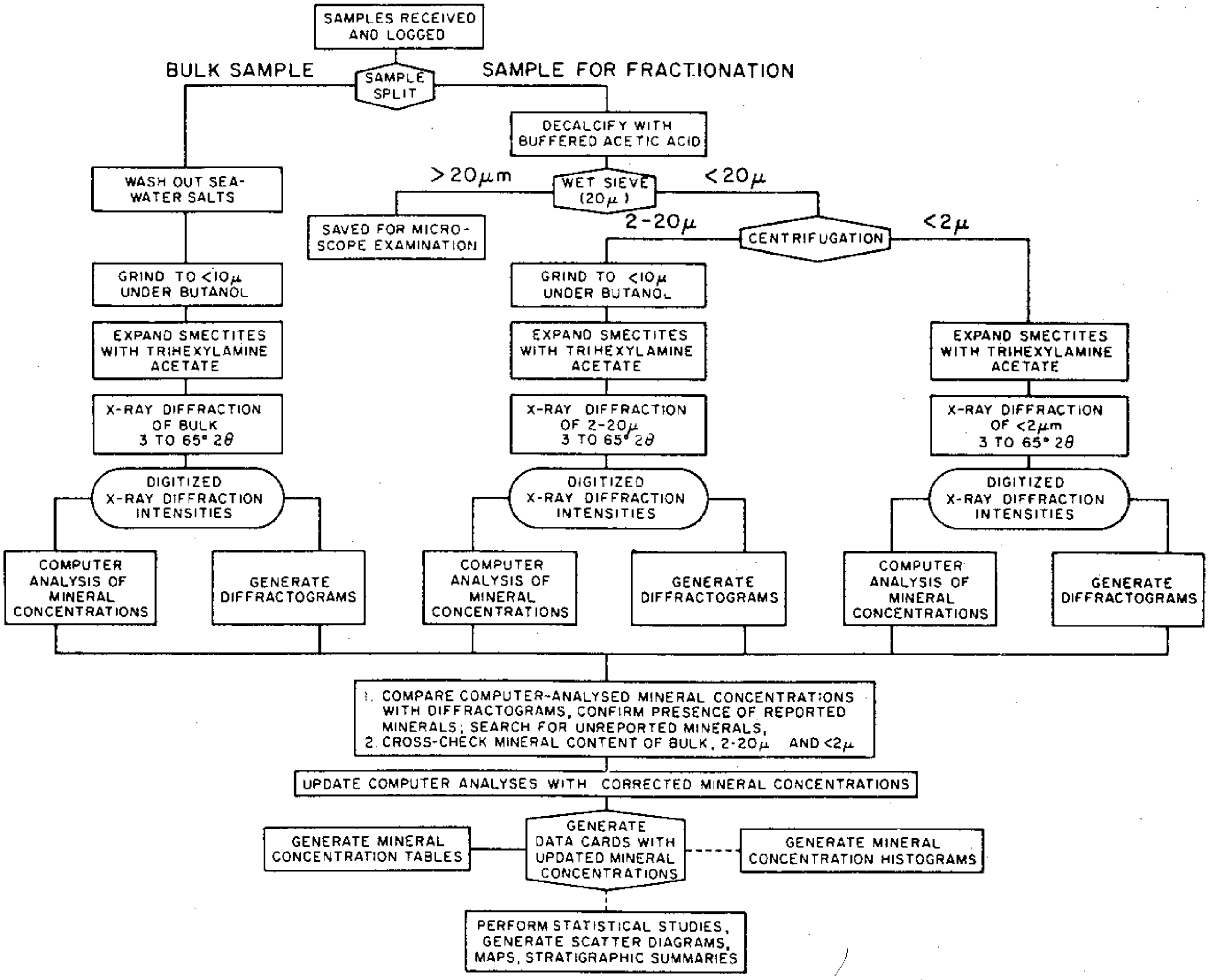

Figure 1. *Method of sample preparation and X-ray diffraction analysis.*

samples by centrifuging the slurries at a speed and for a time calculated to separate <2μ particles. The supernatant liquid containing the <2μ particles is collected. Centrifugation of the <20μ slurries proceeds until the supernatant liquid is clear. The <2μ slurries are flocculated with a few drops of a 10% $CaCl_2$ solution and are concentrated by centrifugation.

The 2-20μ samples are ground for 2 hours under butanol in the Fisher grinders whereas <2μ samples are not ground. Both of the fractionated samples are treated with trihexylamine acetate to expand the smectite minerals and are mounted as random powders for X-raying in a manner similar to that used for the bulk samples.

Mineral Calibration Standards

Mineral specimens which are being considered for mineral calibration standards are first subjected to X-ray diffraction analysis to determine how well their diffraction pattern resembles the diffraction pattern of minerals found in marine sediments and to determine the mineral impurities present. If the diffraction pattern of the mineral proves it to be acceptable as a calibration standard, any impurities are removed by a variety of methods such as chemical dissolution, heavy liquid separation, or hand picking. The purified standard is mixed with an equal weight of quartz and ground for 2 hours in the Fisher automatic mortar and pestle in order to insure uniformity between samples and standards and to homogenize the standard quartz mixture. Mounting and scanning of the standard quartz mixtures are the same as for the samples.

INSTRUMENTATION

A Picker powder diffractometer with a graphite-crystal, diffracted-beam monochrometer is used to run the X-ray diffraction scans. A custom, automated sample changer is used instead of the normal sample holder. This gives the capability of loading up to 100 samples at one time. Automated functions of both the diffractometer and the sample changer are controlled by a Digital Equipment Corporation PDP-8 computer through a modified Picker FACS-1 interface. The FACS-1 is normally used to control a four-axis, single crystal goniometer.

The PDP-8 computer has 12,000 words of memory. It has two 9-track, 800 bpi, 25 ips tape drives which are used for recording and handling of the raw diffraction data in digital form. An 11-inch Houston Instrument Complot digital plotter is used for plotting the diffractogram patterns after they have been smoothed, scaled, and labeled. An 800,000-word disk is used for program and data storage.

The CuKα lines are used for the scans. Scans are normally 3-65° 2θ at 2°/min. The patterns are recorded on magnetic tape as a series of 3100 consecutive data points where each data point is the integrated intensity over a 0.02° 2θ interval. The diffraction data can also be traced simultaneously on a strip-chart recorder. One-degree divergence and scatter slits and a 0.01-inch receiving slit are used. This gives a peak intensity of 30-35 thousand cps on the 26.66° quartz peak using a novaculite slide. The background in highly crystalline samples varies from a high of 200 cps at 3° 2θ to 50 cps at larger angles. All patterns are plotted on the digital plotter to provide a visual means of verifying and correcting the computer-derived analysis.

ANALYTICAL METHOD

The method of analysis is basically one which is performed by an X-ray diffraction data analyst working with diffractometer tracings. Computer methods in mineral identification, mineral quantification, and data tabulation are employed to perform simple, repetitive functions which are costly in time and are prone to human error. A data analyst checks the results of the computer analysis and manually performs the complicated and/or highly variable mineral identifications and quantifications. The precision of the method is approximately ±1% by weight for well-crystallized minerals. However, the method is considered to be only semiquantitative because of inevitable differences in the mineralogy of samples and standards.

The method used for the analysis of the X-ray diffractograms is presented below in two sections. The first section lists the 12 steps of the analysis while the second section describes each step. All the steps, except Step 9, are performed by computer. Steps 1 to 8 and Step 11 are performed by a computer-analysis program (MINLOG) and Steps 10 and 12 are performed by a battery of data handling programs. When corrections to the output of the analysis program are made manually, the data analyst duplicates the logic steps used in the computer-analysis program in order to maintain consistency of the data.

Steps in Data Analysis

1. Smooth the digital pattern.
2. Subtract the background.
3. Determine the location and height of all diffraction peaks.
4. Determine the presence of quartz or calcite using multiple-peak criteria, then correct the location of all peaks using the first mineral identified as a pattern-alignment standard.
5. Identify minerals present on the basis of a single, diagnostic peak.
6. Subtract interfering secondary peaks of other minerals present from the diagnostic peaks.
7. Multiply all corrected diagnostic peak heights by their intensity factors to convert them into mineral ratios.
8. Adjust the total of all identified minerals to 100%.
9. Manually check the output of the computer-analysis program.
10. Correct the computer output.
11. Estimate the content of amorphous material.
12. Generate mineral-concentration tables and histograms.

Description of Steps in Data Analysis

1. Smooth the digital pattern: The raw, digitized diffraction data are smoothed mathematically by averaging the intensities of adjacent data points. This is the first step in the computer-analysis program run on the University of California, Riverside, Computing Center's IBM 360-50. (The smoothed data are also used to generate diffractograms of each X-ray sample using the PDP-8 computer and Houston Instrument plotter. The diffractograms are mathematically scaled so that the maximum intensity of any diffractogram equals 10 in.) The mathematical method of smoothing is similar to the signal-averaging electronic filters in chart recorders but has the advantage that (a) there is more choice in the weighting of adjacent points, and (b) the filter can be applied to data points in front of, as well as behind, the point being calculated.

A circular filter has been found to be the most effective for smoothing the data. The weighting is derived from the equation

$$x^2+y^2=\text{a constant} \qquad (1)$$

where x is the weighting function, and y is the distance from the point being calculated to the point being used for weighting. Presently a 13-point filter with a constant of 49 is used.

The smoothed intensity value of any point I' is given by

$$I_i' = \frac{\sum_{j=-6}^{6} x_j \cdot I_{i+j}}{\sum_{j=-6}^{6} x_j} \qquad (2)$$

where I_i is the i unsmoothed intensity point and $j=y$. The 13-point circular filter is approximately the equivalent of a 3-sec time constant.

2. Subtract the background: The background removal routine attempts to separate diffraction peaks from background in a manner similar to that used by a diffraction data analyst. Figure 2 shows a portion of an

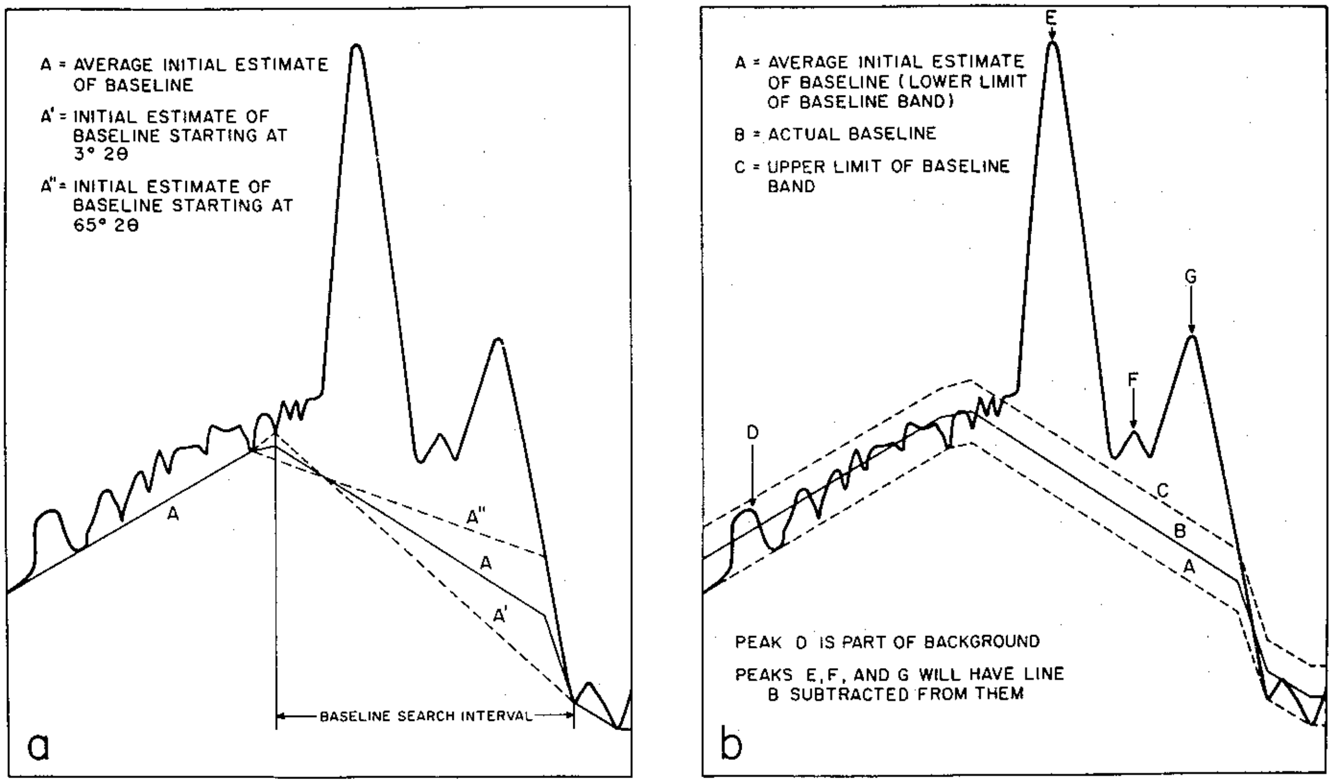

Figure 2. *Method of background removal:* (a) *construction of initial estimate of background,* (b) *construction of baseline band.*

expanded pattern of a clay sample containing a large amount of amorphous silica.

The first estimate of this baseline is made by constructing a series of straight lines from consecutive low points in the pattern. Ideally, these lines have a maximum length which is less than the width of the amorphous hump but greater than the width of any group of overlapping peaks. In practice, the maximum length of these lines, which we call the baseline search interval, is $5°2\theta$ from $3\text{-}11°2\theta$ and $2°2\theta$ for the remainder of the pattern. Since these lines are sometimes dependent on the direction from which they are started, the series is started from both ends of the pattern, and the intensity is averaged for each point. In Figure 2a, line A′ is constructed starting from the 3° end while A″ is constructed starting from the 65° end. Line A is the average of the two lines. Over much of the pattern the lines from the two ends of the pattern coincide.

Since X-rays are given off in a Poisson distribution, the count rate will fluctuate eoen though nothing is changing in the system. The amount of this fluctuation is proportional t the square root of the average count rate. T is fluctuation has two effects: (1) the intensity of the baseline is underestimated since low points are always selected, and (2) some of the intensity fluctuations along the background can appear as small peaks.

The method of background removal assumes that the statistical fluctuation occurs in a band (a range of intensities called the baseline band) above the initial estimate of the background (Figure 2, line A) which is proportional to the square root of the intensity of A at any point. The band is mathematically constructed above A such that the midpoint of the band is $0.7 \times \sqrt{A}$ (line B) and the upper limit is $1.4 \times \sqrt{A}$ (line C). Peaks with intensities less than C, are difficult to resolve from random fluctuation. They are therefore considered as part of the background and are subtracted from the diffraction pattern. Peaks with intensities greater than C are considered to be real. Their height is computed from line B. For example, in Figure 2, peak D will be considered to be background. Peaks E, F, and G will have the intensity of line B subtracted from them and will be retained for the next step in the computer analysis.

3. Determine the location and height of all diffraction peaks: After the background is removed the residual intensities are tested for the presence of peaks. Currently, a criterion of at least five ascending data points followed by five descending data points is used by the analysis program to define a peak. The actual location and the height of any peak is taken to be the location and height of the most intense data point between the two series of points. Ascending and descending series of points need not be contiguous.

4. Determine the presence of quartz or calcite using multiple-peak criteria, then correct the location of all peaks using the first mineral identified as a pattern-alignment standard: A number of factors can cause sample peaks to shift as much as $0.3°2\theta$. These include inaccuracies in positioning of the sample in the sample changer, slight changes in the goniometer alignment, and occasional sample-dimension changes. Although this does not seriously affect manual interpretation of plots, it does make computer identification of minerals much more difficult. Inasmuch as we do not routinely use an internal standard, we attempt to use naturally occuring "standards" to make 2θ corrections. In the bulk fraction, low-magnesium calcite is normally a major constituent, while in all three fractions quartz is frequently a major constituent of the samples.

Quartz is the first mineral sought since it has the most stable crystal lattice. In order to insure that quartz is not missed or misidentified, every peak within 0.8°2θ of 26.66°2θ is checked and compared to secondary quartz peaks to see if it is the major quartz peak. The secondary peaks which are checked must be within 0.1°2θ of the correct distance from the major peak and must have an intensity that is within 30% of the correct ratios of the major peak. The 20.86° and 50.18° peaks are checked, respectively, for intensities of 0.19 and 0.11 of the major quartz peak. The same criteria are applied to calcite. The major calcite peak is 29.44° and the secondary check peaks are 23.06°, 47.56°, and 48.56° with intensities of 0.086, 0.2, and 0.18, respectively. Approximately 80% of the diffractograms can be tested and shifted if needed using the criteria given above.

5. Identify minerals present on the basis of a single, diagnostic peak: The computer identification of the minerals present in a sample is based upon the occurrence of peaks within a narrow range of degrees 2θ called a window. This window is made as narrow as possible to avoid detecting secondary peaks of other minerals but wide enough to include the diagnostic peak of the target mineral considering variations in the crystal structure, sample positioning, etc.

6. Subtract interfering secondary peaks of other minerals present from the diagnostic peaks: The criteria used in selecting the diagnostic peak for a mineral are: (1) high intensity, (2) low degree of variability in peak position and peak intensity due to crystal-lattice variations, and (3) absence of interfering peaks from other minerals.

The third criterion is difficult to satisfy in sedimentary minerals. In numerous cases the diagnostic peak overlies or is on the shoulder of a secondary peak of another mineral which may occur in the sample. In order to correct for the contribution of an interfering peak to the diagnostic peak height, the proportion of counts appearing in the window of the mineral sought to the number of counts of the diagnostic peak of the interfering mineral is determined. This proportion, called the interference factor, is usually measured from the diffraction pattern of the interfering mineral in pure form. If the interfering mineral is detected in the sample, the peak height in the window of the mineral sought is reduced by an amount determined from multiplying the diagnostic peak height of the interfering mineral by the interference factor.

7. Multiply all corrected diagnostic peak heights by their intensity factor to convert them into mineral ratios: The mineral content is quantified using the method of mutual ratios. Klug and Alexander (1954) have shown that

$$X_i = K_i \cdot \frac{I_i}{I_s} \qquad (3)$$

where

X_i = the mineral weight fraction in the sample.

K_i = a constant (intensity factor) which is dependent on instrument geometry, the peak intensities of the mineral being analyzed, and the internal diffraction standard.

I_i = the intensity of a given peak belonging to the mineral being analyzed.

and

I_s = the intensity of a given peak of the internal diffraction standard.

If we form a ratio between minerals i and j we can write

$$\frac{X_i}{X_j} = \frac{K_i \cdot \frac{I_i}{I_s}}{K_j \cdot \frac{I_j}{I_s}} = \frac{K_i \cdot I_i}{K_j \cdot I_j} \qquad (4)$$

If we assign $K_j = 1$ and let it always be the same mineral, we can rewrite (2) as

$$\frac{X_i}{X_j} = K_i \cdot \frac{I_i}{I_j} \qquad (5)$$

or

$$X_i = K_i \cdot I_i \cdot \frac{X_j}{I_j} \qquad (6)$$

If the weight fraction of mineral j (X_j) were known, we could calculate the absolute weight fraction of each mineral present. Since we do not know the weight fraction of mineral j present, we can only calculate the relative fractions for each mineral and say that

$$X_i \propto K_i \cdot I_i \qquad (7)$$

In practice the K factors are obtained from standards made up of 50% mineral i and 50% quartz by weight.

8. Adjust the total of all identified minerals to 100%: There are two portions of the sample for which we cannot use Equation 7 in determining the relative weight fractions: (1) amorphous material, (2) minerals for which we have no standards. We will call the portion of the sample which is either amorphous or composed of a mineral for which we have no standard the nonquantifiable portion and the remainder the quantifiable portion. If we let X_i *be the weight fraction of mineral i* in the quantifiable portion, we can write

$$X_i' = a \cdot K_i \cdot I_i \qquad (8)$$

where

$$a = \frac{1}{\sum_{i=1}^{n} K_i \cdot I_i} \qquad (9)$$

If A = the fraction of the sample which is amorphous and U = the fraction of the sample which cannot be identified or cannot be quantified due to the lack of standard,

$$X_i = (1-A-U) \cdot X_i' \tag{10}$$

The output of the computer-analysis program prints the sample identification, the diffuse scatter value of the sample (explained in Step 11), and the peak intensity (I_i) and the relative concentration (X_i) *for each identified mineral for manual checking. These data are also stored on magnetic tape for later computer use.*

9. Manually check the output of the computer-analysis program: The output of the computer-analysis program is checked against the diffractogram of each X-ray sample by a data analyst. First, the identification of each mineral is confirmed by the presence of secondary peaks of that mineral. Second, the diffractogram is examined for unreported minerals or new minerals. Third, the mineral compositions of the three preparations of one sample (bulk, silt, and clay fractions) are compared for geological consistency among themselves as well as with samples occurring above and below in the stratigraphic column.

If in checking the diffractograms, minerals are found for which interference factors and intensity factors are available, the results of the analysis program are recalculated to include these minerals. Minerals for which factors are not available or which cannot be identified are given an qualitative concentration. A hypothetical intensity factor of 3.0 is assigned for the major peak of any mineral which is to be reported qualitatively. The proportion of the mineral is computed by the method of mutual ratios and is reported according to the following qualitative scale: Trace, <5%; present, 5-25%; abundant, 25-65%; major, >65%. 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%.

10. Correct the computer output: Through a series of computer programs, corrections to the relative concentration percentages as well as minerals which are reported qualitatively are inserted into the original computer output along with descriptive footnotes.

11. Estimate the content of amorphous material: The method by which the content of amorphous material has been estimated since Leg 28 is a modification of the method presented in DSDP Initial Reports, Volume 4, Appendix III. Basically we attempt to measure the amount of amorphous material from the diffuse scatter of a sample. The current method assumes that the diffuse scatter in excess of the sum of the diffuse scatter by the crystalline minerals is a measure of the quantity of amorphous material. It also assumes that the intensity of diffuse scatter per unit weight from the amorphous material is the same as the diffuse scatter from the crystalline components.

The total intensity of an X-ray diffraction pattern can be considered to be a result of five factors: (1) peaks due to Bragg diffraction, (2) diffuse scatter inherent within any crystalline material, (3) diffuse scatter from amorphous material, (4) air scatter, and (5) sample fluorescence, incoherent scatter, extraneous radiation from the instrument, and electronic noise. Air scatter is less than 20% of the total intensity and remains constant for the goniometer geometry. Sample fluorescence, incoherent scatter, extraneous radiation, and electronic noise are eliminated by the diffracted-beam monochrometer and Pulse Height Analyzer.

The total amount of diffuse scatter, D, is calculated by

$$D = \frac{I_T - I_B}{I_T} \times 100 \tag{11}$$

where I_T is the total integrated intensity of diffraction from 3° to 65°2θ, and I_B is the integrated intensity of the Bragg diffraction above the baseline (as computed in Step 2).

A predicted diffuse scatter value, D_P, is calculated by

$$D_P = 0.01 \sum_{i=1}^{n} X_i' \cdot D_i \tag{12}$$

where D_i is the diffuse scattering of the i^{th} mineral (measured from the standard) and X_i' percentage of the i^{th} mineral using corrected data as determined in Step 9. Unknown and qualitatively reported minerals are assumed to have the same diffuse scatter as the quantitatively analyzed portion of the sample. Air scatter is accounted for by the sum of the components.

The percentage of amorphous material present, A, is estimated by

$$A = \frac{D_s - D_p}{1 - D_p} \tag{13}$$

where D_s is the diffuse scatter of the sample as determined by Equation 11.

12. Generate mineral-concentration tables and histograms: A set of cards with sample identification and mineral composition data is punched out by the computer. Cards giving core depths and explanatory comments are inserted to form the complete data decks. These decks are used to generate printed mineral-concentration tables and histograms.

DISCUSSION OF THE METHOD

The goals of the X-ray Mineralogy Laboratory are to (1) determine the minerals which are present, (2) quantify the ratios between the various minerals, (3) estimate the amount of amorphous material which is present, and (4) determine the individual species of the mineral groups (e.g., solid solution series) which are present, if practical. The list is in the order in which analyses are performed and also is in the order of the priorities. The quality of the mineralogy data will be discussed in this framework.

Determine the Minerals Which Are Present

Table 1 is a list of the minerals and mineral groups which are commonly found in sediments and are actively sought by the computer-analysis program and the data analyst. The current windows and intensity factors are also listed. (The lab also has quantitative data for adularia, anorthoclase, anthopyllite, cuprite, grossularite, ilmenite, sphalerite, sylvite, and vermiculite.) Many minerals are identified (and quantified) only on the mineral-group or solid-solution-series level since the mineral species (such as the micas, plagioclases, K-feldspars, and others) have highly similar diffraction patterns and identification of the species becomes impractical using reoutine procedures.

Any analytical method is ultimately limited by its sensitivity; that is, its detection limit and resolution. An experiment was conducted in which gypsum, quartz, dolomite, bytownite, orthoclase, chlorite, apatite, aragonite, and phillipsite were mixed in low concentrations with nannofossil ooze. The samples were randomized and X-rayed by the standard method. The lowest concentration which gave a positive identification of each mineral was deemed to be the detection limit of that mineral. A plot of the intensity factor versus detection limit (in weight percent) gave a straight line which goes to zero and has a slope of 0.12. Thus the detection limits of quartz and phillipsite are approximately 0.1% and 2% by weight, respectively. These detection limits increase linearly with the concentration of diluting amorphous materials and the mass absorption coefficient of the matrix. Interfering peaks also raise the detection limit. Inasmuch as a multiple-peak criterion is used by the analyst to identify most minerals, the actual detection limit will be higher by an amount proportional to the ratio of the diagnostic peak intensity to the secondary peak intensity. In actual pracice we do not report less than 0.3% quartz and 4% phillipsite.

The current instrumentation and method of smoothing allows two sharp peaks of equivalent intensity to be resolved if they are more than approximately 0.2°2θ apart. This permits a resolution of peaks with differences in d-spacing of 1Å at 5°, 2Å at 10°, 0.02Å at 30°, and 0.004Å at 65°.

TABLE 1
Minerals Actively Sought in Diffraction Data Analysis

Mineral	Window (°2θ, CuKα Radiation)	Range of D-Spacings (A)	Intensity Factor[a]
Amphibole	10.30–10.70	8.59– 8.27	2.50
Analcite	15.60–16.20	5.68– 5.47	1.79
Anatase	25.17–25.47	3.54– 3.50	0.73
Anhydrite	25.30–25.70	3.52– 3.46	0.90
Apatite	31.80–32.15	2.81– 2.78	3.10
Aragonite	45.65–46.00	1.96– 1.97	9.30
Augite	29.70–30.00	3.00– 2.98	5.00
Barite	28.65–29.00	3.11– 3.08	3.10
Calcite	29.25–29.60	3.04– 3.01	1.65
Chlorite	18.50–19.10	4.79– 4.64	4.95
Clinoptilolite	9.70– 9.99	9.11– 8.84	1.56
Cristobalite	21.50–22.05	4.13– 4.05	9.00
Dolomite	30.80–31.15	2.90– 2.87	1.53
Erionite	7.50– 7.90	11.70–11.20	3.10
Goethite	36.45–37.05	2.46– 2.43	7.00
Gypsum	11.30–11.80	7.83– 7.50	0.40
Halite	45.30–45.65	2.00– 1.99	2.00
Hematite	33.00–33.40	2.71– 2.68	3.33
Kaolinite	12.20–12.60	7.25– 7.02	2.25
K-Feldspar	27.35–27.79	3.26– 3.21	4.30
Magnetite	35.30–35.70	2.54– 2.51	2.10
Mica	8.70– 9.10	10.20– 9.72	6.00
Montmorillonite	4.70– 5.20	18.80–17.00	3.00
Palygorskite	8.20–8.50	10.70–10.40	9.20
Phillipsite	17.50–18.00	5.06– 4.93	17.00
Plagioclase	27.80–28.15	3.21– 3.16	2.80
Pyrite	56.20–56.45	1.63– 1.62	2.30
Rhodochrocite	31.26–31.50	2.86– 2.84	3.45
Quartz	26.45–26.95	3.37– 3.31	1.00
Sepiolite	7.00– 7.40	12.60–11.90	2.00
Siderite	31.90–32.40	2.80– 2.76	1.15
Talc	9.20– 9.55	9.61– 9.25	2.56
Tridymite	20.50–20.75	4.33– 4.28	3.00
Gibbsite	18.00–18.50	4.93– 4.79	0.95

[a]The intensity factors are determined in 1:1 mixtures with quartz by obtaining the ratio of the diagnostic peak intensity of each mineral with the intensity of the diagnostic peak of quartz, which is assigned a value of 1.00. The detection limit in weight percent of the minerals in a siliceous or calcareous matrix can be obtained by multiplying the intensity factor by 0.12.

The computer-analysis program is effective in identifying the presence of approximately 90% of the minerals. The data analyst must identify the remaining mineral phases. This is done by a visual inspection of the diffractograms. In examining the diffractograms, the analyst assigns every major peak (i.e., greater than 10%) in the diffraction pattern to a mineral.

The major cause of error in the identification of the common minerals by the computer-analysis program is due to the interference of diffraction peaks. The analyst usually identifies the minerals missed by the program on the basis of secondary peaks. The analyst proceeds to measure the peak height of the diagnostic peak by deconvoluting overlapping peaks and subtracting known interferences. By this method, approximately an additional 9% are identified and quantified.

The analyst is aided in the rapid recognition of mineral diffraction patterns, even when they occur in small quantities, by the facts that (1) certain minerals occur in natural assemblages (e.g., in volcaniclastic sediments, as characterized by the presence of augite and magnetite, a special effort is made to look for high-temperature feldspars, hematite, ilmenite, analcite, and mordenite); (2) a mineral occurring as a major component in either the bulk, 2-20μ, or $<2\mu$ fractions commonly occurs as a minor component in another fraction; and (3) a mineral occurring as a significant component at one position in the stratigraphic column may also occur in adjacent samples. Moreover, an experienced analyst develops a keen sense for deviations from "normal" diffraction patterns (produced by the common minerals). The analyst can thereby detect unknown minerals and unusual species of minerals such as high-magnesium calcite, high-temperature feldspars, and mixed-layer clays in concentrations as small as 5% to 10%.

If there are unassigned peaks in the pattern, an attempt to identify the mineral is made by making an optical examination of the sediment and by checking in the Joint Committee on Powder Diffraction Standards (JCPDS) file. When the peaks cannot be assigned to a known mineral after a reasonable amount of work, the peaks are listed as belonging to an unknown mineral and are published in a footnote.

Quantify the Ratios Between the Various Minerals

The mineral percentages which are reported are actually ratios of the quantifiable portion of the sample where the total is normalized to 100%. The nonquantifiable portion of the sample consists of the amorphous material, and any mineral group for which we do not at present have an adequate standard (because of insufficient time, nonavailability of pure material, or failure to identify the mineral). Thus a sample which actually contained 5% quartz, 2% mica, 43% an unidentifiable mineral, and 50% amorphous silica will be reported as 71.8% quartz, 28.2% mica, an unidentified mineral as a major component, and an amorphous value of 50%. The mineral and amorphous data are reported with one digit behind the decimal point in order that minerals having low detection limits can be presented. It is not inetnded to imply that degree of accuracy.

The accuracy of quantitative X-ray mineralogy data is principally dependent upon (1) the precision of the method, and (2) the degree of similarity between the minerals in the samples and the calibration standards.

To determine the precision of the quantitative method, a series of 10 samples in which known amounts of calcite, quartz, kaolinite, and dolomite had been intermixed was analyzed. The samples were then run without any attempt to recheck calibration of the mineral standards or alignment of the goniometer. The average deviation of expected versus analyzed concentrations was 3.4%. An examination of the errors revealed that the intensity factors were slightly in error at the time of running. After correcting the factors, the average deviation was 0.4%. Thus the analytical method and method of sample preparation can be expected to give results which are accurate ±0.4% of the absolute concentration. In practice, replicate samples give concentrations of well-defined minerals which agree within 1%.

The largest source of inaccuracy in the quantitative analysis comes from the differences in crystal structure and the degree of crystallinity between minerals in sediments and mineral calibration standards. For example, a series of high-purity montmorillonites mixed 1:1 with quartz gave intensity factors ranging from 3 to 10. Diluting impurities in the standards also affect the accuracy.

An effort is made to match the standard with commonly occurring species in the sediment and, if possible, the standards are selected from marine sediments. Nevertheless, the error in the reported values could be as much as ±50% of the amount present in the case of montmorillonites, ±20% in the case of micas and chlorites, and ±10% in solid solution series such as the feldspars and carbonates. Stable forms such as quartz, aragonite, gypsum, barite, pyrite, magnetite, and others will have a reliability approaching ±1% of the amount present.

In views of the rather high degree of precision of the method, given a homogeneous mineralogy, concentration trends can be regarded as being highly reliable. However, comparisons of mineral concentrations and mineral concentration ratios among lithologic units with different provenances or different diagenetic histories have to take into account the potential differences in the crystal structure of the minerals.

Estimate the Amount of Amorphous Material Which Is Present

An experiment in which calcite was mixed with 20%, 40%, 60%, and 80% ground glass yielded an average deviation of calculated versus expected concentrations of glass of 2.1%. Thus, in the ideal situation, the amorphous scatter value is an accurate measure of the amorphous material present.

In natural samples, error in the estimate of amorphous material comes from (1) differences in diffuse scatter between the sedimentary minerals and the mineral calibration standards, and (2) difference between the intensity of X-ray scattering between the crystalline phases and the amorphous phases.

The amorphous scatter value is most accurate at high and low concentrations of amorphous material. It should range between 0 and 100% but on occasion, slightly negative values of amorphous scatter have been calculated when the diffuse scatter of the identified crystalline minerals in the sample was less than in the standards.

Determine the Individual Species of the Mineral Groups, if It Is Practical

Normally, distinction between the individual species of a solid solution series or a clay mineral group cannot be made using our methods because further tests are required, or because the sample consists of a mixture of species. When, however, a sample contains a species not commonly found in marine sediments in large concentrations, the species is identified and a footnote is entered in the data tables. Usually the intensity factor of the common form of the mineral is used to quantify the unusual species.

REFERENCES

Klug, H. P. and Alexander, L. E., 1954. X-ray diffraction procedures for polycrystalline and amorphous materials: New York (John Wiley).

Rex, R. W. and Bauer; W. R., 1965. New amine reagents for X-ray determination of expandable clays in dry samples: Clays and clay minerals, 13th Natl. Conf. Proc., p. 411-418.

Rex, R. W. and Chown, R. G., 1960. Planchet press and accessories for mounting X-ray powder diffraction samples: Am. Mineral., v. 45, p. 1280-1282.

5. ESTIMATION OF SEDIMENTATION AND ACCUMULATION RATES

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INTRODUCTION

The rates at which events proceed are critical to the study of the deposition and paleoceanographic history of the ocean basins. The most conveniently obtained rate is the rate of deposition of sediments. Made possible by rapid advances in the absolute chronology of biostratigraphic boundaries, these rates have been used to develop the history of the equatorial zone of high biological productivity (Tracy, Sutton et al., 1971, I.R. DSDP, 8; van Andel et al., 1975) to unravel the oceanographic processes behind temporal changes in the calcite compensation depth (Heath et al., 1977) and to study the change with time of various sediment inputs into the world oceans (Hay and Southam, 1977; Davies et al., 1977). Even with the limited resolution and significant remaining uncertainties of the current absolute chronology of the biostratigraphic time scale, sedimentation rates have proven to be key elements in paleoceanographic work.

The importance of quantitative estimates of rates of deposition was recognized early by Deep Sea Drilling Project researchers. The first explicit estimates and their use in understanding sedimentary history occur in Volume 2 of the Initial Reports; estimates have been included in nearly all subsequent volumes.

DETERMINATION OF SEDIMENTATION RATES

"Sedimentation rates," as used in the Initial Reports, are measured in units of core length per unit of time, usually in meters per million years. Beginning with Volume 8 of the Initial Reports, a standard diagram was adopted for estimating these rates from a plot of biostratigraphic age versus depth in the hole. On such plots the age coordinate is calibrated in millions of years by means of a suitable biostratigraphic time scale generally, but not invariably, cited in the Initial Reports. Core position in the hole is plotted on the other coordinate, and biostratigraphic age determinations are commonly shown as boxes with a height representing top and bottom of the zone as observed in the hole and a width equivalent to the age range of the zone (Fig. 1). A line, commonly in straight segments, is constructed through the data set to represent the increase of age with depth in the hole. The slopes of these line segments yield the average sedimentation rate for each interval.

In some cases, when core recovery and biostratigraphic data permit, more detailed versions of such curves are presented. In these versions, the ages of zone boundaries in cores are plotted as points. Maximum and minimum ages are shown where boundaries were not actually observed. A smooth curve can be drawn through these points (Fig. 2). The first slope derivative of this curve with respect to time yields sedimentation rates in meters per million years for each one-million-year interval (e.g., I.R. DSDP, 40; van Andel et al., 1975). In all versions, the effect of both certain and possible hiatuses must be carefully considered.

CONFIDENCE LIMITS OF SEDIMENTATION RATES

Confidence limits of sedimentation rates depend on three potential sources

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

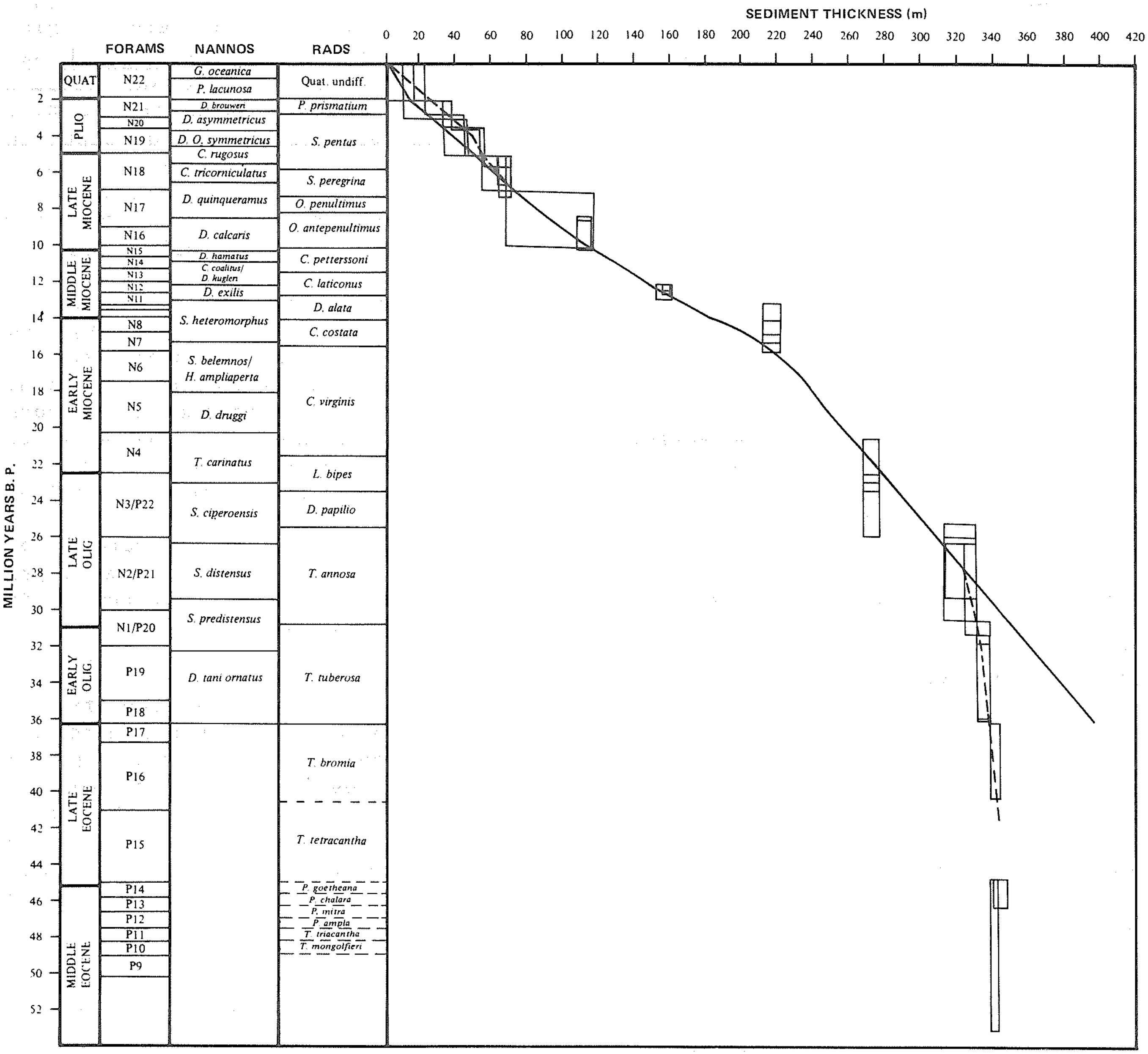

Figure 1. Determination of age versus depth-in-hole curve for Site 72. Sedimentation rates are derived from slope of curve (I.R. DSDP, 8:475).

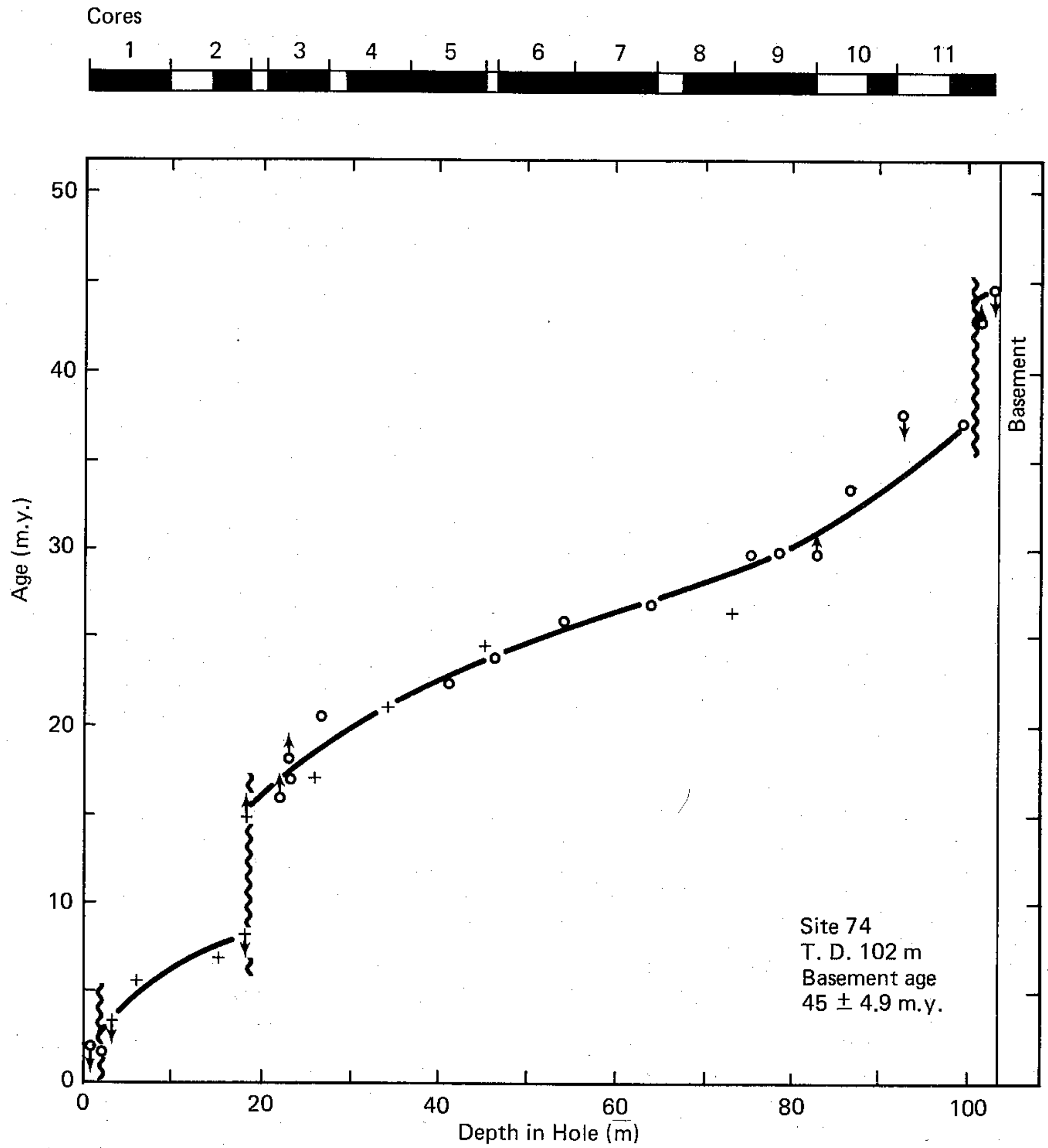

Figure 2. Example of graphic method for determining depth in hole at 1-m.y. intervals. Black dots: foraminiferal zone boundaries; open circles: nannofossil zone boundaries; crosses: radiolarian zone boundaries. Up and down arrows indicate minimum and maximum ages, respectively, at top and bottom of core. Wavy lines are hiatuses. Position and number of cores are shown at the top. The first derivative of this curve yields sedimentation rates in meters per million years (van Andel et al., 1975, fig. 65).

of error - the resolution and precision of the available biostratigraphic data, the precision of the biostratigraphic time scale, and the plotting and reading errors for the age versus depth-in-hole curves. Errors of the third kind usually are small, but some surprisingly large ones can be found in the Initial Reports. The quality of the basic biostratigraphic information varies greatly from core to core, hole to hole, and leg to leg, depending on the coring schedule, core recovery, preservation of fossils, and quality and quantity of the biostratigraphic analysis. In good cases, an age versus depth-in-hole curve that deserves considerable confidence can be obtained (Fig. 2), but Moore (1972) and Moore and Heath (1978) have pointed out that biostratigraphic boundaries are under-represented within cores and over-represented between cores. Even with a program of continuous coring, a significant portion, roughly one third, of the total column may be missing.

It is even more difficult to assess the effect of uncertainties in the biostratigraphic time scale. With few exceptions, the DSDP researchers have relied on successive versions of the Berggren (1969, 1972) time scale for the Cenozoic. Although it has been considerably improved since its first appearance (while still debated for certain intervals such as the middle Miocene or the earliest Paleogene), this scale has remained reasonably constant. Earlier applications generally can be converted to a more updated version without difficulty and simple methods exist for doing so (see, for example, van Andel et al., 1975, p. 113). Estimating quantitatively the confidence limits for each age assignment, on the other hand, is very difficult. Van Andel and Bukry (1973), judging this to be as yet impossible, assumed that the zone boundary age error increases exponentially from an assumed balue of ± 1 m.y. at age 10 m.y. to ± 5 m.y. at age 100 m.y. In light of current time scales, these estimates appear somewhat too high. A more reasonable assumption would be errors of less than 1 m.y. for rocks less than 20 m.y. old, increasing to 3 m.y. for ages between 50 and 75 m.y.

The biostratigraphic time scale for the middle and late Mesozoic is in a less satisfactory state, and several versions of equal acceptability that may differ by as much as 5 m.y. for stage boundaries in some parts of this interval have been proposed (e.g., Bukry, 1974; Thierstein, 1976; Van Hinte, 1976; I.R. DSDP, 33).

The problem of error estimates is much more difficult for high-resolution sedimentation rates such as those used in I.R. DSDP, 40 and in various syntheses. These estimates rest on zone and subzone boundary-age assignments that tend to be less well established and more controversial, and the effects of variations in the quality of the core data are considerably larger. Unfortunately, there is as yet no statistical theory or protocol to deal with confidence limits in time-series analysis when the independent variable, time itself, is subject to uncertainty. In a simple-minded way, one can argue that since the age uncertainty at each one-million-year boundary may be constrained by similar uncertainties at the preceding and following boundaries, a conservative error estimate would be 50%.

Given such an unsatisfactory rate, marine geologists tend to regard actual case histories as testimony to the quality of their data. If a meaningful pattern is systematically obtained in case after case, one tends to accept the data with considerable confidence. Sedimentation rates have been subjected to this test several times (Whitman and Davies, 1979; van Andel et al., 1975) and found to be valuable and informative if used with caution. Users of sedimentation rates in the Initial Reports and secondary publications should keep in mind, however, that it is necessary to examine carefully and at times standardize the data with regard to the biostratigraphic time scale if the data are to be used for comparative purposes.

SEDIMENTATION RATES AND COMPACTION

The sedimentation rate as defined here in units of core length per unit of time has fundamental and sometime severe limitations that must be recognized. The length of a column of sediment of more than zero age and recovered under any amount of overburden is not only a function of the rate of deposition but also, and often mainly, of the amount of compaction and diagenetic change. The reduction of sediment thickness resulting from overburden is, in turn, a function of the sediment type, the initial porosity, and the overburden pressure. In addition, the measured length of the recovered core is affected by a small amount of rebound, ranging from 2 to 9%, as the load is removed (Hamilton, 1976). Initial porosities range from about 90% for diatomaceous oozes and brown pelagic clay to 60-70% for calcareous ooze. With increasing overburden the decrease in porosity is substantial: calcareous sediments convert into chalk with a porosity of about 50% at 600 m depth, pelagic clays reach 65% at 200 m, and diatomaceous oozes suffer a reduction to about 70% at a depth of 300 m (Hamilton, 1976). Below these burial depths the porosity reduction continues but at a much slower rate. Hemipelagic sediments decrease from 60 to 70% at the surface to about 30% under an overburden of 1000 m or more. Consequently, thickness reductions of 30 to 70% with corresponding increases in sediment bulk density are possible depending upon sediment type, age, and depth of burial (Kominz et al., 1977). Diagenetic processes, such as carbonate cementation and intrastratal solution or the dissolution and redistribution of opal resulting in the formation of chert, further complicate the relation between initial and final sediment thickness. These processes are not sufficiently understood to permit theoretical corrections.

Thus, the sedimentation rate as defined here may underestimate the initial rate of deposition. The effect becomes noticeable for deposits under an overburden of more than 100 m and should be taken into account for all sediments of middle Cenozoic and greater age. Hamilton (1976) has provided equations to correct for this effect but they have not been widely used yet.

The problem has, of course, been realized and occasional attempts have been made to circumvent it, such as standardization to 50% porosity in a study of the equatorial Pacific zone of rapid sedimentation by Tracey, Sutton et al., 1971 (I.R. DSDP, 8). If handled with caution, the problem need not invalidate the use of sedimentation rates, as has been demonstrated by many studies dealing with global variations over long time ranges (e.g., Hay and Southam, 1977; Davies et al., 1977; Whitman and Davies, 1979).

SEDIMENT ACCUMULATION RATES

The problems caused by compaction, but not those resulting from diagenesis, can be avoided by using a different parameter proposed and defined by van Andel et al. (1975). This parameter is the accumulation rate, defined as the weight of solids accumulating on a unit area of seafloor per unit of time, usually expressed in grams per square centimeter per million years.

The procedure for calculating accumulation rates is simple, although laborious, and all necessary data are contained in the Initial Reports and DSDP data files. The weight of solids per square centimeter of cross section per meter of core (a unit chosen because the sedimentation rate is normally given in meters per million years) can be obtained from the wet bulk density and porosity of the sediment. A correction for the salt in the pore water is required. The salt correction does not take into account variations of salinity in the interstitial fluids because the error so introduced is small.

wt. solids (g)/m of core/cm^2 = 100 x (wet bulk density - 0.01025 x porosity)

The wet bulk density and porosity values can be obtained from GRAPE records or from shipboard and shore-laboratory determinations. Of these, the GRAPE data are more widely available and, if carefully selected, agree to within a few percent with accurate shore-laboratory measurements (Hamilton, 1976). In practice, GRAPE curves are fitted meter by meter with a smooth curve, avoiding bad values common at core tops and at thin hard layers and concretions or chert. Although GRAPE data from the Initial Reports can be used, such data are plotted with a compressed scale and are sometimes not properly registered. For more accurate estimates, GRAPE curves or data listings provided by the DSDP data bank are preferable. The use of such primary data also avoids plotting errors that crept into some of the Initial Reports. Mean wet bulk density and porosity values for each meter can then be plotted against depth in the hole, and curves fitted through the highest density and lowest porosity values because drilling disturbance tends to lower the former and raise the latter. From these smooth curves values to calculate weight of core per meter per square centimeter can be read. Examples of the results are shown in Fig. 3. From these curves the weight of sediment for each million-year interval can be estimated, accumulation rates can be derived by multiplying, or mean values obtained for each interval by the sedimentation rates.

Bulk accumulation rates can be separated into two parts, the carbonate and residual accumulation rates, by multiplication with the calcium carbonate percentage for the appropriate interval. These percentages are obtained from a smooth curve fitted to all calcium carbonate data plotted against depth in the hole (Fig. 3). In oceanic sediments, the carbonate accumulation rate is a measure of calcareous biogenic sedimentation and has been used successfully for the study of processes involved in changes of carbonate dissolution with time (Heath et al., 1977). The residual accumulation rate measures the combined deposition of terrigenous material, authigenic components, and biogenic opal. Its use depends on other evidence regarding the source of the components, and the rate cannot be directly substituted for a biogenic opal accumulation rate. Accumulation rates have been presented occasionally (I.R. DSDP, 40; see, also, Fig. 4), and have been used in several paleoceanographic studies (van Andel et al., 1975; Leinen, 1979; Leinen and Stakes, 1979).

CONFIDENCE LIMITS OF ACCUMULATION RATES

The errors involved in estimating the weight of solids per meter core per square centimeter can be estimated with fair precision. The error of GRAPE data has been estimated as about 5% for porosity and 0.05 g/cm^3 for wet-bulk density (Bennett and Keller, 1973). Hamilton (1976) states that good GRAPE values approximate good shore-laboratory determinations to within 2 or 3%. Reading errors on copies of GRAPE curves furnished by DSDP are small; about 1% for porosity and 0.02 g/cm^3 for wet bulk density. For the reduced curves in the Initial Reports, these errors can be much larger. The total error of the computed sediment weight is therefore of the order of 5-10%, depending on the accumulation rate.

This rather small error is overshadowed by the problems associated with determining the positions of the one-million-year boundaries in the cores. These problems have been discussed previously in connection with the sedimentation rate and apply in equal measure to the determination of the accumulation rate.

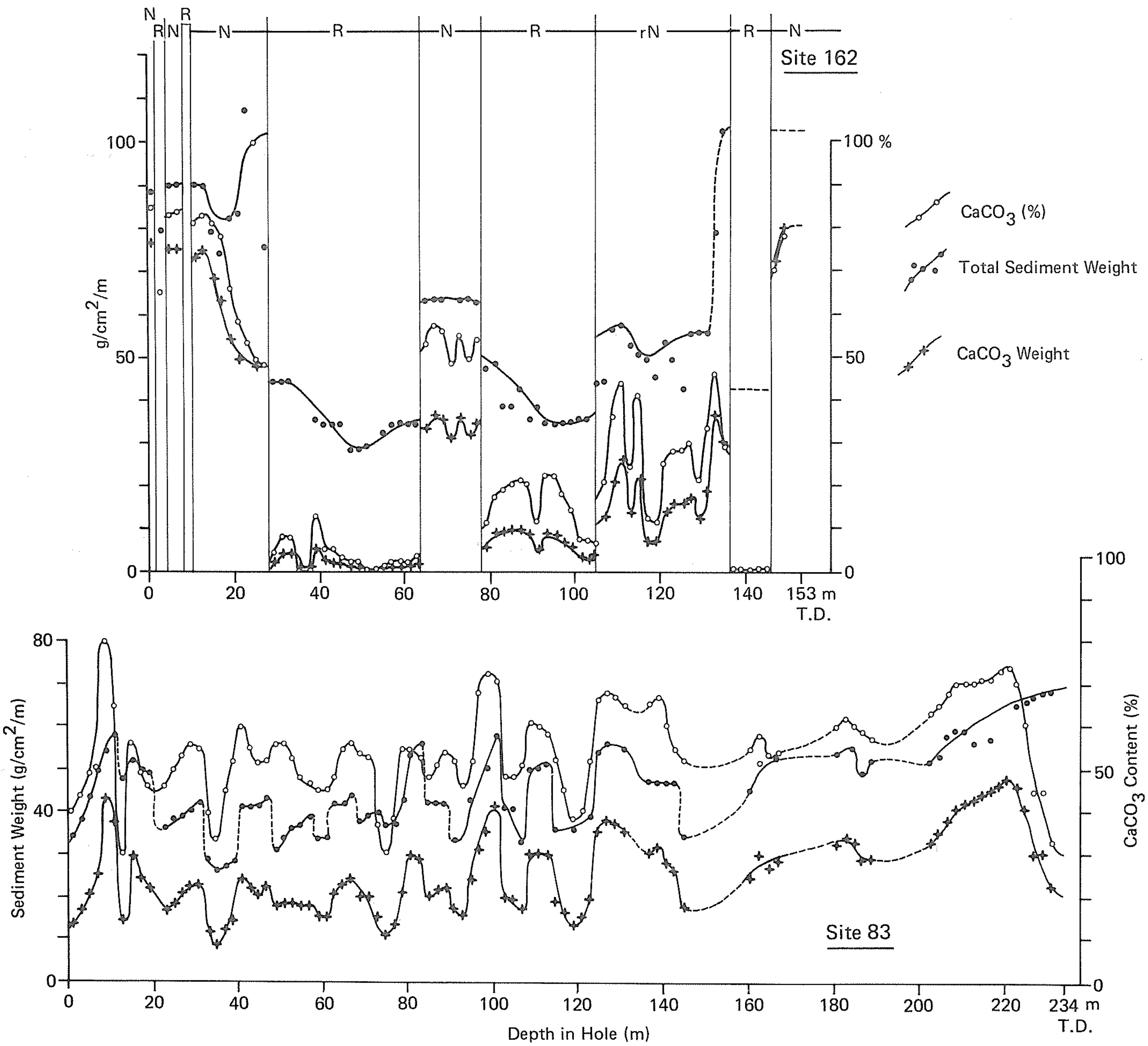

Figure 3. Examples of the determination of accumulation rates in typical (top) and in unusually well-documented DSDP sediments (bottom). Open circles: carbonate content data in percent; black dots: sediment weight in $g/cm^2/m$; crosses: weight of carbonate fraction in $g/cm^2/m$. Using an age versus depth-in-hole diagram like Figure 2, sediment weights, and carbonate weights for each one-million-year interval can be determined (accumulation rates). Lithology of Site 162 shown at top; N: nannofossil ooze or chalk; rN: radiolarian nannofossil ooze or chalk; R: radiolarian ooze. Curves have been fitted by hand. From van Andel et al. (1975, fig. 66).

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REFERENCES

Baldwin, B., Coney, P. J., and Dickinson, W. R., 1974. Dilemma of a Cretaceous time scale and rates of sea-floor spreading. Geology, 2:267-270.

Bennett, R. H., and Keller, G. H., 1973. Physical properties evaluation. I.R. DSDP, 16:513-519.

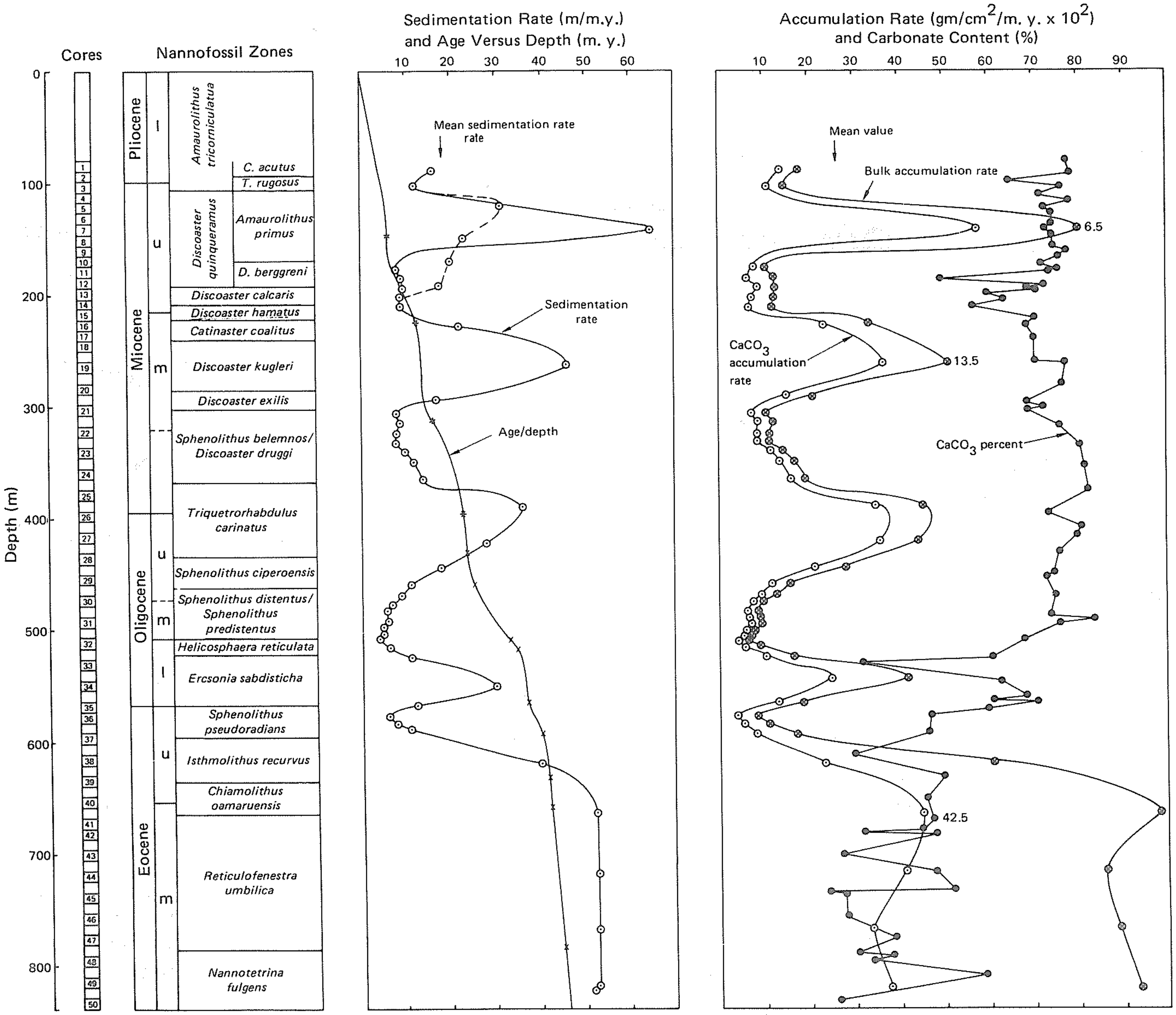

Figure 4. Depth in hole, sedimentation rate, carbonate content, and bulk and carbonate accumulation rates for Site 360 (I.R. DSDP, 40:62).

Berggren, W. A., 1969. Cenozoic stratigraphy, planktonic foraminiferal zonation, and the radiometric time scale. Nature, 224:1072-1075.

_______, 1972. A Cenozoic time scale: some implications for geology and paleo-biogeography. Lethaia, 5:195-215.

Bukry, D., 1974. Coccolith stratigraphy, offshore Western Australia. I.R. DSDP, 27:623-630.

Davies, T. A., Hay, W. W., Southam, J. R., and Worsley, T. R., 1977. Estimates of Cenozoic sedimentation rates. Science, 197:53-55.

Hamilton, E. L., 1976. Variations in density and porosity with depth in deep-sea sediments. J. Sediment. Petrol., 46:280-300.

Hay, W. W., and Southam, J. R., 1977. Modulation of marine sedimentation by the continental shelves. In Anderson, N. R., and Malahoff, A. (Eds.), Fate of Fossil Fuel CO_2 in the Oceans: New York (Plenum), pp. 569-604.

Heath, G. R., Moore, T. C., Jr., and van Andel, Tj. H., 1977. Carbonate accumulation and dissolution in the equatorial Pacific during the past 45 million years. In Anderson, N. R., and Malahoff, A. (Eds.), Fate of Fossil Fuel in the Oceans: New York (Plenum Press), pp. 627-640.

Kominz, M., Heath, G. R., and Moore, T. C., Jr., 1977. Bulk density of pelagic sediments from the equatorial Pacific estimated from carbonate content, age, and subbottom depth. J. Sediment. Petrol., 47:1593-1597.

Leinen, M., 1979. Biogenic silica accumulation in the central equatorial Pacific and its implications for Cenozoic paleoceanography. Geol. Soc. Am. Bull., 90:Pt. II:1310-1370.

Leinen, M., and Stakes, D., 1979. Metal accumulation rates in the central equatorial Pacific Ocean during the Cenozoic. Geol. Soc. Am. Bull., 90:Pt. II:357-375.

Moore, T. C., Jr., 1972. DSDP: successes, failures, proposals. Geotimes, 17:27-31.

Moore, T. C., Jr., and Heath, G. R., 1978. Sea-floor sampling techniques. In Riley, J. P., and Chester, R. (Eds.), Chemical Oceanography, 2nd Ed.: New York (Academic Press), 7:75-126.

Thierstein, H. R., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. Mar. Micropal., 1:325-362.

van Andel, Tj. H., and Bukry, D., 1973. Basement ages and basement depths in the eastern equatorial Pacific. Geol. Soc. Am. Bull., 84:2361-2370.

van Andel, Tj. H., Heath, G. R., and Moore, T. C., Jr., 1975. Cenozoic history and paleoceanography of the central equatorial Pacific. Geol. Soc. Am. Mem. 143.

van Hinte, J. E., 1976. A Cretaceous time scale. Am. Ass. Pet. Geol. Bull., 60:498-516.

Whitman, J. M., and Davies, T. A., 1979. Cenozoic sedimentation rates: how good are they? Mar. Geol., 30:269-284.

PART II. PHYSICAL PROPERTIES

6. THEORY, TECHNIQUES, AND INTERPRETATION OF DOWNHOLE TEMPERATURE MEASUREMENTS

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OBJECTIVE

The objective of measuring temperature in boreholes generally is to determine the rate at which heat is escaping through the ocean floor and/or to determine the temperature distribution with depth. It is necessary, therefore, to make enough temperature measurements at various depths in a single borehole so that the thermal gradient can be calculated over some depth interval. To calculate heat flow, it is necessary also to know the harmonic mean thermal conductivity of the sediment in that interval. The product of the thermal conductivity with the thermal gradient gives the rate of heat flow.

The measurement of *in situ* sediment temperatures at various depths below the seafloor has proven to be an effective method of determining the thermal gradient in the sediment (Erickson et al., 1975). Useful temperature data have also been obtained from measurements in mud- and/or water-filled boreholes drilled into consolidated sedimentary and igneous rocks (Hyndman et al., 1976; Erickson and Hyndman, 1978). These data are much more difficult to interpret and have been used mainly to provide information on the extent to which the movement of water through the seafloor has altered its thermal structure.

EQUIPMENT

Since an important objective of the heat-flow program has been to obtain detailed sets of temperature measurements in a few holes, instead of a few widely spaced measurements in many holes, the downhole temperature recorder and related hardware were originally designed to function along with, rather than in place of, the normal coring procedures used on the *Glomar Challenger*. With this arrangement, one might reasonably expect to obtain downhole temperature measurements before drilling each core with relatively little expenditure of ship time above that normally required for coring alone.

While a self-contained system was being designed and constructed, an interim program of downhole temperature logging was carried out on Legs 5 (Burns, 1970) and 8 (Von Herzen et al., 1971). This interim program took advantage of measurement opportunities during the early stages of the Deep Sea Drilling Project (DSDP) and provided practical experience that aided in the design of the self-contained system.

The instrumentation used for logging measurements in this interim program consisted of a sensing thermistor probe that projected several decimeters ahead of the drill bit. The upper end of the probe was fastened to an instrument package seated in the bottom of a core barrel that was raised and lowered by the logging cable. Thermistor resistance was converted to frequency at the bottom-hole instrument, and this frequency was telemetered to the surface via the logging cable, where it was converted to temperature by the use of calibration tables. Because of operational and instrumentation problems, the data obtained on Legs 5 and 8 was sufficiently variable and ambiguous to preclude meaningful geophysical interpretation.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

A prototype, entirely self-contained heat-flow recorder was tested at sea on the second half of Leg 14 and was subsequently used on Legs 19, 21, 22, 23, and 25. These instruments were able to measure absolute temperature over the range of 0 to 40°C ±0.1°C and were capable of sensing temperature changes of about 0.01°C. The instrument was turned on just before being inserted into the borehole and recorded temperature and calibration data in digital form on a magnetic drum every 4 s for 50 min. (Erickson, 1973). Although these instruments proved to be electrically adequate, they were not rugged enough to endure the mechanical shocks frequently encountered during a measurement. New, more rugged instruments using an endless-loop magnetic tape recorder rather than a magentic drum recorder were introduced on Leg 26 and remain in use.

Prior to Leg 37, several new instruments were built that are capable of recording data every 4, 8, 16, 32, 64, or 128 s, thus allowing their use for the more extended periods of time required to make downhole temperature measurements in very deep water or in water- or mud-filled boreholes drilled into the basement. In addition, the new instruments use variable-frequency converters, rather than variable-frequency oscillators, to convert thermistor resistance to frequency, thus ensuring that variations in the electrical capacitance of the probes do not alter the frequency. The instruments are now capable of recording temperature data every 8 s for about 90 min. or longer if the measurement interval is lengthened. The battery packs, each containing five half "D" size nickel-cadmium cells, can conservatively be used for six downhole measurements. The batteries then should be replaced. The magnetic tape recorder is an endless-loop variety having a two-track tape head. The function of the electronics section is to generate a frequency that depends on the resistance of a thermistor in a probe protruding from the bottom of the pressure case.

The frequency is counted for 1 s, converted to a 16-bit binary "word," and stored serially in the form of 16 0's and 1's on the magnetic tape. The timing, recorder-motor control, and switching functions are also performed by the electronics section.

The external hardware consists of a 2 3/8-in.-OD X 32-in.-long pressure case attached to a hollow 3/4-in. OD stainless steel probe whose tip protrudes 10 to 100 cm below the bottom of the pressure case. The diameter of the tip of the probe containing the thermistor is reduced to 3/8-in. OD in order to provide a faster thermal response time (Fig. 1).

Several types of mechanical latches have been designed to keep the temperature-probe assembly (consisting of the thermistor probe and temperature recorder) firmly locked to the bottom of the inner core barrel, thus providing the force necessary to penetrate the undrilled sediment at the bottom of the hole. Upon completion of the temperature measurement, the latch was designed to allow the temperature-probe assembly to pass up into the inner core barrel on top of the sediment core. A great deal of difficulty was experienced developing a latch that would perform these functions reliably. Frequently the latch would release the pressure case too soon -- sometimes even before the bottom-hole assembly was lowered onto the undrilled sediment. Furthermore, cores obtained with the pressure case in the core liner often were mechanically disturbed and were, of course, shorter than those obtained without the pressure case.

For these reasons, another method of lowering the temperature probe was used on Leg 22 and subsequent legs. This method involved securing the probe to the bottom of the core barrel and lowering both to the bottom of the drill string on the wire line. With the drill bit held above the bottom of the hole, the core barrel could be gently latched into the bottom-hole assembly

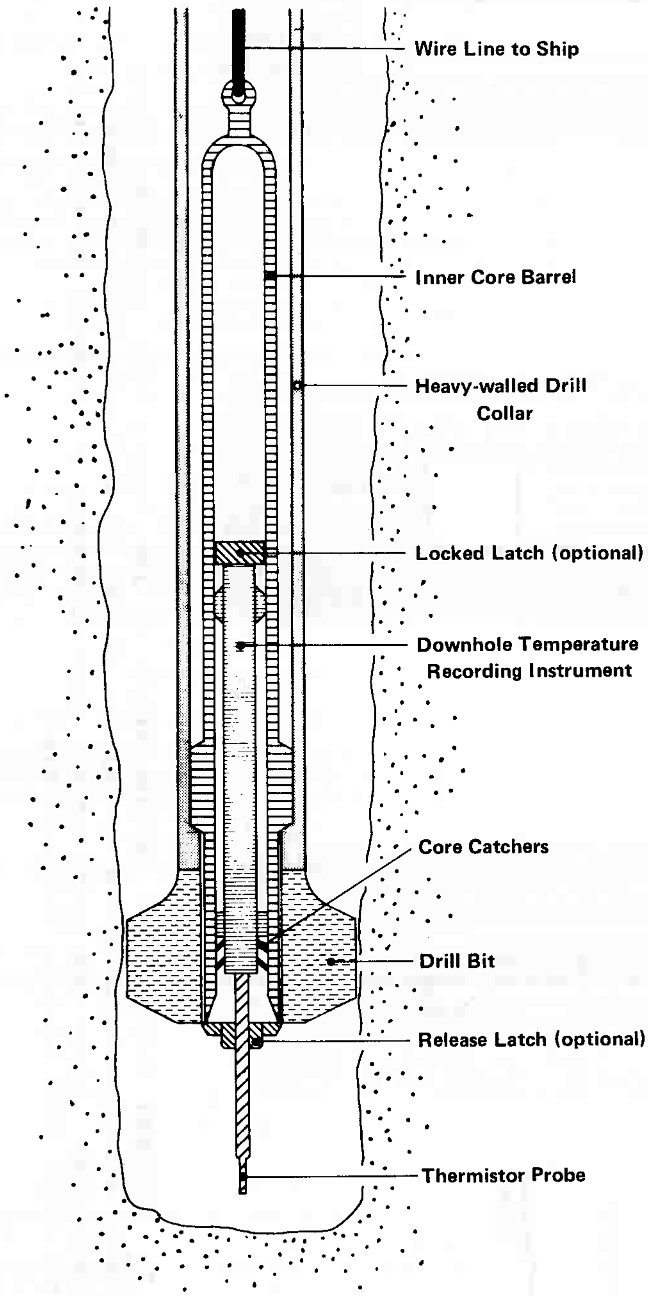

Figure 1. Schematic drawing of the downhole temperature recorder and probe inside the inner core barrel at the bottom of the drill string. (The drill bit is about to be lowered to the bottom of the hole, whereupon the thermistor probe will penetrate into the undrilled, thermally undisturbed sediment.)

and the drill string then could be lowered slowly to the bottom of the hole, thus using the weight of the bottom-hole assembly to push the probe into the undrilled sediment (Fig. 2). This method requires extra time because no core is obtained with the probe rigidly secured to the core barrel; however, it provides the most reliable means of measuring in situ sediment temperatures.

Thus when the instrument is ready for use, it is inserted into the lower end of a specially prepared wire-line core barrel usually reserved for the center bit. The core barrel contains an upper steel baffle, which prevents the pressure case from being pushed farther up inside the core barrel, and a lower 3/4-in.-thick steel disk that prevents the pressure case from falling out through the core cutter. A 7/8-in. hole in the disk permits the extender to protrude downward below the core barrel. Heavy coil springs are used above and below the pressure case to minimize impact. There are two methods of assembling the core barrel, depending on whether a 14 7/8-in. or a 10-in. bit is being used (see Fig. 3).

TECHNIQUES

Different techniques are required for each of the three different types of downhole temperature measurements. They include (1) those made in undrilled, unconsolidated, and semiconsolidated sediment ahead of the drill bit; (2) measurements of the temperatures of the mud or water within a few meters of the bottom of the borehole; and (3) measurements of borehole temperatures over an extended interval between the mudline and the bottom of the borehole.

Sediment Temperature Measurements

The thermal effects of drilling into undisturbed sediment are due primarily to temperature changes associated with drilling fluid (seawater) that is flushed down the drilled hole and secondarily to frictional heating at the

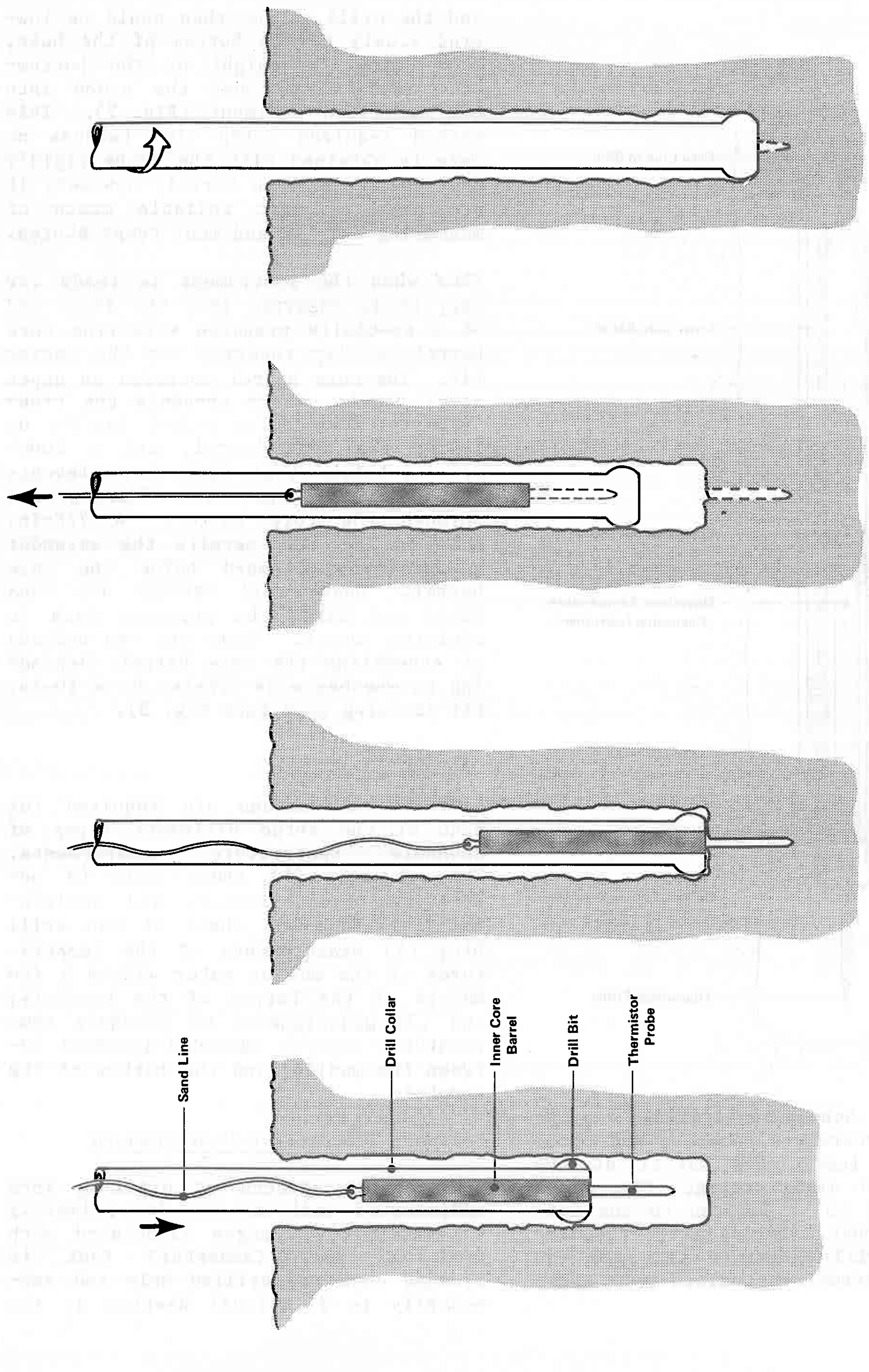

Figure 2. Diagram showing the configuration of the bottom-hole assembly, inner core barrel, and thermistor probe during the stages of a single downhole temperature measurement. (Open and solid arrows show direction of movement of the drill string and inner core barrel, respectively.)

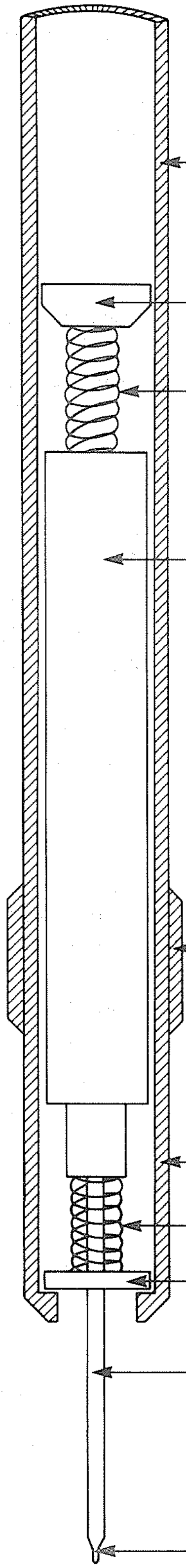

Figure 3. Detailed drawing of the inner core barrel showing the arrangement of the hardware used to restrain and protect the downhole temperature recorder.

bottom of the hole caused by the rotary motion of the drill bit (Bullard, 1947). Specifically, the flow of fluid through the hole will tend to cool the lower portion of the hole, which is warmer than the temperature of the drilling fluid, and to warm the upper portion of the drill hole. The time necessary for the entire borehole to return to thermal equilibrium with its surroundings is dependent upon the length of time during which drilling was in progress and is lower for shorter periods of drilling. On the assumption that a hole 30 cm in diameter is drilled through sediment in 1 day, the hole can be expected to approach thermal equilibrium with the surrounding sediment closely enough to obtain a reliable heat-flow measurement in 15 to 20 days (Bullard, 1947; Cooper and Jones, 1959; Oxburgh et al., 1972), a period of time much greater than a ship can afford to wait.

Because the time necessary for a return to thermal equilibrium is heavily influenced by how long the surrounding sediment is subjected to temperature perturbations, thermal equilibrium is achieved most rapidly at the bottom of the hole. Drilling rates in sediments soft enough to permit penetration by the thermistor probe are typically well above 1 m/h., a rate many orders of magnitude geater than the rate at which heat is conducted through sediment. Therefore the thermal effect of drilling affects the bottom of the hole only for the length of time equal to the interval between cessation of drilling and emplacement of the temperature probe in the undrilled sediment, a period that rarely exceeds 1 or 2 hr. Even after this period the thermal effects of drilling are less than 1% of the temperature difference between the drilling fluid and the in situ sediment temperature for measurements made more than 20 cm below the bottom of the hole (see Carslaw and Jaeger, 1959, p. 63). Our instrumentation is designed to measure sediment temperatures in the undisturbed sediments below the bottom of the hole as soon as possible after drilling has stopped at various depths.

At least two, and preferably three, sediment temperature measurements are usually required to establish a reliable geothermal gradient. Each measurement involves lowering an inner core barrel containing the downhole temperature instrument to the bottom of the drill string using the wire line. Once the core barrel is latched into the bottom-hole assembly, the drill string is lowered to the bottom of the hole so that the thermistor probe is forced into the undrilled sediment ahead of the drill bit.

Except in extremely unusual situations, the drilling vessel, and hence the entire drill string, will have some vertical movement due to the action of waves. Depending upon the amplitude of the movement and the physical properties of the sediment, it may or may not be possible to isolate the thermistor probe from the drill-string movement.

The bottom-hole assembly is usually structured to include units called "bumper subs," each of which is capable of absorbing, by opening or closing, up to 5 ft. of vertical movement. The lowest pair of bumper subs is typically located about 122 ft. above the drill bit and will be open unless the weight of the bottom-hole assembly below (about 14,140 lb) can be supported by the sediment at the bottom of the hole. If they are fully open (or fully closed) then they are of no use as "shock absorbers," and the temperature measurement will very likely be useless, or at least degraded, due to movement of the probe in the sediment. Therefore every effort should be made to have the driller attempt to partially close the bumper subs. If the sediment is too soft, the sinking of the drill bit will be apparent to the driller as a gradual decrease in the weight on the drill bit. Therefore, valid downhole temperature measurements are not usually obtained within 50 m of the mudline except in unusually stiff sediment.

Assuming that the bottom-hole assembly, and thus the thermistor probe, is successfully supported by the sediments, it is then allowed 15 min. to approach thermal equilibrium with the sediments, after which time it is retrieved up the drill pipe. The total length of time required for each measurement is the length of time required for a round trip of the wire line plus 15 min. (2-3 hrs. in 4400 m of water).

Regardless of whether sediment temperature measurement, bottom-hole temperature measurement, or temperature logging is in progress, it is important to keep careful and detailed records of the events that occur on the drilling floor during the measurement and the times at which they occur. Knowledge of the times at which pumping stopped or started, whether the bottom-hole assembly was resting firmly on the undrilled sediment, and the times when the bottom-hole assembly was raised or lowered is crucial to meaningful interpretation of the temperature data.

Bottom-Hole Measurements

Where the sediments or basement rocks are too consolidated for the thermistor probe to penetrate into thermally undisturbed material, the only temperature that can be measured with our equipment is that of the mud and/or water in the hole. Assumptions about the geometry of the hole, the thermal properties of the rock and hole contents, and the nature and duration of the thermal distrubance due to drilling and circulation of drilling fluid permit estimates to be made of the *in situ* wall-rock temperatures by measuring the temperature of the material in the hole (Bullard, 1947; Jaeger, 1956, 1961; Hyndman et al., 1976). Because the rock near the bottom of the hole has been disturbed by drilling for the shortest length of time, temperatures measured near the bottom of the hole will be most representative of the *in situ* rock temperatures. In order to allow the material in the hole to approach thermal equilibrium with the wall rock, temperatures should be measured as long after termination of drilling as possible. When multiple reentry holes are drilled, the best opportunity to make meaningful bottom-hole temperature measurements is immediately following each reentry.

Bottom-hole temperatures are measured using nearly the same method as is used for the measurement of sediment temperatures. A full stand of drill pipe (30 m) is made up above the rig floor. The pressure case is inserted into the core barrel, which is then lowered on the sand line to the bottom of the drill string. If the drill bit is initially about 30 m above the bottom of the hole, the drill string can be lowered slowly in 5-m increments, allowing the temperature probe 2 or 3 min. to come to equilibrium at each level. In this way a set of five or six temperature values can be obtained from which a local bottom-hole thermal gradient can be computed. If the heave compensator is used, the length of the measurement interval will be reduced because less pipe can be handled above the rig floor. After completion of the measurement, the core barrel can be retrieved as usual using the wire line.

Temperature Logging Measurements

Temperature logging techniques differ from those used to measure bottom-hole temperatures only in that temperatures are measured over the entire depth of the hole (or at least a substantial portion thereof), rather than only near the bottom of the hole. To achieve this goal, the wire line usually used to lower the core barrel either must be removed from or not initially present in the drill string to permit the addition of stands of drill pipe necessary to enable the bottom-hole assembly to be lowered over the interval to be logged. Equipment exists such that the core barrel can be lowered to the bottom of the drill string, released, and the wire line retrieved; however, it is not normally used, and it cannot be used with some types of core barrels. An alternative method, in which the core barrel containing the temperature probe is allowed to freefall down the drill pipe from the rig floor, was used in Hole 396B. The speed of descent of the core barrel (with the baffle obstructed above the pressure case to impede the flow of water through the core barrel) was slightly more than 100 m/min. The drill pipe was filled with water up to the level of the rig floor in order to minimize the impact created when the core barrel struck the water in the drill pipe after having fallen through air. The instrument appears to have suffered no damage having been used in this way; however, freefalling is not recommended unless absolutely necessary.

DATA ANALYSIS

On-Deck Data Reduction Components

The on-deck data reduction system is shown schematically in Fig. 4. The central item is the on-deck rack, which performs the following functions:

1) Controls the motor of the magnetic tape recorder in the downhole instrument, thus permitting data playback and tape erasure without opening the pressure case.

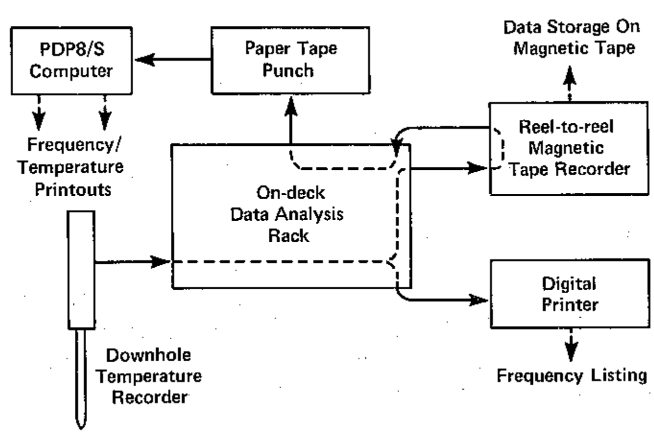

Figure 4. Block diagram of the on-deck data reduction rack and associated equipment used to analyze the downhole temperature data.

2) Accepts the incoming data played back from the tape and amplifies and shapes the pulses to enable them to be rerecorded at 7 1/2 in./s on a reel-to-reel tape recorder.

3) Converts the incoming data from serial-binary form to a binary-coded-decimal form suitable for driving a digital printer.

4) Accepts pulses played back at low speed (1 7/8-in./s) from the reel-to-reel magnetic tape recorder and further amplifies and shapes the pulses so that they can drive a paper tape punch.

In addition to the on-deck rack, the system includes a three-speed, two-track, reel-to-reel tape recorder, a digital printer, and a low-speed paper tape punch.

Conversion of Data to Temperature-Time Plots

After being removed from the core barrel and washed off, the instrument is connected to the on-deck rack through a bulkhead connector at the top of the pressure case. This connection permits control of the magnetic tape recorder motor, playback of existing data on the tape into the rack, and erasure of the tape in preparation for subsequent measurements.

As the data are played into the rack, a printout of the frequency data is obtained and at the same time the data are recorded at 7 1/2 in./s on a reel-to-reel tape recorder. The data taped at 7 1/2 in./s is later played back at 1 7/8 in./s into the on-deck rack, effectively slowing the data flow rate by a factor of four so that the paper tape punch can keep pace with the incoming data. The punched paper tapes and the digital printout both contain sets of ten 16-bit binary "words" arranged in "sentences." The five odd-numbered "words" are temperature data; the other five "words" are from four precision calbiration resistors used to correct for instrument drift and a single "all-zeros" "word" used to indicate the beginning and end of a "sentence."

The raw shipboard data can be reduced in a preliminary but meaningful way or, if there is a PDP8/S computer aboard (or available on shore), the punched paper tapes containing the frequency data can be processed using a computer program called ISMS to generate a listing of temperature. In order to use program ISMS for this purpose, one must know the relationship between thermistor resistance and frequency for the partiular instrument used to make the measurement; one must also know the dependence of thermistor resistance on temperature. To generate the coefficients necessary to express these relationships, the instrument and thermistor are calibrated on shore using multiple-regression, curve-fitting programs. When properly run, ISMS will yield a temperature listing and produce an optional "packed" punched paper tape of temperatures recorded at 8-s intervals (or multiples thereof), which can be used for making a plot of temperature versus time during the measurement interval.

If a PDP8/S computer is not available aboard ship, meaningful preliminary data analysis can be carried out by plotting the raw frequency data listed by the digital printer as a function of time. Once such a plot is complete, temperature values can be assigned by using the shipboard thermistor calibration tables (resistance versus temperature) and the variable frequency oscillator or variable frequency converter calibration data (frequency versus resistance) to assign temperature values to the frequency-versus-time plot generated from the downhole temperature data. This method suffers slightly because of possible human error and because no correction is usually made for drift of the downhole temperature recorder due to changing ambient temperature.

Interpretation of Temperature-Time Plots

Meaningful analysis of temperature-time records is dependent upon careful documentation of the drilling operations while the temperature probe is within the drill string. Knowledge of ship motion, positioning problems, drilling rate, bit pressure, sediment type and hardness, and many other factors associated with each measurement is essential for unambiguous interpretation of these records.

Almost without exception, downhole temperature measurements taken with the instrument firmly locked into the inner barrel have been easier to interpret and have provided more reliable data on in situ sediment temperature than data obtained with the temperature probe held in place by any existing type of release latch.

Fig. 5 depicts a plot of the temperature-time data recorded by a temperature probe that was pushed up inside the inner core barrel prior to bottom contact. Note that almost no temperature increase was observed as the probe was lowered to the bottom of the drill hole. The temperature difference that would be expected between bottom-water temperature and sediment temperature at a sub-bottom depth of 27 m is the order of $1^{o}C$. This compares well with the temperature increase actually observed at 27 min. elapsed time when warm sediment was pushed into the core liner around the thermistor probe at the beginning of the coring process. As the sediment continued to lose heat through the walls of the core liner, the sediment and the thermistor probe gradually cooled.

Fig. 6 shows a second instance where the thermistor probe evidently did penetrate the undrilled sediment but was almost immediately released up into the core barrel before acquiring enough temperature data to define an equilibrium curve. When the probe penetrated the undrilled sediment at the bottom of the hole, an abrupt and large temperature increase occurred, followed almost immediately by a temperature decrease as the latch released prematurely and allowed the temperature probe to slide back up inside the core liner. This temperature measurement thus reflected the temperature of the sediment that had been forced a short distance into the bottom of the core barrel (due to

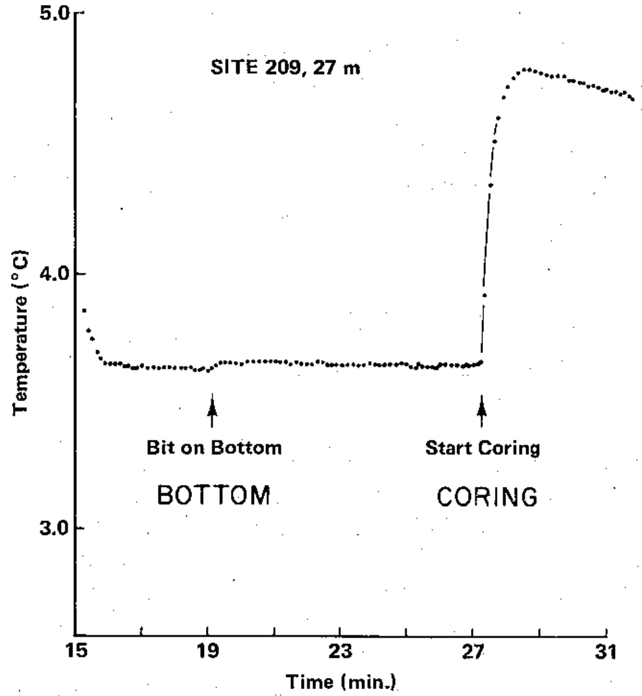

Figure 5. Plot of temperature versus time at Site 209 recorded at 27 m sub-bottom depth.

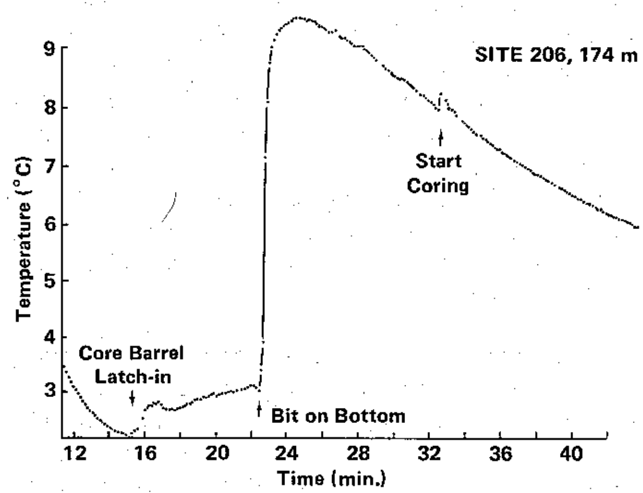

Figure 6. Plot of temperature versus time at Site 206 recorded at 174 m sub-bottom depth.

the weight of the bottom-hole assembly on the seafloor) rather than the in situ sediment temperature. The fact that the small temperature fluctuations following bottom contact ceased after the beginning of coring further confirms the hypothesis that the thermistor probe had been near the bottom of the core barrel, where it could sense frictional heating generated by both the coring procedure and fluctuations in bit pressure.

Since Leg 26, downhole temperature measurements have been made with the temperature probe rigidly locked into the bottom of the core barrel, thus eliminating the problem of premature release of the probe up the core barrel.

The general characteristics shown by most of these records are (1) a rapidly decreasing temperature as the probe passes through the warmer surface water into the cooler abyssal water; (2) a leveling off of the temperature to a nearly constant minimum value as the probe passes through the lower portion of the drill pipe surrounded by cold, nearly isothermal water; (3) a slow temperature rise as the probe enters warmer water in that portion of the borehole beneath the mudline; and (4) a rapid increase in temperature as the thermistor is inserted into the undrilled sediment.

At the end of the measurement interval, when the probe is withdrawn from the sediment, a sequence of events in the opposite order to that just described normally is observed. Variations from the sequence can be expected if the water is shallow (and therefore not isothermal), if the winchman lowers the core barrel erratically, or if he lowers the core barrel into areas of unusual hydrology (e.g., the Red Sea hot brine pools). Estimation of the temperature of the water immediately above the seafloor provides a "free" and important data point for use in constructing a temperature-depth plot; however, care must be taken that the temperature recorded by the instrument prior to entering the borehole is representative of bottom-water temperature. Whether the temperature measured by the probe is the same as the temperature of the bottom water depends on the rate of lowering, the thickness of the isothermal layer, and to what extent, if any, circulation was in progress while the core barrel was being lowered.

Following penetration of the probe into the sediments, a more diverse variety of temperature-time plots may be observed. Some of the more common of these will be discussed briefly later in this chapter.

The most difficult and important job involved in interpreting the downhole temperature data is to understand the significance of the temperature-time data recorded during the critical period while the probe is in the undrilled sediment, and to evaluate the relation of the recorded temperatures to the in situ sediment temperature.

The temperature-time plots often illustrate frictional heating of the probe on penetration and its subsequent decay. When heating brings the probe above the sediment temperature, the decay is a cooling; and when the heating is insufficient to raise the temperature of the probe above the sediment temperature, the approach to equilibrium is a warming (Fig. 7).

The thermal response of a long, thin thermistor probe penetrating sediment at the bottom of the borehole is determined by (1) the frictional heating due to the passage of the probe through the sediment, (2) the initial temperature difference between the probe and the sediment, and (3) the thermal properties of the probe and sediment. If the probe has a much larger thermal diffusivity than the sediment, as is the case for the stainless steel probes used in these measurements, the thermal response of the probe may be represented by the theory of heat conduction for an infinitely

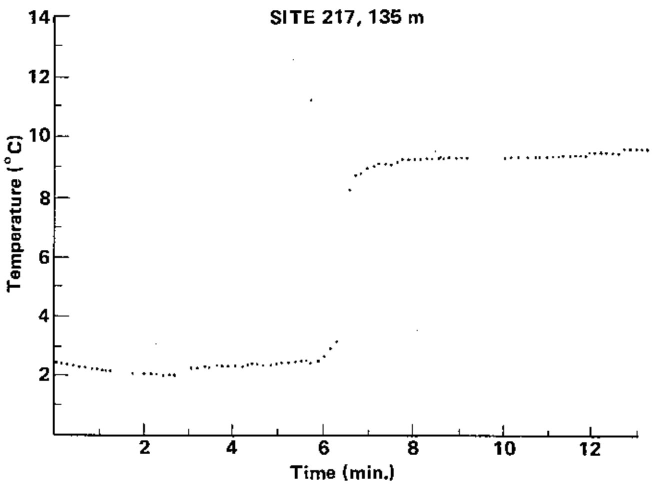

Figure 7. Plot of temperature versus time at Site 217 recorded at 135 m subbottom depth.

long, infinitely conductive rod of radius A and thermal diffusivity K_{ss} in a surrounding medium of density ρ, thermal diffusivity K, and heat capacity c (Bullard, 1954; Cooper and Jones, 1959). The thermal response can be appropriately expressed by the dimensionless parameters α and τ, where

$$\alpha = 2\pi A^2 \rho c / m,$$
$$\tau = K_{ss} t / A^2$$

and the parameter m is the composite heat capacity per unit length of the probe.

The temperature of the thermistor probe after an initial period given by a few times the thermal time constant of the probe (about 70 s for the probes actually used) can be closely approximated as

$$T(\alpha,\tau) = T_f + \Delta T_i F(\alpha,\tau)$$

where T_f is the ambient temperature of the sediment, T_i is the initial temperature difference between the thermistor probe and the surrounding sediment, and $F(\alpha,\tau)$ is a function describing the approach to thermal equilibrium.

If a linear relationship can be discerned in a plot of the observed temperature over a range of time versus the corresponding values of the function $F(\alpha,\tau)$ (Fig. 8), it is possible to confirm the agreement between the theoretical and actual thermal responses of the probe. In addition, by extrapolating the linear curve back to $F(\alpha,\tau) = 0$, it is possible to predict the undisturbed sediment temperature to be expected after the thermal disturbance has decayed. For "long" times (greater than about 5 min. for this probe), F is proportional to $1/t$, and approximate equilibrium temperatures may be estimated by plotting temperature versus $1/t$ and extrapolating to $1/t = 0$ or $t = \infty$. This simple extrapolation is convenient for shipboard evaluation of the data. If the extrapolation plots are not linear, the probe probably has not measured undisturbed sediment temperatures. Usually linear plots of temperature versus F are obtained for at least a portion of the record.

The temperature-versus-time plot shown in Fig. 9 is typical of temperature records in which there is a large initial temperature increase as the temperature probe penetrated the sediment at the bottom of the drill hole. The temperature then decayed rapidly, closely following the expected theoretical thermal decay curve. The temperature dropped abruptly and then stabilized as the drill string was raised above the bottom of the hole upon conclusion of the 10-min. measuring period.

The existence of substantial frictional heating appears to suggest complete penetration of the probe into undisturbed sediments. This heating and subsequent decay is similar to that usually observed with standard ocean temperature probes (Langseth, 1965) and is probably greatest in coarse or stiff sediment.

Other measurements made using the temperature probe locked into the inner core barrel show a smooth temperature increase upon penetration, sometimes

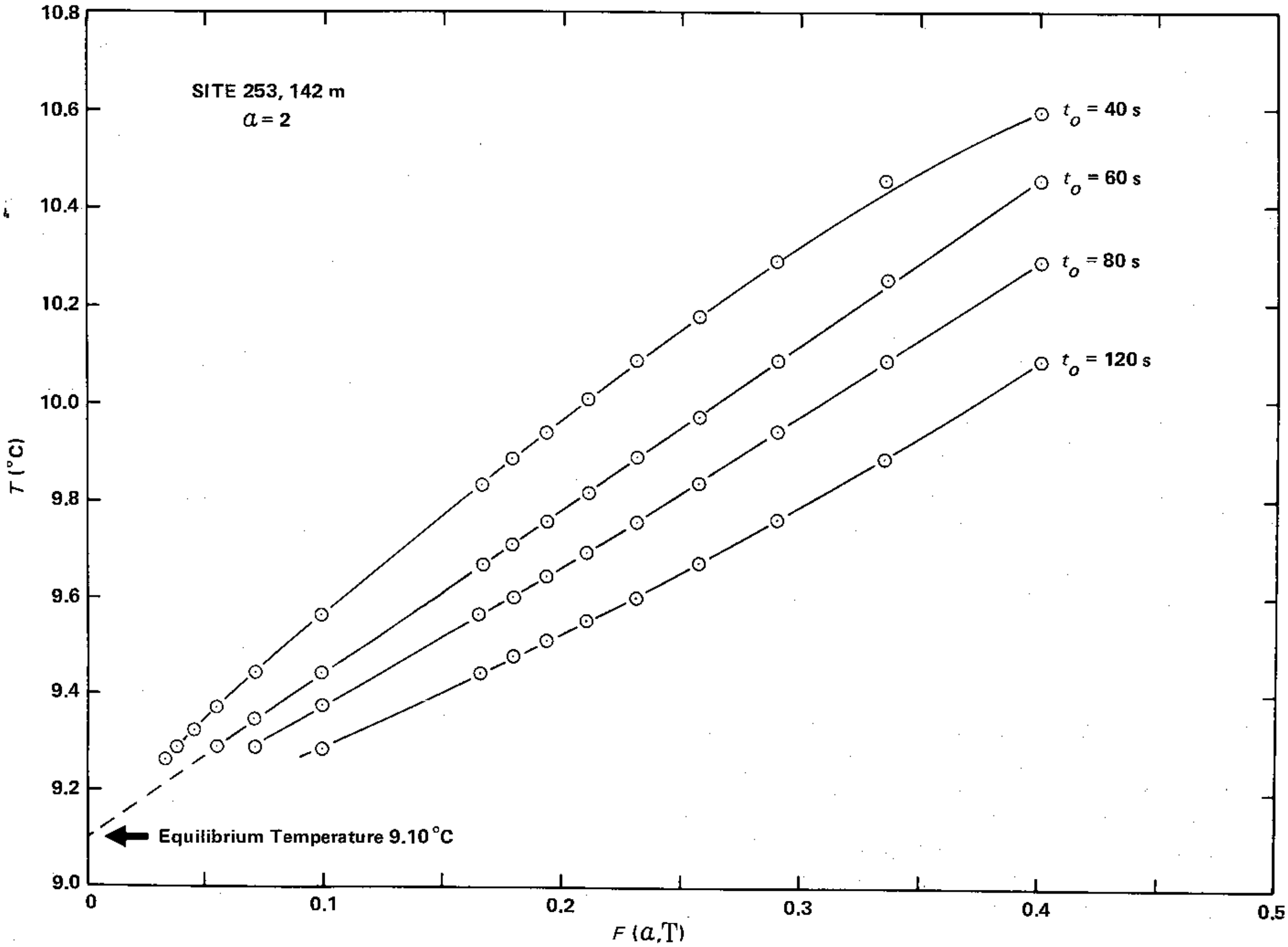

Figure 8. Plot of F (α,τ) against observed sediment temperature T (°C) for several values of the probe thermal relaxation time t_o. (The linear relationship observed for t_o = 60 s has been used to extrapolate the thermal decay to an equilibrium temperature of 9.10°C.)

followed by variable amounts of heating or cooling after only a few minutes. Slight frictional heating probably occurs when the probe either penetrates only a short distance into undisturbed sediment and/or penetrates fine-grained sediment where frictional heating is small. It is probable that the subsequent cooling occurs because of the opening of a passageway along the probe allowing cool water to reach the tip and/or through loss of heat by longitudinal conduction along the heat probe itself in the event of only slight penetration into hard, brittle sediments (Fig. 10).

In addition to the temperature records already discussed, which provide examples for about 75% of the data obtained so far, there are other more unusual records that are worth mentioning because of their diagnostic value in obtaining reliable data in subsequent measurements.

If the undrilled sediment is too soft to support the weight of the bottom drill collars, the bottom-hole assembly (and thus the inner core barrel and temperature probe) will sink slowly through the sediment until either the sediment can support the weight or the

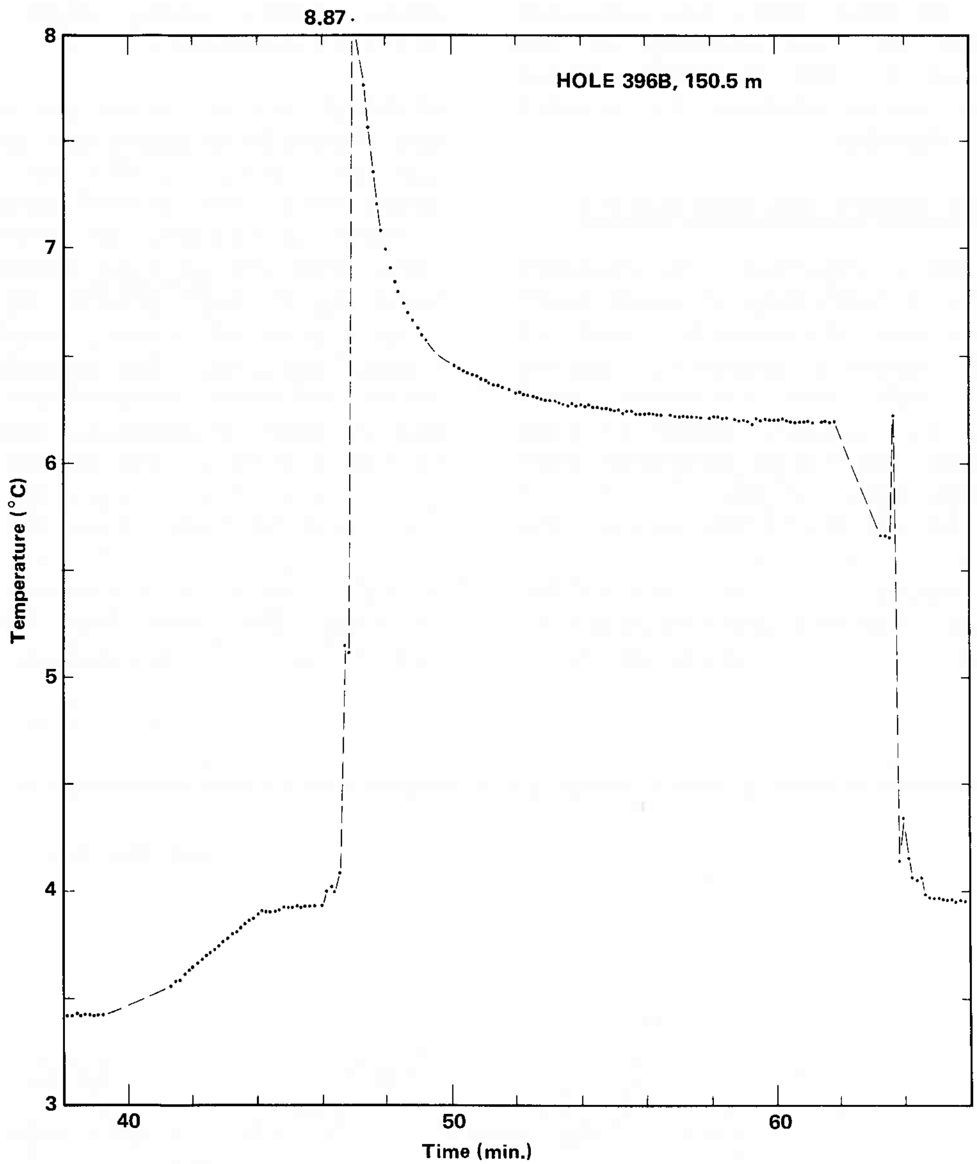

Figure 9. Plot of temperature versus time in Hole 396B recorded at 150.5 m sub-bottom depth.

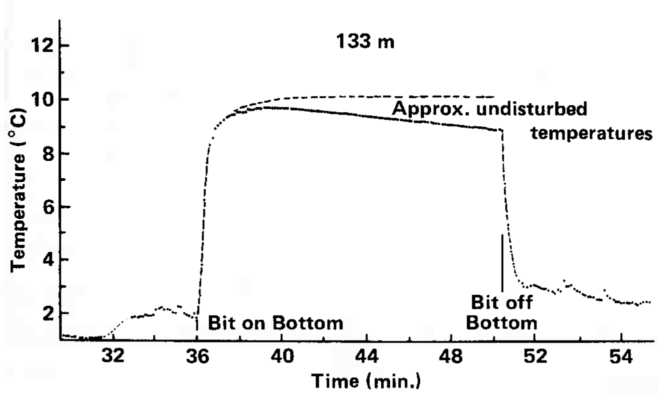

Figure 10. Plot of temperature versus time at Site 257 recorded at 133 m sub-bottom depth.

entire drill string is in tension. If the drill string is in tension, the vertical oscillations of the ship will be conveyed directly to the heat probe, as will longer-period oscillations caused by horizontal movement of the ship about the drill hole. Often a gradual temperature increase will be observed as the probe sinks, because of frictional heating as well as the fact that the probe is moving deeper into warmer sediment. Similar temperature increases have been observed during measurements where the sediment was too firm to allow penetration of the probe

(Fig. 11). In this case, the increase is attributed to slow warming of the mud and water in the borehole rather than to the probe sinking to greater (and warmer) depths.

Estimation of Errors and Reliability

It is extremely important to evaluate carefully the reliability of each downhole temperature measurement used to determine the thermal gradient. Anyone planning to make and interpret such measurements is strongly urged to read the individual heat-flow chapters referenced in the table at the end of this chapter for detailed discussions of the ways in which various investigators interpreted specific temperature-time plots. These chapters contain plots of virtually all of the downhole measurements made, along with comments on their reliability.

Although the accuracy and resolution of the downhole temperature recording system are about 0.10° and 0.01°C, respectively, the actual amount by which a downhole temperature measurement differs from the in situ sediment temperature may be much greater as a result of a multitude of other, sometimes poorly known, factors. For example, an apparently reliable temperature measurement may be made in material that has fallen to the bottom of the borehole, in which case the estimated equilibrium temperature will be lower than the actual sediment temperature. In addition, it is possible to measure temperatures in mud or water that has been heated by the conversion of mechanical energy to

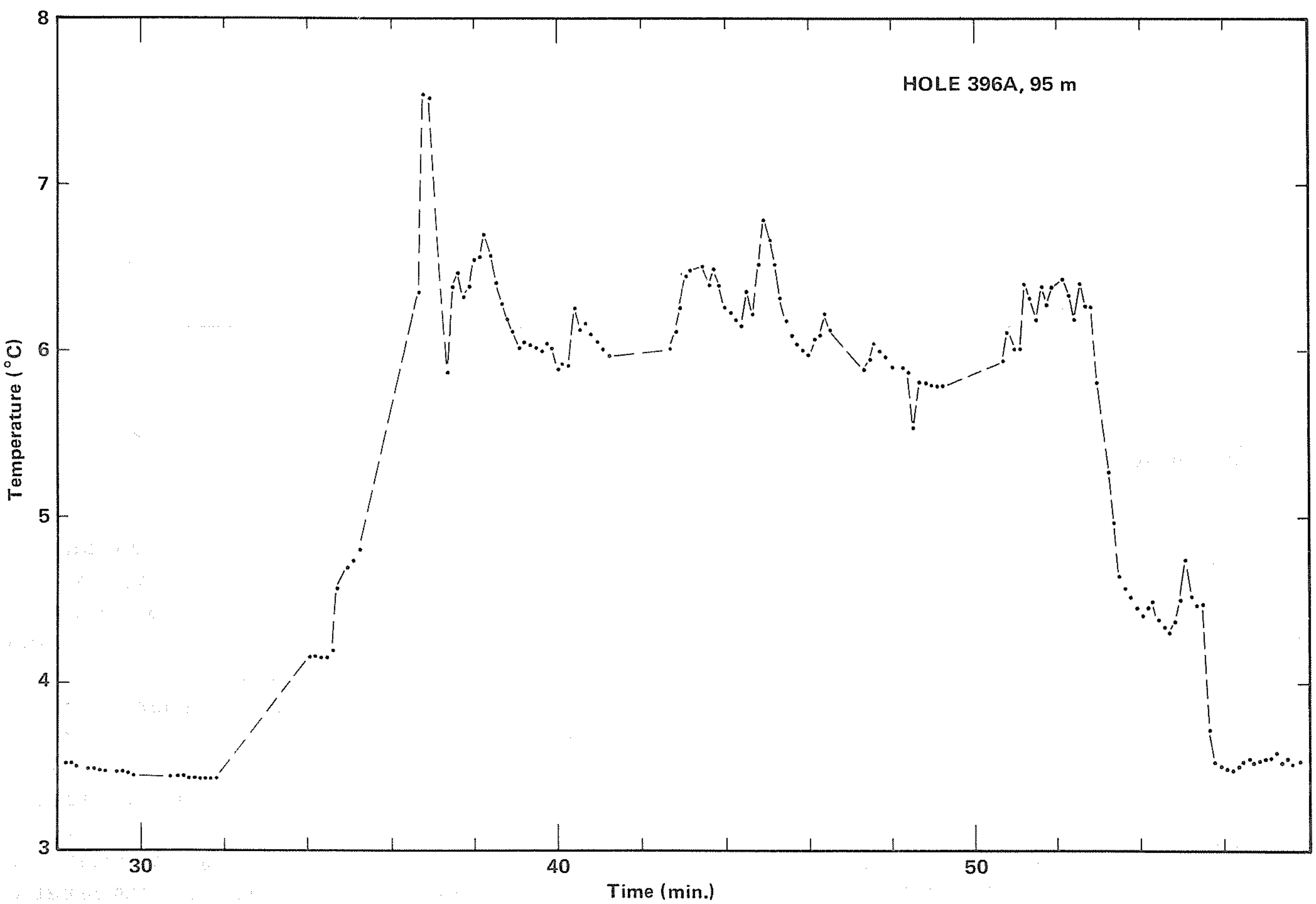

Figure 11. Plot of temperature versus time in Hole 396A recorded at 95 m subbottom depth.

thermal energy due to rotational or vertical movements. Thus although an "equilibrium" temperature may be estimated with some degree of reliability, its equivalence to the in situ sediment temperature cannot always be assumed.

The strongest criterion for a reliable measurement is whether the plot of the temperature versus the function $\underline{F}(\alpha,\tau)$ (discussed earlier) is linear, if so, a sufficient amount of good-quality data permits unambiguous extrapolation to an in situ temperature (Fig. 8). When such is the case, relative temperatures can be determined to a precision of $\pm 0.02^{\circ}$C. There are also cases where the observed temperature-time relation does not fit the expected theory at all well -- in these cases the temperature may indeed be poorly extrapolated ($\pm 1^{\circ}$C); however, the large vertical distance between adjacent temperature measurements often permits meaningful calculation of the thermal gradient using even these data, by virtue of the large absolute temperature differences encountered in the holes.

Under conditions of small swell and good position control, relative depth determinations in the holes are believed to be accurate to a few meters. The extent to which the bumper subs are closed or open obviously affects the relative positions of two measurements and is difficult to estimate accurately. The position of the seafloor, under the best of conditions, is even less well known due to the difficulties of "feeling" the soft mud with the heavy drill string. In cases where one or more of the bumper subs designed to absorb the ship's vertical motion are inoperative, or if the sediment is unusually soft, uncertainty can be as great as ± 5 m.

DATA AVAILABILITY

Data are acquired during downhole temperature measurements in one or more of the following forms:

1) Reels of magnetic tape containing raw temperature and calibration frequency data were recorded on the endless loop magnetic tape in the downhole recorder.

2) A printed listing of the "raw" frequencies recorded during the measurement.

3) A roll of punched paper tape containing the same "raw" frequency data recorded by the digital printer just described.

4) A printed listing of the temperature data (corrected for instrument drift) acquired during the measurement.

5) A "packed" data tape, in the form of a punched paper tape containing only the temperature data contained in the printed listing just described.

6) An "on-deck log" containing the record of how and when a downhole temperature measurement was made and a record of the events that occurred during the measurement.

7) Other information -- notebooks, calibration data, and so on.

At the present time an effort is being made by Dr. R. P. Von Herzen to standardize the storage of these data at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A. Anyone desiring access to any type of data described should contact Dr. Von Herzen. Because of the varied formats of the data available, it is suggested that a brief description of the objectives of the study be included with the data request in order to maximize the probability that the data sent will be adequate. It is expected that a copy of either the temperature listing or the punched paper tape containing the "packed" temperature data will be sufficient for most purposes. Copies of the magnetic tapes and/or raw frequency data will be difficult to work with unless an investigator is willing to make a considerable effort to understand the details of the data reduction process and either to reconstruct or borrow the on-deck data reduction system and required computer program(s).

Table 1 is designed to provide a potential data user with an idea of the availability of the various types of data as of May 1977. It is hoped that with time the remaining data will also be stored at Woods Hole Oceanographic Institution under the management of Dr. Von Herzen.

REFERENCES

1. Ade-Hall, J. M., Von Herzen, R. P., and Erickson, A. J., 1976. In-hole temperatures and heat flow, Site 319, Leg 34. I.R. DSDP, 34:553-556.

2. Bullard, E. D., 1947. The time necessary for a borehole to attain temperature equilibrium; Mon. Not. R. Astron. Soc., Geophys. Suppl., 5:127-130.

3. _______, 1954. The flow of heat through the floor of the Atlantic Ocean: Proc. R. Soc. London, Ser. Y A, 222:408-429.

4. Burns, R. E., 1970. Heat flow operations at holes 35.0 and 35.1. I.R. DSDP, 5:551-554.

5. Carslaw, H. S., and Jaeger, J. C., 1959. Conduction of Heat in Solids (2nd ed.): New York (Oxford University Press).

6. Cooper, C. R., and Jones, C., 1959. The determination of virgin strata temperatures from observations in deep survey boreholes: Geophy. J. R. Astron. Soc., 2:116-131.

7. Erickson, A. J., 1973. Initial report on downhole temperature and shipboard thermal conductivity measurements, Leg 19. I.R. DSDP, 19:643-656.

8. _______, 1974. Leg 27 heat-flow data. I.R. DSDP, 27:208-210.

9. Erickson, A. J., Avera, W. E., and Byrne, R., 1979. Heat-flow results, DSDP Leg 48. I.R. DSDP, 48:277-288.

10. Erickson, A. J., and Hyndman, R. D., 1979. Downhole temperature measurements, Site 396, DSDP Leg 46. I.R. DSDP, 46:389-400.

11. Erickson, A. J., and Von Herzen, R. P., 1978a. Downhole temperature measurements and heat-flow data in the Black Sea -- DSDP Leg 42B. I.R. DSDP, 42B:1085-1104.

12. _______, 1978b. Downhole temperature measurements, Deep Sea Drilling Project, Leg 42A. I.R. DSDP, 42A:857-872.

13. Erickson, A. J., Von Herzen, R. P., Sclater, J. G., Girdler, R. W., Marshall, B. V., and Hyndman, R. D., 1975. Geothermal measurements in deep-sea drill holes. J. Geophys. Res., 80:2515-2528.

14. Girdler, R. W., Erickson, A. J., Von Herzen, R. P., 1974. Downhole temperature and shipboard thermal conductivity measurements aboard Glomar Challenger in the Red Sea (Leg 23). I.R. DSDP, 23:879-886.

15. Hyndman, R., Erickson, A., and Von Herzen, R. P., 1974. Geothermal measurements on Leg 26. I.R. DSDP, 26:461-463.

16. Hyndman, R. D., Von Herzen, R. P., Erickson, A. J., Jolivet, J., 1976. Heat-flow measurements in deep crustal holes in the mid-Atlantic ridge. J. Geophys. Res., 81:4053-4060.

17. _______, 1977. Heat flow measurements, DSDP Leg 37. I.R. DSDP, 37:347-362.

18. Jaeger, J. C., 1956. Numerical values for the temperature in ra-

dial heat flow. J. Math. Phys., 34:316-321.

19. _______, 1961. The effect of the drilling fluid on temperatures measured in boreholes. J. Geophys. Res., 66:563-569.

20. Langseth, M. G., 1965. Techniques of measuring heat flow through the ocean floor: In Lee, W. H. K. (Ed.), Terrestrial Heat Flow, Geophys. Monograph 8: Washington (Am. Geophys. Union).

21. Marshall, B. V., and Erickson, E. J., 1974. Heat flow and thermal conductivity measurements, Leg 25, Deep Sea Drilling Project: I.R. DSDP, 25:349-355.

22. Oxburgh, E. R., Richardson, S. W., Turcotte, D. L., Hsui, A., 1972. Equilibrium borehole temperatures from observation of thermal transients during drilling, Earth. Planet. Sci. Lett., 14:47-49.

23. Sclater, J. G., and Erickson, A. J., 1974. Geothermal measurements on Leg 22 of the Glomar Challenger. I.R. DSDP, 22:387-396.

24. Von Herzen, R. P., 1973. Geothermal measurements on Leg 21, I.R. DSDP, 21:443-457.

25. Von Herzen, R. P., Fiske, R. J., and Sutton, G. 1971. Geothermal measurements on Leg 8: I.R. DSDP, 8:837-849.

26. Watanabe, T., Von Herzen, R. P., and Erickson, A. J., 1975. Geothermal studies, Leg 31, Deep Sea Drilling Project. I.R. DSDP, 31: 573-576.

Table 1. DSDP drill sites at which downhole temperature data were obtained as of May 1977.

Leg	Site	General Location	Reference
19	184	Southeastern Bering Sea	7
	185	Southeastern Bering Sea	
21	204	Pacific Ocean east of Tonga Trench	24
	206	New Caledonia Basin	
	209	Queensland Plateau	
	210	Coral Sea Basin	
22	213	Wharton Basin, Indian Ocean	23
	214	Ninetyeast Ridge, Indian Ocean	
	216	Ninetyeast Ridge, Indian Ocean	
	217	Ninetyeast Ridge, Indian Ocean	
23	225	Axial Trough of Red Sea	14
	227	Axial Trough of Red Sea	
	228	Continental shelf of Red Sea	
25	242	Davie Ridge, southwestern Indian Ocean	21
	248	Mozambique Basin, southwestern Indian Ocean	
	249	Mozambique Basin, southwestern Indian Ocean	
26	251	Southwest branch of Mid-Indian Ocean Ridge	15
	253	Ninetyeast Ridge, Indian Ocean	
	254	Ninetyeast Ridge, Indian Ocean	
	256	Wharton Basin, Indian Ocean	
	257	Wharton Basin, Indian Ocean	
27	262	Timor Trough, northeastern Indian Ocean	8
31	297	Northwestern Shikoku Basin, northwestern Pacific Ocean	26
	298	Nankai Trough, northwestern Pacific Ocean	
	301	Japan Abyssal Plain, Japan Sea	
34	319	Bauer Basin, equatorial East Pacific Ocean	2
37	332	Mid-Atlantic Ridge at 36°52.7'N, 33°38.5'W	17
	333	Mid-Atlantic Ridge at 36°50.5'N, 33°40.1'W	
	334	Mid-Atlantic Ridge at 37°02.1'N, 34°24.9'W	17
	335	Mid-Atlantic Ridge at 37°17.7'N, 35°11.9'W	
38	338	Vøring Plateau, North Atlantic	Von Herzen and Erickson (pers. comm., 1977)
	342	Vøring Plateau, North Atlantic	
42A	372	Western Mediterranean	12
	373	Tyrrhenian Sea	
	374	Ionian Sea	
	376	Levantine Sea	
	378	Aegean Sea	
42B	379	Black Sea	11
	380	Black Sea	
	381	Black Sea	
46	396	Mid-Atlantic Ridge at 22°59.14'N, 43°30.9'W	
47	397	North African continental margin	Ryan (pers. comm., 1977)
	398	Spanish continental margin	
48	402	Northern continental margin of the Bay of Biscay	9
	403	Southwest margin of Rockall Plateau	
	406	Southwest margin of Rockall Plateau	
49	407	West flank of Reykjanes Ridge	
	408	West flank of Reykjanes Ridge	
	410	Mid-Atlantic Ridge at 45°30.53'N, 29°28.56'W	
50	415	Moroccan Basin	Boyce (pers. comm., 1977)

7. SUMMARY OF LOGGING DATA AVAILABLE

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STANDARD LOGGING TOOLS AND AVAILABLE DATA FROM DSDP LEGS 1-44

During Legs 1 through 6 of Phase I (Legs 1-44) of the Deep Sea Drilling Project (DSDP), a few commercial oil-well logging tools were attempted. These included (1) a qualitative density (gamma-gamma) logging tool, (2) a qualitative porosity (neutron) logging tool, (3) a natural gamma radiation logging tool, (4) an acoustic velocity logging tool, and (5) an electrical resistivity and spontaneous potential logging tool. These tools were used in hopes of (1) providing some lithologic identification of the uncored intervals at a drill site, and (2) obtaining some in situ parameters, such as velocity, to help interpret seismic profiles and seismic refraction data.

The purpose of this paper is to summarize for future investigators (1) which sites were logged, (2) which tools were used, and (3) obvious problems likely to be encountered by future investigators. Table 1 lists the tools that were aboard the Glomar Challenger at the beginning of each leg. Table 2 lists the sites where successful or partially successful logging data were obtained as well as the logging tools that were used. The basic principles of these tools are presented in Lynch (1962), and thus will not be discussed further. For technical details on tool construction and operation, the commercial companies involved should be contacted, as some of these details are "proprietary," that is, they are not released in order for the company to maintain a competitive advantage in the field.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

During DSDP Legs 1 through 8, downhole well-logging attempts were made from the Glomar Challenger at 20 holes: 1, 2, 8A, 9A, 10, 13A, 28, 29B, 29C, 32, 33, 35, 53, 57, and 69 through 75. According to Gealy (1969) and available logging data in DSDP files, Holes 1 and 35 were successful and Holes 3, 28, 29C, 53, 57, 70, 71, and 73 were only partially successful. Investigators interested in detailed Phase I logging plans and problems should consult Gealy (1969). Below, we will discuss briefly only the sites and tools used when successful or partially successful logging data were acquired.

All of the logs were required to pass through the opening in the drill bit (2 1/2 in., 6.35 cm), unless logging took place inside the pipe. The drill pipe has a 5-in. (12.7 cm) outside diameter (OD), a 7-in. (17.8 cm) OD at the joints, and a 4 1/8-in. (10.5 cm) inside diameter with a 4-in. (10.2 cm) drift (i.e., a 5-ft. [1.52 m] bar 4 in. [10.2 cm] in diameter can pass through the pipe). The lower part of the bottom-hole assembly (BHA) gradually (over a length of about 130 m, which may be varied from site to site) expands (with insertion of drill collars and bumper subs) to about 9 to 10 in. (23-25 cm) OD, which is the usual OD of the drill bit. Fig. 1 (M. A. Storms, personal communication, 1976) schematically shows a typical BHA.

All the Phase I logging data must be viewed with caution, as DSDP hole conditions, formation conditions, and the tool geometry used were not ideal. One serious problem is the shallow depth of investigation (2-20 in.) of the acoustic log, gamma-gamma-density log, neutron-porosity log, and the 16-in. normal resistivity log. Shallow penetration becomes critical when the formation is soft enough to be disturbed by the drilling operation, as is common at

Table 1. Logging tools available during Phase I.

Logging Tool	Vendor	Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	Leg 6	Leg 8
Accelerometer Logs: (A) downhole and (B) deck mounted	Systron Dorner	x	x	x	x	x	?	
Interval Velocity Tool (array of three hydrophones spaced 10 m apart - designed to receive signals at 20-m intervals from 5-lb. surface charges)	Equipment Procurement Company	x	x	x	x			
Electric Survey Tool (1 1/2 in., Model S56, 16 in. normal, 64 in. normal, SP, 18-ft. lateral logs, [free in hole])	Schlumberger	x	x	x	x	x[b]	x	
Gamma Ray-Neutron (GNT-K) (qualitative, free in hole, 1 11/16 in., Model GNT-K, with collar locator)	Schlumberger	x	x		x	x	x	
Gamma Ray-Neutron Tool (1 11/16 in., with collar locator, free in hole)	[a]Pan. Geo. Atlas Corp. (PGAC)		x	x	x	x		
Gamma Ray (SGDH 235, 8-in.-long scintillator detector) and	Schlumberger	x	x		x	x	x	
Qualitative Density Tool (Gamma-Gamma, 1 11/16 in., modified Neutron Tool casing, noncollimated, free in hole)	Schlumberger	x	x		x	x	x	
Acoustilog (2 1/8 in.) with Caliper (2 1/4 in.)	[d]Dresser Atlas				x	x[c]	x	
Caliper Tools (2 1/4 in.)	Dresser Atlas			x	x	x	x	
Maximum Reading Thermometer	Schlumberger	x	x	x	x	x	?	
DPEL (self-contained, SP, 16 in. normal, 64 in. normal)	Welex							x

[a]Gealy (1969) refers to a Dresser Atlas Gamma Ray-Neutron Tool, but Evans and Grice (1968) and Grice memo about logging results of Leg 1 (<u>in</u> Gealy, 1969), identify PGAC as the vendor of the Gamma Ray-Neutron Log.
[b]An Electric Survey (ES) Log was taken on Leg 5 although Gealy's (1969) attachment "F" indicates that no ES tool was aboard.
[c]Gealy (1969) attachment "F" indicates that no acoustic tool was aboard Leg 5, but a log printout in DSDP files indicates that a Dresser Atlas Acoustilog was taken.
[d]Evans and Grice (1968) suggest that a PGAC Dual Receiver Acoustic Log was to be used. Apparently, a Dresser Atlas dual receiver with calipers was used instead, but no camera was supplied to photograph the wave train.

Table 2. Successful (more or less) deployments of logging tools.

Logging Tool	Vendor	Site									
		1	3	28	29C	35	53	57	70	71	73
Electric Survey Tool SP, 16-in. normal 64° Normal, 18 ft - 18-in laterolog.[a,b]	Schlumberger	x[c]	x[d]		x	x	x	x			
Gamma Ray-Neutron (GNT-K)	Schlumberger			x	x		x	x			
Gamma Ray and Qualitative Density Tools (gamma-gamma)	Schlumberger	x						x			
Acoustilog with Caliper (dual receiver)[a]	Dresser Atlas					x	x	x			
Accelermoter Logs: (A) downhole and (B) deck mounted	Systron Dorner	x									
DPEL (self-contained, 16-in. normal, 64-in normal, and SP)	Welex								x	x	x

[a]Some incomplete logs (gamma ray, electrical, acoustic) exist for Site 33.

[b]At Site 31 the SP was run in the water column as an experiment.

[c]In the Site 1 Electric Survey Tool, the SP was replaced by a gamma ray probe.

[d]SP was not run at Site 3.

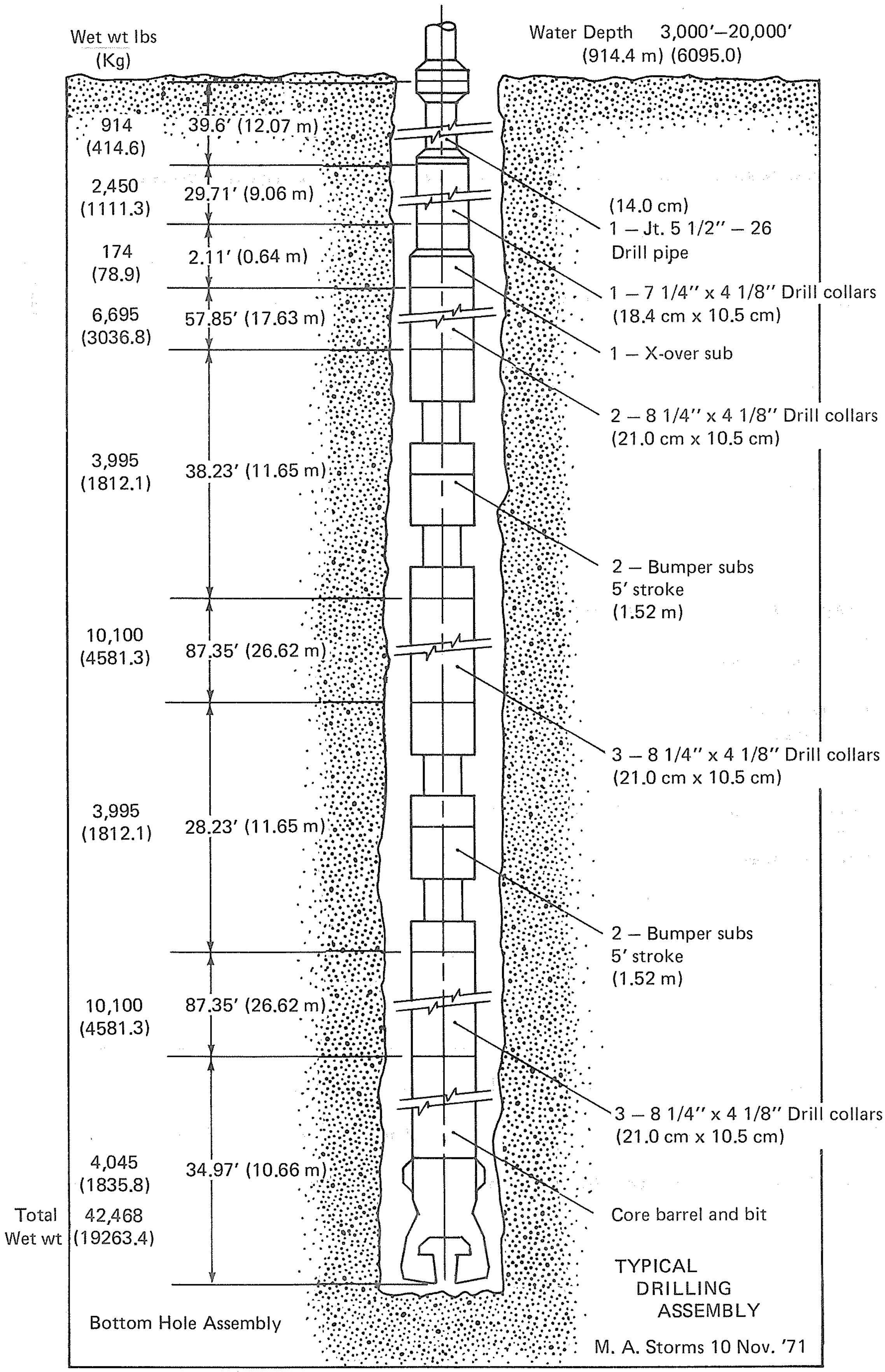

Figure 1. Typical bottom-hole drilling assembly.

sites where the upper 100-200 m of sediment are soft and uncemented. As a result, the data from the logging tools with shallow lateral penetration may be artifacts of the drill-disturbed formation, rather than measures of truly representative in situ parameters. However, the tools with a deeper zone of investigation yield results that probably are characteristic of in situ conditions. The tools with the greatest lateral depth of investigation are the 64-in. Normal Resistivity Log and the 18-ft. 8-in. Lateral Resistivity Log.

The geometry of the borehole and density and thickness of the mud cake and the mud in the hole seriously affect the response of the porosity (neutron) log and the density (gamma-gamma) log. In addition, the logs were affected by lack of knowledge of the location of the tool in the hole relative to the hole wall or the center of the hole. Because these parameters rarely are known, these logs are probably more appropriately considered to be seimqualitative.

The electrical resistivity logs are affected by (1) the hole diameter, (2) the thickness and resistivities of the adjacent strata in the formation, and (3) the resistivity and thickness of the hole mud and mud cake. Resistivity is essentially an inverse function of (1) the porosity of the rock (assuming that the mineral particles are poor conductors), and (2) the conductivity of the interstitial fluids (which is directly related to their salinity and temperature).

The Self-Potential (SP) log measures electric potentials developed between the hole and the formation. Under proper conditions it indicates (1) sand (permeable) versus shaly beds, and (2) some indication of interstitial water salinity relative to the salinity of the interstitial fluids of the drill-mud. For the SP log to work properly, mud in the hole should be slightly conductive (fresh-water will work properly). The SP curve will not show any character, however, if the interstitial water salinity of the mud is equal or close to the salinity of the interstitial water in the formation.

The sonic logging tool takes advantage of a specific geometry and dual receiver system that tend to cancel out the effects of the borehole diameter and mud cake. However, an excessive hole diameter will not allow the acoustic velocity of the formation to be measured (Lynch, 1962). In addition, anomalies will occur at lithologic boundaries when only one of the receivers has crossed the boundary, if the hole diameter abruptly changes. The acoustic tool works best when the hole diameter, mud character, and mud cake thickness are uniform. Anomalous low-velocity spikes, cycle skipping, and high-velocity spikes (noise) are potential problems (Lynch, 1962). The Dresser Atlas acoustic log also incorporated a caliper that aids in the interpretation of not only the acoustic log but the other logs also.

WELEX "DRILL PIPE ELECTRIC LOGS" ATTEMPTED ON LEG 8, HOLES 69 THROUGH 75

On DSDP Leg 8, an attempt was made at Sites 69 through 75 to run a self-contained electric logging package. This commercial logging tool was provided by Welex (a division of Haliburton Company) and is officially referred to as the "Drill Pipe Electric Log" (DPEL). The field data were sent to Welex for editing, splicing, and correctly merging the depth scale with logging parameters. The logging tool measured self-potential (SP); a 16-in. (40.6 cm) normal curve (and an amplified curve), and a 64-in. (162.5 cm) normal curve. These data were never published in the Initial Reports. Although logging was attempted at Sites 69 through 75, completed graphic presentations are available only for Sites 70, 71, and 73

(Tracey, Sutton et al., 1971, I.R. DSDP, 8). Copies of these plots can be obtained from the DSDP Data Group.

The DPEL logging methods and equipment are discussed in detail by Cahill (1966). The principles and proper interpretation of the SP 64-in. (162.6 cm) and 16-in. (40.6 cm) normal resistivity arrays are discussed in detail by Schlumberger (1972), Keller Frischknecht (1966), and Lynch (1962). The Welex tool is self-contained; the logging parameters versus time are recorded on magnetic tape as the pipe is pulled out of the hole. The electrodes hang 8.23 m (22 ft.) below the drill bit and measure the electrical resistivity and SP. The precise times (and depths) that the pipe stands (90 ft., 27.43 m) are raised, disconnected, raised and disconnected, and so on, are recorded on deck. These data for Leg 8 were supplied to Welex. Welex then plotted time versus resistivity and SP (deleting those times when the pipe stands were being disconnected). Pipe movement was also monitored by a logging indicator in the self-contained tool. The "correct" hole depths (precision is unknown) were then merged with the SP and resistivity data, and the logs were redrafted by Welex for submission to DSDP.

TOOL DESCRIPTION

The rigid upper part of the Welex tool is 2 1/8 in. (5.40 cm) in diameter and 22 ft. (6.71 m) long from the DPEL fishing neck to the DPEL nose (bottom of the rigid section of the tool) which sets in the opening of the drill bit. A flexible electrode assembly attaches to the DPEL nose and hangs 22 ft. (6.71 m) below the drill bit, the electrode assembly is stabilized by an additional 5 ft. (1.52 m) of flexible sinker; thus, the lower flexible assembly extends a total of 27 ft. (8.23 m) into the open hole below the drill bit. Ideally, according to Cahill (1966), the drill bit (containing the DPEL nose) should be 27 ft. (8.23 m) off the bottom when the electrodes and sinker assembly are hung below the drill bit. However, these depths varied on Leg 8.

REFERENCES

Cahill, J., 1966. Use of the drill pipe electric log. In Trans. SPWLA Logging Symposium, 7th Ann., Tulsa, Oklahoma, 1966: Houston (Soc. Prof. Well Log Analysts), p. K1-K11.

Evans, B. H., and Grice, C. F., 1968. Logging deep sea test holes: Part I. Fundamentals of geophysical well logging. Part II. Operational Procedures: Core Description Manual, Part VIII: User's Groups: Deep Sea Drilling Project, p. VIII.1/1-26.

Gealy, E. L., 1969. History and evalution of the logging program of the Deep Sea Drilling Project. (unpublished manuscript).

Keller, G. V., and Frischknecht, F. C., 1966. Electrical Methods in Geophysical Prospecting. New York (Pergamon Press).

Lynch, E. J., 1962. Formation Evaluation: New York (Harper & Row).

Schlumberger Ltd., 1972. Log Interpretation: Principles (Vol. 1): New York (Schlumberger Ltd.).

8. STRENGTH MEASUREMENTS

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INTRODUCTION

Reasons for obtaining and studying the strength measurements of geological materials from the ocean basins have ranged from purely academic curiosity to economic and military concerns. Academic curiosity and scientific interest have dominated the practical applications during Deep Sea Drilling Project (DSDP) investigations. A typical example of the use of strength measurements and other phsyical properties data from DSDP sediment cores has been to study and understand these properties in relation to diagenetic changes of soft deep-sea sediment to indurated sedimentary rock (Keller and Bennett, 1973). In contrast, mechanical and physical properties data obtained from continental shelf deposits and deeper continental margin deposits have been used extensively in foundation engineering applications (Focht and Kraft, 1977; Davie et al., 1978). Consequently, the quality and reliability of such data are of utmost importance to both marine geologists and ocean engineers. Among the most perplexing problems in using DSDP strength data are (1) the nonstandardization of techniques among researchers during different legs despite the use of similar instrumentation, and (2) the variation of sediment core quality within single holes as well as among borings.

Strength testing of geological materials by DSDP researchers has varied from attempts to quantitatively determine the shear strength of sediments and rocks to attempts to qualitatively assess the relative degree of sediment induration and core integrity. Because individual researchers involved in the DSDP had different objectives during each leg, inconsistent techniques and methodologies unfortunately have resulted. Different testing procedures were employed using the same type of instrumentation; consequently, the inconsistencies in methodology and technique make comparative studies of data difficult and sometimes confusing when evaluating data from different legs. In addition, the importance of core quality for physical properties testing, especially strength testing of geological materials, cannot be overemphasized. Results and interpretation of strength data are complicated because variable degrees of sediment core disturbance occur during the drilling operations.

This chapter summarizes the existing DSDP information regarding strength-test methodologies and techniques and presents representative data obtained during Legs 1 through 44 to clarify discrepancies, to reveal areas where care should be exercised in using the data, and, generally, to aid data users by sorting out possible problems. The various types of tests and test results, the variability, and the general character of the DSDP strength data are discussed. Important factors concerning data quality that should be considered by data users are reviewed. Only a brief discussion is given regarding standard strength testing, instrumentation, techniques, and theory since numerous articles and books are readily available to those interested. Accuracy and precision of the instrumentation are noted, and appropriate reference material is cited where applicable. Special precautions to be taken when utilizing existing DSDP strength data are also mentioned.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

METHODS AND TECHNIQUES

Numerous techniques and various types of strength tests have been performed on DSDP geological samples. This chapter is devoted almost exclusively to strength measurements on sediment samples because only limited testing of rock samples was carried out during Legs 1-44. The various strength tests performed on samples collected on specific legs are outlined in Table 1 and the vane sizes and rotation rates are given for the miniature vane shear tests.

During the early DSDP legs (Table 1), a needle penetrometer (AP-210) was used extensively. This instrument did not provide quantitative data on sediment strength and at best only measured gross relative differences in induration and/or degrees of core disturbance. Boyce (1973) clearly stated that the needle penetrometer was used to indicate relative differences in sediment stiffness for the purpose of aiding in lithologic descriptions. Details of the instrument can be found in the American Society for Testing and Materials (1965, 1975). The AP-210 needle penetrometer (designed for testing asphalt) will not be discussed further since it has not proven suitable for quantitative use on sediments, and only rough approximations of relative stiffness have been obtained during routine shipboard procedures (Bennett and Keller, 1973).

A special penetrometer (CL 600) was used on a limited basis during Leg 38 (Table 1) to estimate the unconfined compressive strength ($\underline{P_c}$), which is considered to be related to the shear strength ($\underline{\tau_f}$) of the sediment by the relationship:

$$\underline{\tau_f} = 0.5\ \underline{P_c}$$

The reader is referred to selected site chapters (Talwani, Udintsev et al., 1976, I.R. DSDP, 38) for further information regarding the penetrometer test. The CL 700 penetrometer will not be discussed here because of its very limited use aboard the Glomar Challenger.

Unfortunately, no shear strength measurements were carried out and published in the DSDP volumes prior to Leg 16 in 1971. At that time the first shear strengths were measured with a miniature vane shear apparatus, and limited tests were carried out using a Swedish fall cone penetrometer (Bennett and Keller, 1973; Keller and Bennett, 1973; Heath et al., 1973). Subsequently, the miniature vane shear apparatus (mini-vane test) was used on several legs (19, 27, 40, 41, 42A, 43, 44). The mini-vane test has been a standard tool for several years and has been adapted for use on submarine sediments (Richards, 1961). This apparatus and the techniques employed will be discussed later in this chapter.

The hand-operated Torvane shear device was used on only two legs (31 and 38); a brief description of this device will be given later. The Torvane, the miniature vane shear, and instruments such as the CL 600 penetrometer have the advantage over other devices in that they can be used easily aboard ship. On the other hand, the remaining strength tests performed on DSDP materials required shore-based laboratory equipment. These include the triaxial shear test (Legs 19, 20, 43); the "unconfined compression" test (Leg 42B); and the two-plane shear device test (Leg 42B). A brief description of these laboratory apparatus and testing procedures will be given; however, details of various techniques, testing procedures, and theory that are beyond the scope of this chapter can be found in numerous textbooks and laboratory manuals on soil mechanics. With the exception of the needle penetrometer, the miniature vane shear apparatus was used more than any other device for determining the strength of sediments collected during Legs 1 through 44. In all of the strength tests performed, the most critical factor in the reliability of

Table 1. DSDP strength tests on geological materials.

Leg[a]	Mini-Vane Shear			Torvane	Triaxial	Penetrom.	Fall Cone Penetrom.	Unconf. Compression	Two-Plane Shear Method
	Used	Vane Size	Rate						
16	X	2.54 x 1.27 cm	6^o/min.				X		
19	X	0.5 x 0.5 in.	83^o/min.		X				
27	X	0.41 x 0.50 in.	8.3^o/min.						
38				X		X (CL 700)		X	
39									
40	X	1.2 x 1.2 cm	65^o/min.						
41	X	0.5 x 0.5 in.	90^o/min.						
42A	X	unknown	89^o/min.						
42B								X'	X
43	X	0.5 x 0.5 in.	60^o/min.		X				
44	X	0.5 x 0.5 in.	89^o/min.						

Note: X' - Non-standard technique used.

[a]Legs 1-6, 8-15, penetrometer only used. Legs 7, 17-18, 21-26, 28-37, no strength tests except Leg 31, torvane.

the data is the quality of the core material used for testing.

TYPES OF GEOLOGICAL MATERIALS TESTED

Strength data are summarized in Tables 2 and 3 for sediments tested on material collected during Legs 1 through 44. The type of test used is indicated along with the direction in which the test was made relative to the core length. The strength data are summarized by major lithology, detailed descriptives of the sediment type (these were not consistent during early legs -- see van Andel, Chapter 2), leg, site, water depth, and depth below the mudline (seafloor). The maximum and minimum values found for each depth interval are given, but a complete listing of all the data is beyond the scope of this paper. The highest strength values are considered the most reliable for a given lithologic type because of the severe disturbance usually encountered with DSDP core materials. Table 4 summarizes the limited strength data available on rock samples. Numerous strength units have been used to express shear strength values throughout the DSDP legs. All values for shear strength are reported here in kilopascals (6.89 kPa = 1 psi).

The types of sediments tested during Legs 1 through 44 include clays; fossiliferous clays; diatomaceous oozes; nanno oozes, nanno chalks, and chalk oozes, radiolarian oozes, and, as defined here, undifferentiated sediments. (The undifferentiated category includes various mixtures and admixtures of sediments and were "lumped" because of the difficulty in identifying a sediment in a specific interval as a "clean," well-definable sediment type). Strength tests on rock materials included limestone, chalk, basalt, and mudstone. Because the rock data are very limited, no further discussion will be given, and the interested reader is referred to Table 4 and the respective DSDP volumes for further details.

CONCEPTS OF SHEAR STRENGTH TESTING OF SEDIMENTS

The shear strength of a sediment is a function of the resistance to sliding between and among particles when subjected to stress. The shear strength of cohesive sediment is due to its frictional resistance to sliding and its cohesion. The frictional forces are a function of the component of normal stress to the shear plane carried by the soil skeleton (solid particles). For saturated sediments the normal stress on the shear plane is a function of the total normal stress minus the pore water pressure. Cohesion is a function of the physicochemical forces acting between particles, which is significant in fine-grained clayey sediments. In contrast, "clean" sands possess virtually no cohesion and their strength depends upon the frictional forces acting between particles (Bishop and Henkel, 1962; Lambe and Whitman, 1969). Discussions regarding the shear strength testing of sediment can be found in the above references and in an excellent book by Lambe (1951).

The maximum shearing resistance on any plane can be expressed by:

$$\tau_{\underline{f}} = \underline{c} + \sigma' \tan\phi$$

where: $\underline{c}$ is equal to the cohesion, σ' is the effective normal stress on the shear plane, ϕ is the angle of shearing resistance. σ' is equal to the total normal stress (σ) minus the pore pressure ($\underline{\mu}$) or $' = (\sigma - \underline{\mu})$. Theoretically, when a saturated fine-grained sediment is stressed during shear without loss of pore water (undrained test), the total normal stress is equal to the pore water pressure that results in an effective stress (σ') equal to zero. In this case, shear strength is considered to be equal to cohesion ($\tau_{\underline{f}} = \underline{c}$). Frequently, the undrained shear strength of fine-grained cohesive sediment is expressed as cohesion.

Table 2. Differentiated sediments.

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Direction[a]	Shear Strength[b] (kPa)	Type of Test[c]
			A. CLAY SEDIMENTS				
Zeolitic	16	160	4940	3-4	¢	4.8-6.2	MV
Ferruginous zeolitic	16	163	5230	141-150	¢	58.8-64.7	MV
	19	183	4708	210-239	⊥	29.4-117.7	MV
	19	183	4708	248-290	⊥	39.2-137.3	MV
Diatomaceous silty	19	186	4522	10-210	⊥	7.8-51.0	MV
Silty-diatomaceous	19	189	3437	0-290	⊥	5.9-78.5	MV
Diatomaceous silty	19	190	3875	0-230	⊥	3.9-98.1	MV
Diatomaceous silty	19	191	3854	0-225	⊥	1.0-78.5	MV
Diatomaceous silty	19	192	3014	0-140	⊥	3.9-73.5	MV
Pelagic	27	259	4696	70-80	⊥	58.8-93.2	MV
Pelagic	27	259	4696	200-300	⊥	88.3-205.9	MV
Pelagic	27	260	5702	165-225	⊥	137.9-176.5	MV
Pelagic	27	261	5667	55	⊥	49.0	MV
Pelagic	27	261	5667	200	⊥	98.0-176.5	MV
Silty	31	293	5599	205.5	¢	50.8	TV
Silt rich	31	294	5784	50-55	⊥	7.2-11.1	TV
	31	294	5784	75-80	⊥	17.8-26.8	TV
	31	294	5784	90-100	⊥	33.1-51.7	TV
	31	295	5808	155-160	⊥	23.8-45.8	TV
Silty	31	299	2599	15-55	⊥	6.8-27.3	TV
Zeolitic	31	302	2399	24-85	⊥	9.8-68.0	TV
Silty	41	370	4214	4-325	⊥	60.8-490.3	MV
Sticky gray silty	43	382	5526	0-100	⊥	2.9-32.8	MV
Silty, clay	43	382	5526	100-200	⊥	50.7-80.5	MV
Clay, sand	43	382	5526	200-300	⊥	41.3-316.0	MV
Green clay	43	385	4936	24.0-28.1	⊥	13.6-16.1	MV
Gray-green clay	43	385	4936	69.1-107.5	⊥	30.9-57.8	MV
Light pink-brown	43	385	4936	175.9-185.1	⊥	27.8-32.3	MV
Stiff brown	43	386	4782	60.4-61.4	⊥	49.5-52.8	MV
Green-blue	43	386	4782	107.5	⊥	36.7	MV
Brown	43	386	4782	152.6-155.2	⊥	69.6-130.4	MV
Brown, silty	43	386	4782	160.1-161.5	⊥	97.5-118.1	MV
Light brown	43	387	5117	8.6-40.5	⊥	7.2-30.8	MV
Gray-brown	43	387	5117	139.4-139.5	⊥	58.1-74.5	MV
			B. FOSSILIFEROUS CLAY SEDIMENTS				
Nanno	16	159	4484	37	¢	7.4	MV
Nanno	16	159	4484	56-58	¢	24.5-35.3	MV
Pelagic with nanno	27	261	5667	160	⊥	127.5-196.0	MV
Foram, nanno	31	296	2920	0-20	unk	6.6-17.5	TV
Foram, nanno	31	296	2920	22-50	unk	31.2-45.8	TV
			C. DIATOMACEOUS OOZE SEDIMENTS				
Diatomaceous ooze	19	184	1910	0-600	⊥	4.9-196.0	MV
Diatomaceous ooze	19	185	2110	0-225	⊥	2.9-137.2	MV
Diatomaceous ooze	19	188	2649	5-275	⊥	2.9-50.0	MV

Table 2. Differentiated sediments. (Cont.)

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Direction[a]	Shear Strength[b] (kPa)	Type of Test[c]
Diatomaceous ooze	19	192	3014	140-230	⊥	39.2-137.2	MV
Diatomaceous ooze	31	302	2399	120-361	unk	19.5-92.7	TV
D. NANNO OOZE, NANNO CHALK, AND CHALK OOZE SEDIMENTS							
Nanno chalk with ooze, diatoms	16	157	1591	25-225	∥	2.0-3.9	MV
Semi-indurated chalk ooze	16	157	1591	225-265	∥	21.0-60.8	MV
Nanno chalk	16	157	1591	265-333	∥	19.6-39.2	MV
Nanno chalk ooze	16	158	1953	9-135	∥	1.76-15.8	MV
Nanno ooze to chalk	16	158	1953	135-170	∥	24.9-72.0	MV
Nanno chalk	16	158	1953	170-175	∥	25.3-31.3	MV
Chalk ooze	16	160	4940	81	∥	12.0	MV
Nanno chalk ooze	16	161	4939	40	∥	2.5	MV
Nanno chalk ooze	16	161	4939	81	∥	4.3	MV
Nanno chalk ooze	16	161	4939	99	∥	8.6	MV
Nanno chalk ooze	16	161	4939	115	∥	2.0	MV
Nanno chalk ooze	16	162	4854	9-18	∥	8.6-9.0	MV
Nanno chalk ooze	19	183	4708	0-210	⊥	4.9-98.0	MV
Nanno ooze	27	259	4696	0-50	⊥	3.9-58.8	MV
Nanno ooze	27	259	4696	120-145	⊥	127.4-240.2	MV
Nanno ooze	27	260	5702	95-100	⊥	19.6-29.4	MV
Nanno ooze	27	261	5667	48-56	⊥	19.6-29.4	MV
Nanno ooze	27	261	5667	96	⊥	24.5	MV
Nanno ooze	27	262	2298	30	⊥	24.5	MV
Clay rich	31	297	4458	54-90	unk	17.6-36.3	TV
Nanno ooze	44	390	2665	0-9	⊥	3.2-7.9	MV
E. RADIOLARIAN OOZE SEDIMENTS							
Clayey	16	163	5230	55	∥	27.2	MV
With nannofossils	27	260	5702	0-4	⊥	1.0-4.9	MV
Light brown-green	43	385	4936	139.3-140.3	⊥	37.3-50.0	MV
Pink-brown	43	385	4936	150.4	⊥	49.0	MV
Pale green	43	387	5117	180.3-180.5	⊥	86.5-89.4	MV

[a]Direction in which strength test was made relative to the core. ∥ = parallel to core; ⊥ = perpendicular to core.

[b]Minimum-maximum.

[c]MV = miniature vane; TV = Torvane.

Table 3. Undifferentiated sediments.

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Direction[a]	Shear Strength[b] (kPa)	Type of Test[c]
Calcareous clay	16	159	4484	27	ϕ	5.2	MV
Diatom silty clay and clayey diatom ooze	19	193	4811	0-32	+	4.9-48.1	MV
Nanno or radiolarian ooze	27	260	5702	40-50	+	2.0-14.7	MV
Nanno ooze with clay, radiolarians, forams	27	262	2298	0-12	+	2.0-19.6	MV
Nanno ooze with clay, radiolarians, forams	27	262	2298	50-250	+	29.4-151	MV
Nanno ooze with clay, radiolarians, forams	27	262	2298	250-300	+	88.2-333.2	MV
Sandy, silty, and clayey silt	31	293	5599	96.5	+	19.5	TV
Sandy silt	31	293	5599	106	+	52.7	TV
Silt	31	293	5599	158	+	33.2	TV
Silt	31	293	5599	161.5	+	21.5	TV
Clayey silt	31	293	5599	354.5	+	70.3	TV
Clay and volcanic ash	31	295	5808	100-110	ϕ +	22.5-39.0	TV
Clay and volcanic ash	31	295	5808	120-150	+	27.5-40.0	TV
Clay-rich nanno ooze	31	296	2920	70-120	+	46.8-63.4	TV
Clay-rich nanno ooze, chalk	31	296	2920	130-150	+	35.1-63.4	TV
Diatom ash-rich clay	31	297	4458	25-54	+	6.5-16.6	TV
Claystone	31	297	4458	90-210	+	14.3-61.1	TV
Sandy siltstone	31	298	4628	130-136	+	2.3-3.7	TV
Mudstone, shale	31	298	4628	190-202	+	41.5-58.6	TV
Mudstone, shale	31	298	4628	280-290	+	34.1-65.9	TV
Clayey silt, silty clay with sand beds	31	299	2599	80-115	+	21.7-47.8	TV
Sandy silt, clayey silt	31	299	2599	145-190	+	31.2-50.7	TV
Gray mud, sandy mud, clay, sand, silt	38	336	811	0-168	+	2.9-18.2	TV
Olive, dusky yellow mud, clay, mudstone, claystone	38	336	811	168-210	+	16.2-18.2	TV
Olive, dusky yellow mud, clay, mudstone, claystone	38	336	811	220-340	+	18.2-326	P
Mud, sandy mud, clay, nanno oozes	38	337	2631	0-42	+	6.7-13.4	TV
Mud, clay, sandy mud	38	337	2631	42-110	+	7.7-18.2	TV
Mud, clay, sandy mud	38	337	2631	86-92	+	24.0-182	P
Mud, sandy mud, calcareous ooze, pebbles	38	338	1297	0-20	+	3.5-10.2	TV
Soft sandy mud with pebbles	38	339	1262	0-57	+	1.9-18.2	TV
Sandy mud, some pebbles	38	340	1206-1217	0-10	+	5.4-11.5	TV
Mud, calcareous mud with pebbles	38	341	1439	0-32	+	2.7-13.3	TV

Table 3. Undifferentiated sediments. (Cont.)

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Direction[a]	Shear Strength[b] (kPa)	Type of Test[c]
Calcareous pebbly mud, sandy mud	38	342	1303	0-9	⊥	2.6-10.4	unk
Terrig. muds, sandy muds, ash, clay	38	344	2156	0-60	⊥	9.4-19.2	TV
Terrig. muds, sandy muds, ash, clay	38	344	2156	33-153	⊥	53.0-431	TV
Muds, sandy mud, silic. seds, foram ooze, clay	38	345	3195	0-125	⊥	2.7-19.2	TV
Mud, sandy mud, foram ooze	38	345	3195	0-46	⊥	34.0-72	TV
Clay, mud, transitional silic. seds, foram ooze, claystone	38	345	3195	46-331	⊥	19.2-124	P
Mudstone, sandy mud, calc. sandy mud, limestone	38	345	3195	331-540	⊥	128	P
Calcareous ooze	40	360	2949	80-235	⊥	2.3-58.0	MV
Mud, marly nanno ooze	40	361	4549	0-263	⊥	23.0-362.8	MV
Diatom. marly nanno ooze, chalk, foram nanno chalk	40	362	1325	50-300	⊥	118	MV
Foram nanno ooze, chalk, calc. mudstone, pyrite	40	363	2248	0-112	⊥	14.7-111.1	MV
Calc. mud, clay, marly nanno ooze, pelagic clay, marly chalk	40	364	2448	11-275	¢	3.2-154	MV
Mud, nanno ooze, mudstone (saporel)	40	365	3018	233.5-234.5	¢	8.0-113	MV
Nanno ooze, marls, grading to chalk	41	366	2853	0-160	¢	29.4-176.5	MV
Marl, silty clay	41	367	4748	237	¢	42.2	MV
Marl, ooze, nanno ooze, marl	41	368	3366	4-174	¢	11.8-54	MV
Clay, silty clay, volcanic shards, stiff clay, silty clay	41	368	3366	201-279	¢	80.4-490.3	MV
Nanno ooze, nanno marl	41	369	1752	3-38	¢	26.5-68.6	MV
Clayey nanno marl, nanno marl	41	369A	1752	46-103	¢	318.7-392.2	MV
Nanno marl	41	369A	1752	131-179	¢	441.0-490.3	MV
Calcareous muds, mudstones, sandy beds, laminae	42A	371	2792	5.6-415.6	unk	4.4-137.3	MV
Nanno marl, gypsum, dolomitic nanno marls, marlstones, mudstones, nanno marlstones	42A	372	2699	0-885	unk	22.6-286	MV
Terrig. mud, diatomaceous mud, sandy silts, turbidites, dolomitic marls	42B	380A	2107	0-440	¢ ⊥	128.5-357.9 49.0-63.7	TPM
Terrig. mud, diatomaceous mud, sandy silts, turbidites, dolomitic marls	42B	380A	2107	440-1000	¢ ⊥	98.1-500.1 64.7-495.2	TPM

Table 3. Undifferentiated sediments. (Cont.)

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Direction[a]	Shear Strength[b] (kPa)	Type of Test[c]
Terrig. mud					∥	8.8-96.1	
to clay	42B	381	1728	0-170	⊥	22.6-45.1	TPM
Diatomaceous mud to clay	42B	381	1728	170-360	∥	35.3-235.8	TPM
					⊥	28.4-176.5	
Marly ooze	43	384	3909	52.9-88.1	⊥	9.5-64.5	MV
Nanno ooze	43	384	3909	91.7-102.8	⊥	20.0-36.0	MV
Nanno ooze	43	386	4782	54.7-59.6	⊥	1.7-6.1	MV
Pale olive radiolarian mud	43	387	5117	105.3-105.6	⊥	60.0-115.5	MV
Gray-green radiolarian mud	43	387	5117	146.7	⊥	83.6	MV
Gray-brown radiolarian mud	43	387	5117	147.5	⊥	60.0-92.3	MV
Olive-gray radiolarian mud	43	387	5117	169.4	⊥	111.4-122.3	MV

[a]Direction in which strength test was made relative to the core. ∥ = parallel to core; ⊥ = perpendicular to core; unk = unknown.

[b]Minimum-maximum.

[c]MV = miniature vane; TV = Torvane; unk = unknown; TPM = two-plane shear method; p = penetrometer, unconfined compression.

Table 4. Rock types, Leg 20.

Descriptives	Leg	Site	Water Depth (m)	Depth below Mudline (m)	Shear Strength (kPa) Min.	Shear Strength (kPa) Max.	Type of Test
Chert-limestone	20	195	5958	190-196		228.561×10^3	Triaxial
Chert-limestone, siltstone	20	196	6184	197-200	87.91×10^2	116.04×10^3	Triaxial
Basalt	20	197	6143	275-280	540.54×10^2	262.69×10^3	Triaxial
Chert nanno-chalk	20	199	6090	285-295	143.96×10^2	179.08×10^2	Triaxial
Nanno chalk, chert	20	199	6090	304-314	10.34×10^2	667.07×10^2	Triaxial
Nanno chalk, tuff	20	199	6090	371-380	131.69×10^3	222.528×10^3	Triaxial
Nanno chalk, limestone	20	199	6090	399-409	291.30×10^2	719.81×10^2	Triaxial
Oolitic limestone	20	202	1505	74-84	49.16×10^2	63.16×10^2	Triaxial

TECHNIQUES AND METHODS

Swedish Fall Cone Penetrometer

During Leg 16 limited use was made of the Swedish fall cone penetrometer for comparison with miniature vane shear measurements (Heath et al., 1973) and for assessing its suitability for obtaining strength measurements on DSDP sediments. Although extensively used in Europe, the fall cone method has had limited use in the United States, but, because of its simplicity, it was tested on a limited basis during Leg 16 (Table 1). Basically, the technique consists of dropping a weighted cone from a specific height and measuring the depth of cone penetration into the sediment sample (Fig. 1). Fall cone penetration is related to undrained shear strength by $S = KQ/h$ where Q is the weight of the cone, K is a constant that depends on the cone angle and sampler type (which determines the particular degree of sediment disturbance), and h is the depth of penetration for a specific test. Hansbo (1957) has discussed the details of this type of strength test. Usually the fall cone is calibrated with the vane shear device to determine the correct value for K that is characteristic of a particular coring device and sediment type. During Leg 16, some K values proved to be very close to unity while others deviated significantly from a value of one. This undoubtedly was a result of the varying degrees of sediment disturbance observed in the DSDP core materials. Because of these inconsistencies in the value of K, the strength measurements obtained during Leg 16 with the fall cone were useful mainly as a means of assessing relative degrees of sediment strength (Heath et al., 1973; Keller and Bennett, 1973; Bennett and Keller, 1973).

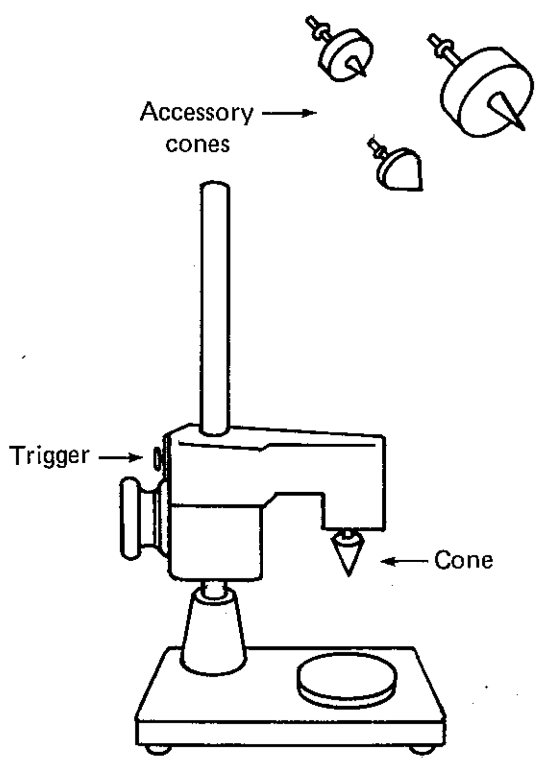

Figure 1. Swedish fall cone apparatus with accessory cones.

Miniature Vane Shear Apparatus

The miniature vane shear test is carried out by inserting a four-bladed vane into a sediment sample and applying an increasing torque through a calibrated spring (or load cell) until shear failure occurs (Fig. 2). Various sizes of vanes are available for particular soil types and sample sizes (Fig. 3). Measurements were performed on samples by inserting the vane normal to the core (on split cores) or parallel to the core (on small core segments) (Fig. 4, 5). The choice depended upon the researchers' evaluation of the sediment quality and, of course, the availability of the DSDP material for testing. Because of the common DSDP procedure of cutting (splitting) the core sections in half, many vane shear tests were performed on material in a direction normal to the core length. The effect of this procedure and the relation of the values obtained to values determined by shearing normal to the bedding (standard soil practice) are unknown. However, the direction the strength tests were made relative to the core section lengths is indicated for each strength measurement reported (Tables 2 and 3). In some cases, the direction was not indicated

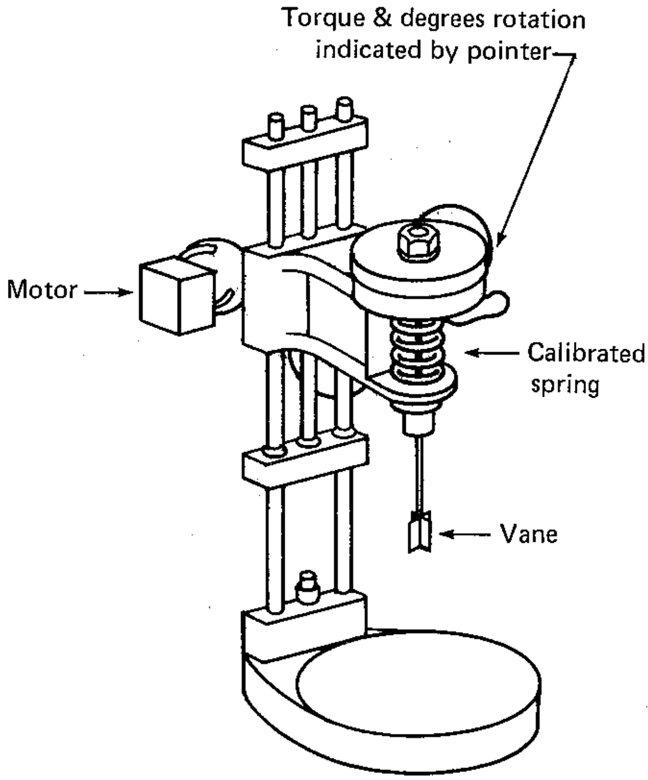

Figure 2. Miniature vane shear apparatus.

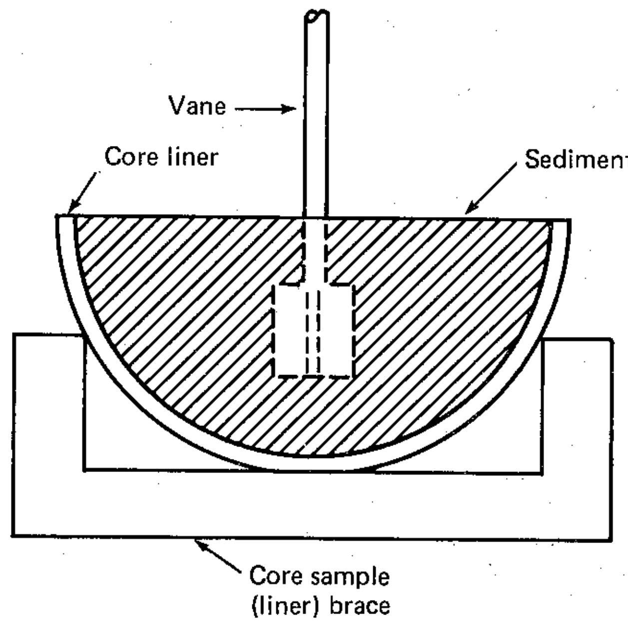

Figure 4. Typical arrangement for insertion of mini-vane into split DSDP cores. Vane is inserted normal to core length (parallel to bedding).

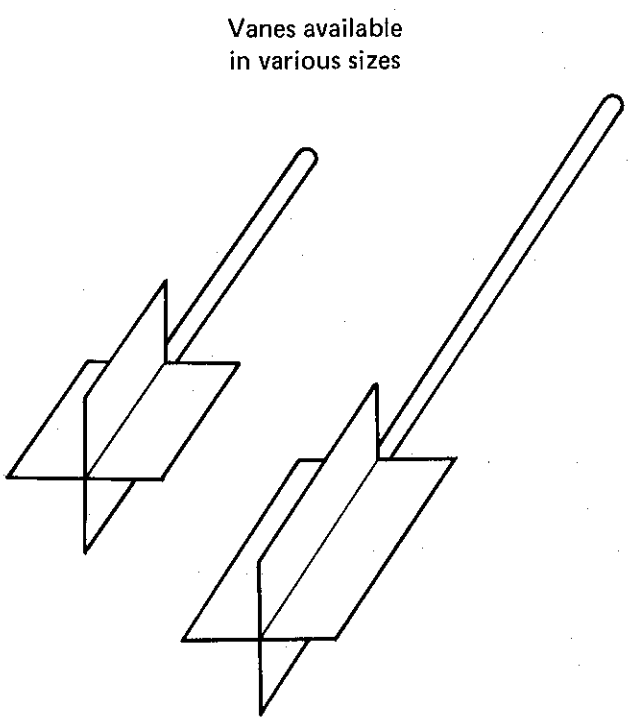

Figure 3. Examples of various sizes and shapes of miniature vanes.

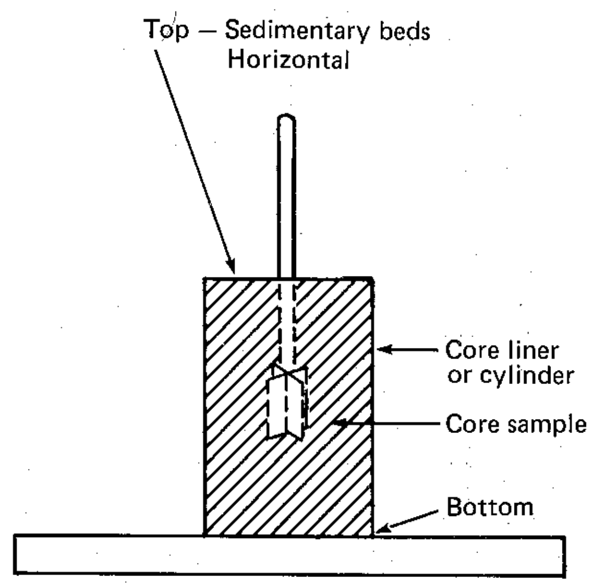

Figure 5. Typical arrangement for inserting mini-vane into short core sections. Vane is parallel to core length.

in the Initial Reports and is indicated in Tables 2 and 3. Details of vane shear testing of soils can be found in Evans and Sherratt (1948), Richards (1961), and the American Society for Testing Materials (1957). Details of the vane shear tests and the recommended procedure for its use aboard the Glomar Challenge have been thoroughly discussed by Boyce (1976). An advantage of miniature vane testing is that tests can be performed aboard ship, minimizing potential degradation and core disturbance due to excessive handling and shipment to shore-based laboratories. However, the extreme pressure to process cores as soon as possible after they come aboard has restricted the number of miniature vane tests. Vane shear testing provides quantitative estimates of shear strength of soil samples but does not necessarily represent the in-place strength of the materials (Demars and Nacci, 1978). Factors affecting the strength measurements of core samples will be discussed later in this chapter.

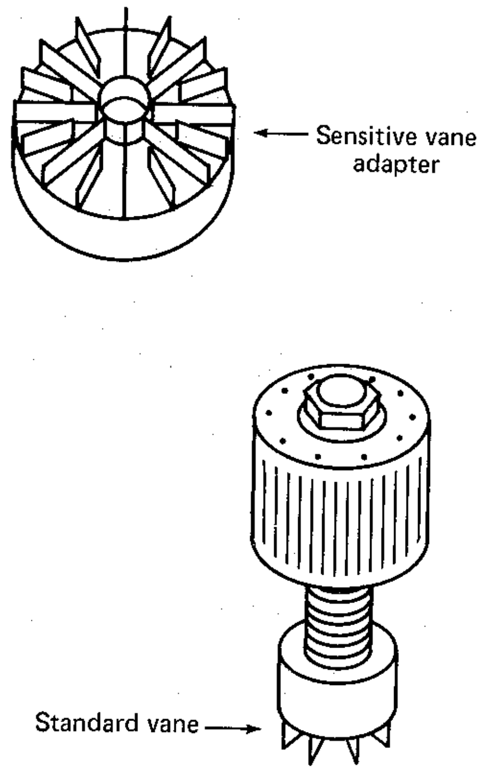

Figure 6. Torvane shear device and sensitive vane adapter.

Torvane Shear Device

The Torvane shear device is a hand-held unit that has been used on Legs 31 and 38. The device offers the advantage of being easy to operate, and strength tests can be performed rapidly. The Torvane consists of a hand-held wheel with pointer, a calibrated spring through which torque is transmitted, and two types of multi-bladed vanes -- one for "standard" soils (insensitive) and one for sensitive material (Fig. 6). Basically, the vane is inserted into the sediment (a smooth surface is required) and torque is applied through the movable hand-held wheel until failure occurs. Numerous measurements can be carried out quickly. Unfortunately, the speed and consistency at which torque is applied depend upon the operator. No known comparisons or calibrations with the miniature vane test have been performed on DSDP materials, although R. Faas (written communication, 1980) finds good correlations for the two methods within lithotypes for continental margin sediments. Therefore, it is unknown how the values reported may compare with miniature vane measurements even in similar lithological units (Tables 2 and 3).

The majority of Torvane tests were made perpendicular to the long axis of the cores. Although the method is somewhat crude, the Torvane provides a means of collecting strength data on shipboard samples with minimal time and effort.

Direct Shear Tests

Limited strength testing was carried out on Leg 42 samples (Kuprin et al., 1978) using a "two-plane shear method," which, from the Volume 42 descriptions, appears to be essentially equivalent to the well-known direct shear test. The test is performed with a split-ring soil sample retainer (Fig. 7). One half of the sample retainer is held fixed while a shear stress is applied

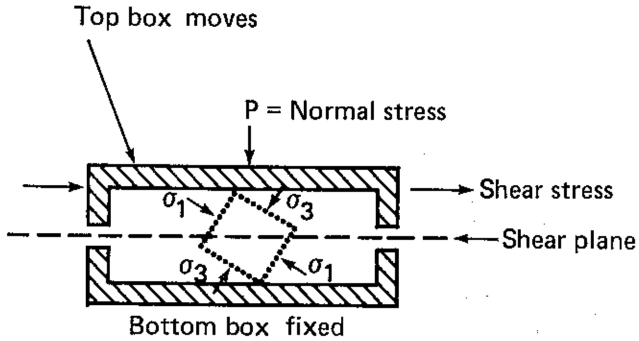

Figure 7. Sediment sample shown in a split-ring soil sample retainer for use in the direct shear test. Principal stresses at failure shown (σ_1 and σ_3). (From Sowers, 1963).

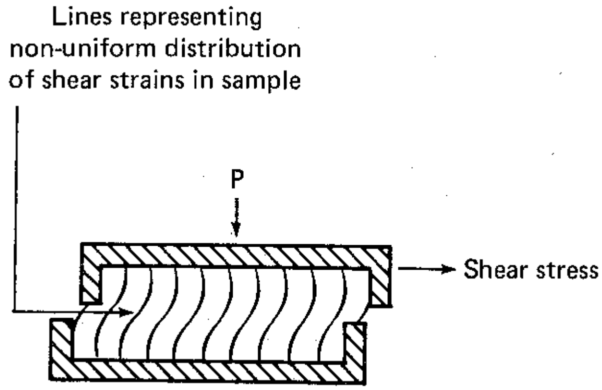

Figure 8. Example of shear configuration at failure in the direct shear test. Note direction of normal load, shear plane, and nonuniform distribution of shear strains. (From Sowers, 1963).

to the adjoining but slightly separated retainer. Prior to applying the shear stress a normal load is applied to the sample (load P, Fig. 7, 8). When a sufficient magnitude of shear stress is applied to the movable retainer, the soil sample deforms and ultimately shears along a fixed surface (Fig. 8, see shear plane). Shear stress, deformation, and consolidation of the sample can be monitored with this method and the test is relatively simple to perform. With the standard direct shear test, drained or undrained (consolidated or unconsolidated) testing can be carried out (Lambe, 1951). Details and well-documented discussions on the theory and testing can be found in numerous textbooks on soil mechanics (Lambe, 1951; Lambe and Whitman, 1969; and Sowers, 1963).

Triaxial Test

The triaxial test was performed on a very limited number of DSDP samples and is a more rigorous strength test than the aforementioned techniques. The common triaxial test, also referred to as the "cylindrical compression test" (Lambe, 1951), utilizes a cylindrical specimen and chamber fluid that produces a stress in two principal planes (Fig. 9, 10) when pressure is applied through the confining pressure unit. Thus, a confining stress is produced in which $\sigma_2 = \sigma_3$ and a uniaxial shearing stress is produced by σ_1 through a movable piston or ram.

The triaxial test is time consuming and requires considerably more sample preparation than the direct shear test. It has advantages because the complete state of stress is known at all stages of testing. Specimen volume changes can be determined more accurately, and pore pressure can be monitored and controlled. Readers with further interest in these tests are referred to a good review by Lambe (1951, chap. XI) of the advantages of the triaxial and direct

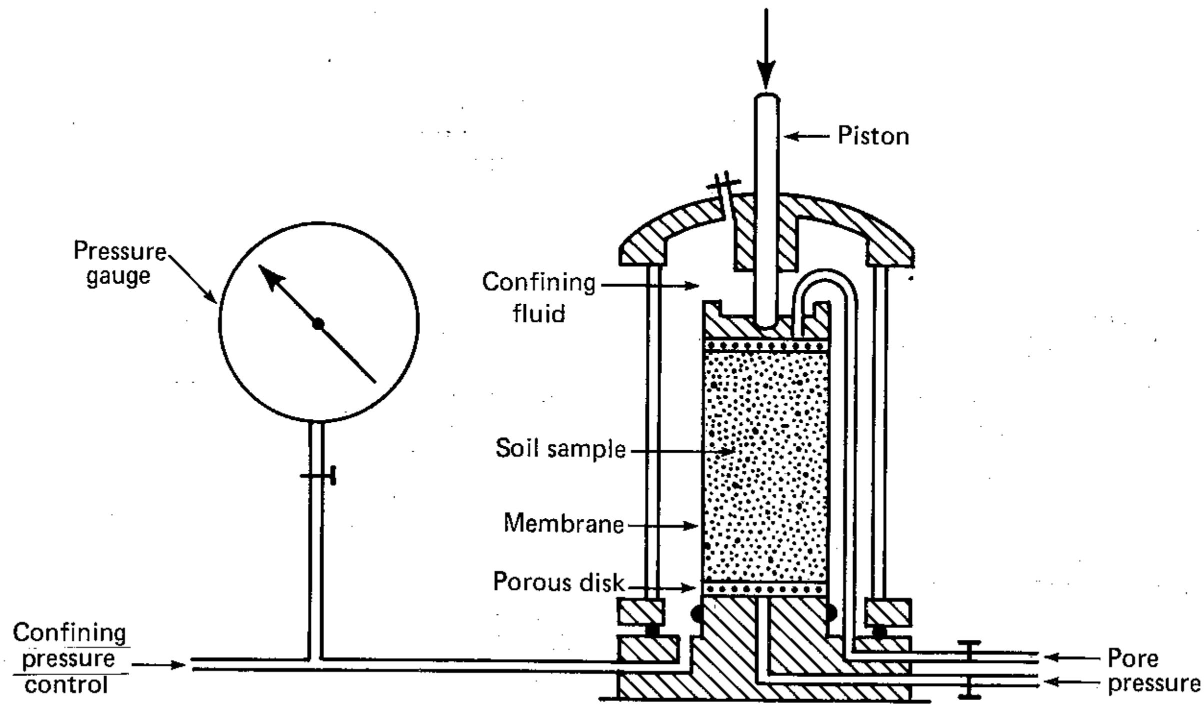

Figure 9. Typical configuration of triaxial test apparatus and cylindrical soil sample. (From Bishop and Henkel, 1962.)

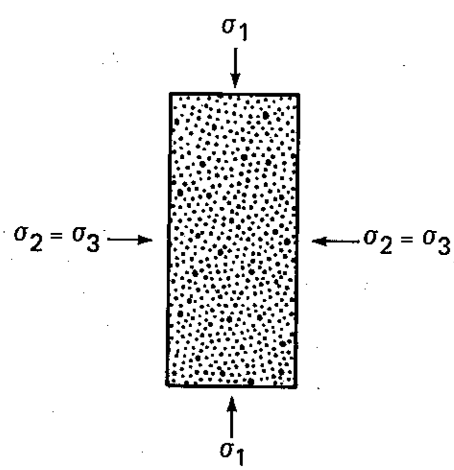

Figure 10. Typical example of principal stresses on cylindrical soil sample in triaxial test.

shear test. An excellent book on triaxial testing is available (Bishop and Henkel, 1962). A book giving further information regarding the shear strength of cohesive soils is available through the American Society of Civil Engineers (1960). Details of shear strength testing of soils can be found in Lambe and Whitman (1969). Further details of the concepts, theory, and practice of strength testing of soils is beyond the scope of this paper.

Vane shear testing (mini-vane and Torvane) was the predominant strength method used on DSDP geological samples (Table 1). Data from these types of tests form the bulk of the strength data presented in Tables 2 and 3. Limited triaxial testing was carried out on rock samples (Table 4).

DISCUSSION

The most important factor that determines the quality and reliability of the DSDP strength data is the quality of the core material used for testing. Again, this cannot be overemphasized. Generally, the lowest section of a core (Section 6) is less disturbed than the remaining upper sections. The "zero" section and Section 1 contain sediment that has passed through the entire 9-m length of the core barrel. The greater the distance from the lower end of the core barrel, the greater the general degree of sediment disturbance. Quite often the core-catcher section and the material in the steel sleeve is the least disturbed. Also, the ends of core sections are considerably disturbed from ongoing shipboard sampling and subsampling activities. A detailed discussion of DSDP core quality and core disturbance in relation to geotechnical properties measurements is presented by Bennett and Keller (1973).

These general comments on core disturbance should be considered by data users. Specific data points and the quality of the strength data should be evaluated in terms of core disturbance, which can be obtained from the core descriptions and core photography in the respective volumes of the Initial Reports. Generally, "zero" section material is the least reliable sediment and is not suitable for geotechnical measurements: specifically for strength testing. Strength data summarized in Tables 2 and 3 demonstrate the wide range of values reported even within the same lithological units. In general, high strength values are considered most reliable; however, it should be recognized that the strength of normally consolidated sediment increases with increasing depth of burial. Very low strength values are quite common in surficial clayey sediment of high water content. Therefore, a low strength value need not necessarily be invalid, but rather, the previous discussion of core disturbance factors should be considered carefully by the data user who should evaluate thoroughly the sediment strength data of all DSDP sediment cores.

An additional perplexing problem is the nonstandardization of techniques despite the use of the same instrumentation. Specifically, samples were tested with the miniature vane apparatus using different vane rotation rates (Table 1). Even though all the minivane tests were considered to be undrained measurements, vane rotation rates varied among legs from 6^o/min. [1.7×10^{-3} rad/s] to as much as 90^o/min. [2.6×10^{-2} rad/s]. Such inconsistency makes comparison of data sets collected on different legs difficult. Different vane rotation rates and angular shear velocities of the shearing surface can produce significant differences in strengths, resulting in values as much as 27% greater at high rotation rates (Smith and Richards, 1976; Perlow and Richards, 1977). Smith and Richards noted that sampling disturbances tend to reduce or minimize the increase in shear strength obtained at high rotation rates. In addition, the relationship between shear strength and the rotation rate appeared to be independent of soil particle size. Thus, researchers and data users should be aware of the potential limitations and problems when comparing various shear strength measurements obtained using different techinques. Comparison of data from a single leg with consistent techniques would therefore be more reliable than direct comparison among data sets from many legs.

The effect of shearing direction (i.e., vane insertion direction) relative to core length is also an unknown. Presumably, sedimentary deposits possessing fundamental anisotropic properties (such as strongly preferred particle orientations) would possess different shear characteristics in different directions. These anisotropic effects would be expected to become more pronounced with increasing depth of burial in normally consolidated sediments as observed in silty-clay sediment (Bennett and Bryant, 1977; Bennett et al., 1979). Tables 2 and 3 reveal that vane shear measurements were carried out both normal and parallel to core lengths. In some cases, the direction of the vane measurement is unknown. Unfortunately, no studies apparently were made to determine the possible difference that may exist for DSDP core materials as a result of shearing direction. Many strength measurements have been reported, but very limited data are available for comparison of strength measurements carried out normal and parallel to core section lengths within the 1.5-m intervals. Therefore, any conclusions regarding the effect of direction on the strength values obtained are virtually impossible (Tables 2A and 3).

In general, the highest consistent strength values obtained were reported for the two-plane shear method (Leg 42B, Table 3) that deserves further assessment as an analytical tool. A few relatively high strength values were reported, however, for the mini-vane test in clay (Legs 27, 41, 43, Table 2); nannofossil ooze (Leg 27, Table 2A, 3, and Leg 40, Table 3); undifferentiated units (Leg 38, Table 3); and nanno marl (Leg 41, Table 3). Although it is difficult to draw any firm conclusions, the Torvane strengths reported generally appear to be somewhat less than mini-vane values (Tables 2A, 3).

The precision and accuracy of the instrumentation used on DSDP samples are far better than the quality of the data obtained because of the factors (discussed earlier) that affect sample integrity. The precision and accuracy of state-of-the-art laboratory instrumentation have far exceeded our ability to obtain consistent, high-quality, representative material for strength testing of DSDP samples. With the advent of the new Hydraulic Piston Corer (HPC), studies of geotechnical properties of DSDP materials hold considerable promise, and much higher quality data are possible than was obtained during earlier legs, provided that each method is used consistently and is cross calibrated with other methods.

CONCLUSIONS AND RECOMMENDATIONS

This review of DSDP Legs 1-44 strength measurements on geological materials has revealed considerable differences in the methodology applied to materials recovered from separate legs. Little consideration appears to have been given to standardizing DSDP testing techniques from leg to leg. In addition, the units used to express the strength of the materials have been quite varied, which alone makes comparison of data difficult without first converting the basic data to common strength units. SI units are now the recommended and internationally preferred standards and should be used in all future DSDP geotechnical research papers and reports (Richards, 1974; NBS Special Publication 330, 1977).

Considerable sediment core disturbance of DSDP samples has made reliable strength testing difficult. Often the quality of the data obtained is uncertain. Data users are cautioned to review carefully core descriptions and disturbance notations and, when possible, to check available core photography against locations (core sections) where strength data are reported. Care also should be exercised when comparing DSDP strength data obtained on shear tests using different vane rotation rates (Table 1). The DSDP strength data are best used in terms of assessing relative differences observed for given boreholes and sediment lithologies rather than as absolute values of strength. For specific consistent techniques, strength measurements in different boreholes may be grossly comparable provided the core sample quality is generally similar from core to core (this seems to be the case rarely and difficult to determine).

For future testing of the strength of soil samples, standard techniques and procedures and careful selection of high-quality material would greatly improve the resulting data sets to be reported in future DSDP Initial Reports.

The use of SI would improve communication from researcher to data user. The miniature vane shear apparatus holds much promise as being the best device for obtaining onboard quantitative strength measurements. When the work load is extreme, the Torvane may be an acceptable substitute providing that it is calibrated against the mini-vane for each lithotype on each leg. More sophisticated strength tests using triaxial and direct shear devices should be used only on high-quality samples for specific research and engineering projects at shore-based laboratories. Whenever possible, strength measurements should be made parallel to core lengths (normal to bedding). When this is generally not possible, selected measurements on similar material should be made in both directions for comparison of data sets for assessing discrepancies. Standardization and consistency in techniques should be the rule for future strength testing of DSDP geological materials.

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REFERENCES

American Society of Civil Engineers, 1960. Research conference on shear strength of cohesive soils. Soil Mech. Found. Div. ASCE: Boulder (Univ. of Colorado), 1164 p.

American Society for Testing Materials, 1957. Proceedings, symposium on vane shear testing of soils. Spec. Tech. Pub. 193.

American Society for Testing and Materials, 1965. Standard method of test for penetration of bituminous materials. ASTM Designation D5-65, pp. 5-9.

_______, 1975. Standard method of test for penetration of bituminous materials, ASTM Designation D5-73. Ann. Book of ASTM Standards, Part 15, pp. 59-63.

Bennett, R. H., and Bryant, W. R., 1977. Clay fabric and geotechnical properties of selected submarine sediment cores from the Mississippi Delta. NOAA Prof. Paper 9, U.S. Dept. of Commerce, 86 p.

Bennett, R. H., Bryant, W. R., and Keller, G. H., 1979. Clay fabric and related pore geometry of selected submarine sediment: Mississippi Delta, scanning electron microscopy, V.I., SEM, Inc., AMF, O'Hare, IL, pp. 519-524.

Bennett, R. H., and Keller, G. H., 1973. Physical properties evaluation. I.R. DSDP, 16:513-519.

Bishop, A. W., and Henkel, D. J., 1962. The Measurement of Soil Properties in the Triaxial Test (2nd ed.): London (Edward Arnold), 227 p.

Boyce, R. E., 1973. Appendix I. Physical properties -- methods. I.R. DSDP, 15:1115-1127.

_______, 1977. Deep Sea Drilling Project procedures for shear strength measurement of clayey sediment using modified Wykeham Ferrance laboratory vane apparatus. I.R. DSDP, 36:1059-1068

Davie, J. R., Fenske, C. W., and Serocki, S. T., 1978. Geotechnical properties of deep continental margin soils. Mar. Geotech., 3:85-119.

Demars, K. R., and Nacci, V. A., 1978. Significance of Deep Sea Drilling Project sediment physical property data. Mar. Geotech., 3:151-170.

Evans, I., and Sherratt, G. G., 1948. A simple and convenient instrument for measuring the shear resistance of clay soils. J. Sci., Inst. Phys. in Industry, 25:411.

Focht, J. A., and Kraft, L. M., 1977. Progress in marine geotechnical engineering. J. Geotech. Eng. Div., 103: 1097-1118.

Hansbo, S., 1957. A new approach to the determination of the shear strength of clay by the fall-cone test. R. Swed. Geotech. Inst. Proc., 8:1.

Heath, G. R., Bennett, R. H., and Rodolfo, K. S., 1973. Introduction. I.R. DSDP, 16:3-18.

Keller, G. H., and Bennett, R. H., 1973. Sediment mass physical properties; Panama Basin and northeastern equatorial Pacific. I.R. DSDP, 16:499-512.

Kuprin, P. N., Stcherbakov, F. A., Poljakov, A. S., Shlikov, U. G., and Nesterova, M. P., 1978. Physical and mechanical properties of the Black Sea's Pliocene-Quaternary sediments (Sites 380 and 381). I.R. DSDP, 42B: 1107-1123.

Lambe, T. W., 1951. Soil Testing for Engineers: New York (John Wiley and Sons, Inc.), 365 p.

Lambe, T. W., and Whitman, R. V., 1969. Soil Mechanics: New York (John Wiley and Sons, Inc.), 553 p.

NBS Special Publication 330, 1977. The international system of units (SI): Washington (U.S. Dept. of Commerce, Nat'l Bureau of Standards, U.S. Gov't Printing Office), 0-236-406.

Perlow, M., Jr., and Richards, A. F., 1977. Influence of shear velocity on vane shear strength. Am. Soc. Civil Eng., Geotech. Eng. Div. J., GT-1, pp. 19-32.

Richards, A. F., 1961. Investigations of deep-sea sediment cores, shear strength bearing capacity and consolidation. TR-63: Washington (U.S. Navy Hydrographic Office), 70 p.

________, 1974. Standardization of marine geotechnics, symbols, definitions, units, and test procedures. In Inderbitzen, A. L. (Ed.), Deep Sea Sediments, Physical and Mechanical Properties: New York (Plenum Press), pp. 271-292.

Smith, A. D., and Richards, A. F., 1976. Vane shear strengths at two high rotation rates. Civil Engineering in the Oceans, Proceedings 3 (Vol. 1): New York (Am. Soc. Civil Eng.), 421-433.

Sowers, G. F., 1963. Strength testing of soils. In Laboratory Shear Testing of Soils. ASTM Special Tech. Pub. No. 361, Am. Soc. Testing and Materials, pp. 3-21.

9. MAGNETIC STUDIES OF SAMPLES FROM DSDP LEG 1-44: CROSS REFERENCES TO PAPERS IN THE *INITIAL REPORTS*

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MAGNETIC STUDIES OF SAMPLES FROM DSDP LEGS 1-44: CROSS REFERENCES TO PAPERS IN THE INITIAL REPORTS

Magnetic studies were done on 4500 sediment and sedimentary rock samples and 2100 igneous rock samples from 132 sites on Legs 1 through 44. The results are contained in 75 articles contributed by 72 authors. Thirty-four volumes of the Initial Reports contain articles on magnetic studies. Those that do not are the reports for Legs 9-12, 20, 21, 24, 31, 35, 36, and 39.

A large number of sediment samples from Legs 1-4 were studied. Interest in the magnetic properties of the sediments waned, however, when it became apparent that the core material was highly disturbed by drilling and that the resulting lack of preserved declination made it difficult to do traditional paleomagnetic time-scale studies. Interest in studying the sediments shifted to determining reliable paleo-inclinations that in turn could be used to test plate rotation models. Recently, an effort has been made by Keating and Helsley using sites from Legs 40, 41, 43, and 44 to develop a Cretaceous paleomagnetic stratigraphy for the Atlantic.

Magnetic studies of the igneous rocks recovered by drilling were reported beginning with Volume 14. These studies included all aspects of the magnetic properties of the rocks. The first basement drilling leg, Leg 34, and the second basement drilling leg, Leg 37 resulted in a total of 25 articles on the rocks recovered at the seven sites. Much of the interest was focused on the magnetic properties of the basaltic material that makes up seismic layer 2 and the origin of magnetic anomalies.

The purpose of this compilation is to tabulate the magnetic information available for each site and articles that deal with particular kinds of studies. Three tables are included for this purpose. In Table 1, volume and page references to relevant chapters in the Initial Reports are numerically ordered by leg and site number. In addition, Table 1 includes information on the number of sediment and the number of rock samples used in the article for each hole. In a given article, holes which had fewer than 15 samples have been added together. Table 2 is an author index and lists the reference number of each article on which the author worked. Table 3 is a subject index divided into two parts; the first part for rock studies and the second part for sediment studies. The subject headings chosen are not the most complete possible and in several cases a number of parameters which are usually measured together have been lumped together. Within each subject heading, the references are in order by volume and chapter and include in parentheses the sites for which the kind of study or measurement were made.

REFERENCES

1. Ade-Hall, J. M., 1974. Strong field magnetic properties of basalts from DSDP Leg 26. I.R. DSDP, 26:529-532.

2. Ade-Hall, J. M., and Johnson, H. P., 1976. Paleomagnetism of basalts, Leg 34. I.R. DSDP, 34: 513-532.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

3. _______, 1976. Paleomagnetism of sediments, Leg 34. I.R. DSDP, 34: 533-539.

4. Ade-Hall, J. M., Johnson, H. P., and Ryall, P. J. C., 1976. Rock magnetism of basalts, Leg 34. I.R. DSDP, 34:459-468.

5. Allis, R. G., Barrett, P. J., and Christoffel, D. A., 1975. A paleomagnetic stratigraphy for Oligocene and early Miocene marine glacial sediments at Site 270, Ross Sea, Antarctica. I.R. DSDP, 28: 879-884.

6. Bleil, U., and Petersen, N., 1977. Magnetic properties of basement rocks, Leg 37, Site 332. I.R. DSDP, 37:449-456.

7. Brecher, A., Atwater, T., Stein, J., and Carter, E., 1977. Some magnetic properties of some Leg 37 samples. I.R. DSDP, 37:465-469.

8. Carmichael, C. M., 1977. Magnetization and paleomagnetic field intensity of selected samples from Sites 332, 334, and 335. I.R. DSDP, 37:481-487.

9. Cockerham, R. S., and Jarrard, R. D., 1976. Paleomagnetism of some Leg 33 sediments and basalts. I.R. DSDP, 33:631-647.

10. Denham, C. R., and Guertler, J. C., 1976. Magnetic stability of eleven basalt specimens from DSDP Leg 34. I.R. DSDP, 34:469-472.

11. Deutsch, E. R., and Pätzold, R. R., 1976. Magnetic properties and domain state of basalt cores from the Nazca Plate. I.R. DSDP, 34:501-512.

12. Deutsch, E. R., Pätzold, R. R., and Murthy, G. S., 1977. Paleomagnetism of Leg 37 basalts. I.R. DSDP, 37:475-479.

13. Doell, R. R., 1970. Preliminary paleomagnetic results, Leg 5. I.R. DSDP, 5:523-524.

14. _______, 1971. Preliminary paleomagnetic results, Leg 6. I.R. DSDP, 6:961-963.

15. _______, 1971. Preliminary paleomagnetic results, Leg 8. I.R. DSDP, 8:851.

16. Dunlop, D. J., and Hale, C. J., 1977. Magnetic properties of Leg 37 basalts and a determination of paleomagnetic field intensity. I.R. DSDP, 37:457-463.

17. Ellwood, B. B., and Watkins, N. D., 1976. Diagnosis of emplacement mode of basalt in Hole 319A and Site 321. I.R. DSDP, 34:495-499.

18. _______, 1977. Some magnetic properties of specimens from Hole 332B and Sites 334 and 335, and corresponding analysis in terms of emplacement mode. I.R. DSDP, 37: 511-514.

19. Evans, M. E., and Wayman, M. L., 1977. Magnetic properties of igneous samples, Leg 37. I.R. DSDP, 37:471-473.

20. Green, K. E., and Brecher, A., 1974. Preliminary paleomagnetic results for sediments from site 263, Leg 27. I.R. DSDP, 27:405-413.

21. Gromme, S., and Mankinen, E., 1976. Natural remanent magnetization, magnetic properties and oxidation of titanomagnetite in basaltic rocks from Leg 34. I.R. DSDP, 34:485-494.

22. Hailwood, E. A., 1978. A preliminary paleomagnetic stratigraphy for lower Eocene sediments at Site 366 (Sierra Leone Rise) and Miocene and Oligocene sediments at

Site 368 (Cape Verde Rise), northwest African continental margin. I.R. DSDP, 41:987-993.

23. Hailwood, E. A., and Hamilton, N., 1978. Quaternary geomagnetic secular variation and polarity reversal record at DSDP Sites 379 and 380, Black Sea. I.R. DSDP, 42B: 1069-1076.

24. Hall, J. M., and Ryall, P. J. C., 1977. Paleomagnetism of basement rocks, Leg 37. I.R. DSDP, 37:425-448.

25. _______, 1977. Paleomagnetism of sediments, Leg 37. I.R. DSDP, 37: 531-536.

26. _______, 1977. Rock magnetism of basement rocks, Leg 37. I.R. DSDP, 37:489-501.

27. Hamilton, N., 1974. Site 220. I.R. DSDP, 23:126.

28. _______, 1974. Site 221. I.R. DSDP, 23:176-178.

29. _______, 1974. Site 222. I.R. DSDP, 23:221-222.

30. _______, 1974. Site 223. I.R. DSDP, 23:311-312.

31. _______, 1974. Site 224. I.R. DSDP, 23:390-391.

32. Hamilton, N., Hailwood, E. A., and Kidd, R. B., 1978. Preliminary paleomagnetic chronology of Cenozoic sediments from DSDP Sites 372, 374, and 376 of the Mediterranean Sea. I.R. DSDP, 42A:873-880.

33. Hammond, S. R., Kroenke, L. W., and Theyer, F., 1975. Northward motion of the Ontong-Java plateau between -100 and -30 M.Y.: A Paleomagnetic investigation of DSDP Site 289. I.R. DSDP, 30:415-418.

34. Heinrichs, D. F., 1973. Paleomagnetic studies of basalt core from DSDP 163. I.R. DSDP, 16:641-645.

35. _______, 1973. Paleomagnetic studies of sediments from DSDP Site 173. I.R. DSDP, 18:843-846.

36. Henry, K. W., and Opdyke, N. D., 1970. Paleomagnetism of specimens from Leg 3 of the Deep Sea Drilling Project. I.R. DSDP, 3:667-696.

37. _______, 1970. Preliminary report on paleomagnetism of Deep Sea Drilling Project, Leg 4 specimens. I.R. DSDP, 4:439-454.

38. Jarrard, R. D., 1973. Paleomagnetism of Leg 17 sediment cores. I.R. DSDP, 17:365-376.

39. _______, 1974. Paleomagnetism of some Leg 27 sediment cores. I.R. DSDP, 27:415-423.

40. Jarrard, R. D., and Sclater, J. G., 1974. Preliminary paleomagnetic results, Leg 22. I.R. DSDP, 22:369-374.

41. Keating, B. H., and Helsley, C. E., 1978. Magnetostratigraphy of Cretaceous age sediments from Sites 361, 363, and 364. I.R. DSDP, 40:459-467.

42. _______, 1978. Magnetostratigraphic studies of Cretaceous sediments from DSDP Site 369. I.R. DSDP, 41:983-986.

43. _______, 1979. Magnetostratigraphy of Cretaceous sediments from DSDP Site 386. I.R. DSDP, 43:781-784.

44. _______, 1978. Paleomagnetic results from DSDP Hole 391C and the magnetostratigraphy of Cretaceous sediments from the Atlantic Ocean floor. I.R. DSDP, 44:523-528.

45. Kent, D. V., and Lowrie, W., 1977. VRM studies in Leg 37 igneous rocks. I.R. DSDP, 37:525-529.

46. Kent, D. V., and Opdyke, N. D., 1976. Paleomagnetism and magnetic properties of igneous rock samples -- Leg 38. I.R. DSDP, 38:3-8.

47. Kent, D. V., and Tsai, L. P., 1978. Paleomagnetism and rock magnetism of upper Jurassic limestone and basalt from Site 367. I.R. DSDP, 41:995-1002.

48. Larson, R. L., and Lowrie, W., 1975. Paleomagnetic evidence for motion of the Pacific Plate from Leg 32 basalts and magnetic anomalies. I.R. DSDP, 32:571-577.

49. Larson, P. A., and Opdyke, N. D., 1979. Paleomagnetic results from early Tertiary/Late Cretaceous sediments of Site 384. I.R. DSDP, 43:785-788.

50. Lowrie, W., and Hayes, D. E., 1975. Magnetic properties of oceanic basalt samples. I.R. DSDP, 28:869-878.

51. Lowrie, W., and Israfil, M. N., 1975. Paleomagnetism of basalt samples from Leg 29. I.R. DSDP, 29:1109-1115.

52. Lowrie, W., and Kent, D. V., 1976. Viscous remanent magnetization in basalt samples. I.R. DSDP, 34:479-484.

53. Lowrie, W., and Opdyke, N.D., 1972. Paleomagnetism of igneous samples. I.R. DSDP, 14:777-784.

54. _______, 1973. Paleomagnetism of igneous and sedimentary samples. I.R. DSDP, 15:1017-1022.

55. Løvlie, R., 1976. Paleomagnetism of some red clays from Site 336, Leg 38; implications for the time of subsidence of the Iceland-Faeroe Ridge. I.R. DSDP, 38:30-35.

56. McElhinny, M. W., 1974. Paleomagnetism of basalt samples, Leg 27. I.R. DSDP, 27:403-404.

57. Murthy, G. S., Deutsch, E. R., and Pätzold, R. R., 1977. Inferences on the magnetic domain state of Leg 37 basalts. I.R. DSDP, 37:515-523.

58. Opdyke, N. D., 1970. Preliminary report on paleomagnetism of Deep Sea Drilling Project Leg 2 specimens. I.R. DSDP, 2:375-386.

59. Opdyke, N. D., and Phillips, J. D., 1969. Paleomagnetic stratigraphy of Sites 1-7 (Leg 1) preliminary report. I.R. DSDP, 1:501-517.

60. Petersen, N., Bleil, U., and Eisenach, P., 1978. Rock and paleomagnetism of Leg 42A, Hole 373A basalts. I.R. DSDP, 42A:881-886.

61. Pierce, J. W., Denham, C. R., and Luyendyk, B. P., 1974. Paleomagnetic results of basalt samples from DSDP Leg 26, Southern Indian Ocean. I.R. DSDP, 26:517-527.

62. Plessard, C., and Prevot, M., 1977. Magnetic viscosity of submarine basalts, Deep Sea Drilling Project, Leg 37. I.R. DSDP, 37:503-506.

63. Ryan, W. B. F., 1973. Paleomagnetic stratigraphy. I.R. DSDP, 13:1380-1387.

64. Ryan, W. B. F., and Flood, J. D., 1973. Preliminary paleomagnetic measurements on sediments from the Ionian (Site 125) and Tyrrhenian (Site 132) basins of the Mediterranean Sea. I.R. DSDP, 13:599-603.

65. Schwartz, E. J., and Fujiwara, Y., 1977. Remanent magnetization and magnetic mineralogy in DSDP Leg 37 oceanic basalts. I.R. DSDP, 37:507-509.

66. Sclater, J. G., and Jarrard., R. D., 1971. Preliminary paleomagnetic results, Leg 7. I.R. DSDP, 7:1227-1234.

67. Sclater, J. G., Jarrard, R. D., McGowran, B., and Gartner, S., Jr., 1974. Comparison of the magnetic and biostratigraphic time scales since the Late Cretaceous. I.R. DSDP, 22:381-386.

68. Shipboard Staff, 1977. Site 332. I.R. DSDP, 37:48-61.

69. ________, 1977. Site 333. I.R. DSDP, 37:206-207.

70. ________, 1977. Site 334. I.R. DSDP, 37:243-246.

71. ________, 1977. Site 335. I.R. DSDP, 37:292-297.

72. Tarasiewicz, G., Tarasiewicz, E., and Harrison, C. G. A., 1976. Some magnetic properties of Leg 34 igneous rocks. I.R. DSDP, 34:473-478.

73. Whitmarsh, R. B., Hamilton, N., and Kidd, R. B., 1974. Paleomagnetic results for the Indian and Arabian plates from Arabian Sea cores. I.R. DSDP, 23:521-524.

74. Whitney, J., and Merrill, R. T., 1973. Preliminary paleomagnetic results, basalts, Leg 19. I.R. DSDP, 19:699.

75. Wolejszo, J., Schlich, R., and Segoufin, J., 1974. Paleomagnetic studies of basalt samples, Deep Sea Drilling Project, Leg 25. I.R. DSDP, 25:555-572.

APPENDIX 1 -- DSDP HARD ROCKS DATA BASE: MAGNETIC STUDIES OF IGNEOUS ROCKS FROM LEGS 1-44[1]

The DSDP magnetic studies data file contains shipboard and shore laboratory measurements of igneous rock samples recovered on Legs 1-43. The file contains shipboard and shore-based laboratory measurements. It is complete through Leg 43 and contains studies on 1252 igneous rock samples.

Shipboard paleomagnetic measurements were made during Legs 34 and 37. The remaining records are from studies reported in the Initial Reports by investigators working at shore-based laboratories. These data are from DSDP Legs 14-16, 19, 23, 25-29, 32-34, 37-38, and 41-43. No igneous rocks were recovered on DSDP Legs 1, 10, 40, 42B, or 44.

Paleomagnetic properties contained in the data base are: Natural remanent magnetization intensity, inclination and declination; Stable inclination and declination; Mean demagnetizing field and Evidence of the quality of sample orientation. Rock magnetic properties contained in the data base are: Initial susceptibility, Curie temperature, Saturation intensity, Saturation remanence, Coercive force, and Remanent coercive force. There are also fields for the Koenigsberger ratio, the piece number of the sample and the grain-size of the opaque minerals carrying the magnetic signal.

The magnetic properties listed above are stored in fixed-field format. Provision has been made for up to 8 cards of free-field comment about the sample and the magnetic studies. An effort is always made to include the rock type and information about the degree of alteration on the first comment card.

The data base is available on magnetic tape or as a printed listing. Searches on one or several magnetic properties can be made and, of course, the search can be limited by leg or site.

[1]Appendices 1 and 2 were contributed by Donna Hawkins, Deep Sea Drilling Project, La Jolla, California 92093.

APPENDIX 2 -- MAGNETIC STUDIES OF SEDIMENT SAMPLES FROM DSDP LEGS 1-44: AVAILABILITY OF DATA

Work has not yet begun on completing a DSDP data file for magnetic studies of samples from rotary drilled cores. Paleomagnetic studies of sediment cores recovered by the hyraulic piston corer began with Leg 68. Data from these studies have been compiled and are available from the DSDP Information Handling Group.

Table 1. Volume index to magnetic studies in the *Initial Reports*, Volumes 1-44.

Leg	Site	No. Samples Seds.	No. Samples Basalts	Ref. No.	Pages
1	2, 4, 4A, 5, 7, 7A	22		59	501-517
	1P, 1	24			
	3	30			
	6, 6A	20			
2	8, 8A, 12B, 12C	21		58	375-386
	9, 9A	20			
	10	63			
3	13A, 21, 21A, 22	23		36	667-696
	14, 14A	35			
	15	119			
	16	20			
	17, 17A, 17B	120			
	18	16			
	19	61			
	20A, 20B, 20C	75			
4	23, 24, 24A, 25A, 26, 28, 30, 31	56		37	439-454
	27, 27A	36			
	29, 29A, 29B	91			
5	33, 34, 35, 36	16		13	523-524
6	50.1, 51.1, 55.0, 56.2, 58.2, 59.1, 59.2, 60.0, 60	35		14	961-963
7	66-0	51		66	1227-1234
	66-1	19		pt. 2	
8	68	5		15	851
13	125, 125A	39		64	599-603
	132	112		pt. 2	
14	136, 137, 138, 141		6	53	777-784
15	146	12	8	54	1017-1022
	150, 151, 152, 153	11	4		
16	163		3	34	641-645
	157		4	4	459-468
	157		4	2	513-532
17	164	24		38	365-376
	165, 165A	18			
	166	62			
18	173	151		35	843-846
19	183, 191, 192		9	74	699

Table 1. (Cont.)

Leg	Site	No. Samples Seds.	Basalts	Ref. No.	Pages
22	212	82		40	369-375
23	220	14	17	27	126
	221	13	6	28	176-178
	222	88		29	221-222
	223	5	7	30	311-312
	224	19	1	31	390-391
	219, 223	17		73	521-525
	220	31			
	221	17			
	222	88			
	224	55			
25	239, 245, 248, 249		9	75	555-572
26	250, 251, 253, 254		20	61	517-527
	256		17		
	257		30		
	250, 253, 254, 256, 257		27	1	529-532
27	259, 260, 261		9	56	403-404
	263	41		20	405-413
	260	73		39	415-423
	261	31			
	263	134			
28	265, 266, 267		15	50	869-878
	274		17		
	270	50		5	879-884
29	279, 280, 282, 283		30	51	1109-1115
30	289	52	14	33	415-418
32	303A, 304, 307, 313		32	48	571-577
33	315A	84		9	631-647
	317A	83	8		
34	319, 319A		20	4	459-468
	320B, 321		20		
	319A, 321		11	10	469-472
	319, 319A, 320B, 321		24	72	473-478
	319A, 321		11	52	479-484
	319, 319A, 320B, 321		24	21	485-494
	319A		33	17	495-499
	321		10		
	319, 319A		29	11	501-512
	320B		2		
	321		17		
	319, 319A, 320B, 321		34	2	513-532
	319, 320, 320B, 321	44		3	533-539
37	332A, 332B		344	68	48-61
	333A		37	69	206-207
	334		26	70	243-246
	335		43	71	292-297
	332A, 332B, 332C, 332D		284	24	425-448
	333A		6		
	334		18		
	335		30		
	332A, 332B		22	6	449-456
	332B, 334, 335		21	16	457-463
	332B		18	7	465-469
	334, 335		10		
	332B		27	12	475-479
	334		2		
	335		16		

Table 1. (Cont.)

Leg	Site	No. Samples Seds.	No. Samples Basalts	Ref. No.	Pages
	332B		12	8	481-487
	334		3		
	335		16		
	332A		152	26	489-501
	332B		192		
	333A		37		
	334		26		
	335		43		
	332A, 335		8	62	503-506
	332B		32		
	332B		16	65	507-509
	335		12		
	332B		25	18	511-514
	334, 335		12		
	332B		27	57	515-523
	334		2		
	335		16		
	332B, 334, 335		16	45	525-529
	332A, 332B	18		25	531-536
	333, 333A	28			
	334	38			
	335	10			
38	336	7		55	30-35
38	336, 337, 338, 342, 343, 344, 345, 348, 350		40	46 suppl. v.	3-8
40	361	330		41	459-467
	363	242			
	364	432			
41	369	189		42 suppl. v.	983-986
	366	44		22	987-993
	368	43		suppl. v.	
	367	49	7	47 suppl. v.	995-1002
42A	372	14		32	873-880
	374	50		pt. 1	
	376	37			
	373A		13	60	881-886
42B	379A	4		23	1069-1076
	380A	24		pt. 2	
43	384	146		49	785-788
	386	7		43	781-784
44	391C	375(?)		44	523-528

Table 2. Author index to magnetic studies in the *Initial Reports*, Volumes 1-44.

Author	Articles (by reference no.)
Ade-Hall, J. M.	1, 2, 3, 4, 24, 25, 26
Allis, R. G.	5
Atwater, T.	7
Barrett, P. J.	5
Bleil, U.	6, 60
Brecher, A.	7, 20
Carmichael, C. M.	8
Carter, E.	7
Christoffel, D. A.	5
Cockerham, R. S.	9
Denham, C. R.	10, 61
Deutsch, E. R.	11, 12, 57
Doell, R. R.	13, 14, 15
Dunlop, D. J.	16
Eisenach, P.	60
Ellwood, B. B.	17, 18
Evans, M. E.	19
Flood, J. D.	64
Fujiwara, Y.	65
Gartner, S.	67
Green, K. E.	20
Gromme, S.	21
Guertler, J. C.	10
Hailwood, E. A.	22, 23, 32
Hale, C. J.	16
Hamilton, N.	23, 27, 28, 29, 30, 31, 32, 73
Hammond, S. R.	33
Harrison, C. G. A.	72
Hayes, D. E.	50
Heinrichs, D. F.	34, 35
Helsley, C. E.	41, 42, 43, 44
Henry, K. W.	36, 37
Israfil, M. N.	51
Jarrard, R. D.	9, 38, 39, 40, 66, 67
Johnson, H. P.	2, 3, 4
Keating, B. H.	41, 42, 43, 44
Kent, D. V.	45, 46, 47, 52
Kidd, R. B.	32, 73
Kroenke, L. W.	33
Larson, P. A.	49
Larson, R. L.	48
Løvlie, R.	55
Lowrie, W.	45, 48, 50, 51, 52, 53, 54
Luyendyk, B. P.	61
Mankinen, E.	21

Table 2. (Cont.)

Author	Articles (by reference no.)
McElhinny, M. W.	56
McGowran, B.	67
Merrill, R. T.	74
Murthy, G. S.	12, 57
Opdyke, N. D.	36, 37, 46, 49, 53, 54, 58, 59
Pätzold, R. R.	11, 12, 57
Petersen, N.	6, 60
Phillips, J. D.	59
Pierce, J. W.	61
Plessard, C.	62
Prevot, M.	62
Ryall, P. J. C.	4, 24, 25, 26
Ryan, W. B. F.	63, 64
Schlich, R.	75
Schwarz, E. J.	65
Sclater, J. G.	40, 66, 67
Segoufin, J.	75
Stein, J.	7
Tarasiewicz, E.	72
Tarasiewicz, G.	72
Theyer, F.	33
Tsai, L. P.	47
Watkins, N. D.	17, 18
Wayman, M. L.	19
Whitney, J.	74
Whitmarsh, R. B.	73
Wolejszo, J.	75

Table 3. Subject index to magnetic articles in the Initial Reports, by reference number, in site order (site number in parentheses), Volumes 1-44.

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NRM, A.F. Cleaning

53 (136, 137, 138, 141), 54 (146, 150, 151, 152, 153), 34 (163), 74 (183, 191, 192), 27 (220), 28 (221), 30 (223), 31 (224), 73 (220, 221, 223), 75 (239, 245, 248, 249), 61 (250, 251, 253, 254, 256, 257), 56 (259, 260, 261), 50 (265, 266, 267, 274), 51 (279A, 280A, 282, 283), 33 (289), 48 (303A, 304, 307, 313), 9 (317A), 4 (157, 319, 319A, 320B, 321), 10 (319A, 321), 72 (319, 319A, 320B, 321), 52 (319A, 321), 17 (319A, 321), 11 (319, 319A, 320B, 321), 2 (319, 319A, 320B, 321), 68 (332A, 332B), 69 (333A), 70 (334), 71 (335), 24 (332A, 332B, 333A, 334, 335), 6 (332A, 332B), 16 (332B, 334, 335), 7 (332B, 333A, 334, 335), 12 (332B, 334, 335), 65 (332B, 335), 18 (332B, 334, 335), 45 (332B, 334, 335), 46 (336, 338, 342, 343, 334, 345, 348, 350), 47 (367), 60 (373A)

Stepwise A.F. Demagnetization

53 (136, 137, 138, 141), 54 (146, 150, 151, 152, 153), 34 (163), 75 (239, 245, 248, 249), 61 (250, 251, 253, 254, 256, 257), 56 (259, 260, 261), 50 (265, 266, 267, 274), 51 (279, 280, 282, 283), 33 (289), 48 (303A, 304, 307, 313), 9 (317A), 10 (319A, 321), 72 (319, 319A, 320B, 321), 21 (319, 319A, 320B, 321), 11 (319A, 321), 2 (157, 319, 319A, 320B, 321), 24 (332B), 6 (332A, 332B), 16 (332B, 334, 335), 7 (332B, 333A, 334, 335), 12 (332B, 334, 335), 8 (332B, 335), 62 (332B), 57 (332B, 335), 60 (373A)

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54 (146, 150, 151, 152, 153), 75 (239, 245, 248, 249), 61 (250, 251, 253, 254, 256, 257), 50 (265, 266, 267, 274), 51 (279A, 280A, 282, 283), 48 (303A, 304, 307, 313), 52 (319A, 321), 17 (319A, 321), 24 (332A, 332B, 333A, 334, 335), 7 (332B, 333A, 334, 335), 12 (332B, 334, 335), 26 (332A, 332B, 333A, 334, 335), 18 (332B, 334, 335), 45 (332B, 334, 335), 46 (336, 337, 338, 342, 343, 344, 345, 348, 350), 47 (367), 60 (373A)

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54 (General), 34 (163), 75 (239, 245, 248, 249), 61 (250, 251, 253, 254, 256, 257), 50 (274), 51 (279A, 280A, 282, 283), 10 (319A, 321), 72 (319, 319A, 320B, 321), 52 (319A, 321), 16 (332B, 334, 335), 7 (332B, 334, 335), 19 (332B, 334, 335), 62 (332A, 332B, 335), 45 (332B, 334, 335), 47 (367)

Stepwise Thermal Demagnetization

75 (239, 245, 248, 249), 61 (257), 11 (319A, 321), 6 (332A, 332B), 16 (332B, 335), 19 (332B, 334, 335), 12 (332B, 334, 335), 8 (332B, 335)

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34 (163), 74 (183, 191, 192), 1 (250, 251, 253, 254, 256, 257), 50 (265, 266, 267, 274), 51 (279A, 280A, 282, 283), 48 (303A, 304, 307, 313), 4 (157, 319, 319A, 320B, 321), 52 (319A, 321), 21 (319, 319A, 320B, 321), 11 (319A, 321), 68 (332A, 332B), 69 (333A), 70 (334), 71 (335), 6 (332A, 332B), 16 (332B, 334, 335), 26 (332A, 332B, 333A, 334, 335), 65 (332B, 335), 45 (332B, 334, 335), 46 (336, 337, 338, 342, 343, 344, 345, 348, 350), 47 (367), 60 (373A)

SIRM, IRM, HC

53 (136, 137, 138, 141), 54 (146, 150, 151, 152, 153), 34 (163), 75 (239, 245, 248, 249), 61 (250, 251, 253, 254, 256, 257), 6 (332A, 332B), 16 (332B, 334, 335), 8 (332B, 335), 26 (332A, 332B, 333A, 334, 335), 57 (332B, 335), 47 (367), 60 (373A)

Table 3. (Cont.)

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53 (136, 138, 141), 54 (146, 150, 151, 152, 153), 73 (220, 221, 223), 61 (250, 251, 253, 254, 256, 257), 56 (259, 260, 261), 50 (265, 266, 267, 274), 33 (289), 48 (303A, 304, 307, 313), 9 (317A), 21 (319, 319A, 320B, 321), 68 (332A, 332B), 69 (333A), 70 (334), 71 (335), 24 (332A, 332B, 333A, 334, 335)

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34 (163), 74 (192), 19 (332B, 334, 335), 8 (332B, 335), 60 (373A)

Correlation with Magnetic Anomalies

50 (265, 266, 267, 274), 48 (303A, 304, 307), 11 (General), 68 (332A, 332B), 70 (334), 71 (335), 24 (332, 333A, 334, 335)

Anisotropy of Magnetic Susceptibility

17 (319A, 321), 19 (332B, 334, 335), 18 (332B, 334, 335)

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11 (319A), 19 (332B, 334, 335), 47 (367)

Domain State Studies, Rayleigh Loops

11 (319, 319A, 320B, 321), 57 (332B, 334, 335)

Titanomaghemite Cation Deficiencies

4 (319, 321), 26 (332A, 332B, 333A, 334, 335)

Shock-Remanent Magnetism

61 (257)

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NRM, A-F Cleaning

59 (1P, 1, 2, 3, 4, 4A, 5, 6, 6A, 7, 7A), 58 (8, 8A, 9, 9A, 10, 12B, 12C), 36 (13A, 14, 14A, 15, 16, 17, 17A, 17B, 18, 19, 20A, 20B, 20C, 21, 21A, 22), 37 (23, 24, 24A, 25A, 26, 27, 27A, 28, 29, 29A, 29B, 30, 31), 13 (33, 34, 35, 36), 14 (50.1, 51.0, 51.1, 55.0, 56.2, 58.2, 59.1, 59.2, 60.0, 60), 66 (66-0, 66-1), 15 (68), 64 (125, 125A, 132), 54 (146, 152), 38 (164, 165, 165A, 166, 167, 169, 170, 171), 35 (173), 40 (212), 27 (220), 28 (221), 29 (222), 30 (223), 31 (224), 73 (219, 220, 221, 222, 223, 224), 20 (263), 39 (260, 261, 263), 33 (289), 9 (315A, 317A), 3 (319, 320, 320B, 321), 25 (332A, 332B, 333, 333A, 334, 335), 55 (336), 41 (361, 363, 364), 42 (369), 22 (366, 368), 47 (367), 32 (372, 374, 376), 23 (379A, 380, 380A), 43 (386), 49 (384), 44 (391C)

Stepwise A-F Demagnetization

59 (1P, 1, 2, 3, 4, 4A, 5, 6, 6A, 7, 7A), 58 (8, 8A, 9, 10, 12B, 12C), 36 (13A, 14A, 15, 16, 17, 17A, 17B, 18, 19, 20A, 20B, 20C, 21), 37 (23, 24, 24A, 25A, 26, 28, 29), 66 (66-0, 66-1), 64 (132), 54 (146, 152), 38 (164, 166, 167, 169), 40 (212), 39 (260, 263), 33 (289), 9 (315A, 317A), 55 (336), 41 (361, 363, 364), 22 (368), 47 (367), 32 (372, 374, 376), 23 (379A, 380A), 43 (386), 49 (384), 44 (391C)

Table 3. (Cont.)

Paleomagnetic Time Scale

59 (3), 66 (66-0), 64 (125, 125A, 132), 38 (167), 35 (173), 67 (14, 15, 16, 19, 20A, 20C, 32, 36, 39, 213), 5 (270), 41 (361, 363, 364), 42 (369), 22 (366, 368), 32 (372, 376), 23 (379A, 380, 380A), 43 (386), 49 (384), 44 (361, 363, 364, 369, 386, 391C)

Correlation with Biostratigraphy

59 (1, 2, 3, 4, 4A, 5, 6, 6A, 7, 7A), 58 (8, 8A, 9, 10, 12B, 12C), 36 (14, 15, 16, 17, 18, 19, 20), 37 (23, 26, 28, 29, 29B), 63 (125, 125A, 132), 35 (173), 67 (14, 15, 16, 19, 20A, 20C, 32, 36, 39, 213), 22 (366, 368), 49 (384)

Paleolatitude

59 (1, 3, 5, 6), 66 (66-0), 38 (164, 165A, 166, 167, 169, 170, 171), 40 (212), 73 (220, 221, 223), 20 (263), 39 (260, 261, 263), 33 (289), 9 (315A, 317A), 3 (319, 320B, 321), 25 (332A, 332B, 333, 333A, 334, 335)

Storage Tests VRM

55 (336)

Susceptibility

64 (125, 125A, 132), 54 (146, 152), 55 (336), 47 (367)

SIRM, IRM, HC

54 (146, 152), 55 (336)

Thermal Demagnetization

5 (270), 55 (336)

Anisotropic Susceptibility

9 (315A, 317A)

Mineralogy

3 (319, 320, 321)

10. INTERSTITIAL WATER METHODS

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and
Joris M. Gieskes, Graduate Division, A-031, Scripps Institution of Oceanography, La Jolla, California

INTRODUCTION

Interstitial waters have been extracted and analyzed from the inception of the Deep Sea Drilling Project (Manheim et al., 1969; Kaplan and Presley, 1969). A turning point in methodology and a comprehensive evaluation of methodologies took place on Leg 15, when all aspects of pore fluid studies were examined thoroughly. In I.R. DSDP, 20:751-904, articles were published on this subject, which provide much pertinent detail. Refinement of techniques and new types of analyses have continued since then and are cited in this chapter.

Methodologies for specific constituents are described by (1) reference only, (2) reference plus special comments, or (3) brief description or complete outline where published methods are not available or require modification. General methodologies are outlined in Manheim and Sayles (1974); Presley (1971); Gieskes (1973, 1974); and Gieskes and Lawrence (1976).

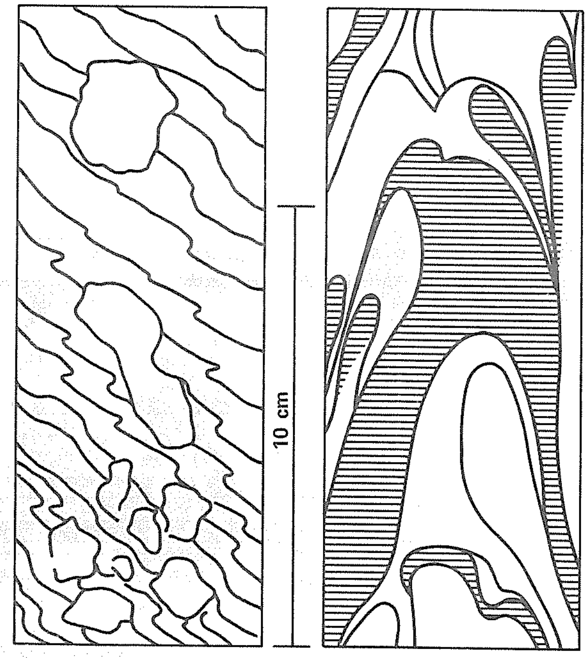

Figure 1. Results of sediment disturbance during coring process. (A) "Islands" of more consolidated materials float in matrix of drilling slurry. (B) Plastic deformation of sediment.

SAMPLING

Sample selection and proper handling aboard ship are critical. Fig. 1 shows types of cores that offer potential contamination by drilling fluid -- the source of greatest potential error in interstitial water studies. This problem can be reduced to low or insignificant levels by choosing relatively undeformed core materials and by excluding external "mush" or contaminated zones before extraction of fluid. This process becomes more important the more consolidated the sediment and the lower the "true" porosity and fluid extractability of the sediment.

To avoid delaying the sampling of pore fluids until cores have been split or otherwise processed, a common procedure has been to saw 10- to 20-cm sections from the ends of core sections, cap them, and take them to the chemical laboratory, where they are trimmed with a spatula, a knife (or occasionally a hammer) before extraction in special squeezers (Fig. 2). Speed is important in this process to avoid evaporation of fluids or oxidation of cores.

In most strata penetrated by DSDP cores so far, the rocks and sediments retain appreciable diffusive permeability.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

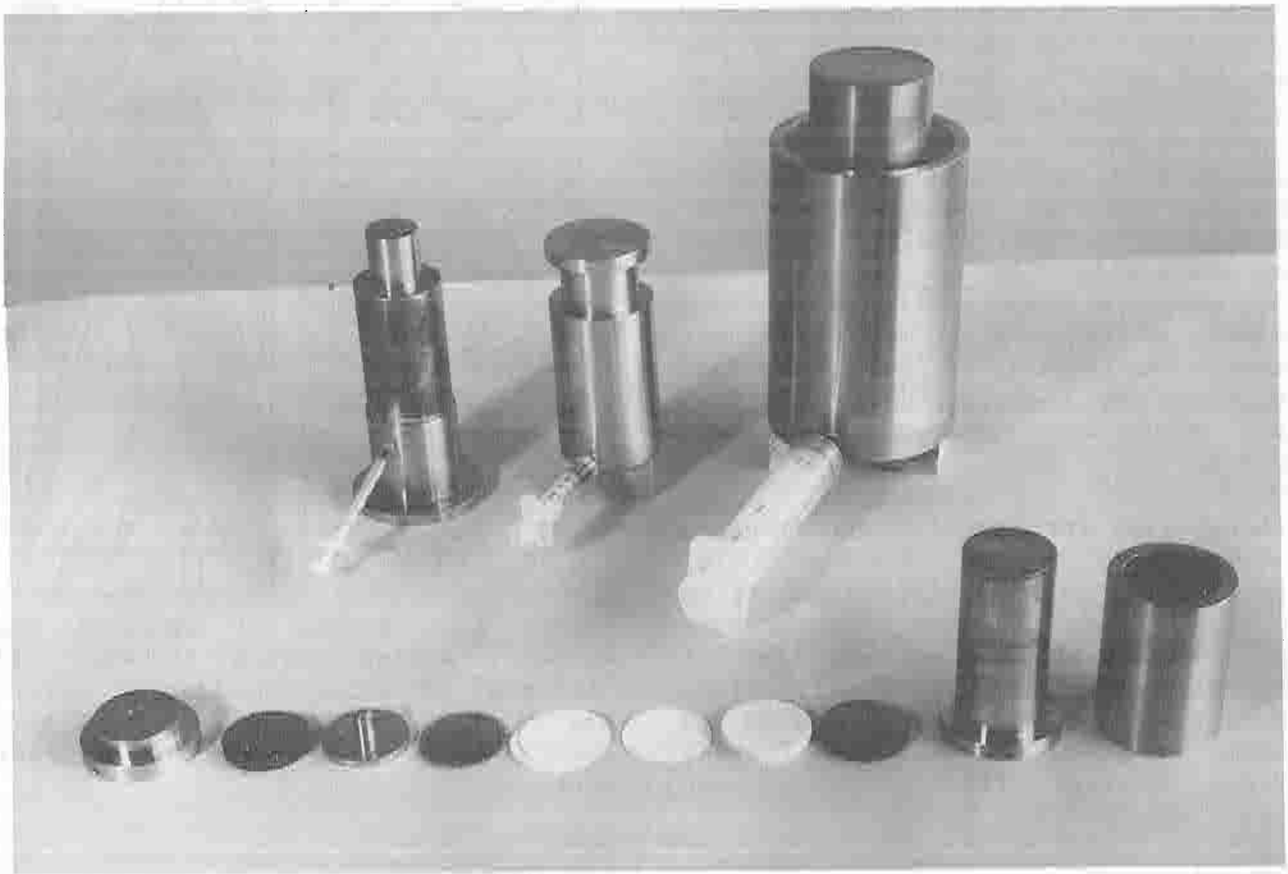

Figure 2. Stainless steel squeezers used to extract fluid from sediments. The right two models are standard aboard Glomar Challenger. An exploded view of the interior parts is shown at the bottom of the picture for the middle squeezer. From left, parts are: squeezer base, rubber "doughnut" gasket, retainer plate (nose emplaced down through doughnut gasket into retainer), stainless screen edged with silicone rubber (bathtub caulk), filter circles, (sediment not shown), filter circle, Teflon spacer and "wiper," rubber gasket, piston, and cylinder. All rubber parts should be butyl rubber to avoid zinc and other contaminants used in curing or filling natural rubber. From Manheim and Sayles (1974).

PART III. GEOCHEMISTRY

Vertical communication means that if sampling and analytical work are done well, the concentrations of constituents should not vary erratically with depth, with the possible exception of highly labile trace constituents. Only in areas of rapid deposition (i.e., nearshore settings where large concentrations of degradable organic carbon are deposited) are more complex patterns found with depth. Here, production of ammonia, as well as other organic breakdown products, can occur, resulting in irregularities in dissolved magnesium and other ions (e.g., Sites 262, 278-280, 440, and 479). These reversals can be understood best in terms of ion-exchange processes between pore fluids and solid phases as a result of the ammonia production. In general, however, adequate descriptions of pore-fluid profiles require fewer samples than lithological, mineralogical, or paleontologic descriptions (e.g., Fig. 3).

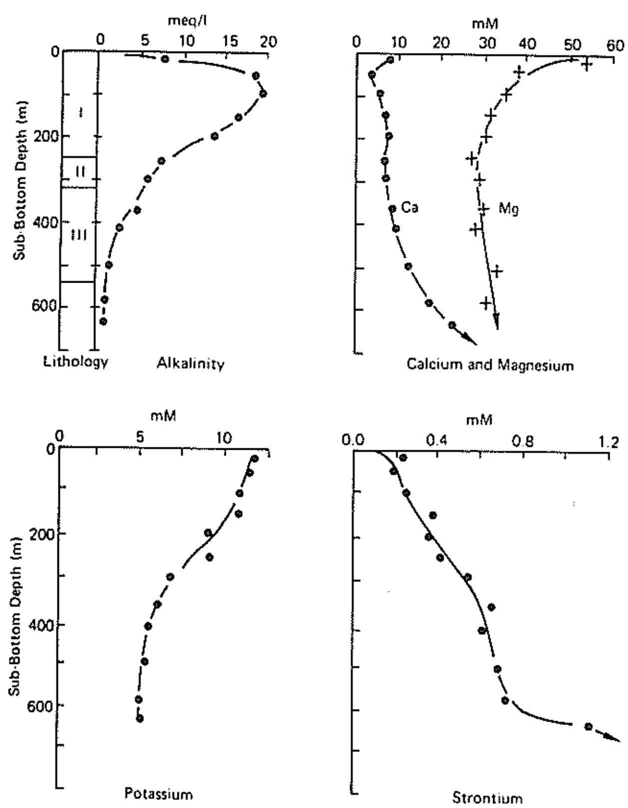

Figure 3. Distribution of interstitial species with depth, Site 397 (Barnes et al., 1979).

Until Leg 23, most recovered sediments were sampled routinely at a rate of about 50 pore-fluid samples per leg. Interstitial-fluid chemistry was discussed in articles in each volume. Subsequently, sampling and improved shipboard analysis have been performed routinely. Detailed write-ups and interpretations have been undertaken on selected legs (i.e., 24, 25, 28, 31, 33, 34, 35, 38, 40, 41, 42A, 42B, 43 47A, 47B, 48, 50, 51-53, 57, 58, 59, 60, 63, 64, and 65).

For solid-phase studies 20-30 ml of unsqueezed sample, as well as the squeezed cakes, are stored. Interstitial waters are stored both in heat-sealed polyethylene tubes and glass ampules (the latter for oxygen and hydrogen isotope studies). If "Gran" titrations for alkalinity are performed, the titrated samples are stored with a note on how much 0.1N HCl was added. Such samples may then be analyzed later in shore laboratories for major and minor constituents.

EXTRACTION

Except for special problems (e.g., metallic trace elements), most fluid extraction has been performed with stainless steel squeezers (modified from Manheim, 1966, fig. 2). For unconsolidated sediments, centrifugation also has been used successfully (Bender, 1980). The squeezers employ the principle -- first developed by Russian geochemist, P. A. Kriukov -- of "floating" and self-sealing rubber gaskets that expand against steel walls as pressure is exerted on the system by a hydraulic press. 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. When extraction is complete, normally a 2-30-min.-process, the syringe is capped with a micropore filter attachment (Fig. 3), and aliquots are taken for shipboard analyses and for archive purposes. The larger sampler (employing a Whatman 1 9-cm filter paper circle) yields from a few ml to more than 15 ml, depending on sediment permeability or degree of consolidation. For special purposes and relatively consolidated materials, a smaller squeezer (4.25-cm filter circle) designed along identical lines allows the use of greater pressures. Standard laboratory presses, capable of up to 12 tons of pressure, are employed.

In practice the procedure is broken down as follows:

1) Assembled squeezer with silicone rubber-edged, stainless steel screen placed on retainer plate inside cylinder. Three filter circles of hardened laboratory paper are placed on the screen.

2) Add sediment (20-50 cm), followed by a filter.

3) Insert the Teflon spacer, followed by rubber gasket and piston in squeezer. Depress manually and place in press.

4) Apply pressure slowly at first so as not to form impermeable sediment layer at the juncture join with filter paper.

5) When fluid recovery is complete, draw vacuum on disposable syringe to "milk" last drops and withdraw from squeezer. Release hydraulic pressure.

6) Remove squeezer from press, remove base of squeezer. Replace on "half-round" or appropriate device (see later) and expel sediment pellet and screen retainer plate using piston and press.

7) Wash all parts and rinse with acetone or alcohol to dry quickly for next run.

In most cases the disposable syringe plunger will be pushed outward by gases expelled from the squeezer. On first application of pressure, gas can be removed and syringe reemplaced in depressed mode, even if a few drops of liquid have been collected already.

SHIPBOARD ANALYTICAL PROCEDURES

From Legs 1 to 23, shipboard procedures included:

1) Total "salinity" estimation to 0.2 g/kg by Goldberg temperature compensated refractometer, hand-held model (American Optical Co.)[1]. A few drops on the slide of the instrument suffices for measurement. Thirty seconds is allowed for temperature equilibration and the value is read and interpolated directly from an optical grid. Afterward, the instrument is rinsed with distilled water (NEVER acetone) and dried with tissue.

2) Alkalinity determination by Bruevich mixed-color indicator (methyl red and methylene blue). One milliliter of distilled water is added to vial. Sample is titrated with 0.005M HCl to green-purple end-point with 2-ml precision hand burette with long micro-tip, while nitrogen or propane gas capillary tube sweeps out CO_2 and agitates solution. The burette is zeroed first by "titrating" any residual blank in distilled water to end-point before adding sample aliquot.

3) Archiving samples in heat-sealed polyethylene pipe and/or ampules.

Any annular "Luer" ring on the syringes should be cut off with a knife prior to syringe use, so that the syringe nose can be inserted into the appropriate hole in the squeezer base.

Radiolarian and calcareous oozes are moist and squeeze readily. Clayey sediments, especially montmorillonite-rich materials, may pack tightly and resist water recovery. The use of small

[1]Use of brand names in this report does not imply endorsement by the U.S. Geological Survey.

portions of sediment (thin layers) of about 10 cc, and, if necessary, admixture with clean, washed and dried sand, aids in obtaining fluids from consolidated clays. The sand may be mixed by placing sediment chunks in strong plastic bags or envelopes and pounding with a mallet, followed by homogenization. Fluid recovery from sediments having as little as 10% moisture has been obtained.

Actual pressure data for the small and large squeezers are given in Table 1.

Some of the shipboard equipment utilized in the interstitial operations are shown in Fig. 4. Note that the hand burette may also be used as a weight burette.

After Leg 24 the expanded microchemical analytical routine was added to shipboard procedures by Gieskes as follows:

1) Total "salinity" by refractive index (as previously mentioned).

2) Alkalinity: Titration of 1-10 ml volumes of solution with 0.15N HCl using semi-microcombination pH electrodes to determine a "Gran" end-point. A water-jacketed vessel is used for thermal stability. For details see Gieskes and Rogers (1973) and Gieskes (1974).

3) pH: "Punch-in" determinations are performed by inserting glass electrodes and reference electrodes directly into sediment (accuracy of measurement 0.08 pH units). The alternative procedure involves measurement of pH on fluid effluent by means of glass capillary or micro-combination electrodes, or at the start of the alkalinity titration. Standardization with pH 7 and 9 buffers is performed in the usual manner. As Fanning and Pilson (1971) and Gieskes (1974) pointed out, many laboratory filter papers have been acid-washed, and may "titrate" pore fluid as it passes through in the squeezer. Approximately 25 ml interstitial water may lose 0.09 meg/l due to the effect of two filter papers. Whatman No. 1 paper

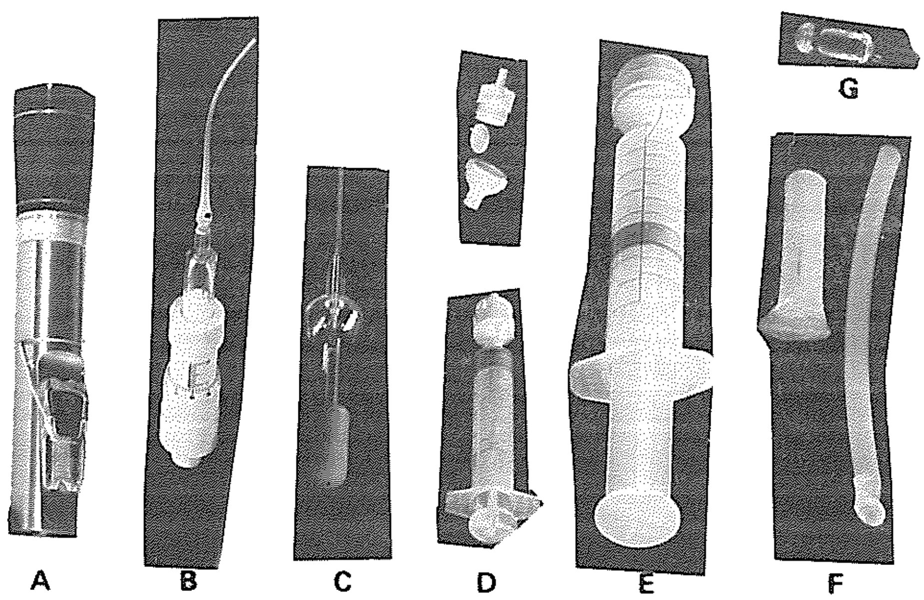

Figure 4. Equipment used for handling and analyzing interstitial waters aboard ship. (A) Goldberg compensating refractometer (Spencer A/O); (B) 2-ml hand burette, readable to 0.001 ml; (C) Grunbaum automatically filling micropipette; (D & E) disposable syringes for inserting in base of squeezer to receive fluid, capped with "Swinney" micropore filter attachments (Millipore Corp.); (F) plastic pipe to heat-seal and archive fluids; (G) 1-ml ampule (glass).

Table 1. Pressures developed in stainless steel pore-fluid squeezers.

Load		Pressure			
		Small Squeezer (4.25 cm)		Large Squeezer (9 cm)	
lb	kg	psi	kg/cm^2	psi	kg/cm^2
200	91	91	6.4	20	1.4
500	227	227	16.0	51	3.6
1,000	454	454	32	102	7.1
2,000	910	910	64	203	14.3
5,000	2,270	2,270	160	510	35.7
1,000	4,540	4,540	320	1,020	71
20,000	9,100	9,100	640	2,040	142

Table 2. Temperature-of-extraction effects on samples from Leg 15 (Sayles, et al., 1974). Note: The values refer to percent change in concentration between extractions at 22°C and 4°C (i.e., [(22°C - 4°C)/4°C]). The 4°C extraction was performed by chilling squeezer and sediment in a refrigerator aboard the drilling vessel. Sites 147 and 148 recovered clayey carbonate.

Component	Site 147	Site 148	Site 149	
			(carbonate)	(siliceous)
B	+30	+61	+7[b]	
Si[a]	+26	+41	+27	0
K	+18	+24	+16	12
Na	+0.9	+1.3	+1.0	+1.0
Li	-3(?)	0.0	0.0[b]	
Ca	variable	-6.5	-3.1	-1.1
Mg	-7.3	-7.3	-3.1	-1.4
Sr	-19	-7	0.0	
Cl	0.5	0.5	0.5	0.5
SO_4	0.5	0.5	0.5	0.5

[a]Colloidal.
[b]Total site.

has been preferred as it is not acid-washed. Precision of pH measurements is about 0.05 pH/unit. Studies have shown that the loss of CO_2 and changes in gas equilibria upon raising cores from depth or during squeezing raise the pH in most cases, rendering shipboard measurements of dubious validity for determining in situ pH.

4) Calcium and magnesium: Calcium (plus strontium) is determined using the method of Tsunogai et al. (1968) modified by Gieskes (1974) and Gieskes and Lawrence (1976). The method involves complexometric titration with EGTA, using GHA as indicator in a layer of n-butanol. Total alkaline earths (including Sr) are determined by complexometric titration with EDTA and Eriochrome Black -T as indicator. Potassium cyanide-hydroxylamine hydrochloride serves as a trace metal complexing agent, when needed. Magnesium is then determined by the difference.

5) Chloride: A 0.1-ml sample is titrated by microburette with approximately 0.06N $AgNO_3$ and potassium chromate as indicator. Titer is calibrated with IAPSO Standard Seawater.

6) Diffusimetry (measurement of diffusion coefficient): A four-electrode probe is inserted into the sediment to determine electrical resisitivity. The cell constant is determined by establishing the resistivity of known solutions with the same electrodes in a vessel of similar geometry to the core sample. The formation factor $F = R_s/R_w$, where R_s is the sediment resistivity in ohm meters or other suitable unit, and R_w is the pore-fluid resistivity. R_w is determined directly on expelled pore fluid using a micro-resistivity cell, is estimated from standard micro-cell, or is estimated indirectly and approximately by analogy with seawater solutions of similar "salinity" or choloride content as the experimental solution. The formation factor, or F, is inversely proportional to the effective diffusion coefficient of the main mobile ions in solution in the sediment core in question. Thus, a free solution has F = 1, and sediments have F values ranging from a minimum of two to several hundred. Practical details are provided in Manheim and Waterman (1974).

7) Gases: Hydrocarbon gases are routinely analyzed from gas pockets in sediment cores aboard Glomar Challenger for safety reasons. These gases are mainly interstitial in origin and are exsolved from solution when cores are raised to the 1-atm surface pressure. More specialized methods for sampling gases were developed on Leg 15 (Horowitz et al, 1973). (See, also, in situ sampling procedures of Barnes et al, 1979.) The most serious problems encountered are contamination with air and gas fractionation. For this reason the in situ sampling approach (Barnes, 1979) is preferred.

8) Temperature equilibration: Temperature affects the exchange capacity of certain sediments (Mangelsdorf et al., 1969). Significant compositional changes have occurred as a result of extracting sediments under a temperature different from that in situ.

Two approaches toward control of this problem have been developed: (1) storage of squeezers and sediments at 4^oC, followed by rapid extraction, and (2) heating squeezers during extraction (Fig. 5). In either case, changes per unit temperature between extraction temperature(s) and presumed in situ temperature may be used to estimate the true in situ fluid composition assuming that changes are reversible.

In many cases, the temperature equilibration effects are small relative to overall concentration changes, especially for Ca^{+2} and Mg^{+2}. However, effects for Si, K, and B are particularly significant (Table 2). In very hot sites with temperatures as high as 300^oC, such as at Site 477 (Gieskes and Reese, 1980), the concentrations of the alkali metals K, Li, and Rb are

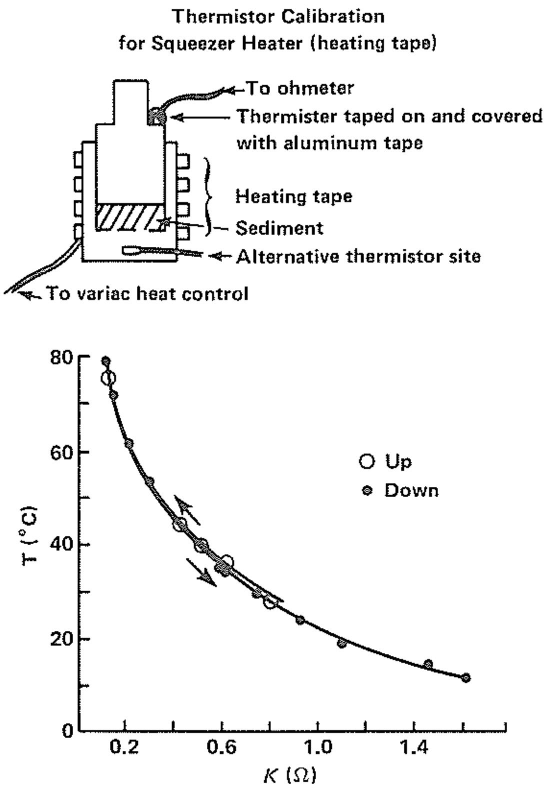

Figure 5. Sketch of apparatus (and calibration curve) for heating squeezer.

markedly higher than in normal seawater -- ; 10 to 45 mM/1, 28 to 900 M, and 2.5 to 50 M, respectively. The solids, in contrast, are almost completely depleted in these metals.

Examples of more normal temperature-of-extraction effects are given in Table 2.

9) In situ Sampling: Barnes (1979) developed a relatively simple sampler for in situ collection of pore waters. The instrument is designed to capture fluid in partly consolidated material under near ambient pressure, with part of the fluid in Teflon-coated stainless steel (for chemical analysis) and part in copper tubes (for gas analysis). The sampler has worked effectively at depths of as much as 450 m beneath the seafloor (Moore and Gieskes, 1980). It may be ineffective in very gassy sediments.

LABORATORY ANALYTICAL PROCEDURES

Fluid transfer procedure and storage

A critical aspect of microchemical and semi-microchemical analysis is precise fluid transfer. Modern automatic pipette types such as Eppendorf, Oxford, Pipetman, and so forth may achieve repeatabilities of less than 1% but have been shown in practice to be subject to systematic and erratic errors greater than these. For certain constituents, principally Cl for which precision requirements are the highest, the analytical goal may be 0.1% reproducibility. To achieve this level, evaporation must be kept to an absolute minimum. All transfers should be by weight (micro- or semi-microbalance). A convenient method is the use of an automatic pipette, corrected by weighing before and after delivery to better than 0.1 mg. For 100 mg fluid weight, 0.1 mg error corresponds to 0.1% reproducibility.

Storage of fluids has most commonly been in polyethylene pipes heat-sealed with forceps aboard ship (Fig. 4). In the absence of poor heat seals, such containers are capable of limiting evaporation to less than 0.1% for one month or more when not exposed to appreciable heat. However, gas communication (oxygen) is not necessarily precluded, making this mode unsuitable for isotope determination.

Glass ampules are resistant to evaporation loss and gas transfer and, therefore, are suitable for isotope work. The glass dissolves slightly, however, raising sodium, pH, and alkalinity levels. Constituents unaffected by these properties, such as Cl, Br, or Mg, may be determined on the ampule samples.

Sulfate

Microgravimetric determination: 0.5 to 1 ml aliquots of pore fluid are reacted in test tubes with 10 ml of hot 0.2N

$BaCl_2$ solution 0.1N in HCL and allowed to digest overnight in a hot block. The solutions are filtered and washed through micropore filters. Dried filters are moistened with alcohol, folded into platinum foil crucibles,[2] and burned to char with alcohol. The residue is ignited in an electric muffle furnace at 800°C to constant weight, and is then reweighed on a microbalance. Blanks are carried through the procedure. The method is a modification of the procedure of Shishkina (1956).

Microvolumetric determination (according to Cescon and Macchi, 1973): 0.5 to 1 ml of sample with 10 ml H_2O and 1 ml IAPSO Standard Seawater is passed through cation exchange columns made from 10 ml pipettes. To 5 ml effluent are added four drops of 0.2g/100 ml Thorin reagent and 1 to 18 drops of diethylamine until the color changes to orange. Two to four drops of 10% HBr are added to achieve yellow color at pH 2-4. The solution is then titrated to the orange end-point using a 2-ml microburette with 0.02M $BaCL_2$ in 80% alcohol. Final values are obtained by subtracting the SO_4 due to IAPSO Standard Seawater (0.056 moles/ml).

Polarographic determination: According to Barnes et al. (1979) and Luther and Meyerson (1975), as modified by Gieskes (1974).

Major and minor cations by spectrochemical analysis

Convenient and precise standards for conservative anions as well as cations and some minor constituents are provided by IAPSO Standard Seawater (Table 3).

[2]Since platinum prices have risen steeply, experiments with aluminum foil show that reasonable weight constancy can be achieved if ignition temperatures are not too high. Further checks may be needed.

The most common means of analysis of the major cations is by atomic absorption, with dilutions of 1 to 100 ml for K, Ca, and Mg (for lines other than the resonance spectral line) and a further dilution of 1:20 for Mg and Na and possibly Ca where significant enrichments of this element are obtained. Details are provided in the Perkin-Elmer Corporation standard analytical databook (e.g., EN-1, 1971). To minimize matrix effects on analysis of the alkaline earths, 0.1% Lanthanum chloride solution is incorporated in all final solutions as a releasing agent. Dilution medium is 0.01N HCl in distilled water. All solutions must be stored in plastic, not glass (uptake of sodium). Careful control of evaporation must be maintained to obtain the necessary precision to record small deviations from seawater concentrations. Samples must be undiluted or diluted only a few fold to determine Li and Sr, except where significant enrichment is obtained (Presley, 1971).

An alternate procedure used in early legs was spark-source emission spectrometry using the "vacuum cup" (Zink, 1959) electrode (Manheim, unpublished). In this varient Ba, Sr, B, Li, Mn, and Zn were determined simultaneously utilizing a direct-reading spectrometer and Be and Co internal standards.

Summation and ion balance

Where chloride is done precisely, better values for Na are generally obtained by the difference between total anions (Cl, SO_4, HCO_3) and cations (K, NH_4, Ca, Mg) than by direct analysis. Total dissolved salt concentration is then derived by summing the weight contributions of all significant constituents. Weight-weight units (g/kg) are preferred to weight-volume (g/l) because the former are independent of temperature and correspond to standard ocean Cl and salinity measurement units.

Table 3. Composition of IAPSO Standard Seawater.

Salinity (nominal)	35.00 (g/kg)	Na	10.77
Cl	19.354	K	0.399
SO_4	2.712	Ca	0.412
Br	0.0673	Mg	1.290
F	0.0013	Sr	0.0079
B	0.0045	Li	0.00018

Table 4. Optimum instrumental settings for chloride determination by Buechler chloridometer. Optimum range lies between 500-1000 counts. Counts beyond this are usable but become excessively time-consuming without substantial contribution to overall analytical accuracy. Digital counts on the instrument are calibrated by the manufacturer in milliequivalents (meq) per liter, for high range and .1 ml sample. Low range expands sensitivity 10-fold.

Sample concentration and (mM Cl/liter)	Instrument Setting (range) sample volume (ml) Hi 0.1	Hi 0.2	Hi 1.0	Lo 0.1	Lo 0.2	Lo 1.0	Range setting Sample volume (ml)
1.2						122 (X)	
2.5						250 (X)	
6.15					123 (X)	615 X	
12.2					244 (X)	1220 X	
23.85			238 (X)	238 (X)	576 Xq		
47.7			477 X	477 X	955 X		
95.5		191 (X)	955 X	955 X			
191.0	191 (X)	382 X					
500.0	500 X	1000 X					

Note: X's denote optimum sample range (between 500 and 1200 counts) and numbers are counts (mM Cl). Parentheses denote range between 100 and 250 counts, adequate for obtaining a 1-2% precision. Experience has shown that the buffer reagent as well as sample solution must be precisely delivered to obtain the maximum precision of 0.1-0.2%.

Bromide

The colorimetric method of Baltare (1936) utilizes chloramine T to oxidize Br, and phenol red as indicator. See Presley (1971).

Chloride microanalysis

Precision in determining chloride is critical for several reasons. Therefore, though the analytical methods are well known, some discussion is in order:

1) Cl dominates seawater-related solutions and is essential for making meaningful cation-anion balances. With a Cl analysis having an accuracy of $\pm 0.5\%$ or better, and reasonable accuracies for SO_4, alkalinity, and major cations (5% or better), sodium values can be determined by difference more accurately than by most direct analytical methods. The ionic balances also permit major errors in analysis or calculation to be detected.

2) As a conservative (nonreactive) constituent, chloride is a good reference element for ratioing more reactive elements to assess, increments or decrements from seawater concentrations.

3) Chloride is the best tracker of mixing and migrational systems involving deviations from seawater composition. Examples include diffusion of salt from evaporites, loss of water in basalt weathering, and mixing with Pleistocene (fossil) fresh-water bodies.

The highest precisions and accuracies ($\pm 0.1\%$) are obtained by employing gravimetric rather than volumetric methods to measure samples and reagents. Chloride has been determined by titration with silver nitrate in the presence of mixed potassium chromate and dichromate indicator. From 0.1 to 1 g of sample may be used, with appropriate $AgNO_3$ titer, and microburette (e.g., Shishkina, 1956; Saruhashi, 1973, Anonymous, 1969). More recently, laboratory determinations have been done by coulometric titration, using an automatic Buechler Chloridometer. To 0.1-1 g of sample is added 4.5 ml of buffer reagent containing nitric and acetic acid, gelatin, and iodine. Blanks are determined. Then the silver wire consumed in titrating available halogens in solution to the end-point is automatically counted and displayed in milliequivalents. Table 4 gives the optimum range settings. This method determines total halogens, including bromine and chlorine. For most precise work, or where Br is high, a correction can be made from separate determinations of the other halogens (e.g., Shishkina, 1978).

Phosphate

Although measurements of phosphate have been performed by modifications of standard techniques (Strickland and Parsons, 1968), recent studies suggest that most values are too low owing to the growth of microorganisms and algae in storage containers or to the precipitation with iron during core recovery, fluid extraction, and subsequent storage (Bray et al., 1973). In anoxic sediments, measurements done quickly can yield semiquantitative values.

Silicate

Silicate is subject to systematic errors due to temperature of extraction effects (Fanning and Pilson 1971; Sayles et al., 1974) and to oxygenation of anoxic sediments during extraction (Loder et al., 1978). However, many DSDP sediments are not strongly reducing, and silicate values may be taken as having at least semiquantitative validity.

Silicate has been determined principally by micromodifications of the colorimetric method of Strickland and Parsons (1968) or Brewer and Riley (1966) utilizing the molybdenum blue method with metol-sulfite or other reducing agents.

The nutrient salt measurements in the Black Sea leg were performed by Technicon Autoanalyzer (Manheim and Schug, 1978).

Ammonia

The determination is by the indophenol blue reaction (Solorzano, 1969) for 0.2-ml samples as modified by Presley. Straight laundry bleach (5.25% available Cl in sodium hypochlorite) is used instead of the recommended dilution. The reagents are added by disposable pipettes, such as Eppendorf.

Boron

The colorimetric curcumin method of Grinstead and Snider (1967) was modified for micro-samples (Presley, 1971).

Oxygen isotopes

For analysis of $^{18}O/^{16}O$ ratios in interstitial waters the CO_2 equilibration technique of Epstein and Mayeda (1953) is the preferred procedure. For D/H determinations, see Friedman (1965).

Strontium isotopes

Strontium isotope measurement by mass spectrometry has been discussed by Hawkesworth and Elderfield (1978).

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REFERENCES

Anonymous, 1969. Gravimetric titrimetry, a review of the literature. Princeton, NJ, Tech. Inf. Bull.: (Mettler Instrument Corp.).

Baltare, P., 1936. Colorimetric determination of small quantities of bromide in the presence of a large excess of chloride. J. Pharm. Clin., 24:409.

Barnes, R. O., 1979. Operation of the IPOD in situ pore water sampler. I.R. DSDP, 47B:19-21.

Barnes, R. O., Gieskes, J. M., Horvath, J., and Akiyama, W., 1979. Interstitial water studies, Legs 47A, B. I.R. DSDP, 47B:577-582.

Bender, M. L., 1980. Written communication, Univ. Rhode Island.

Bray, J., Bricker, J. T., and Troup, O. P., 1973. Phosphate in interstitial water of anoxic sediments. Earth Planet. Sci. Let., 18:1362-1364.

Brewer, P. G., and Riley, J. P., 1966. The automatic determination of silicate-silicon in natural waters with special reference to seawater. Anal. Chim. Acta., 35:514-519.

Cescon, B. W., and Macchi, G., 1973. A microvolumetric method for the determination of sulfate in pore water. I.R. DSDP, 20:811-812.

Epstein, S., and Mayeda, T., 1953. Variations in the ^{18}O content of waters from natural sources. Geochim. Cosmochim. Acta, 4:213-224.

Fanning, K. A., and Pilson, M. E. Q., 1971. Interstitial silica and pH in marine sediment: some effects of sampling procedures. Science, 173:1228.

Friedman, I., 1965. Interstitial water from deep sea sediments. J. Geophys. Res., 70:4066.

Gieskes, J. M., 1973. Interstitial water studies, Leg 15. Alkalinity, pH, Mg, Ca, Si, PO_4 and NH_4. I.R. DSDP, 20:813-829.

________, 1974. Interstitial water studies, Leg 25. I.R. DSDP, 25:361-394.

Gieskes, J. M., and Lawrence, J. R., 1976. Interstitial water studies, Leg 35. I.R. DSDP, 35:407-423.

Gieskes, J. M., and Reese, H., 1980. Interstitial water studies, Legs 51-53. I.R. DSDP, 51-53:747-751.

Gieskes, J. M., and Rogers, W. C., 1973. Alkalinity determination in interstitial waters of marine sediments. J. Sediment. Petrol., 43:272-277.

Grinstead, R. R., and Snider, S., 1967. Modification of the curcumin method for low level determination. Analyst, 92:532.

Hawkesworth, C. J., and Elderfield, H., 1978. The strontium isotopic composition of interstitial waters from Sites 245 and 336, Deep Sea Drilling Project. Earth Planet. Sci. Lett., 40:423-432.

Horowitz, A. R., Waterman, L. S., and Broecker, W. S., 1973. Interstitial water studies, Leg 15 -- New procedures and equipment. I.R. DSDP, 20:757-763.

Kaplan, I. R., and Presley, B. J., 1969. Deep Sea Drilling Project, Leg 1. I.R. DSDP, 1:411-412.

Kriukov, P. A., and Manheim, F. T., 1982. Extraction and investigative techniques for study of interstitial water of unconsolidated sediments: A review. In Fanning, K. A. and Manheim, F. T. (Eds.) The Dynamic Environment of the Ocean Floor: London (O. C. Heath), 3-26.

Loder, T. C., Lyons, W. B., Murray, S., and McGinness, H. D., 1978. Silicate in anoxic pore waters and oxidation effects during sampling. Nature, 273:73.

Luther, G. W., and Meyerson, A. L., 1975. Polarographic analysis of sulfate ion in seawater samples. Anal. Chem., 47:2058-2059.

Mangelsdorf, P. C., Jr., Wilson, T. R. S., and Daniell, E., 1969. Potassium enrichment in interstitial waters of recent marine sediments. Science, 165:171-173.

Manheim, F. T., 1966. A hydraulic squeezer for obtaining interstitial water from consolidated and unconsolidated sediments. U. S. Geol. Surv., Prof. Paper 550C, 256.

Manheim, F. T., and Sayles, F. L., 1974. Composition and origin of interstitial waters of marine sediments, based on deep sea drill cores. In Goldberg, E. D. (Ed.), The Sea (Vol. 5): New York (Wiley-Interscience), 527-568.

Manheim, F. T., Sayles, F. L., and Friedman, I., 1969. Interstitial water studies on small core samples. Deep Sea Drilling Project, Leg 1. I.R. DSDP, 1:403-404.

Manheim, F. T., and Schug, D. M., 1978. Interstitial waters of Black Sea cores. I.R. DSDP, 42B:637-651.

Manheim, F. T., and Waterman, L. S., 1974. Diffusimetry (diffusion constant estimation) on sediment cores by resistivity probe. I.R. DSDP, 22:663-670.

Moore, G. W., and Gieskes, J. M., 1980. Interaction between sediment and interstitial water near the Japan Trench, DSDP, Leg 57. I.R. DSDP, 57: 1269-1275.

Presley, B. J., 1971. Techniques for analyzing interstitial water samples. Pt. 1. Determination of selected minor and major inorganic constituents. I.R. DSDP, 7:1749-1755.

Presley, B. J., and Claypool, G., 1971. Determination of total dissolved carbonate and carbonate isotope ratios. Pt. 2. I.R. DSDP, 7:1756-1759.

Saruhashi, K., 1973. The chlorinity determination of seawater by microanalytical method. Rec. Oceanogr. Works. Jap. New Ser., 1:52-54.

Sayles, F. L., Manheim, F. T., and Waterman, L. S., 1974. Interstitial water samples on studies on small core samples, Leg 15. I.R. DSDP, 15:783-804.

Shishkina, O. V., 1956. Methods of extracting marine interstitial water and analysis of its chemical composition. (Russ.) Trudy Inst. Okeanol., Akad. Nauk, SSSR, 17:148.

________, 1978. Distribution of bromine,, Cl/Br relationships and iodine in interstitial water of the Black Sea, based on DSDP Leg 42B. I.R. DSDP, 42B: 631-635.

Solorzano, L., 1969. Determination of ammonia in natural waters by the phenolhypochlorite methods. Limnol. Oceanogr., 14:799.

Strickland, J. D. H., and Parsons, T. R., 1968. A practical handbook of seawater analysis. Fisheries Res. Board Canada, Bull. 167.

Tsunogai, S., Nishimura, M., and Nakaya, S., 1968. Complexometric titration of calcium in the presence of larger amounts of magnesiums. Talanta, 15:385-390.

Zink, T. H., 1959. A "vacuum cup" electrode for the spectrochemical analysis of solutions. Appl. Spectro., 13:94.

11. ELEMENTAL ANALYSES

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ELEMENTAL ANALYSES

A review of elemental analyses reported in the Initial Reports is necessarily somewhat different from a review of laboratory or other studies carried out as part of the Deep Sea Drilling Project. Geochemical studies have been carried out as separate, ancillary investigations aimed, at least in the later stages of the project, at specific problems by many different individuals or research groups. The reports contain descriptions of methodology of widely differing completeness, and it is for these sundry reasons that it was decided to compile a checklist, site by site, of what had been done, with a reference guide to the relevant chapters in the Initial Reports (Table 1).

Some notes are included here to aid the reader and to explain some of the reasons behind the choice of entries in the list.

1) Although chemical information is not available for all sites, all are tabulated to give a rapid guide to what is not, as well as what is, available.

2) Descriptions of analytical methods in the various chapters are extremely uneven. Methods of calibration or standardization very rarely are given. I have only been able to list the reported methods of analysis, where available, and the reader should consult the relevant chapters for specific details.

3) It has been difficult to interpret the meaning of some of the analytical methods given by Soviet authors; in particular, I am not sure what "spectral" methods means.

4) For completeness, I have included reference to reports of chemical analyses included in chapters dealing with mineralogical studies.

5) I have resisted the temptation to produce an additional tabulation element by element with cross-references to sites. It seems fairly simple to scan the list for any particular element. In any case, information on the whole range of analyses available at any site is an important prerequisite for interpretation of the results.

REFERENCES

1. Anon (Activation Analysis Research Lab., Texas A and M University, College Station, Texas), 1969. 14-MeV neutron activation analyses of selected Leg 1 core samples. I.R. DSDP, 1:368.

2. _______, 1970. 14 MeV neutron activation analysis of selected Leg 2 core samples. I.R. DSDP, 2:347-348.

3. Aumento, F., and MacGillivray, J. M., 1975. Geochemistry of buried Miocene-Pleistocene ferromanganese nodules from the Antarctic Ocean. I.R. DSDP, 28:795-803.

4. Berger, W. H., and Von Rad, U., 1972. Cretaceous and Cenozoic sediments from the Atlantic Ocean. I.R. DSDP, 14:787-954.

5. Bogdanov, Y. A. et al. 1976. Chemical composition of sediments. I.R. DSDP, 35:447-464.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

6. Boström, K., Joensuu, O., Valdes, S., Charm, W., and Glaccum, R., 1976. Geochemistry and origin of east Pacific sediments sampled during DSDP Leg 34. I.R. DSDP, 34:559-574.

7. Calvert, S. E., and Batchelor, C. H., 1978. Major and minor element geochemistry of sediments from Hole 379A, Leg 42B, DSDP. I.R. DSDP, 42B:527-541.

8. Cook, P. J., 1974. Major and trace element geochemistry of sediments from DSDP Leg 27, Sites 259-263, Eastern Indian Ocean. I.R. DSDP, 27:481-497.

9. _______, 1974. Geochemistry and diagenesis of interstitial fluids and associated calcareous oozes, DSDP, Leg 27, Site 262, Timor Trough. I.R. DSDP, 27:463-480.

10. _______, 1974. Phosphate content of sediments from Deep Sea Drilling Sites 259 to 263, eastern Indian Ocean. I.R. DSDP, 27:455-461.

11. Conwes, F., and Boltenhagen, C., 1978. Trace element distribution in DSDP Sites 372, 374, 375, and 376 in the Mediterranean Sea. I.R. DSDP, 42B:493-506.

12. Cronan, D. S., 1973. Manganese nodules in sediments cored during Leg 16, DSDP. I.R. DSDP, 16:605-608.

13. _______, 1973. Basal ferruginous sediments cored during Leg 16, Deep Sea Drilling Project. I.R. DSDP, 16:601-604.

14. _______, 1977. Geochemical investigations on sediments from the mid-Atlantic Ridge: Leg 37, DSDP. I.R. DSDP, 37:631-632.

15. Delevaux, M. H., and Doe, B. R., 1974. Preliminary report on uranium, thorium and lead contents and lead isotopic composition in sediment samples from the Red Sea. I.R. DSDP, 23:943-946.

16. Connelly, T., and Nalli, G., 1973. Mineralogy and chemistry of Caribbean sediments. I.R. DSDP, 15:929-961.

17. Dean, W. E., and Schreiber, B. C., 1978. Authigenic barite, Leg 41 DSDP. I.R. DSDP, 41:915-931.

18. Donnelly, T. W., and Wallace, J. L., 1976. Major element chemistry of the Tertiary rocks at Site 317 and the problem of the origin of the non-biogenic faction of pelagic sediments. I.R. DSDP, 33:557-562.

19. _______, 1976. Major- and minor-element chemistry of Antarctic clay-rich sediments: Sites 322, 323, and 325, DSDP Leg 35. I.R. DSDP, 35:427-446.

20. Drever, J. I., 1971. Chemical and mineralogical studies, Site 66. I.R. DSDP, 7:965-975.

21. _______, 1976. Chemical and mineralogical studies, Site 323. I.R. DSDP, 35:471-477.

22. Dudley, W. C., and Margolis, S. V., 1975. Authigenic and detrital "glauconie" encountered in Leg 29 sediments. I.R. DSDP, 29: 1093-1096.

23. Dymond, J., Corliss, J. B., and Stillinger, R., 1976. Chemical composition and metal accumulation rates of metalliferous sediments from Sites 319, 320, and 321. I.R. DSDP, 34:575-588.

24. Emelyanov, E. M., 1977. Geochemistry of sediments in the Western Central Atlantic, DSDP Leg 39. I.R. DSDP, 39:477-492.

25. Emelyanov, E. M., Blazchishin, A. I., Kharin, G. S., Lozovaya, N. G., and Zangalis, K. P., 1979. Mineral and chemical composition of sediments of the Vøring Plateau, DSDP Leg 38. I.R. DSDP, 38:(Suppl.):31-44.

26. Emelyanov, E. M., Lisitzin, A. P., Shimkus, K. M., Trimonis, E. S., Lukashev, V. K., Lukashin, A., Mitropolskiy, Y., and Pilipchuk, M. F., 1978. Geochemistry of Late Cenozoic sediments of the Black Sea, Leg 42B. I.R. DSDP, 42B:543-605.

27. Fleet, A. J., and Kempe, D. R. S., 1974. Preliminary geochemical studies of the sediments from DSDP Leg 26, southern Indian Ocean. I.R. DSDP, 26:541-551.

28. Frakes, L. A., 1975. Geochemistry of Ross Sea Diamicts. I.R. DSDP, 28:789-794.

29. Harrington, J., 1978. Effects of burrowing organisms in deep ocean sediments on the distribution of chemical elements and the preservation and orientation of microfossils. I.R. DSDP, 41:933-936.

30. Houghton, R. L., Rothe, P., and Galehouse, J. S., 1979. Distribution and chemistry of phillipsite, clinoptilolite, and associated zeolites at DSDP Sites 382, 385 and 386 in the western north Atlantic. I.R. DSDP, 43:463-483.

31. Hoffman, E. W., Kuykendall, W. E., and Wainderi, R. E., 1970. 14-MeV neutron activation analysis of selected Leg 3 core samples. I.R. DSDP, 3:583-587.

32. Jenkyns, H. C., and Hardy, R. G., 1976. Basal iron-titanium-rich sediments from Hole 315A (Line Islands, Central Pacific). I.R. DSDP, 33:833-836.

33. Jones, E. J. W., 1973. Volcanic glass in abyssal clays sampled at DSDP Leg 20 drilling sites, northwest Pacific. I.R. DSDP, 20:389-416.

34. Kempe, D. R. C., and Easton, A. J., 1974. Metasomatic garnets in calcite (micarb) chalk at Site 251, Southwest Indian Ocean. I.R. DSDP, 26:593-601.

35. Kossovskaya, A. G., and Drits, V. A., 1979. Mineralogy, geochemistry, and petrography of sediments recovered at Site 345, DSDP Leg 38. I.R. DSDP, 38:(Suppl.): 45-54.

36. Kuehn, R., and Hsü, K. J., 1978. Chemistry of halite and potash salt cores, DSDP Sites 374-376, Leg 42A, Mediterranean Sea. I.R. DSDP, 42A:613-619.

37. Kuykendall, W. E., Hoffman, B. W., and Wainerdi, R. E., 1970. 14-MeV neutron activation analysis of selected Leg 4 core samples. I.R. DSDP, 4:371-374.

38. ________, 1970. 14-MeV neutron activation analysis of selected Leg 5 core samples. I.R. DSDP, 5:485-486.

39. ________, 1971. 14-MeV neutron activation analysis of selected Leg 6 core samples. I.R. DSDP, 6:1121.

40. Lancelot, Y., Hathaway, J. C., and Hollister, C. D., 1972. Lithology of sediments from the western North Atlantic Leg 11 DSDP. I.R. DSDP, 11:901-949.

41. Lange, J., Wedepohl, K. H., Heinrichs, H., and Gohn, E., 1978.

Notes about the specific chemical composition of "black shales" from Site 367 (Leg 41). I.R. DSDP, 41: 875-877.

42. Lisitzin, A. P. et al., 1971. Geochemical, mineralogical, and paleontological studies. I.R. DSDP, 6:829-960.

43. Manheim, F. T., 1974. Red Sea geochemistry. I.R. DSDP, 23:975-998.

44. Manheim, F. T., and Siems, D. E., 1974. Chemical analyses of Red Sea sediments. I.R. DSDP, 23:923-938.

45. Marchig, V., and Vallier, T. L., 1974. Geochemical studies of sediment and interstitial water, Sites 248 and 249, Leg 25, DSDP. I.R. DSDP, 25:405-414.

46. Matsumota, R., Utada, M., and Kagami, H., 1978. Sedimentary petrology of DSDP cores from Sites 362 and 363, The Walvis Ridge, and Site 364, the Angola Basin, drilled on Leg 40. I.R. DSDP, 40: 469-485.

47. Matter, A., Douglas, R. G., and Perch-Nielsen, K., 1975. Fossil preservation, geochemistry, and diagenesis of pelagic carbonates from Shatsky Rise, Northwest Pacific. I.R. DSDP, 32:891-921.

48. Müller, J., and Fabricius, F., 1978. Lüneburgite $[Mg_3(PO_4)_2B_2O(OH)_2 \cdot 6H_2O]$ in Upper Miocene sediments of the eastern Mediterranan Sea. I.R. DSDP, 42A:661664.

49. Murdmaa, I. O., 1978. Mesozoic variegated and red sediments of the western north Atlantic, DSDP Legs 43 and 44. I.R. DSDP, 44: 503-513.

50. Murdmaa, I. O., Gorduv, V. V., Bazilevskaya, E. S., and Emelyanov, E. M., 1978. Inorganic geochemistry of Leg 44 sediments. I.R. DSDP, 44:575-582.

51. Murdmaa, I. O., Gorduv, V. V., Emelyanov, E. M., and Bazilevskaya, E. S., 1979. Inorganic geochemistry of Leg 43 sediments. I.R. DSDP, 43:675-694.

52. Natland, J. H., 1973. Basal ferromanganoan sediments at DSDP Site 183, Aleutian Abyssal Plain and Site 192, Meigi Guyot, Northwest Pacific, Leg 19. I.R. DSDP, 19:629-641.

53. _______, 1978. Composition, provenance, and diagenesis of Cretaceous clastic sediments drilled on the Atlantic continental rise off Southern Africa, DSDP Site 361 -- implications for the early circulation of the South Atlantic. I.R. DSDP, 40:1025-1061.

54. Nesterova, M. P., Scherbakov, F. A., Shevchenko, A. J., Turanskaya, N. W., Kazakov, W. P., Samosudova, A. G., Kuzmina, T. G., and Rudakova, A. N., 1979. Origin of the late Cenozoic sediments of the Icelandic Basin, DSDP Site 348, Leg 38. I.R. DSDP, 38: (Suppl.):73-93.

55. Perry, E. A., Jr., Beckles, E. C., and Newton, R. M., 1976. Chemical and mineralogical studies, Sites 322 and 325. I.R. DSDP, 35:465-469.

56. Pimm, A. C. 1973. Trace element determinations compared with X-ray diffraction results of brown clay in the central Pacific. I.R. DSDP, 17:511-513.

57. _______, 1974. Mineralization and trace element variation in deep-sea pelagic sediments of the Wharton Basin, Indian Ocean. I.R. DSDP, 22:469-476.

58. Rateev, M. A., Renngarten, N. V., Shutov, V. D. and Drits, V. A.,

1979. Lithology and clay mineralogy of sediments from Hole 346. I.R. DSDP, 38:(Suppl.):55-65.

59. Renard, M., Letolle, R., Bourbon, M., and Richebois, G., 1978. Some trace elements in the carbonate samples recovered from Holes 390, 390A, 391C, 392A of DSDP Leg 44. I.R. DSDP, 44:557-566.

60. Siesser, W. G., 1979. Native copper in DSDP Leg 40 sediments. I.R. DSDP, 38:(Suppl.):761-765.

61. ________, 1979. Petrography and geochemistry of pyrite and marcasite in DSDP Leg 40 sediments. I.R. DSDP, 38:(Suppl.):767-775.

62. Stoffers, P., and Kühn, R., 1974. Red Sea evaporites: A petrographic and geochemical study. I.R. DSDP, 23:821-847.

63. Supko, P. R., Stoffers, P., and Copler, T. B., 1974. Petrography and geochemistry of Red Sea dolomite. I.R. DSDP, 23:867-878.

64. Tarney, J., and Donnellan, N. C. B., 1977. Minor element geochemistry of sediments at Site 328, Falkland Outer Basin and Site 329, Falkand Plateau, Leg 36, Deep Sea Drilling Project. I.R. DSDP, 36:929-939.

65. Udintsev, G. B. and Kharin, G. S. 1979. Sedimentary rocks of the Jan-Mayen Ridge. I.R. DSDP, 38:(Suppl.):95-99.

66. Unruh, D. M., and Tatsumoto, M., 1976. Lead isotopic composition and uranium, thorium and lead concentrations in sediments and basalts from the Nazca Plate. I.R. DSDP, 34:341-347.

67. von der Borch, C. C., and Rex, R. W., 1970. Amorphous iron oxide precipitates in sediments cored during Leg 5, DSDP. I.R. DSDP, 5:541-544.

68. Warner, T. B., and Gieskes, J. M., 1974. Iron-rich basal sediments from the Indian Ocean: Site 245, DSDP. I.R. DSDP, 25:395-403.

Table 1. Checklist of elemental analyses.

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
1	1	Pleist.	O Si Fe Al Mg	NA		1
	2					
	3	L. Mio.	O Si Fe Al Mg	NA		1
	4	Pleist.	O Si Fe Al Mg	NA		1
	5	Pleist. - L. Cret.	O Si Fe Al Mg	NA		1
	6	? - M. Eoc.	O Si Fe Al Mg	NA		1
	7/7A	Pleist. - ?	O Si Fe Al Mg	NA		1
2	8	Quat.	O Si Fe Al Mg	NA		2
	9/9A	Quat. - Cret.	O Si Fe Al Mg	NA		2
	10	Plio. - L. Cret.	O Si Fe Al Mg	NA		2
	11/11A	Pleist. - M. Mio.	O Si Fe Al Mg	NA		2
	12/12A-C	Quat. - Eoc.	O Si Fe Al Mg	NA		2

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
3	13/13A	L. Plio. - M. Eoc.	O Si Fe Al Mg	NA		31
	14	E. Mio. - L. Olig.	O Si Fe Al Mg	NA		31
	15	Pleist. - E. Mio.	O Si Fe Al Mg	NA		31
	16	Pleist. - L. Mio.	O Si Fe Al Mg	NA		31
	17/17A	L. Plio. - L. Olig.	O Si Fe Al Mg	NA		31
	18	E. Mio.	O Si Fe Al Mg	NA		31
	19	Pleist. - M. Eoc.	O Si Fe Al Mg	NA		31
	20/20A-C	L. Olig. - L. Eoc.	O Si Fe Al Mg	NA		31
	21/21A	E. Plio. - L. Cret.	O Si Fe Al Mg	NA		31
	22	Pleist. - L. Olig.	O Si Fe Al Mg	NA		31
4	23	L. Mio. - E. Mio.	O Si Fe Al Mg	NA		37
	24/24A	E. Mio.	O Si Fe Al Mg	NA		37
	25	Pleist. - L. Mio.	O Si Fe Al Mg	NA		37
	26	Pleist.	O Si Fe Al Mg	NA		37
	27/27A	L. Olig. - ?	O Si Fe Al Mg	NA		37
	28	L. Eoc.	O Si Fe Al Mg	NA		37
	29/29A-B	Pleist. - M. Eoc.	O Si Fe Al Mg	NA		37
	30	Pleist. - E. Eoc.	O Si Fe Al Mg	NA		37
	31	Pleist. - L. Olig.	O Si Fe Al Mg	NA		37
5	32	E. Plio. - L. Mio.	O Si Fe Al Mg K	NA		38,67
	33	L. Plio. - M. Mio.	O Si Fe Al Mg K	NA		38,67
	34	L. Plio. - M. Mio.	O Si Fe Al Mg K	NA		38,67
	35	Pleist. - ?	O Si Fe Al Mg K	NA		38,67
	36	Pleist. - M. Mio.	O Si Fe Al Mg K	NA		38,67
	37	Pleist. - ?	O Si Fe Al Mg K	NA		38,67
	38	? - E. Eoc.	O Si Fe Al Mg K	NA		38,67
	39	?	O Si Fe Al Mg K	NA		38,67
	40	?	O Si Fe Al Mg K	NA		38,67
	41	L. Mio.	O Si Fe Al Mg K	NA		38,67
	42	M. Eoc.	O Si Fe Al Mg K	NA		38,67
6	43					
	44	E. Olig. - M. Eoc.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	45	Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	46	E. Olig. - L. Eoc.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	47	Pleist. - Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	48	L. Mio. - L. Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	49	Pleist. - E. Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	50	Pleist. - E. Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	51	Pleist. - L. Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	52	Mio. - Cret.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	53	L. Mio. - E. Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
6	54	M. Mio. - E. Mio.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	55	Pleist. - L. Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	56	L. Mio. - L. Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	57	Plio. - L. Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	58	Pleist. - L. Olig.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	59	Pleist. - L. Pal.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	60	L. Mio. - E. Mio.	Si Al Ti Fe Ca Mg Na K P Mn F Li Rb Cs Cd Cu Ni Zn Cr Co Pb Zr Mo V	NA/Col./Grav./ OS/AA/FP/Wet		42
	45	Olig.	O Si Fe Al Mg K	NA		39
	46	E. Olig. - L. Eoc.	O Si Fe Al Mg K	NA		39
	50	? - Pleist.	O Si Fe Al Mg K	NA		39
	51	Pleist.	O Si Fe Al Mg K	NA		39
	52	Cret.	O Si Fe Al Mg K	NA		39
	53	L. Mio.	O Si Fe Al Mg K	NA		39
7	61-65					
	66	Olig. - L. Cret.	Fe Mn Ni Cu Zn Ca S Si Ba Rb V Cr As Mo	XRF		20
	67					
8	68-75					
9	76-84					
10	85-97					
11	98-104					
	105	? L. Mio. - L. Cret.	Si Al Fe Mg Ca K Mn Ti Zn Cu Pb Sr Cr Ni V B Mo Co Ba Mn	XRF (majors) OS (minors)		40
	106-108					
12	109-119					
13	120-134					
14	135					
	136	E. Mio. - L. Cret.	Fe Mn Zn Cu Ni Co Pb	XRT (semi-quant.)	Mn micronodules, glauconite, sulfides	4
	137	Tert. - L. Cret.	Fe Mn Zn Cu Ni Co Pb			4
	138					
	139					
	140					

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
14	141	E. Plio. - L. Plio.	Fe Mn Zn Cu Ni Co Pb	XRF (semi-quant.)	Mn micronodules, glauconite, sulfides	4
	142		Fe Mn Zn Cu Ni Co Pb	XRF (semi-quant.)	Mn micronodules, glauconite, sulfides	4
	143					
	144					
15	145					
	146	L. Mio. - M. Cret.	Si Al Ti Fe Mn Mg Ca Na K P Ba Sr Cu	Wet		16
	147					
	148	E. Plio.	Si Al Ti Fe Mn Mg Ca Na K P Ba Sr Cu			16
	149	Pleist. - M. Eoc.	Si Al Ti Fe Mn Mg Ca Na K P Ba Sr Cu			16
	150	Plio. - Cret.	Si Al Ti Fe Mn Mg Ca Na K P Ba Sr Cu			16
	151					
	152					
	153					
	154					
16	155					
	156	L. Pleist.	Fe Mn Cu Pb Zn Ni Co	AA	Mn nodules only	12
	157					
	158					
	159	E. Mio. - L. Olig.	Fe Mn Cu Pb Zn Ni Co	AA	Mn nodules only	12
	160	Pleist. - E. Mio.	Fe Mn Cu Pb Zn Ni Co			12
	161	E. Mio. - M. Mio.	Fe Mn Cu Pb Zn Ni Co		Mn nodules only	12
	162	E. Olig. - M. Eoc.	Fe Mn Cu Pb Zn Ni Co		Mn nodules only	12
	163					
16	155					
	156					
	157					
	158					
	159	L.-E. Mio.	Fe Mn Ni Co Cu Pb Zn	AA/Tit.(Fe)	Basal Fe-rich sediments	13
	160	E. Mio. - M. Eoc.	Fe Mn Ni Co Cu Pb Zn	AA/Tit.(Fe)	Basal Fe-rich sediments	13
	161	M. Eoc.	Fe Mn Ni Co Cu Pb Zn	AA/Tit.(Fe)	Basal Fe-rich sediments	13
	162	L. Olig. - L. Eoc.	Fe Mn Ni Co Cu Pb Zn	AA/Tit.(Fe)	Basal Fe-rich sediments	13
	163					
17	164	E. Mio. - L. Cret.	Mn Cr Ni Ti V	AA		56
	165					
	166					
	167					
	168	E. Mio. - M. Eoc.	Mn Cr Ni Ti V	AA		56
	169	M. Cret.	Mn Cr Ni Ti V	AA		56
	170	L. Olig.	Mn Cr Ni Ti V	AA		56
18	172-182					
19	183	L. Eoc.	Fe Mn Cu Zn Ni Co Cr Pb	AA	Basal ferromanganoan sediments	52
	184-191					
	192/192A	L. Eoc. - U. Cret.				52
	193					

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
20	194	Quat. - L. Mio.	Si Al Ca Ti Mg Fe Mn K Na	EM	Volcanic glass	33
	195	Pleist. - M. Mio.				
	196					33
	197					
	198					
	199	M. Mio.	Si Al Ca Ti Mg Fe Mn K Na	EM		33
	200					
	201					
	202					
21	203-210					
22	211	Quat. - Plio.	Ni Cu Pb Zn Mn Fe Cr V Ti	AA		57
	212	E. Plio. - L. Cret.	Ni Cu Pb Zn Mn Fe Cr V Ti	AA		57
	213	Quat. - L. Pal.	Ni Cu Pb Zn Mn Fe Cr V Ti	AA		57
	214-218					
23	219-225					
	226	L. Quat.	U Th Pb	ID		15
	227	E. Plio.	U Th Pb	ID		15
	228	?	U Th Pb	ID		15
	229					
	230					
23	225	Pleist. - L. Mio.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
	226	Pleist.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
	227	Pleist. - L. Mio.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
	228	Pleist. - ?. Mio.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
	229	Hol. - Pleist.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
	230	Pleist.	Si Al K Fe Ti Ca Mg Mn Pb Ag Cu Zn Sn Cd Mo Ni Co V Ba Sr B As Zr Cr	Spectr./Wet		43,44
23	225	Tert.	Ca	XRD	Carbonates	63
	227	Tert.	Ca	XRD	Carbonates	63
	228	Tert.	Ca	XRD	Carbonates	63
23	225	L. Mio.	Br Rb Sr Ca	Wet	Evaporites	62
	227	L. Mio.	Br Rb Sr Ca	Wet	Evaporites	62
	228	? Mio.	Br Rb Sr Ca	Wet	Evaporites	62
24	231-238					
25	239-247					
	248	Pleist. - L. Pal.	Si Ti Fe Mn Cu Zn Mg Sr Ca Cr Ni Co Mo V Ba Na K	AA/Col./Grav./ FP/OS/Tit.		45
	249	L. Mio. - L. Cret.	Si Ti Fe Mn Cu Zn Mg Sr Ca Cr Ni Co Mo V Ba Na K	AA/Col./Grav./ FP/OS/Tit.		45
25	245	L-E. Pal.	Ca Al Si Fe Mn K Ti Sr Cu Zn	XRF	Basal Fe-rich sediments	68

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
26	250 251 252-257 258	L. Mio.	Si Al Ti Cr Fe Mn Mg Ca Na K H_2O^-	AA/Col.	Garnets	34
26	250/250A	Quat. - L. Cret.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	251/251A	Quat. - E. Mio.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	252	Quat. - L. Mio.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	253	Quat. - M. Eoc.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	254	Quat. - Olig.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	255	Mio.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	256	Plio. - E. Cret.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	257	Quat. - E. Cret.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
	258	Quat. - E. Cret.	Si Al Ti Fe Mn Ca Mg K Li Be Sr Ba Sc V Cr Co Ni Cu Zn Ga Mo Ag Cd Sn Pb; lanthanides	DRES/NA		27
27	259	Pleist. - E. Cret.	Si Al Fe Ca Mg Na K Mn P Ti Cr V Sr Ba Li Cu Pb Zn Co Ni CO_2, H_2O	DRES/Wet AA/Grav.		8
	260	Pleist. - E. Cret.	Si Al Fe Ca Mg Na K Mn P Ti Cr V Sr Ba Li Cu Pb Zn Co Ni CO_2, H_2O	DRES/Wet AA/Grav.		8
	261	Pleist. - L. Jur.	Si Al Fe Ca Mg Na K Mn P Ti Cr V Sr Ba Li Cu Pb Zn Co Ni CO_2, H_2O	DRES/Wet AA/Grav.		8
	262	Hol. - Plio.	Si Al Fe Ca Mg Na K Mn P Ti Cr V Sr Ba Li Cu Pb Zn Co Ni CO_2, H_2O	DRES/Wet AA/Grav.		8
	263	Quat. - E. Cret.	Si Al Fe Ca Mg Na K Mn P Ti Cr V Sr Ba Li Cu Pb Zn Co Ni CO_2, H_2O	DRES/Wet AA/Grav.		8
27	262	Hol. - Plio.	Fe Al P Ca Mg K Sr Ba Li Cu Pb Zn Co Ni Mn Cr CO_2	AA/Col./Grav.		9
27	259	Pleist. - E. Cret.	P	Col.		10
	260	Pleist. - E. Cret.	P	Col.		10
	261	Pleist. - L. Jur.	P	Col.		10
	262	Hol. - Plio.	P	Col.		10
	263	Quat. - M. Plio.	P	Col.		10

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
28	264					
	265					
	266					
	267	Pleist.	Fe Mn Co Cu Ni Ti Ca Si Al Na K Zn H_2O	EM/Grav.	Mn nodules	3
	268-273					
	274	Mio.	Fe Mn Co Cu Ni Ti Ca Si Al Na K Zn H_2O	EM/Grav.	Mn nodules	3
28	270	Hol. - ? Olig.	Fe Mn Ni Cu V	AA	100 mesh only	28
	271	Quat. - ?	Fe Mn Ni Cu V	AA	100 mesh only	28
	272	E. Plio. - M. Mio.	Fe Mn Ni Cu V	AA	100 mesh only	28
	273/273A	Quat. - M. Mio.	Fe Mn Ni Cu V	AA	100 mesh only	28
29	275	L. Cret.	Si Al Fe K Mg	SEM/XRF	Glauconite	22
	276					
	277	M. Olig.	Si Al Fe K Mg	SEM/XRF	Glauconite	22
	278					
	279					
	280/A	L. Mio. - L. Eoc.	Si Al Fe K Mg	SEM/XRF	Glauconite	22
	281	E. Mio.	Si Al Fe K Mg	SEM/XRF	Glauconite	22
	282					
	283					
	284					
30	285-289					
31	290-302					
32	303					
	304					
	305	Quat. - E. Cret.	Ca Sr Mg	AA/Tit.	Carbonates	47
	306	E. Cret.		AA/Tit.	Carbonates	47
	307-313					
33	314					
	315/315A	L. Cret.	Si Al Fe Mn Mg Ca Na K Ti S P Ba Nb Zr Y Sr Rb Zn Pb Cu Ni Cr Co	XRF	Basal Fe-, Ti-rich sediments	32
	316					
	317					
	318					
33	317	Quat. - L. Eoc.	Si Ti Al Fe Mn Mg Ca Na K P	AA/Col.		18
34	319	Quat. - E. Mio.	Si Al Fe Mn P Cu Zn Mg Sr Ti B Ba Cu Co Ni La Sc Y Cr V Zr	OS/AA		6
	320/320A	Quat. - L. Olig.				6
	321	Quat. - L. Eoc.				6
34	319	Quat. - E. Eoc.	Fe Mn Si Al Ba Sc Cr Co Ni Cu Zn Sb La Ce Nd Sm En Tb Yb Lu Hf Th Ca	NA/AA		23
	320	L. Olig. - E. Mio.	Fe Mn Si Al Ba Sc Cr Co Ni Cu Zn Sb La Ce Nd Sm En Tb Yb Lu Hf Th Ca			23
	321	L. Olig. - L. Eoc.	Fe Mn Si Al Ba Sc Cr Co Ni Cu Zn Sb La Ce Nd Sm En Tb Yb Lu Hf Th Ca			23
34	319	Plio. - M. Mio.	U Th Pb	ID		66

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
35	322	Plio. - Olig.	Si Al Ca Mg Ti Fe Mn K Na Li Rb Cs Ga Cr Ni V Zr Y Co Ni Zn Cu Hf Ta Sm Se La Eu Sb Ce Th Ba P	FP/AA/NA/ Wet/Spectr.		5
	323	Plio. - Cret.	Si Al Ca Mg Ti Fe Mn K Na Li Rb Cs Ga Cr Ni V Zr Y Co Ni Zn Cu Hf Ta Sm Se La Eu Sb Ce Th Ba P			5
	324	Pleist. - ? Plio.	Si Al Ca Mg Ti Fe Mn K Na Li Rb Cs Ga Cr Ni V Zr Y Co Ni Zn Cu Hf Ta Sm Se La Eu Sb Ce Th Ba P			5
	325	Plio. - E. Mio.	Si Al Ca Mg Ti Fe Mn K Na Li Rb Cs Ga Cr Ni V Zr Y Co Ni Zn Cu Hf Ta Sm Se La Eu Sb Ce Th Ba P			5
35	322	Plio. - Olig.	Si Al Ti P K Na Ca Mg Fe Mn Ci Ba Sr Rb Zr Y	AA/XRF/ Col./Tit.		19
	323	Plio. - Cret.				
	325	Plio. - E. Mio.				
35	322	Plio. - Olig.	Si Al Ti Fe Ca Mg K Na Mn	EM		55
	323					
	324					
	325					
35	323	Plio. - Cret.	Si Al Fe Ca Mg Na K Mn Cu Zn Co Ni Pb Mo Sr Ba	AA		21
36	326					
	327					
	328	Quat. - L. Cret.	Ti Fe Mn Cr Ni Cu Zn Rb Sr Y Zr Nb Ba La Ce Pb Th	XRF		64
	329	Quat. - Olig.				
	330					
	331					
37	332/332A	L. Plio.	Ca Al Fe Ni Cd Cu Co Mn Zn Pb Cr Ti Mg	AA		14
	333	Pleist. - E. Plio.	Ca Al Fe Ni Cd Cu Co Mn Zn Pb Cr Ti Mg	AA		14
	334	Pleist. - L. Mio.	Ca Al Fe Ni Cd Cu Co Mn Zn Pb Cr Ti Mg	AA		14
	335	L. Plio. - L. Mio.	Ca Al Fe Ni Cd Cu Co Mn Zn Pb Cr Ti Mg	AA		14
38	336					
	337					
	338					
	339	Pleist. - Eoc./Olig.	Fe Mn Ti P Cu Zn Ni Co Cr Cd K Na	Col./FP		25
	340	L. Eoc.		Col./FP		25
	341	Pleist. - M. Mio.	Fe Mn Ti P Cu Zn Ni Co Cr Cd K Na	Col./FP		25
	342	Pleist. - E. Mio.	Fe Mn Ti P Cu Zn Ni Co Cr Cd K Na	Col./FP		25
	343					
	344					

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
	345	E. Mio. - Eoc.	Si Al Ti Fe Ca Mg Mn Na K H_2O CO_2 C P Cl	NG		35
	346	Eoc.	Si Al Ti Fe Ca Mg Mn Na K H_2O CO_2 C P Cl	NG		58
	347					
	348	Pleist. - Olig.	Si Ti Al Fe Mn Mg Ca K Na P C CO_2	XRF		54/65
	349					
	350					
	351					
	352					
39	353	L. Pleist.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O	AA/FP/ Tit./ Col. Spectr. Wet		24
	354	Plio. - L. Cret.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O Ba Zr V Mo Be Ge	NG		24
	355	Pleist. - L. Cret.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O Ba Zr V Mo Be Ge	NG		24
	356	Plio. - E. Cret.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O	NG		24
	357	E. Pleist. - L. Cret.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O	NG		24
	358	Pleist. - L. Cret.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O	NG		24
	359	E. Plio. - L. Eoc.	Fe Mn Ti P Na K Zn Cu Ni Co Cr Cd CO_2 C Si Al Fe Mn Ca Mg K Na P CO_2 S F H_2O	NG		24
40	360	L. Mio.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61
	361	L. Cret. - E. Cret.	Si Al Fe Ca K Ti Ba Zr Mg Na Mn Sr Rb Ni Cu U Cr Zn Pb	XRF		53
	361	Mio. - E. Cret.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61
	362					
	362	M. Olig.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61
	363	E. Cret.	Mg Ca Fe Mn Na CO_2	EM	Dolomite and ankerite only	46
	363	E. Cret.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61
	364	L. Plio. - E. Cret.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61
	364	E. Cret.	Mg Ca Fe Mn Na CO_2	EM	Dolomite and ankerite only	46
	364	M. Mio.	K Si Ca Al Ti Mg Fe Mn S	EM	Dolomite and ankerite only	46
	365	Cret.	K Si Ca Al Ti Mg Fe Mn S Cu As	EM	Pyrite and marcasite	61

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
41	366	Pal.	Si Ca K Mn Mg Fe Cu Co Ba	SEM/XRF	"normalized data"	29
			S Fe K Na Mn Cu Ni Zr Cr	AA		41
			Ba Cd Pb Tl Bi Hg			
			U Th			
			V Mo	OS		
			C CO_2	Cou.		
	367	E. Cret.	Si Ca K Mn Mg Fe Cu Co Ba S	SEM/XRF	"normalized data"	29
	368	L. Cret.	Si Ca K Mn Mg Fe Cu Co Ba S	SEM/XRF	"normalized data"	29
	369	Olig.	Si Ca K Mn Mg Fe Cu Co Ba S	SEM/XRF	"normalized data"	29
	370	Cret.	S Ba Ca Mg Na Mn Fe	EM	Barite	17
42A	371	Pleist. - E. Mio.	Ba C Pb Zn Cu Cr Ni Co Sr	UV		11
	372		Ba Ga Mn As Fe Al Ca Mg Ti			
	373					
	374		Ba C Pb Zn Cu Cr Ni Co Sr	UV		11
			Ba Ga Mn As Fe Al Ca Mg Ti			
	374	Mio.	Mg Ca Cl Br	Tit.	Halite and potash	36
			Na K	FP		
			Sr Rb	AA		
			SO_4	Grav.		
	374	L. Mio.	Ca Mg	AA	Lüneburgite	48
			P B	Tit.		
	375	Mio.	Mg Ca Cl Br	Tit.	Halite and potash	36
			Na K	FP		
			Sr Rb	AA		
			SO_4	Grav.		
	376	Mio.	Mg Ca Cl Br	Tit.	Halite and potash	36
			Na K	FP		
			Sr Rb	AA		
			SO_4	Grav.		
	377					
	378					
42B	379	Pleist.	Si Al Ti Fe Mg K P Mn S	XRF		7
			As Ba Br Cu 1 Mo Ni Pb Rb			
			Sr Y Zn Zr			
			C CO_2	Gas		
	379	Pleist.	Fe Mn Cu Zn Ni Cr Cd K Na	AA		26
			Ba Zr V Be Ge Mo Sn Ni	OS		
			Cr B Co Li Rb Cs Pb Ag			
			La Ce Eu Hf Ta Th Sr Sc	NA		
			Co Fe Sb Ta Rb Ge Cs			
			P Ti F B	Col.		
			Na K	FP		
			Se W	NG		
	380	Pleist. - L. Plio.	Fe Mn Cu Zn Ni Cr Cd K Na	AA		26
			Ba Zr V Be Ge Mo Sn Ni	OS		
			Cr B Co Li Rb Cs Pb Ag			
			La Ce Eu Hf Ta Th Sr Sc	NA		
			Co Fe Sb Ta Rb Ge Cs			
			P Ti F B	Col.		
			Na K	FP		
			Se W	NG		

Table 1. Checklist of elemental analyses. (Cont.)

Leg	Site/Hole	Age	Elements	Method(s)[a]	Notes	Ref
42B	381	M. Mio.	Fe Mn Cu Zn Ni Cr Cd K Na	AA		26
			Ba Zr V Be Ge Mo Sn Ni	OS		
			Cr B Co Li Rb Cs Pb Ag			
			La Ce Eu Hf Ta Th Sr Sc	NA		
			Co Fe Sb Ta Rb Ge Cs			
			P Ti F B	Col.		
			Na K	FP		
			Se W	NG		
43	382	Pleist. - L. Cret.	Si Al Fe Mg Ca Ba Na K Mn Ti P	EM	Zeolites	30
		Pleist. - L. Cret.	Nb Y Sr Rb Zr Ba	NG		
	383					
	384					
	385	Pleist. - L. Cret.	Nb Y Sr Rb Zr Ba	NG	Zeolites	30
	385	L. Olig. - Cret.	Si Al Ti Fe Mn Mg Ca K Na P	XRF		49,51
	386	L. Mio. - E. Cret.	Si Al Ti Fe Mn Mg Ca K Na P	XRF		49,51
	386	Pleist. - E. Cret.	Si Al Fe Mg Ca Ba Na K Mn Ti P	EM	Zeolites	30
			Nb Y Sr Rb Zr Ba	NG		
	387	M. Eoc. - L. Jur.	Fe Mn Ti	Wet		49,51
			Al Zn Ni Co Cr Cu Fe Mn	AA		
44	388	Pleist. - M. Mio.	Fe Mn Ti	Wet		50
			Al Fe Mn Cu Zn Ni Co Cr	AA		
			Si Ti Al Fe Mn Mg Ca K	XRF		
	389					
	390	Pleist. - E. Cret.	Fe Mn Ti	Wet		50
			Al Fe Mn Cu Zn Ni Co Cr	AA		
			Si Ti Al Fe Mn Mg Ca K	XRF		
	391	Pleist. - E. Cret.	Fe Mn Ti	Wet		50
			Al Fe Mn Cu Zn Ni Co Cr	AA		
			Si Ti Al Fe Mn Mg Ca K	XRF		
44	390	M. Eoc. - E. Cret.	Sr Mn Mg Na K Zn Fe	AA		59
	391	E. Cret. - Jur.	Sr Mn Mg Na K Zn Fe	AA		59
	392	Cret.	Sr Mn Mg Na K Zn Fe	AA		59

[a]XRF = X-ray fluorescence spectrometry; NA = neutron activation; OS = optical emission spectrometry; DRES = direct reading emission spectrometry; AA = atomic absorption spectrophotometry; FP = flame photometry; Col. = colorimetry; Grav. = gravimetry; Tit. = titrimetry; Wet = wet chemical - unspecified; EM = electron microprobe; Spectr. = "Spectral" - unspecified; SEM/XRF = scanning electron microscopy - X-ray emission; ID = isotope dilution; XRD = X-ray diffraction spectrometry; = gamma-ray spectrometry; Cou. = coulometry; UV = UV spectrometry; Gas = gasometry; NG = not given.

12. STABLE-ISOTOPE DATA

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The first 44 volumes of the Initial Reports of the Deep Sea Drilling Project have 89 chapters that contain analytical information and data on the stable isotopes of hydrogen, carbon, oxygen, and sulfur. Table 1 shows the distribution of data by volume and isotope. Table 2 classifies the data by sample type. The numbers in all but the first columns of both tables refer to the numbered reference list. The tables are intended to serve as a convenient index for the stable-isotope data reported in the Initial Reports.

REFERENCES

1. Anderson, T. F., and Lawrence, J. R., 1976. Stable isotope investigations of sediments, basalts, and authigenic phases from Leg 35 cores. I.R. DSDP, 35:497-505.

2. Baker, E. W., Huang, W. Y., Rankin, J. G., Castaño, J. R., Guinn, J. R., and Fuex, A. N., 1978. Electron paramagnetic resonance study of thermal alteration of kerogen in deep-sea sediments by basaltic sill intrusion. I.R. DSDP, 41:839-847.

3. Bernoulli, D., Garrison, R. E., and McKenzie, J., 1978. Petrology, isotope geochemistry, and origin of dolomite and limestone associated with basaltic breccia, Hole 373A, Tyrrhenian Basin. I.R. DSDP, 42A:541-558.

4. Boersma, A., and Shackleton, N., 1977. Tertiary oxygen and carbon isotope stratigraphy, Site 357 (Mid-Latitude South Atlantic). I.R. DSDP, 39:911-924.

5. _______, 1978. Oxygen and carbon isotope record through the Oligocene, DSDP Site 366, equatorial Atlantic. I.R. DSDP, 41:957-962.

6. Boersma, A., Shackleton, N., Hall, M., and Given, Q., 1979. Carbon and oxygen isotope records at DSDP Site 384 (North Atlantic) and some Paleocene paleotemperatures and carbon isotope variations in the Atlantic Ocean. I.R. DSDP, 43:695-717.

7. Brenneke, J. C., 1978. A comparison of the stable oxygen and carbon isotope composition of Early Cretaceous and Late Jurassic carbonates from DSDP Sites 105 and 367. I.R. DSDP, 41:937-950.

8. Calder, J. A., Horvath, G. J., Shultz, D. J., and Newman, J. W., 1974. Geochemistry of the stable isotopes in some Indian Ocean sediments. I.R. DSDP, 26:613-617.

9. Cita, M. B., Wright, R. C., Ryan, W. B. F., and Longinelli, A, 1978. Messinian paleoenvironments. I.R. DSDP, 42A:1003-1035.

10. Claypool, G. E., Presley, B. J., and Kaplan, I. R., 1973. Gas analyses in sediment samples from Legs 10, 11, 13, 14, 15, 18, and 19. I.R. DSDP, 19:879-884.

11. Coplen, T. B., and Schlanger, S. O., 1973. Oxygen and carbon isotope studies of carbonate sediments from Site 167, Magellan Rise, Leg 17. I.R. DSDP, 17:505-509.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

12. Deuser, W. G., 1974. Oxygen and carbon isotope analyses (in Chapter 18, Site 228). I.R. DSDP, 23:687-690.

13. Deuser, W. G., Degens, E. T., and Stoffers, P., 1978. O^{18} and C^{13} contents of carbonates from deep-sea drilling sites in the Black Sea. I.R. DSDP, 42B:617-623.

14. Doose, P. R., Sandstrom, M. W., Jodele, R. Z., and Kaplan, I. R., 1978. Interstitial gas analysis of sediment samples from Site 368 and Hole 369A. I.R. DSDP, 41:861-863.

15. Douglas, R. G., and Savin, S. M., 1971. Isotopic analysis of planktonic foraminifera from the Cenozoic of the northwest Pacific, Leg 6. I.R. DSDP, 6:1123-1127.

16. ________, 1973. Oxygen and carbon isotope analyses of Cretaceous and Tertiary foraminifera from the central North Pacific. I.R. DSDP, 17:591-605.

17. ________, 1975. Oxygen and carbon isotope analyses of Tertiary and Cretaceous microfossils from Shatsky Rise and other sites in the North Pacific Ocean. I.R. DSDP, 32:509-520.

18. Eade, J. V., and Anderson, T. F., 1975. Oxygen and carbon isotope composition and diagenesis of Eocene clay nanno-chalk at DSDP Site 287, Coral Sea Basin. I.R. DSDP, 30:419-422.

19. Erdman, J. G., and Schorno, K. S., 1976. Geochemistry of carbon: DSDP Leg 38. I.R. DSDP, 38:791-799.

20. ________, 1978. Geochemistry of carbon: DSDP Leg 41. I.R. DSDP, 41:849-853.

21. ________, 1979. Geochemistry of carbon: DSDP Leg 40. I.R. DSDP, 38 (Suppl.):651-658.

22. ________, 1978. Geochemistry of carbon: DSDP Legs 42A & 42B. I.R. DSDP, 42B:717-721.

23. ________, 1979. Geochemistry of carbon: DSDP Leg 43. I.R. DSDP, 43:651-655.

24. ________, 1978. Geochemistry of carbon: DSDP Leg 44. I.R. DSDP, 44:605-615.

25. Erdman, J. G., Schorno, K. S., and Scalan, R. S., 1974. Geochemistry of carbon: DSDP Legs 22, 24, 26, 27, and 28. I.R. DSDP, 24:1169-1176.

26. ________, 1975. Geochemistry of carbon: DSDP Leg 31. I.R. DSDP, 31:633-638.

27. ________, 1975. Geochemistry of carbon and sulfur: DSDP Leg 29. I.R. DSDP, 31:911-916.

28. Eslinger, E. V., and Savin, S. M., 1976. Mineralogy and O^{18}/O^{16} ratios of fine-grained quartz and clay from Site 323. I.R. DSDP, 35:489-496.

29. Faber, E., Schmitt, M., and Stahl, W., 1978. Carbon isotope analyses of head space methane from samples of Leg 42B, Sites 379, 380, and 381. I.R. DSDP, 42B:667-672.

30. Field, C. W., Dymond, J. R., Heath, G. R., Corliss, J. B., and Dasch, E. J., 1976. Sulfur isotope reconnaissance of epigenetic pyrite in ocean-floor basalts, Leg 34 and elsewhere. I.R. DSDP, 34:381-384.

31. Fontes, J.-Ch., Létolle, R., Nesteroff, W. D., and Ryan, W. B. F.,

1973. Oxygen, carbon, sulfur, and hydrogen stable isotopes in carbonate and sulfur mineral phases of Neogene evaporites, sediments, and in interstitial waters. I.R. DSDP, 13:788-795.

32. Foresman, J. B., 1978. Organic geochemistry, DSDP Leg 40, continental rise of Southwest Africa. I.R. DSDP, 40:557-567.

33. Friedman, I., and Hardcastle, K., 1973. Interstitial water studies, Leg 15, isotopic composition of water. I.R. DSDP, 20:901-903.

34. _______, 1974. Deuterium in interstitial waters from Red Sea cores. I.R. DSDP, 23:969-970.

35. Garrison, R. E., Schreiber, B. C., Bernoulli, D., Fabricius, F. H., Kidd, R. B., and Mélières, F., 1978. Sedimentary petrology and structures of Messinian evaporitic sediments in the Mediterranean Sea, Leg 42A, Deep Sea Drilling Project. I.R. DSDP, 42A:571-611.

36. Gieskes, J. M., and Lawrence, J. R., 1976. Interstitial water studies, Leg 35. I.R. DSDP, 35: 407-424.

37. Gieskes, J. M., Lawrence, J. R., and Galleisky, G., 1979. Interstitial water studies, Leg 38. I.R. DSDP, 38 (Suppl.):121-133.

38. Gray, J., Cumming, G. L., and Lambert, R. St. J., 1977. Oxygen and strontium isotopic compositions and thorium and uranium contents of basalts from DSDP 37 cores. I.R. DSDP, 37:607-611.

39. Hahn-Weinheimer, P., Fabricius, F., Müller, J., and Sigl, W., 1978. Stable isotopes of oxygen and carbon in carbonates and organic material from Pleistocene to upper Miocene sediments at Site 374 (DSDP Leg 42A). I.R. DSDP, 42A:483-488.

40. Hoernes, S., and Friedrichsen, H., 1977. Oxygen isotope investigations of rocks of Leg 37. I.R. DSDP, 37:603-606.

41. Hsü, K. J., 1978. Correlation of Black Sea sequences (with isotopic analyses by J. McKenzie). I.R. DSDP, 42B:489-497.

42. Hunt, J. M., and Whelan, J. K., 1978. Dissolved gases in Black Sea sediments (with analyses by W. Deuser & E. Ross). I.R. DSDP, 42B:661-665.

43. Krouse, H. R., Brown, H. M., and Farquharson, R. B., 1977. Sulfur isotopic composition in DSDP Leg 37 cores. I.R. DSDP, 37:621-623.

44. Lawrence, J. R., 1973. Stable oxygen and carbon isotope variations in bulk carbonates from late Miocene to Present, in Tyrrhenian Basin, Site 132. I.R. DSDP, 13:796-798.

45. _______, 1973. Interstitial water studies, Leg 15, stable oxygen and carbon isotope variations in water, carbonates, and silicates from the Venezuela Basin (Site 149) and the Aves Rise (Site 148). I.R. DSDP, 20:891-899.

46. _______, 1974. Stable oxygen and carbon isotope variations in the pore waters, carbonates, and silicates, Sites 225 and 228, Red Sea. I.R. DSDP, 23:939-942.

47. Létolle, R., Renard, M., Bourbon, M., and Filly, A., 1978. O^{18} and C^{13} isotopes in Leg 44 carbonates: A comparison with the Alpine series. I.R. DSDP, 44:567-573.

48. Lloyd, R. M., 1973. Interstitial water studies, Leg 15, O^{18} in sulfate ion. I.R. DSDP, 20:887-889.

49. Lloyd, R. M., and Hsü, K. J., 1973. Preliminary isotopic investigations of samples from deep-sea drilling in the Mediterranean Sea. I.R. DSDP, 13:783-787.

50. Longinelli, A., and Cita, M. B., 1973. Isotopic evidence of changes in oceanic circulation. I.R. DSDP, 13:1400-1404.

51. Lyon, G. L., 1973. Interstitial water studies, Leg 15, chemical and isotopic composition of gases from Cariaco Trench sediments. I.R. DSDP, 20:773-774.

52. Manheim, F. T., and Sayles, F. L., 1969. Interstitial water studies on small core samples, Leg 1 (with deuterium determinations by I. Friedman). I.R. DSDP, 1:403-410.

53. Manheim, F. T., and Schug, D. M., 1978. Interstitial waters of Black Sea cores (with Appendix -- Deuterium in interstitial water, Holes 379A and 381, Leg 42B, by K. Hardcastle and I. Friedman). I.R. DSDP, 42B:637-651.

54. McDuff, R. E., Gieskes, J. M., and Lawrence, J. R., 1978. Interstitial water studies, Leg 42A. I.R. DSDP, 42A:561-568.

55. McIver, R. D., and Rogers, M. A., 1978. Insoluble organic matter and bitumens in Leg 44 samples. I.R. DSDP, 44:645-649.

56. McKenzie, J. A., and Ricchiuto, T. E., 1978. Stable isotopic investigations of carbonate samples related to the Messinian salinity crisis from DSDP Leg 42A, Mediterranean Sea. I.R. DSDP, 42A:650-655.

57. McKenzie, J., Bernoulli, D., and Garrison, R. E., 1978. Lithification of pelagic-hemipelagic sediments at DSDP Site 372: oxygen isotope alteration with diagenesis. I.R. DSDP, 42A:473-478.

58. Miller, R. S., Lawrence, J. R., and Gieskes, J. M., 1979. Interstitial water studies, Sites 386 and 387, Leg 43. I.R. DSDP,, 43:669-674.

59. Morris, D. A., 1976. Organic diagenesis of Miocene sediments from Site 341, Vøring Plateau, Norway. I.R. DSDP, 38:809-814.

60. Muehlenbachs, K., 1976. Oxygen isotope geochemistry of DSDP Leg 34 basalts. I.R. DSDP, 34:337-339.

61. ________, 1977. Oxygen isotope geochemistry of DSDP Leg 37 rocks. I.R. DSDP, 37:617-619.

62. Pierre, C., and Fontes, J. C., 1978. Isotope composition of Messinian sediments from the Mediterranean Sea as indicators of paleoenvironments and diagenesis. I.R. DSDP, 42A:635-650.

63. Presley, B. J., Culp, J. H., Petrowski, C., and Kaplan, I. R., 1973. Interstitial water chemistry, Leg 17. I.R. DSDP, 17:515-516.

64. ________, 1973. Interstitial water studies, Leg 15, major ions, Br, Mn, NH_3, Li, B, Si, and C^{13}. I.R. DSDP, 20:805-809.

65. Presley, B. J., Goldhaber, M., and Kaplan, I. R., 1970. Interstitial water chemistry, Deep Sea Drilling Project, Leg 5. I.R. DSDP, 5:513-522.

66. Presley, B. J., and Kaplan, I. R., 1971. Interstitial water chemistry: Deep Sea Drilling Project, Leg 6. I.R. DSDP, 6:823-828.

67. ________, 1971. Interstitial water chemistry: Deep Sea Drilling Project, Leg 7. I.R. DSDP, 7:883-887.

68. _______, 1971. Interstitial water chemistry: Deep Sea Drilling Project, Leg 8. I.R. DSDP, 8:853-856.

69. _______, 1972. Interstitial water chemistry: Deep Sea Drilling Project, Leg 9. I.R. DSDP, 9:841-844.

70. _______, 1972. Interstitial water chemistry: Deep Sea Drilling Project, Leg 11. I.R. DSDP, 11: 1009-1012.

71. Presley, B. J., Petrowski, C., and Kaplan, I. R., 1973. Interstitial water chemistry: Deep Sea Drilling Project, Leg 10. I.R. DSDP, 10:613-614.

72. _______, 1973. Interstitial water chemistry: Deep Sea Drilling Project, Leg 13. I.R. DSDP, 13: 809-811.

73. _______, 1973. Interstitial water chemistry: Deep Sea Drilling Project, Leg 14. I.R. DSDP, 14: 763-765.

74. _______, 1973. Interstitial water chemistry, Leg 16. I.R. DSDP, 16: 573-574.

75. _______, 1973. Interstitial water chemistry, Leg 12. I.R. DSDP, 16: 891-892.

76. Ricchiuto, T. E., and McKenzie, J. A., 1978. Stable isotopic investigation of Messinian sulfate samples from DSDP Leg 42A, eastern Mediterranean Sea. I.R. DSDP, 42A:657-660.

77. Rogers, M. A., van Hinte, J. E., and Sugden, J. G., 1972. Organic carbon C^{13} values from Cretaceous, Tertiary, and Quaternary marine sequences in the North Atlantic. I.R. DSDP, 12:1115-1126.

78. Rothe, P., and Hoefs, J., 1979. Isotopic composition of Cretaceous shallow-water carbonates from Site 384. I.R. DSDP, 43:719-720.

79. Shackleton, N. J., and Kennett, J. P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP Sites 277, 279, and 281. I.R. DSDP, 29:743-755.

80. _______, 1975. Late Cenozoic oxygen and carbon isotope changes at DSDP Site 284. Implications for glacial history of the Northern Hemisphere and Antarctica. I.R. DSDP, 29:801-807.

81. Shanks, W. C., Bischoff, J. L., and Kaplan, I. R., 1974. Sulfur isotope studies of evaporites and shales from Sites 225, 227, and 228 in the Red Sea. I.R. DSDP, 23:947-950.

82. Simoneit, B. R. T., 1978. Leg 41 sediment lipids -- search for eolian organic matter in Recent samples and examination of a black shale. I.R. DSDP, 41:855-858.

83. _______, 1979. Lipid analyses of sediments from Site 364 in the Angola Basin, DSDP Leg 40. I.R. DSDP, 38:(Suppl.):659-662.

84. _______, 1978. Organic geochemistry of terrigenous muds and various shales from the Black Sea, DSDP Leg 42B. I.R. DSDP, 42B:749-753.

85. _______, 1979. Organic geochemistry of the shales from the northwestern Protoatlantic, DSDP Leg 43. I.R. DSDP, 43:643-649.

86. Stuermer, D. H., and Simoneit, B. R. T., 1978. Varying sources for the lipids and humic

substances at Site 391, Blake-Bahama Basin, DSDP Leg 44. I.R. DSDP, 44:587-591.

87. van Donk, J., and Mathieu, G., 1973. Interstitial water studies, Leg 15, isotopic measurements on CO_2 gas from gas pockets in deep-sea cores, Site 147. I.R. DSDP, 20:775-776.

88. van Donk, J., Saito, T., and Shackleton, N. J., 1973. Oxygen isotopic composition of benthonic and planktonic foraminifera of Earliest Pliocene age at Site 132, Tyrrhenian Basin. I.R. DSDP, 13: 798-800.

89. Vergnaud Grazzini, C., 1978. Miocene and Pliocene oxygen and carbon isotopic changes at DSDP Sites 372, 374, and 375: Implications for the pre-Messinian history of the Mediterranean. I.R. DSDP, 42A:829-836.

Table 1. Distribution of stable-isotope data by volume and isotope.

Volume	H^2	C^{13}	O^{18}	S^{34}	No Isotope Data
1	52				
2					X
3					X
4					X
5		65			
6		15, 66	15	66	
7		67			
8		68			
9		69			
10		71			
11		70			
12		77			
13	31	31, 44, 49, 50, 72, 88	31, 44, 49, 50, 88	31	
14	73				
15					X
16		74, 75			
17		11, 16, 63	11, 16		
18					X
19		10	10		
20	33, 51	45, 51, 64, 87	45, 48, 51, 87		
21					X
22					X
23	34	12, 46	12, 46	81	
24		25			
25					X
26		8			
27					X
28					X
29		79, 80	79, 80		
30		18	18		
31		26, 27		27	
32		17	17		
33					X
34			60	30	
35		1	1, 28, 36		
36					X
37			38, 40, 61	43	
38		19, 59			
39		4	4		
40		32			
41	2	2, 5, 7, 14, 20, 82	5, 7		
Suppl. to 38-41		21, 83	37		
42A	62	3, 9, 35, 39, 56, 57, 62, 89	3, 9, 35, 39, 54, 56, 57, 62, 76, 89	62, 76	
42B	53	13, 22, 29, 41, 42, 84	13, 41		
43		6, 23, 78, 85	6, 58, 78		
44		24, 47, 55, 86	47		

Table 2. Distribution of stable-isotope data by sample type.

Sample Type	H^2	C^{13}	O^{18}	S^{34}
Sediment, organic	2	2, 8, 10, 14 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 32, 39, 42, 55, 59, 77, 82, 83, 84, 85, 86, 87		
Sediment, fossils		4, 5, 6, 9, 12, 15, 16, 17, 50, 79, 80, 88, 89	4, 5, 6, 9, 12, 15, 16, 17, 50, 79, 80, 88, 89	
Sediment, inorganic (including bulk carbonate)	31, 62	1, 3, 7, 9, 11, 13, 18, 31, 35, 39, 41, 44, 45, 46, 47, 49, 56, 57, 62, 78	1, 3, 7, 9, 11, 13, 18, 28, 31, 35, 39, 41, 44, 45, 46, 47, 49, 56, 57, 62, 76, 78	27, 31, 43, 62, 76, 81
Igneous rocks		1, 3	1, 3, 38, 60, 61	30
Pore water	33, 34, 52, 53	63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75	31, 36, 37, 40, 45, 46, 48, 54, 58	43, 66
Gas	2, 51	2, 10, 14, 29, 32, 42, 51, 59, 87	10, 51, 87	

13. ORGANIC GEOCHEMISTRY

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ORGANIC GEOCHEMISTRY

Techniques of organic geochemistry have been applied to approixmately 2300 samples recovered from sites on 35 of the first 44 legs of the Deep Sea Drilling Project. Information on organic geochemical techniques is contained in 120 chapters in the Initial Reports. Many of these articles describe for the first time occurrences in deep-sea sediments of several different kinds of organic compounds including hydrocarbons, organic acids, alcohols, ketones, amino compound, sugars, pigments, humic compounds, and kerogen. Some objectives of the organic geochemical studies have been (1) to measure the abundance and composition of major classes of organic matter, (2) to characterize significant organic molecules, and (3) to follow the diagenesis of organic matter in sediments. Much of the work on hydrocarbons and kerogen, especially since Leg 38, has been directed toward determining the potential of sediments as source rocks of petroleum. In addition, 33 of the first 44 Initial Reports contain articles in which routine organic carbon analyses are reported for about 10,900 samples.

Although the main purpose of the JOIDES Technical Manual is to summarize and evaluate techniques used in obtaining results during the course of drilling on Legs 1-44, the data from the papers on organic geochemistry do not lend themselves well to this kind of approach. Information on organic geochemistry is scattered in a nonsystematic way throughout the Initial Reports. The object of this paper is to provide a guide to this organic geochemical literature and to facilitate searches for information on aspects of this field that are covered in the Initial Reports, Volumes 1 through 44.

Table 1 is an index organized mainly by compound type. The following major headings are used: Acids (Organic); Alcohols; Amino compounds; Asphaltenes, asphaltics, NSO; Hydrocarbons; Humic compounds; Isotopes; Kerogen; Ketones; Lipids; Pigments; Sugars; Sulfur (Organic); and Summary Articles.

Table 2 lists the legs and sites where samples have been studies for organic geochemistry. This table also shows the number of samples examined at each site. Table 2 should be used in conjunction with Table 1 to determine which compounds have been studied at each site.

Table 3 lists the articles where routine organic carbon determinations are reported. Where organic carbon determinations have not been included in the Initial Reports, these results are available at the Deep Sea Drilling Project.

REFERENCES

1. Ames, R. L., and Littlejohn, R., 1975. Diagenesis of organic matter and estimated temperature history from carbonization measurements, Shikoku Basin. I.R. DSDP, 31:621-627.

2. Anders, D. F., Claypool, G. E., Lubeck, C. M., and Patterson, J. M., 1978. Preliminary results, organic geochemical investigation of Black Sea sediments: Deep Sea Drilling Project, Leg 42B. I.R. DSDP, 42B:755-763.

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

3. Bada, J. L., and Man, E. H., 1973. Racemization of isoleucine in cores from Leg 15, Site 145. I.R. DSDP, 20:947-951.

4. Bada, J. L., Man, E. H., Katz, B. J., and Hsü, K. J., 1978. Racemization of isoleucine in foraminifer tests from Leg 42A, Sites 372 and 376. I.R. DSDP, 42A:489-491.

5. Bada, J. L., Man, E. H., and Walker, A. C., 1977. Racemization of isoleucine in Leg 37, Site 332 and 333 cores. I.R. DSDP, 37:633-636.

6. Baker, E. W., 1969. Porphyrins. I.R. DSDP, 1:498-499.

7. _______, 1970. Tetrapyrrole pigments. I.R. DSDP, 4:431-438.

8. Baker, E. W., Huang, W. Y., Rankin, J. G., Castaño, J. R., Guinn, J. R., and Fuex, A. N., 1977. Electron paramagnetic resonance study of thermal alteration of kerogen in deep-sea sediments by basaltic sill intrusion. I.R. DSDP, 41:839-847.

9. Baker, E. W., Palmer, S. E., and Huang, W. Y., 1978. Chlorin and porphyrin geochemistry of DSDP Leg 40 sediments. I.R. DSDP, 10: 639-647.

10. _______, 1977. Intermediate and late diagenetic tetrapyrrole pigments, Leg 41: Cape Verde Rise and Basin. I.R. DSDP, 41:825-837.

11. _______, 1978. Early and intermediate diagenesis of Black Sea sediments: Sites 379, 380, 381. I.R. DSDP, 42B:707-715.

12. _______, 1978. Miocene and Cretaceous tetrapyrrole pigments from Leg 44, Site 391. I.R. DSDP, 44:639-643.

13. Baker, E. W., Palmer, S. E., and Parrish, K. L., 1976. Tetrapyrrole pigments in DSDP Leg 38 sediments. I.R. DSDP, 38:785-789.

14. Baker, E. W., and Smith, G. D., 1973. Chlorophyll derivatives in sediments, Site 147. I.R. DSDP, 20:943-946.

15. _______, 1975. Chlorophyll derivatives in DSDP Leg 31 sediments. I.R. DSDP, 31:629-632.

16. _______, 1975. Chlorophyll derivatives in DSDP Leg 14, 20, 26, 27, and 29 sediments. I.R. DSDP, 31:905-909.

17. Bogolyvbova, L. J., and Timofeev, P. P., 1976. Plant organic matter in sediments from Hole 336, DSDP Leg 38. I.R. DSDP, 38:815-821.

18. Boon, J. J., van der Meer, F. W., Schuyl, P. J. W., de Leeuw, J. W., Schenck, P. A., and Burlingame, A. L., 1978. Organic geochemical analyses of core samples from Site 362, Walvis Ridge, DSDP Leg 40. I.R. DSDP, 40:627-637.

19. Calder, J. A., Horvath, G. J., Shultz, D. J., and Newman, J. W., 1974. Geochemistry of the stable carbon isotopes in some Indian Ocean sediments. I.R. DSDP, 26: 613-617.

20. Cardoso, J. N., Wardroper, A. M. K., Watts, C. D., Barnes, P. J., Maxwell, J. R., Eglinton, G., Mound, D. G., and Speers, G. C., 1978. Preliminary organic geochemical analyses: Site 391, Leg 44 of Deep Sea Drilling Project. I.R. DSDP, 44:617-623.

21. Cernock, P. J., 1974. Geochemical analyses of potential petroleum source beds. I.R. DSDP, 24: 791-797.

22. Claypool, G. E., and Baysinger, J. P., 1978. Thermal analysis/

pyrolysis of Cretaceous sapropels: DSDP Leg 44, Hole 391C, Blake-Bahama Basin. I.R. DSDP, 44:635-637.

23. Claypool, G. E., Presley, B. J., and Kaplan, I. R., 1973. Gas analyses in sediment samples from Legs 10, 11, 13, 14, 15, 18, and 19. I.R. DSDP, 19:879-884.

24. Comer, J. B., and Littlejohn, R., 1977. Content, composition, and thermal history of organic matter in Mesozoic sediments, Falkland Plateau. I.R. DSDP, 36:941-944.

25. Davis, J. B., 1969. Petroleum acids. I.R. DSDP, 1:489.

26. Davis, J. B., and Bray, E. E., 1968. Analyses of oil and cap rock from Challenger (Sigsbee) Knoll. I.R. DSDP, 1:415-500.

27. Deroo, G., Herbin, I. P., and Roucaché, J., 1978. Organic geochemistry of some Neogene cores from Sites 374, 375, 377, and 378: Leg 42A, eastern Mediterranean Sea. I.R. DSDP, 42A:465-472.

28. Deroo, G., Herbin, J. P., Roucaché, J. R., Tissot, B., Albrecht, P., and Dastillung, M., 1978. Organic geochemistry of some Cretaceous claystones from Site 391, Leg 44, western North Atlantic. I.R. DSDP, 44:593-598.

29. Deroo, G., Herbin, J. P., Roucaché, J., Tissot, B., Albrecht, P., and Schaeffle, J., 1977. Organic geochemistry of some Cretaceous black shales from Sites 367 and 368, Leg 41, Eastern North Atlantic. I.R. DSDP, 41:865-873.

30. Doose, P. R., Sandstrom, M. W., Jodele, R. Z., and Kaplan, I. R., 1977. Interstitial gas analysis of sediment samples from Site 368 and Hole 369A. I.R. DSDP, 41:861-863.

31. Dow, W. G., 1977. Contact metamorphism of kerogen in sediments from Leg 41: Cape Verde Rise and Basin. I.R. DSDP, 41:821-824.

32. ________, 1978. Geochemical analyses of samples from Holes 391A and 391C, Leg 44: Blake-Bahama Basin. I.R. DSDP, 44:625-633.

33. Erdman, J. G., Borst, R. L., and Scalan, R. S., 1969. Composition of gas sample 1 by components. I.R. DSDP, 1:461-467.

34. ________, 1969. Studies performed on samples from Challenger Knoll. I.R. DSDP, 1:456-460.

35. Erdman, J. G., and Schorno, K. S., 1976. Geochemistry of carbon, DSDP Leg 38. I.R. DSDP, 38:791-799.

36. ________, 1977. Geochemistry of carbon: Deep Sea Drilling Project, Leg 41. I.R. DSDP, 41:849-853.

37. ________, 1978. Geochemistry of carbon: Deep Sea Drilling Project, Leg 40. I.R. DSDP, 40:651-658.

38. ________, 1978. Geochemistry of carbon: Deep Sea Drilling Project, Leg 42A. I.R. DSDP, 42B:717-721.

39. ________, 1978. Geochemistry of carbon: Deep Sea Drilling Project, Leg 44. I.R. DSDP, 44:605-615.

40. ________, 1979. Geochemistry of carbon: Deep Sea Drilling Project, Leg 43. I.R. DSDP, 43:651-655.

41. Erdman, J. G., Schorno, K. S., and Scalan, R. S., 1974. Geochemistry of carbon: DSDP Legs 22, 24, 26, 27, and 28. I.R. DSDP, 24:1169-1176.

42. ________, 1975. Geochemistry of carbon and sulfur: DSDP Leg 29. I.R. DSDP, 31:911-916.

43. ________, 1975. Geochemistry of carbon: DSDP Leg 31. I.R. DSDP, 31:633-638.

44. Evans, E. D., Bray, E. E., Bendoraitis, J. G., and Middleton, H. R., 1969. Hydrocarbon group type analysis. I.R. DSDP, 1:492-497.

45. Evans, E. D., and Orr, W. L., 1969. Extraction of Core 5-1. I.R. DSDP, 1:426-427.

46. Faber, E., Schmitt, M., and Stahl, W., 1978. Carbon isotope analyses of head space methane from samples of Leg 42B, Sites 379, 380, and 381. I.R. DSDP, 42:667-672.

47. Foresman, J. B., 1978. Organic geochemistry: DSDP Leg 40, Continental Rise of Southwest Africa. I.R. DSDP, 40:557-567.

48. Geodekyan, A. A., Ulmishek, G. F., Tcherova, T. G., Avilov, V. I., Bokovoy, A. P., Verkhovskaya, Z. I., and Fedorova, M. S., 1978. Bituminological studies of the samples from Site 379 and laboratory simulation of dispersed organic matter transformation. I.R. DSDP, 42B:683-696.

49. Hahn-Weinheimer, P., Fabricices, F., Müller, J., and Sigl, W., 1978. Stable isotopes of oxygen and carbon in carbonates and organic material from Pleistocene to upper Miocene sediments at Site 374 (DSDP Leg 42A). I.R. DSDP, 42A:483-488.

50. Hare, P. E., 1973. Amino acids, amino sugars, and ammonia in sediments from the Cariaco Trench. I.R. DSDP, 20:941-942.

51. Hoering, T. C., 1973. Characterization of the organic matter in a Site 147 core from the Cariaco Trench. I.R. DSDP, 20:937-939.

52. Hood, A., Castaño, J. R., and Kendrick, J. W., 1976. Petroleum-generating potential and thermal history of DSDP Leg 38 sediments. I.R. DSDP, 38:801-803.

53. Huc, A. Y., Durand, B., and Monin, J. C., 1978. Humic compounds and kerogens in cores from Black Sea sediments, Leg 42B -- Holes 379A, B, and 380A. I.R. DSDP, 42B:737-748.

54. Hunt, J. M., 1973. Organic geochemical studies: Introduction and Summary. I.R. DSDP, 20:905.

55. ________, 1974. Hydrocarbon and kerogen studies. I.R. DSDP, 22:673-675.

56. ________, 1974. Hydrocarbon and kerogen studies on Red Sea and Gulf of Aden cores. I.R. DSDP, 24:1165-1167.

57. ________, 1975. Hydrocarbon studies. I.R. DSDP, 31:901-903.

58. ________, 1976. C_4-C_7 alkane yield. I.R. DSDP, 38:807-808.

59. ________, 1978. Light hydrocarbons in Holes 361 and 364, Leg 40. I.R. DSDP, 40:649-650.

60. Hunt, J. M., and Whelan, J. K., 1977. Light hydrocarbons at Sites 367-370, Leg 41. I.R. DSDP, 41:859.

61. ________, 1978. Dissolved gases in Black Sea sediments. I.R. DSDP, 42B:661-665.

62. _______, 1978. Light hydrocarbons, in sediments of DSDP Leg 44 holes. I.R. DSDP, 44:651-652.

63. Kendrick, J. W., 1979. Geochemical studies of black clays from Leg 43, Deep Sea Drilling Project. I.R. DSDP, 43:633-642.

64. Kendrick, J. W., Hood, A., and Castaño, J. R., 1977. Petroleum-generating potential of sediments from Leg 41, Deep Sea Drilling Project. I.R. DSDP, 41:817-819.

65. _______, 1978. Petroleum-generating potential of sediments from Leg 40, Deep Sea Drilling Project. I.R. DSDP, 40:671-676.

66. _______, 1978. Petroleum-generating potential of sediments from Leg 44, Deep Sea Drilling Project. I.R. DSDP, 44:599-603.

67. _______, 1978. Petroleum-generating potential of sediments from the eastern Mediterranean and Black Seas. I.R. DSDP, 42B:729-735.

68. _______, 1979. Petroleum-generating potential of Cretaceous sediments from Leg 43, Deep Sea Drilling Project. I.R. DSDP, 43:663-668.

69. King, J. D., and White, D. C., 1978. Muramic acid as a measure of microbial biomass in Black Sea sediments. I.R. DSDP, 42B:765-770.

70. Koons, B., and Monaghan, P. H., 1969. Data and discussion of analyses by Esso Production Research Company, including C^{12}/C^{13} ratios. I.R. DSDP, 1:478-489.

71. Kvenvolden, K. A., 1976. Organic geochemistry, Leg 38: Introduction to studies. I.R. DSDP, 38:783-784.

72. _______, 1977. Organic geochemistry Leg 41: Introduction and summary. I.R. DSDP, 41:815.

73. _______, 1978. Introduction to organic geochemistry studies, DSDP Leg 44. I.R. DSDP, 44:585.

74. McIver, R. D., 1971. JOIDES cores-evidence of migration of hydrocarbons in Pleistocene sediments of the Shatsky Plateau, western Pacific Ocean. I.R. DSDP, 6:1327-1329.

75. _______, 1971. Organic geochemical analyses of frozen samples from DSDP Leg 8 cores. I.R. DSDP, 8:871-872.

76. _______, 1972. Bitumens and organic carbon in samples from DSDP Leg 9 cores. I.R. DSDP, 9:857-858.

77. _______, 1973. Cyclical geochemical properties of organic matter in Cariaco Basin cores -- Leg 15, Site 147. I.R. DSDP, 20:935-936.

78. _______, 1973. Geochemical significance of gas and gasoline-range hydrocarbons and organic matter in Miocene samples from Site 134 -- Balearic Abyssal Plain. I.R. DSDP, 13:813-816.

79. _______, 1973. Hydrocarbon gases from canned core samples -- Sites 174A, 176, and 180. I.R. DSDP, 18:1013-1014.

80. _______, 1973. Hydrocarbons in canned muds from Sites 185, 186, 189, 191 -- Leg 19. I.R. DSDP, 19:875-877.

81. _______, 1973. Low residual gas contents of four Leg 21 canned-sediment samples. I.R. DSDP, 21:721.

82. _______, 1974. Analysis of ten Leg 22 cores for organic carbon

and gasoline-range hydrocarbons. I.R. DSDP, 22:671.

83. ________, 1974. Gaseous and heavy hydrocarbons in canned core samples from Leg 24, DSDP. I.R. DSDP, 24:1157-1158.

84. ________, 1974. Methane in canned core samples form Site 262, Timor Trough. I.R. DSDP, 27:453-454.

85. ________, 1974. Residual gas contents of organic-rich canned sediment samples from Leg 23. I.R. DSDP, 23:971-973.

86. ________, 1975. Hydrocarbon gases in canned core samples from Leg 28, Sites 271, 272, and 273, Ross Sea. I.R. DSDP, 28:815-817.

87. ________, 1975. Organic-matter lean sediments of Site 278, Leg 29, DSDP. I.R. DSDP, 31:899-900.

88. ________, 1978. Residual hydrocarbon gases in canned core material from Holes 379A and 380A, Leg 42B. I.R. DSDP, 42B:679-681.

89. McIver, R. D., and Rogers, M. A., 1978. Insoluble organic matter and bitumens in Leg 44 samples. I.R. DSDP, 44:645-649.

90. Mommessin, P. R., Hood, A., Ellington, W. E., and Mannel, A. F., 1969. Analyses of organic matter in Core 5, Leg 1, Site 2. I.R. DSDP, 1:468-477.

91. Mopper, K., Michaelis, W., Garrasi, C., and Degens, E. T., 1978. Sugars, amino acids, and hydrocarbons in Black Sea sediment from DSDP Leg 42B cores. I.R. DSDP, 42B:697-705.

92. Morris, D. A., 1976. Organic diagenesis of Miocene sediments from Site 341, Vørring Plateau, Norway. I.R. DSDP, 38:809-814.

93. Palmer, S. E., Huang, W. Y., and Baker, E. W., 1979. Tetrapyrrole pigments from Bermuda Rise: DSDP Leg 43. I.R. DSDP, 43:657-661.

94. Paulus, F. J., 1972. Leg 11 measurements of physical properties in sediments of the western North Atlantic and their relationship to sediment consolidation. I.R. DSDP, 11:667-722.

95. Raymaud, J. F., and Robert, P., 1978. Microscopical survey of organic matter from DSDP Sites 361, 362, and 364. I.R. DSDP, 40:663-669.

96. Rogers, M. A., van Hinte, J. E., and Sugden, J. G. 1972. Organic carbon ^{13}C values from Cretaceous, Tertiary, and Quaternary marine sequences in the North Atlantic. I.R. DSDP, 12:1115-1121.

97. Silverman, S. R., 1969. Reference to C^{13}/C^{12} ratio of Challenger Knoll oil. I.R. DSDP, 1:500.

98. Simoneit, B. R. T., 1973. Identification of isoprenoidal ketones in Deep Sea Drilling Project core samples and their geochemical significance. I.R. DSDP, 21:909-923.

99. ________, 1974. Complex triterpanoidal acids and hydrocarbons in DSDP core samples and their geochemical significance. I.R. DSDP, 24:1159-1163.

100. ________, 1976. Sources of the solvent-soluble organic matter in the glacial sequence of DSDP samples from the Norwegian-Greenland Sea, Leg 38. I.R. DSDP, 38:805-806.

101. _______, 1977. Leg 41 sediment lipids -- search for eolian organic matter in recent samples and examination of a black shale. I.R. DSDP, 41:855-858.

102. _______, 1977. Search for terrigenous lipids in carbonate-rich samples from Site 39-354. I.R. DSDP, 39:497-500.

103. _______, 1978. Lipid analyses of sediments from Site 364 in the Angola Basin, DSDP Leg 40. I.R. DSDP, 40:659-662.

104. _______, 1978. Organic geochemistry of terrigenous muds and various shales from the Black Sea, DSDP Leg 42B. I.R. DSDP, 42B:749-753.

105. _______, 1979. Organic geochemistry of the shales from the northwestern proto-Atlantic, DSDP Leg 43. I.R. DSDP, 43:643-649.

106. Simoneit, B. R., and Burlingame, A. L., 1971. Further preliminary results on the higher molecular weight hydrocarbons and fatty acids in the DSDP cores, Legs 5-8. I.R. DSDP, 8:873-900.

107. _______, 1971. Some preliminary results on the higher molecular weight hydrocarbons and fatty acids in the Deep Sea Drilling Project cores, Legs 5-7. I.R. DSDP, 7:889-912.

108. _______, 1972. Further preliminary results on the higher molecular weight hydrocarbons and fatty acids in the DSDP cores, Leg 9. I.R. DSDP, 9:859-901.

109. _______, 1973. Preliminary organic analyses of DSDP cores, Legs 12 and 13. I.R. DSDP, 17: 561-590.

110. _______, 1974. Preliminary organic geochemical analyses of the Site 217 core samples in the Bengal Basin, DSDP Leg 22. I.R. DSDP, 22:681-692.

111. Simoneit, B. R., Howells, W. G., and Burlingame, A. L., 1973. Preliminary organic geochemical analyses of the Cariaco Trench Site 147 Deep Sea Drilling Project, Leg 15. I.R. DSDP, 20:907-933.

112. Simoneit, B. R., Scott, E. S., and Burlingame, A. L., 1973. Prelimimary organic analyses of the Deep Sea Drilling Project cores, Leg 10. I.R. DSDP, 10: 625-636.

113. _______, 1973. Preliminary organic analyses of DSDP cores, Leg 14, Atlantic Ocean. I.R. DSDP, 16:575-600.

114. Simoneit, B. R., Scott, E. S., Howells, W. G., and Burlingame, A. L., 1972. Preliminary organic analyses of the Deep Sea Drilling Project cores, Leg 11. I.R. DSDP, 11:1013-1045.

115. Smith, G. D., and Baker, E. W., 1974. Chlorophyll derivatives in DSDP Leg 22 sediments. I.R. DSDP, 22:677-679.

116. Stuermer, D. H., and Simoneit, B. R. T., 1978. Varying sources for the lipids and humic substances at Site 391, Blake-Bahama Basin, DSDP Leg 44. I.R. DSDP, 44:587-591.

117. Swain, F. M., and Bratt, J. M., 1978. Carbohydrate residues in Leg 44 core samples. I.R. DSDP, 44:653-654.

118. Vuchev, V. T., Ivanov, C. P., St. Kabakchieva, M., Petrov, L. L., Stojanova, R. Zh., Stephanov, D. D., Djakova, D. N., and Petrova, L. K., 1978. Preliminary organic geochemical studies of DSDP cores, Leg 42B, Black Sea. I.R. DSDP, 42B:723-728.

119. Wehmiller, J. F., and Hare, P. E., 1972. Amino acid content of some samples from the Deep Sea Drilling Program. I.R. DSDP, 9: 903-905.

120. Whelan, J. K., and Hunt, J. M., 1978. C_1-C_7 hydrocarbons in Holes 378A, 380/380A, and 381. I.R. DSDP, 42B:673-677.

Table 1. Compound types.

Compound	References
Acids (organic)	
Dicarboxylic acids	20, 114
Hydroxy acids	18, 20
Isoprenoid acids (also includes iso- and anteiso-)	18, 20, 101, 103, 105
Naphthenic acids	25, 26
Saturated fatty acids	18, 51, 101, 103-109, 111-114
Terpenoid acids	20, 99, 101-105, 116
Unsaturated acids	18, 20, 114
Alcohols	
Fatty alcohols	18, 51
Sterols	106, 108, 111
Amino Compounds	
Amino acids	3-5, 50, 91, 118, 119
Amino sugars	50, 69, 91
Amines	50
Asphaltenes, Asphaltics, NSO	21, 27-29, 31, 32, 36, 39, 40, 48, 55-57, 70, 73, 76, 77, 80, 89, 90, 92
Hydrocarbons	1, 2, 8, 18, 20, 21, 23, 24, 26-33, 36, 38-40, 44, 46-48, 55-61, 66, 70, 74-92, 94, 99-104, 106-116, 118, 120
Alkanes (saturated)	2, 8, 18, 20, 21, 23, 24, 26-33, 36, 38-40, 44, 46-48, 55-62, 70, 74-92, 94, 100-114, 116, 118, 120
C_1-C_2	8, 23, 79, 90, 83, 84, 85, 86, 87, 88, 89, 94
C_1-C_4 or C_7	30, 33, 46, 47, 55, 60-62, 78, 81, 86, 92, 120
C_4-C_7 or C_{10}	33, 55, 57-59, 70, 73, 77, 78, 82, 90
C_{10+} or C_{15+}	2, 18, 20, 21, 24, 27-29, 31, 32, 36, 38, 40, 47, 48, 55-57, 70, 73, 74, 76-78, 80, 83, 85, 89-92, 100-114, 116, 118
Alkenes (unsaturated)	2, 20, 29, 101, 104, 105, 111
Aromatic Hydrocarbons	18, 21, 27-29, 31, 32, 36, 39, 44, 48, 55-57, 61, 70, 74, 77, 78, 83, 85, 89, 92, 101, 103-105, 116
Isoprenoid hydrocarbons (pristane, phytane, etc.)	2, 18, 21, 29, 48, 55-57, 89, 90, 100-101, 103-105, 109, 111, 113, 116, 118

Table 1. Compound types. (Cont.)

Compound	References
Steranes	2, 29, 100, 101, 104-106, 108, 109, 111, 113
Triterpanes	2, 20, 29, 99-101, 103, 105, 107, 109, 113
Humic Compounds	27-29, 53, 105, 116, 118
Isotopes	
Carbon	8, 19, 23, 26, 30, 33, 35-43, 46, 47, 49, 61, 70, 77, 88, 89, 92, 96, 97, 101, 103-105, 116, 120
Sulfur	26, 34
Kerogen (includes optical studies)	1, 2, 8, 20-22, 24, 27-29, 31, 32, 35-43, 47, 49, 52, 53, 55, 63-68, 83, 85, 88, 89, 95
Ketones	
Isoprenoid ketones	98, 104, 105, 109
Methyl ketones	104, 105
Pentacyclic ketones	99, 104
Sterones	108, 113
Lipids	20, 35-43, 47, 91, 92, 101-105, 116
Pigments	
Carotenoids	20
Tetrapyrroles	
Chlorins	7, 9-16, 93, 115
Porphyrins	6, 7, 9-13, 15, 16, 26, 93, 103, 115
Sugars	91, 117
Sulfur (organic)	26, 34, 63
Summaries	54, 71-73

Table 2. Legs and sites with organic geochemical information.

Leg	Sites	No. Samples	Reference
1	2	18	26
4	26, 27, 30	3	7
	30	1	74
5	34, 35	2	74
	32, 33, 34, 35, 36, 37, 38, 40, 42	16	107
	36, 42	2	119
6	47, 49, 50	3	74
	47, 49, 50, 51, 52, 53, 55, 56, 58	13	107
	47	1	119
7	62, 64, 65, 66	8	107
	62, 64	2	119
8	73, 74, 75	4	75
	72, 73, 74, 75	6	106
9	78, 80, 82, 83, 84	6	76
	77, 78, 79, 80, 82, 83, 84	10	108
	82	1	119
10	90, 92	2	112
	88, 90, 91	14	23
	90, 92	2	98
	92	1	99
11	102, 103, 104, 106B	19	94
	98, 105	2	114
	102, 104, 106	8	23
	105	1	98
	105	1	99
12	111, 112, 116, 118, 119	153	96
	112, 114	2	109
	112, 114	2	98
13	134	1	78
	128, 130, 134	4	109
	128	3	23
	128, 130	3	98
	125	1	67
14	138, 144	6	113
	144	2	23
	138, 144	5	98
	144	2	16
15	147, 154	12	23
	147	3	111
	147	1	51
	147	3	50
	147	7	14
	148	12	3
	147	8	77
	147	4	98
18	174, 176, 180	29	79
	174, 176	9	23
	174, 176, 180	29	86

Table 2. Legs and sites with organic geochemical information. (Cont.)

Leg	Sites	No. Samples	Reference
19	185, 186, 189, 191	19	80
	185, 186, 189, 191	4	23
	185, 186, 189, 191	19	86
20	198	1	16
21	204, 210	4	81
	204, 210	4	86
22	217, 218	10	82
	217, 218	4	55
	217, 218	10	115
	217	4	110
	217, 218	8	41
23	222, 229	6	85
	229	1	56
	222, 229	6	86
24	231	3	21
	231, 232	9	83
	232, 233	5	56
	233	4	41
	231, 232	9	86
26	250, 254, 257	3	41
	252, 253, 254, 256, 257, 258	72	19
	250	1	16
27	259, 263	2	41
	262	11	84
	262	11	86
	259, 263	2	57
	259, 263	2	16
28	267	1	41
	271, 272, 273	21	86
	265	1	57
29	278	12	87
	280, 281, 282	15	57
	280, 281	5	16
	280, 281, 282	12	42
31	297, 298	21	1
	299, 302	11	15
	299, 302	11	43
36	327A, 330	10	24
37	332A, 333	6	5
38	336, 338, 341, 343, 344, 345, 346	36	13
	338, 339, 341, 344, 346, 348, 349	42	35
	338, 341, 342, 343, 344, 346, 348, 350	39	52
	339, 345	4	100
	336, 338, 345, 348	13	58
	341	34	92
	336	27	17
39	354	2	102
	356	10	47
	356	1	9

Table 2. Legs and sites with organic geochemical information. (Cont.)

Leg	Sites	No. Samples	Reference
40	360, 361, 362, 362A, 363, 364, 365	136	47
	362	4	18
	361, 362, 363, 364	19	9
	361, 364	10	59
	361, 362, 362A	40	37
	364	3	103
	361, 362, 364	8	95
	361, 362, 363, 364, 365	29	65
	364	1	105
41	367, 368, 369, 370	6	64
	367, 368	6	31
	367, 368, 369, 369A, 370	28	10
	367, 368	30	8
	368	11	36
	367, 369	3	101
	367, 368, 369, 370	6	60
	368, 369A	22	30
	367, 368	7	29
42A	374, 375, 377, 378	32	27
	374	23	49
	372, 376	3	4
	376	4	38
	376, 378	4	67
42B	379A, 380/380A, 381	300	61
	379A, 379B, 380A, 380B, 381	44	46
	379, 380/380A, 381	38	120
	379A, 380A	9	88
	379, 379A	23	48
	379A, 380A, 381	25	91
	379A, 379B, 380, 380A, 381	25	11
	380	10	38
	379A, 381	6	118
	379, 380, 381	21	67
	379A, 379B, 380A	63	53
	379A, 380A, 381	11	104
	379A, 379B, 380, 380A, 381	67	2
	379A, 379B, 380	10	69
43	386, 387	24	63
	386, 387	4	105
	386	7	40
	382, 386, 387	16	93
	386, 387	13	68
44	391A, 391B, 391C	8	116
	391A, 391C	8	28
	391, 392	15	66
	388A, 390, 390A, 391, 391A, 391C	37	39
	391A, 391C	18	20
	391A, 391C	15	32
	391C	4	22
	391A, 391B, 391C	12	12
	388A, 391A, 391C	18	89
	388A, 391C	7	62
	390, 391A, 391B, 391C, 392	15	117

Table 3. Organic carbon determinations.

Leg	Authors	Volume	Pages	No. of Samples Analyzed
1	DSDP	1	340-347	127
2	DSDP	2	319-321	37
3	A. C. Pimm	3	495-507	404
4	A. C. Pimm	4	307-314	225
5	T. L. Vallier	5	431-440	286
6	A. C. Pimm	6	739-752	422
7	E. L. Gealy	7 Pt. 2	845-862	513
8	DSDP	8	1017-1036	688
9	R. E. Boyce, G. W. Bode	9	797-816	645
10	R. E. Boyce	10	641-642	93
11	R. E. Boyce	11	1059-1071	466
15	G. W. Bode	15	1129-1137	934
16	G. W. Bode, D. S. Cronan	16	521-528	732
17	G. W. Bode	17	927-930	376
18	G. W. Bode	18	1069-1076	788
19	G. W. Bode	19	663-665	217
20	G. W. Bode	20	741-742	80
23	G. W. Bode	23	1131-1135	320
24	G. W. Bode	24	1155-1156	78
25	W. A. Girdley	25	841[a]	196
27	G. W. Bode	27	499-502	329
30	D. H. Cameron	30	687-688	124
32	G. W. Bode	32	561-562	123
33	D. H. Cameron	33	959-963	471
34	D. H. Cameron	34	601-602	135
35	D. H. Cameron	35	755-756	38
36	D. H. Cameron	36	1047-1050	144
37	G. W. Bode	37	637-639	93
38	K. Thompson	38 Suppl.	433-436	309
39	B. Scott	39	501-504	182
42A	R. B. Kidd	42 Pt. 1	1151-1156	321
42A	W. Siyl	42 Pt. 1	1221-1224	392
43	D. H. Cameron	43	1043-1047	233
44	R. Myers	44	983-986	360

[a]Table of data is missing in this *Initial Report*.

PART IV. OVERVIEW

14. INFORMATION HANDLING

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INTRODUCTION

Information handling comprises both the calculations necessary to generate data from a given observation or experiment and the later manipulation and management of complete files of data. In this chapter we attempt to summarize the events that befall the data subsequent to their generation and calculation by the techniques described in the previous chapters of this manual. In those chapters that deal with experimental method and related calculation a change in method may significantly influence the interpretation of results; the description and timing of such changes have been described. The consideration of data management in this chapter requires no such extensive retrospection; the original data values are never lost or changed during the evolution of the information handling system.

The total responsibility for all activities concerning data collected under the scientific program of the Deep Sea Drilling Project lies with the Scientific Services Section at DSDP. The functions of this section are shown on Fig. 1; advice and guidance are given by the JOIDES Advisory Panel on Information Handling. Some of the associated independent programs (e.g., heat flow and organic geochemistry) at present maintain their own data files. These are discussed in the appropriate chapters.

It is altogether proper that this discussion of information handling be included in this manual on sampling and analytical techniques. During 1967, when the original JOIDES Panel on Sedimentary Petrology and Geochemistry was selecting parameters to be measured and developing techniques and procedures, subsequent data handling and processing were considered vital and integral to the process. In October of that year it was decided to form a sub-panel to consider specifically the problems of data processing, programming, and distribution. From this beginning, in early 1968 the JOIDES Panel on Information Handling was constituted formally. Information handling at DSDP became an important functional part of the operation.

It is much to the credit of these early planners that a uniform system of core and sample designation and identification was developed. This has continued unchanged and provides a solid basis for correlation of observed and measured core properties. Also, considerable early attention was given to source recording procedures always with a view to the requirements of later data processing. Although shipboard data gathering operations and recording forms have undergone evolutionary changes over the years, the original provisions for subsequent data handling have not been impaired. Considering the large mass of data, the number and variety of properties, and the individual preferences of hundreds of participating scientists, there was always a potential for gross mismanagement of the data. It is gratifying to know that his has not happened.

At present the data-related responsibilities at DSDP include the following broad categories:

Archiving

1) To preserve, as much as possible, the original raw data records including

G. Ross Heath (Ed.), Sedimentology, Physical Properties and Geochemistry in the Initial Reports of the Deep Sea Drilling Project: An Overview. Boulder, Colorado (U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service), 1983.

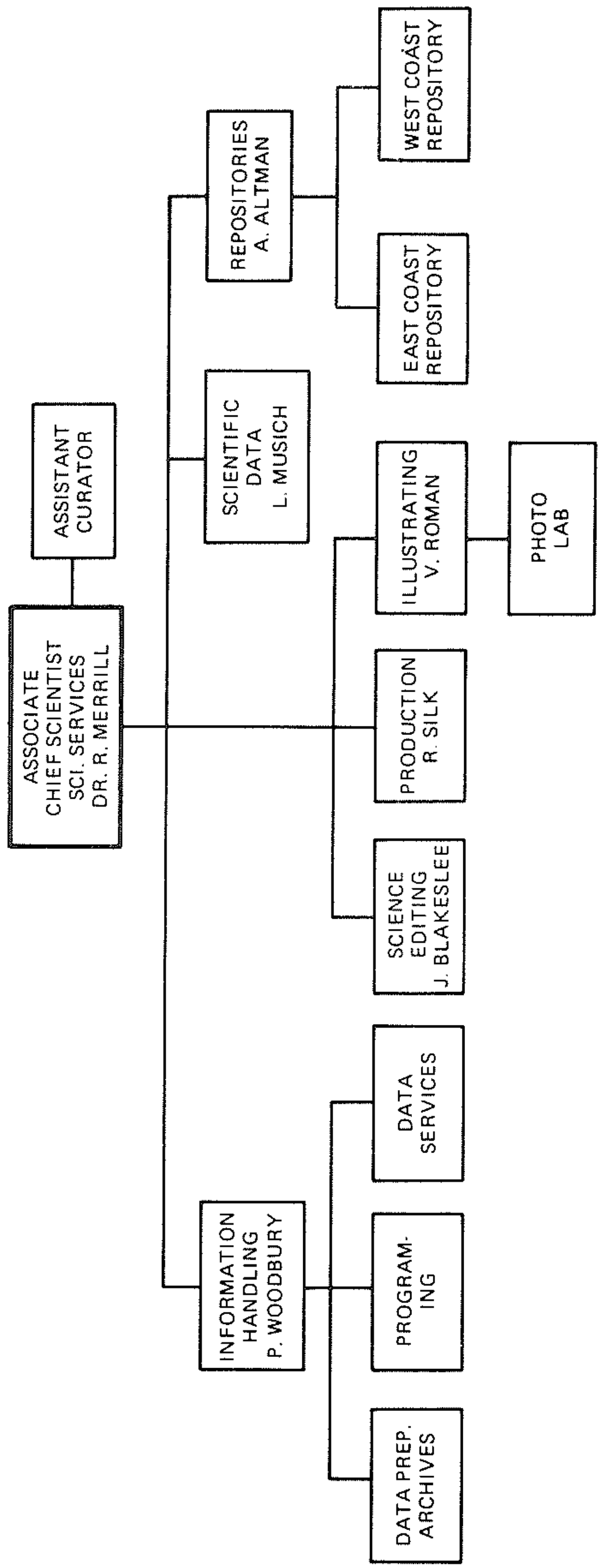


Figure 1. Organization of the scientific services section at DSDP.

all observations by the participating scientists.

2) To encode many of these data into computer-compatible form suitable for retrieval and analysis. (Methods for doing this are described, along with computational procedures, in each technique chapter of this manual.)

Distributing

1) To publish certain primary documents (Initial Core Descriptions and Initial Reports) on a regular basis as soon as possible after the completion of a leg.

2) To furnish, upon request from members of the scientific community, selected segments or combinations of the data at any required level of search.

Processing

1) To prepare the data files and computer programs necessary to support a rational scheme of archiving, to facilitate publication, and to provide easy means to accomplish direct searches for specifically requested data.

2) To write more advanced programs that will provide the capability for more sophisticated use of the data. For example, inverted searches by combinations of parameters are now possible. Also, the ability now exists, using the original raw data, to change the rock name of a sediment if the classification scheme should be changed. Increasingly there will be demands for the continuing development of processing programs that will aid scientists in their use of the data for geologic syntheses and other investigations.

Assisting Researchers

1) To publish, from time to time, guides that describe, in condensed form, the actual core material available for research use. These provide potential users with the information necessary to specify their requirements for both material and more detailed data.

2) To maintain a record of the distribution of core materials and to publish, from time to time, a guide to the investigators who have these materials and for what research purposes they have the material.

3) To develop, publish, and keep up-to-date a comprehensive index of publications resulting from work on DSDP materials. This will provide investigators who receive samples with information about what has been published both in the Initial Reports and in the open literature.

At this point it is necessary to say something about data quality in general. In the processing of data by the Information Handling and Publication Production groups at DSDP every effort has been made to avoid errors of transcription and editing. However, even with care, some errors occur when such large amounts of data are being prepared within tight time constraints. An errata for Volumes 1-44 of the Initial Reports is now available.

As for the merit of the data (precision and accuracy), neither the Information Handling Group nor the Panel has had the resources -- nor , in fact, the mandate -- to investigate these properties. Over the years, we have been greatly concerned that the formality of publication and the carefully designed computer-based files bestow a perhaps undeserved mantle of correctness upon the data. Nevertheless, these are the data that exist; the technique descriptions and error assessments presented in this manual should provide the reader with a basis for judgment. More about this later.

INFORMATION HANDLING CONCEPTS

Basic Principles

In the early stages of DSDP it was not entirely clear what the ultimate role of the information handling system would be, although the goals of archiving the data and publishing the Initial Reports were cearly identified. From the outset, however, all data-related activities, from archiving to publications, were considered to be simply different facets of a single, unified system. This concept dictated the adoption of certain basic principles:

1) The original observational (raw) data should never be changed or lost from the system, regardless of any subsequent processing.

2) There would be no attempt to design a highly sophisticated and complex system that would be all things to all users. Rather, we would strive for a system that could evolve as user needs became better defined.

3) Whatever approach was adopted, it should be flexible enough to adapt to the needs of the scientists and not vice versa.

4) Data should be captured in a way that would facilitate later machine processing.

Application of these principles led to the concept of acquiring the package of routine observational data on standard data sheets and developing a Master Data File, which would form the principal archive and the source for the data appearing in the Initial Reports (besides being the ultimate resource file for any subsequent activities). In fact, the Master Data File was to be a system of coordinated files, continually evolving through various stages of growth from hard copy to full computerization. At any one time, different files would be in various stages of evolution, depending on user needs and the status of software development. Thus, GRAPE data were early candidates for computer processing, whereas now visual core descriptions have moved from hand-written data sheets to computer manageable files. All the files, however, would be coordinated by the common system of core and sample observation designation. In practice the core-sample label is often converted by a standard algorithm into a sub-bottom depth, and the data manipulated and displayed in a sub-bottom depth framework. However, the determination of sub-bottom depths corresponding to specific observations is an interpretive exercise, and the original core-sample label remains the ultimate link among the different data files.

It was recognized that the first demand on the information handling system would be the preparation of the Initial Reports. These were originally conceived as catalog-like publications of all the data regarding the cores that would, in effect, obviate the need for anything more than a publication production facility at DSDP. However, it quickly became apparent that publication of all the data was unrealistic, indeed undesirable, and the present format of data synopsis and preliminary interpretation was adopted. This change in publication philosophy meant that the data storage and retrieval facet of DSDP information handling activities immediately assumed considerable importance.

The demand of a rigorous publication schedule has resulted in the development of procedures and software unique to DSDP and the UCSD computer system. This has been considerably simpler to develop and manage than any interactive system with multiple remote-access capability. However, despite the obvious limitation, the Information Handling Panel concluded that in the absence of any clearly demonstrated need for a multiple-user, remote-access facility the simpler system would meet adequately the needs of the scientific community.

Problems of Implementation

Implementation of such an apparently simple concept produced various complex problems. These are broadly grouped into problems of (1) data capture (2) data reliability and (3) changing user priorities.

Before September 1982, Glomar Challenger had limited scientific computing capabilities. Thus the shipboard demand for immediately available hardcopy data more or less precluded the direct recording of data in machine-readable form. Consequently all data capture and subsequent manipulation aboard ship were done manually. Exceptions to this general rule were some of the underway data and physical properties data that were directly recorded as analog records on paper stripcharts. To simplify the task of recording data accurately and consistently for possible future machine processing we have attempted to use standard data recording forms, and this attempt has been moderately successful. The principal problems have come from three sources: poor design of the original forms; the reluctance and, in some cases, out-and-out refusal of some scientists to use anything that looks remotely like a standard form; and, finally, the fact that a surprising number of original records are not written legibly, so that future transcription becomes difficult if not impossible.

The decision was made at the outset that the design of the data recording forms should place as few constraints as possible on the person making the observations, and that any problems of formating should be dealt with by DSDP personnel in subsequent processing. This approach, while complicating the task of information handling at DSDP, has to a great extent mitigated the problems of poor design of forms and observer resistance. Some of the data recording forms, especially those for numerical data, have changed little from their original design; others, for example, smear slide and visual core description forms, have ranged all the way from rigid complex forms to essentially blank sheets of paper, and back again. Even so, it has been possible to accommodate all the variations successfully into the DSDP system. The problem of illegible handwriting so far has been insoluble.

A second problem associated with data capture has resulted from the lack of any generally acceptable scheme of lithologic nomenclature for deep-sea sediments. Indeed, it was not until DSDP had been operating for more than three years that any consistency began to appear. This problem has now, to a great extent, been overcome by using automated techniques to classify the sediments into a uniform scheme developed by the JOIDES Panel on Sedimentary Petrology and Physical Properties (Davies et al., 1977).

The problems of data reliability are much more complex. There are, of course, those errors of technique and interpretation that may affect the accuracy of the data. This manual has been prepared to allow the scientific community an opportunity to understand these techniques and their limitations. Then there are the random errors of sampling and observation that determine the precision of the data and, in principle, could be treated statistically. Finally, there are many opportunities for human error in the recording and transmittal of data. Fig. 2 shows the series of steps through which data must pass before entering a computer-readable form, or becoming enshrined in the Initial Reports; with each step some of the possibilities are listed for the introduction of discrepancies. Everything possible is done to screen out these errors, and little more can be said about them other than the user of DSDP data should be cognizant of these possible pitfalls.

A particularly troublesome source of error has been in the assignment of sub-bottom depths. There are two sources of discrepancy: the assignment of depths to the cored interval and the assignment of depths to the material

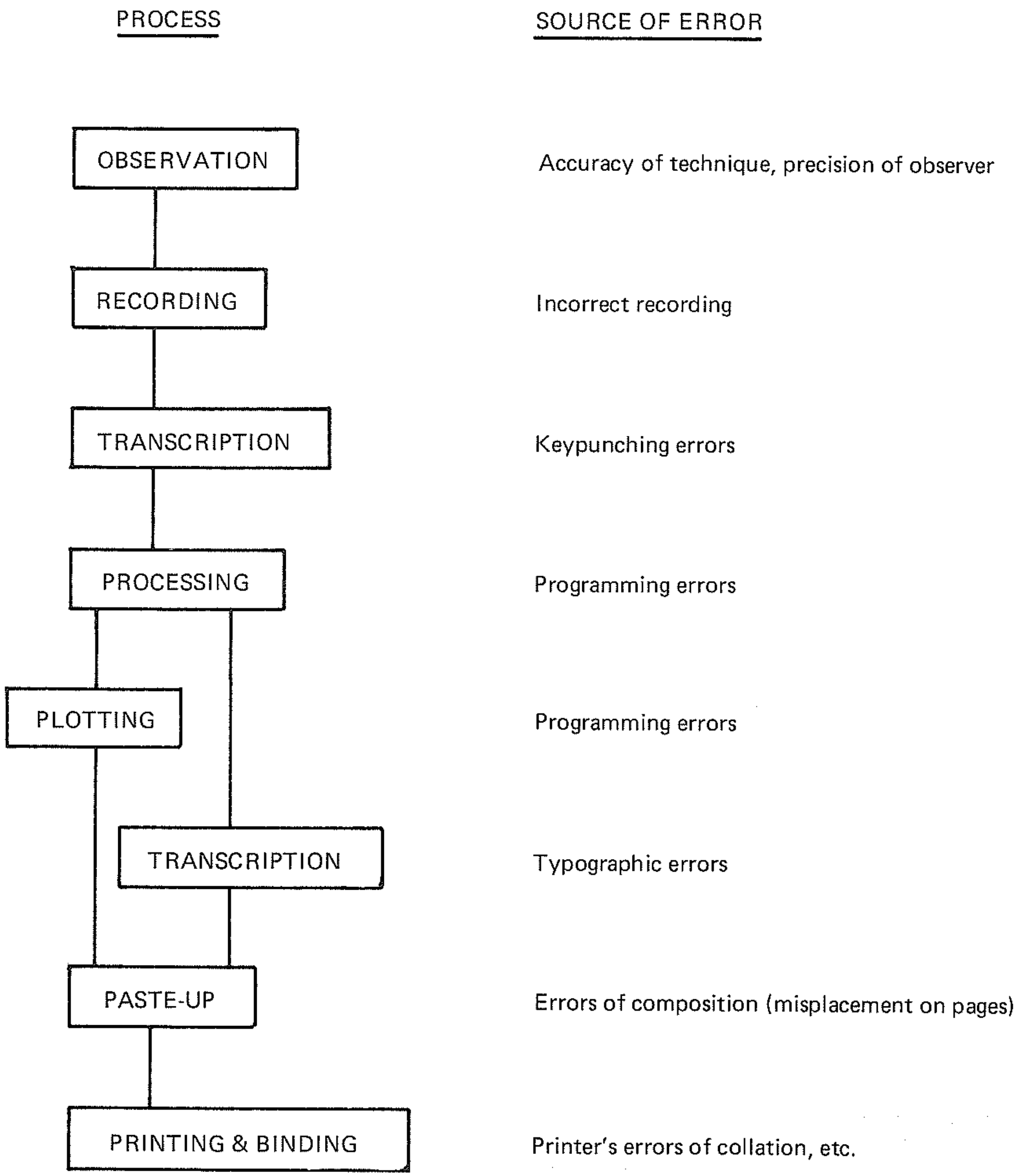


Figure 2. General scheme of data flow in assembly of *Initial Report* to illustrate potential sources of error.

recovered from the cored interval. In each case the problem originates on the ship as one of communication between drillers and scientists and within the scientific party. Ultimately it is resolved, in an admittedly arbitrary fashion, by reference to the core-sample label and an agreed-upon table of sub-bottom depths of cored intervals. However, many preliminary manuscripts and reports by individual scientists contain a significant number of apparently unavoidable discrepanices.

As user priorities have changed, so have the information handling activities of DSDP. Thus, in the early stages emphasis was almost entirely upon preparation and publication of the Initial Reports. An elaborate publication production shop was established, devoted to strenuous efforts to meet a somewhat unrealistic publication schedule. The handwritten data-recording forms were archived, but virtually all data-processing activity was directed toward preparation of the Initial Reports. Later, as publication preparation became routine and the volume of published material swelled, the emphasis switched toward finding ways to assist the user in locating core material or data relevant to his particular research interests. Now the effort is devoted to the problems of a full-scale data storage and retrieval system, generating processed output to meet the needs of investigators with broad regional interests.

PRESENT PROCEDURES

In the Introduction to this chapter the data-related activities of DSDP were summarized as the archiving, processing, and distribution of data, and the preparation of guides and other aids for researchers. In this section we will discuss some of the important features of the overall information handling scheme shown in Fig. 3. Further details of the procedures and capabilities of the Information Handling Group (IHG) are published in a series of bulletins (Data Data) designed to aid the prospective user.

The archiving and processing activities of the IHG at DSDP are so interwoven that they can best be described together. The distribution activities can be divided into publications, a function of the Publication Production Group with support from the IHG, and responding to requests for specific data, a function of the IHG. The preparation of the various aids to research is carried out jointly by the curatorial staff and the IHG.

Archiving and Processing

Virtually all of the original data ever recorded aboard Glomar Challenger are available, in one form or another, in archives at DSDP and at Lamont-Doherty Geological Observatory. The exceptions are data, such as heat flow, gathered aboard the ship as part of special programs ancillary to DSDP, and some X-radiographs of cores that were discarded as valueless after consultation with several experienced sedimentologists. All of the data exist as hardcopy raw data,[1] but many have also been computer-processed to a greater or lesser degree. It should be emphasized, however, that even for data that have been processed, the original raw data are preserved so that the observations may be reexamined and reprocessed by other procedures at any time. Following are descriptions of procedures for handling the various categories of data.

1) Underway data

While underway between sites, bathymetric, magnetic, and sub-bottom profiles are recorded aboard Glomar Challenger. Processing of these underway

[1] A program to convert paper data records to microfilm has been completed.

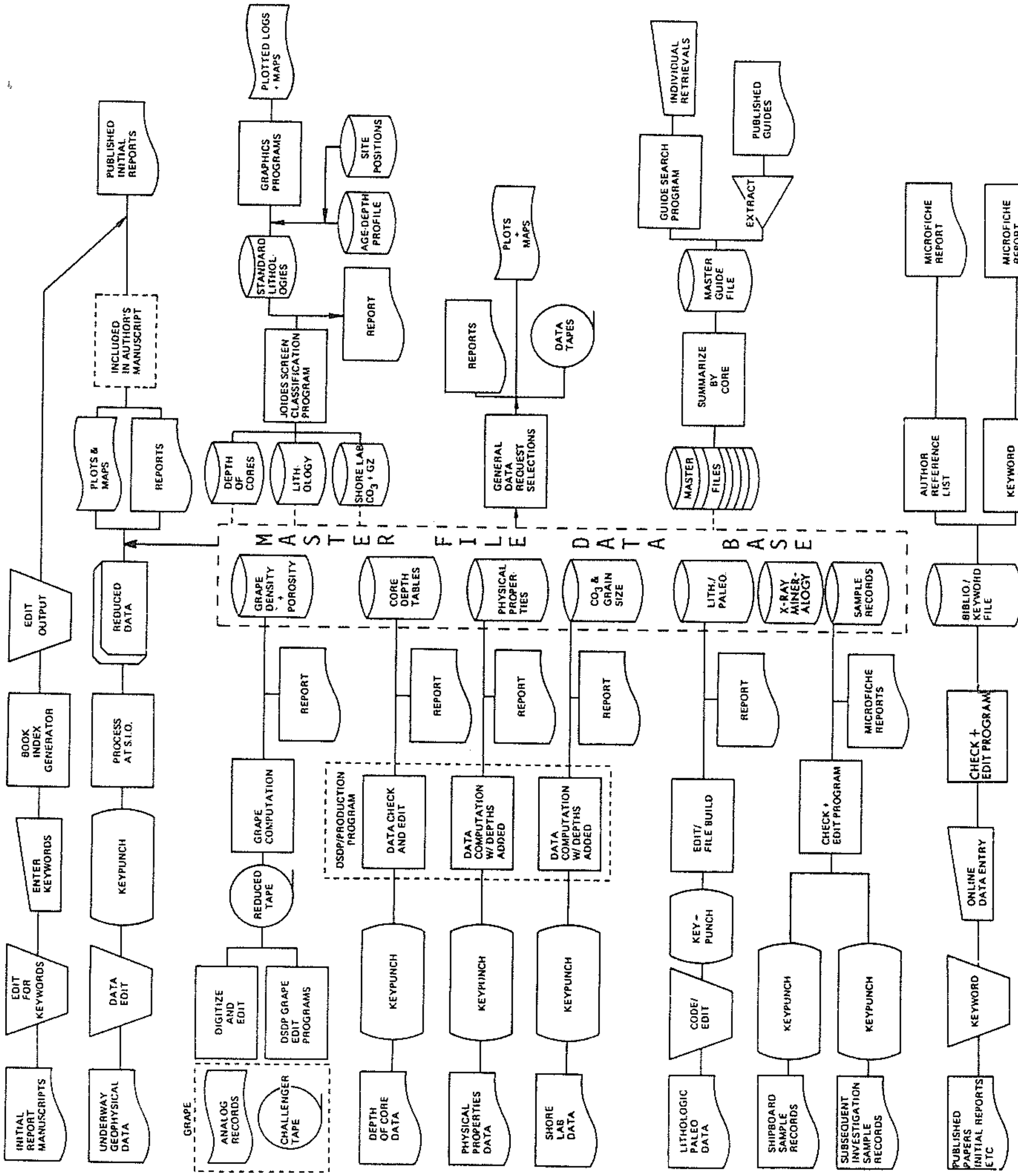


Figure 3. Information flow for deep sea drilling data.

data is handled jointly by DSDP and SIO Geological Data Center.

a) Navigation: Satellite fixes and course and speed changes are recorded aboard Glomar Challenger from data in the Underway Geophysical Log. The data are keypunched on shore and put through a navigation smoothing program, edited on the basis of reasonable ship and drift velocities, and a deck of corrected navigation points is punched out for later merging with the depth and magnetic data.

b) Magnetics: Analog records produced on the Varian magnetometer are recorded in gammas at 5-min intervals in the Geophysical Log, keypunched, put through a profile program, and edited by comparison with the original analog records.

c) Depth: Depths are logged at sea at 5-min intervals from a digital display of the Precision Depth Recorder (PDR). The depths are keypunched on shore from the Geophysical Log and edited in the same fashion as the magnetics.

d) Sub-bottom profiles: These records are photographed at DSDP and then microfilmed at the SIO Geological Data Center.

Commencing with DSDP Leg 22, processed data are summarized in a Preliminary Report and Index of Navigation, Depth, Magnetic and Sub-bottom Profiler Data, which contains an explanation of what forms of data are available from whom, an index chart giving the track of the cruise and the boundaries of the depth compilation plots, and track charts annotated with dates and hour ticks. Copies of this preliminary report are distributed through the SIO Geological Data Center, DSDP, and the National Geophysical Data Center. Original records, plots, and lists of the processed data are stored at DSDP for subsequent publication and for use by prospective investigators.

2) Physical properties and other quantitative core data

Several physical properties of the sediments are routinely recorded on Glomar Challenger as the cores are brought on board. These measurements include: (1) water content, porosity, bulk density by the syringe method; (2) density and porosity by the GRAPE method; (3) acoustic velocities by the Hamilton Frame method; (4) overall core-section density (by weighing) (discontinued after Leg 38). At the DSDP shore laboratory, sediment samples are anlayzed for grain size (sand-silt-clay) and carbon-carbonate content (discontinued after Leg 79), and the laboratory at U.C. Riverside in the past has examined sediment samples for mineral content by X-ray diffraction. The techniques for all of these measurements have been described in this manual.

All of the classes of data mentioned previously are routinely converted to computer-readable form and exist either on disk or on magnetic tape in simple Fortran or Algol readable formats, the choice of storage medium being determined by the volume of the class of data in question. The density and porosity data from the GRAPE device and the X-ray mineralogy data are the only two properties routinely stored on magnetic tape (at present). All of the quantitative data are processed by a series of data reduction programs. These programs reduce the raw data to the appropriate quantitative units and scan for points that apparently are in error. Both a printed report and a clean disk or tape file are generated for each set of data. After further inspection and correction, a final, clean report is prepared. The data reduction programs also convert the standard DSDP labeling notation to a sub-bottom depth in meters, to provide a more readily interpretable location for the sample (see Fig. 3).

One of the most convenient methods for comparing sets of coordinated data taken on particular core samples is graphical display against a common depth axis. To do this, an extremely flexible graphics package (MUDPAK) has been developed using the standard graphics routines. MUDPAK permits precise location of any data curve in a composite plot that may contain several curves derived from separate files. For purposes of publication we have constructed plots containing up to 10 parameters derived from 5 separate data files in one coordinated plot presentation. The capability for specifying placement of the data curves permits superposition of like parameters measured by different methods.

Lithologic data

Many scientists with different backgrounds have participated in the cruises of D/V Glomar Challenger. Despite efforts to encourage them to adhere to uniform standards, a considerable variability in lithologic description and nomenclature has resulted. Such nonuniform information seriously hampers any attempt to discover regional patterns and trends, and can render such attempts meaningless unless treated with extreme caution. For this reason we have been concerned with bringing uniformity to the lithologic data gathered by DSDP.

Gross lithologic features of the DSDP cores are described from visual observation. Lithologic names are assigned after microscopic examination of smear slides. The visual core descriptions have been encoded using a simple data grammar and a minimum of editing. The resulting computer-readable files can be processed to generate an index of terms, or searched for specific keywords. The smear-slide data are available for further processing as component-abundance couplets. The processed smear-slide file also can be used to generate a selective or exhaustive index by component. IHG has developed a program that uses the existing body of observational data and, by using computer processing techniques, reclassifies the sediments according to a standard scheme. This uses a modification of a classification scheme developed by a working group from the JOIDES Advisory Panel on Sedimentary Petrology and Physical Properties (van Andel et al., 1973). The basic visual description prepared by the shipboard geologist is retained but the smear-slide data are processed by the classification program (JOIDESSCREEN) to rename the rock types. This technique operates with reasonable success, giving sensible consistent rock and sediment names and substantially reducing the number of names used. Failures usually are due to incomplete or inadequate data rather than to failure of the classification logic.

It must be emphasized that the JOIDESSCREEN program is flexible; changes, even to the extent of incorporating an entirely new classification scheme, can be incorporated subject to the limitations imposed by the original data. A more comprehensive account of the treatment of lithologic data is given by Davies et al. (1977). Using results from JOIDESSCREEN in conjunction with MUDPAK and other graphics programs, standard logs of the drilling results can be prepared (Musich et al., in preparation).

4) Paleontologic data

Paleontologic data are encoded and processed now through Leg 44. Using data from the Initial Report (this is more complete than shipboard data), we have made occurences, abundance, and preservation information searchable.

It is possible now to generate range charts as well as to coordinate paleontologic data with other DSDP encoded information.

5) DSDP hard rocks data base

Five hard rocks data bases have been established by the IHG (Table 1). They are (1) chemical analyses: major-elements, (2) Chemical analyses: minor-

Table 1. DSDP hard rocks data base.

Data File	Shipboard Data[a]	Shore-Laboratory Data Reported in the *Initial Reports*[a]	Hard Rocks Recovered[b]
Chemical Analyses: Major elements	37	13-19, 22-30, 32-39, 41-43	2-9, 11-12, 20-21, 31
Chemical Analyses: Minor and trace elements	37	13-19, 22-26, 28-34, 36-39, 41-43	2-9, 11-12, 20-21, 27, 35
Paleomagnetic Measurements	34, 37	14-16, 19, 23, 25-29, 32-34, 37-38, 41-43	2-9, 11-13, 17-18, 20-22, 24, 30-31, 35-36, 39
Thin-Section Descriptions	37	none encoded	
Visual Descriptions of igneous and metamorphic rocks	none endoded	- -	

[a]No igneous or metamorphic rocks were recovered on DSDP Legs 1, 10, 40, 42B, or 44.

[b]Hard rocks were recovered, but no analyses were done aboard *Glomar Challenger* or published in the *Initial Reports*.

and trace-elements, (3) Paleomagnetic measurements, (4) Thin-section descriptions, (5) Visual descriptions of igneous and metamorphic rocks.

Both igneous and metamorphic rock data are included. Only a samll number of records contain metamorphic rock data and these are flagged to distinguish them from the igneous rock data. There are also a few chemical analyses of volcanogenic sedimentary rocks. These analyses also are flagged. The hard rocks thin-section and visual description files, when complete, will contain some metamorphic and volcanogenic sedimentary rock data.

Distribution of Data

The first means of distributing DSDP data is through formal and informal publications. A second, though no less important, means of distribution is by responding to requests from individual investigators for copies of original or partly processed data from the archives. Responding to such requests is a function of the IHG. Data are available to the scientific community approximately 12 months after completion of the cruise on which the data were gathered. This is in accordance with the data and sample distribution policy approved by NSF. Charges will be made to cover the costs of responding to unusually large or complex requests.

Publications are the responsibility of a separate Publication Production Group (see Fig. 1). This group consists of scientific and technical editors and a small graphics unit for preparation of illustrations and copy paste-up. Typesetting is done by a sub-contractor working under the direction of DSDP. The U.S. Government Printing Office, under the direction of NSF, prints and distributes the formal Initial Reports of the Deep Sea Drilling Project. Printing and distribution of informal publications are under the supervision of DSDP.

These Initial Reports, a volume for each leg, were originally conceived as comprehensive presentations of all of the observational data concerning the core material. They have evolved, however, into what might be best described as comprehensive descriptions of the core material, with presentations of the key data and preliminary interpretations of the results of drilling on each leg. It is clearly impractical, and indeed would render the reports so massive as to be incomprehensible and unmanageable, to publish all of the observational data.

In addition to the formal Initial Reports there are also seven more or less informal preliminary publications. A short Site Summary message about the results of drilling at each site is transmitted by radio and distributed by DSDP to JOIDES members and other interested parties. A Summary of Deep Sea Drilling Project - Leg nn is prepared by the shipboard scientific party at the conclusion of each leg, summarizing their finding. Also, at the end of each leg the Cruise Operations Manager produces an Operational Resume that describes the ship activities and drilling operations. These reports also are distributed by DSDP to JOIDES member and others. The scientific Summary is then edited and published as a short article in Geotimes so the results of drilling may quickly reach the wider geological community. The Preliminary Report and Index of Navigation, Depth, Magnetic and Subbottom Profiler Data was discussed previously. A comprehensive description of the core material, including graphic displays and preliminary interpretations, is prepared aboard ship by the scientific party. These Summary of Scientific Results are distributed by DSDP only to individuals actually working on material for inclusion in the Initial Reports. Finally, the graphic core description from the Summary are updated by members of the scientific party, redrafted at DSDP, and distributed to approximately 250 libraries around the world about 10 months after the cruise, as Initial Core Descriptions (green books) designed to form the basis for sample selection by outside investigators, pending publication of the appropriate volume of the Initial Reports. All of these publications (except the Operational Resume) are interim and are rendered obsolete by publication of the Initial Reports. Therefore we will not discuss them further.

The Initial Reports are in two parts: individual site reports, and more specialized topical papers. The site reports consist of a descriptive text followed by a series of graphic displays showing the core material recovered at the site. The graphic displays are updated versions of those prepared aboard ship and are the same as those published in the Initial Core Descriptions. The drafting and much of the data preparation for the Initial Reports, especially the graphic displays (which use the MUDPAK programs), are done at DSDP. The ultimate responsibility for the contents of the Initial Reports rests with the shipboard chief scientists, who work in close collaboration with a shipboard scientific representative. The scientific representative is a DSDP staff scientist who serves as a member of the shipboard scientific party and who, on shore, acts as an intermediary between the contributors to the Initial Reports and the editorial, data preparation, drafting, and copy preparation staffs at DSDP. He is more of a coordinator than an editor in the traditional sense of the word. The contents of the site reports is the joint responsibility of the shipboard scientific staff. The specialized papers are individually authored by members of the shipboard party or by invited colleagues in instances where the shipboard party did not include the necessary specialists. Through Phase III of DSDP there was no formal mechanism for review of contributions to the Initial Reports, although authors were encouraged to have their contributions reviewed by colleagues before submittal, and science editors frequently submitted papers informally to colleagues for opinions. Beginning in 1976 efforts were started to institute a more formal method of refereeing papers.

From Volumes 21 through 44, the Initial Reports contained a brief index. This is not a comprehensive index in the bibliographer's sense of the word. Rather, it is an alphabetic listing of key topics. It is prepared at DSDP by a member of the IHG from suggestions for suitable entries submitted by authors. The following items are always indexed: (1) geographic locations; (2) formation names; (3) paleontologic zones; (4) common minerals or rocks that are discussed; (5) unusual minerals or rocks that are mentioned only or discussed; (6) generic names of macrofossils (e.g., Inoceramus); (7) sedimentary and tectonic structures (e.g., slump folds, faults); (8) appendices containing subject matter that is pertinent but not included in the main body of the text.

Aids to Research

In addition to responding to specific requests for original data, DSDP has developed a number of tools designed to aid researchers in locating core materials and data relevant to their studies. A few of these are described here.

1) Guide to DSDP cores

Because of the large volume of core material being accumulated by DSDP and the great amount of information contained in the Initial Reports, a summary of the core material and available information to guide researchers in locating materials has been prepared.

The Guides, covering core material gathered during Phases I and II of DSDP from the Atlantic, Pacific, and Indian oceans, are now available and work is proceeding on incorporating material gathered during Phase III. The information contained in the Guides is also available for computer search.

In consultation with a number of sedimentologists, paleontologists, and stratigraphers, 30 categories of data have been selected to give the information most generally useful for the selection of core material. For each category the range of values within each core is tabulated (i.e., each entire core is reduced to a single line of entries in the Guides). The data have been extracted manually from the published volumes of the Initial Reports and should be considered only as a guide to these volumes and to the cores. The appropriate sections of the Initial Reports should be consulted for qualifying statements that could not be included in the compressed format of the Guides. Since samples used to determine different parameters are taken at different levels within a core, these parameters often are not precisely correlatable. The Guides, however, do provide a general, tabular summary of what may be found within specific cores.

At the present time, copies of the Guides may be obtained by writing to DSDP.

2) Quick reference key to core data

As a companion to the Guides, Quick Reference Keys to Phase I through III data have been issued as Data Data publications numbers 6, 10, and 11. For each leg of the project these tabulate, the locations of sites drilled and the track of the drilling vessel, the members of the scientific party, and the kinds of data collected and their storage media. The tables deal only with data that are presently available from DSDP. To our knowledge, these Quick Reference Keys are the only place where this amount of information about a given leg is reduced to two pages (see Fig. 4).

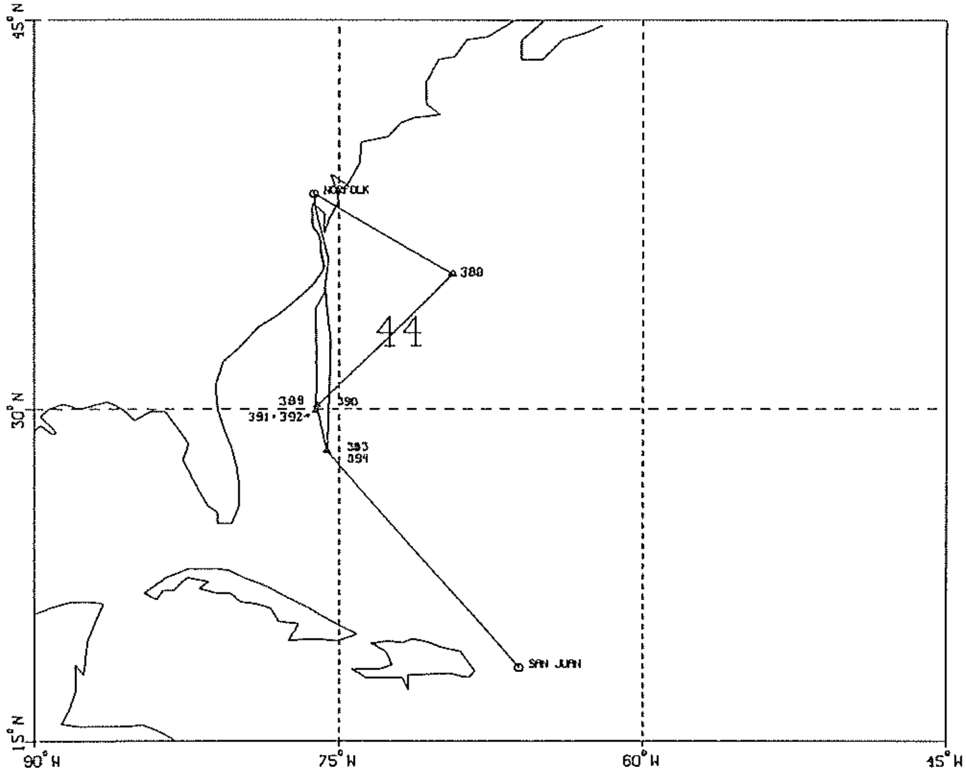
3) Information about samples and publications

After the preparation of the initial shipboard description of the core material, samples of cores gathered by DSDP are made available to qualified investigators wishing to conduct their own detailed studies. In response to a growing need for information pertaining to such subsequent sample requests, DSDP has devised a system whereby necessary information can be retrieved quickly and efficiently. The data base is built from the sample request and bibliography files of the West Coast Repository and was initially used in the preparation of a computer-generated listing made available to investigators entitled A Guide to Publications and Subsequent Investigations of DSDP Materials. Until January 1976, it was updated periodically in hardcopy printed form. In July 1976, this was combined with and superseded by a microfiche publication entitled DSDP Keyword Index to the Initial Reports, Publications, and Investigations of DSDP Materials.

The Keyword Index includes information on investigations in progress and on completed studies reported in the open literature. The index consists of two parts:

a) Index of keywords -- citations: This index has four facets -- viewpoint from which the author investigated his material, nature of material investigated, geographic area, and age of material investigated. Generally, each item (pulbished paper or investigation underway) is described in four or more terms, one or more for each of these facets. A short referral citation consisting of authors' names, year and serial, type code of the reference, and identification number follows the

LEG 44



SITES 388 to 394

Norfolk, Virginia To Norfolk, Virginia

C - punched cards
T - magnetic tape
M - microfilm

DSDP PRIME DATA	MEDIAS	HOLES	EXCEPT:
Carbon Carbonate	T	NONE	
Core Barrel Inventory	T	ALL	
Core Log	M	ALL	
Core Section Weight	T	NONE	
Grain Size	T	ALL	389,393 and 394
G.R.A.P.E.	T	NONE	
Interstitial Water	T	388,390	
Paleont. / Biostrat.	T	ALL	393 and 394
Sampling Record	T	ALL	
Smear Slide Description	T	ALL	
Sonic Velocity	T	ALL	393 and 394
Visual Core Description	T	ALL	
Water Content	T	ALL	389,393 and 394
SPECIAL STUDIES DATA			

LATITUDE	LONGITUDE	SITE
35°31.33'N	69°23.76'W	388
30°08.54'N	76°05.57'W	389
30°08.54'N	76°06.74'W	390
28°13.7 'N	75°36.9 'W	391
29°54.63'N	76°10.68'W	392
28°11.78'N	75°35.98'W	393
28°11.70'N	75°35.76'W	394

DSDP UNDERWAY DATA	
Geophysical Log	M
Magnetometer	M
PDR	M
Profiler EDO #1 & #2	M
Satellite Navigation	C

X-Ray Mineralogy - Legs 10-37 only (Master searchable tape)

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Figure 4. Example of a quick reference key to core data (reprinted from Data Data No. 11).

keywords. This referral citation allows location of the proper reference in the author-reference list.

b) Author-reference list: This is a bibliographic listing of all publications and investigations of DSDP materials. For any one author-investigator, all published papers are listed first followed by his studies in progress. For all junior authors-investigators there is a short referral to the complete citation. After each complete citation is a list of keywords used and sites investigated.

ACKNOWLEDGMENTS

We thank Peter Woodbury and Lillian Musich of the Deep Sea Drilling Project at Scripps Institution of Oceanography for their invaluable assistance in preparing this chapter.

REFERENCES

Davies, T. A., Musich, L. F., and Woodbury, P. B., 1977. Automated classification of deep sea sediment. J. Sediment. Petro., 47:650-656.

Davies, T. A., Musich, L. F., and Woodbury, P. B., in preparation. Lithologic data from Pacific Ocean deep sea drill sites.

van Andel, Tj. H., Winterer, E. L., and Duncan, J. 1973. Report of the subcommitte on sediment classification of Advisory Panel on Sedimentary Petrology and Physical Properties. Unpublished JOIDES Report.

Worsley, T. R., Blank, R. G., and Suchland, C., in press. Cenozoic biostratigraphy and age-depth relationships of Pacific Ocean deep sea drill sites. Rosenstiel School of Marine and Atmospheric Science, U. Miami, Preliminary Analyses of the Deep Sea Drilling Project Data, Volume II.

APPENDIX. *Initial Reports of the Deep Sea Drilling Project*, Vols. 1-44

The Deep Sea Drilling Project

All volumes are published by the U.S. Government Printing Office, Washington, D.C., and those still in print are available for purchase from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Volume No.	Authors	Date of Publication	Cruise Location	Drilling Sites
1	Ewing, M., Worzel, J. L., et al.	1969	Orange, Texas to Hoboken, New Jersey	1-7
2	Peterson, M. N. A., Edgar, N. T., et al.	1970	Hoboken, New Jersey to Dakar, Senegal	8-12
3	Maxwell, A. E., Von Herzen, R. P., et al.	1970	Dakar, Senegal to Rio de Janeiro, Brazil	13-22
4	Bader, R. G., Gerard, R. D., et al.	1970	Rio de Janeiro, Brazil to San Cristobal, Panama	23-31
5	McManus, D. A., Burns, R. E., et al.	1970	San Diego, California to Honolulu, Hawaii	32-43
6	Fischer, A. G., Heezen, B. C., et al.	1971	Honolulu, Hawaii to Apra, Guam	44-60
7,Pt.1	Winterer, E. L., Riedel, W. R., et al.	1971	Apra, Guam to Honolulu, Hawaii	61-67
7,Pt.2	Winterer, E. L., Riedel, W. R., et al.	1971		
8	Tracey, J. I., Jr., Sutton, G. H., et al.	1971	Honolulu, Hawaii to Papeete, Tahiti	68-75
9	Hays, J. D., et al.	1972	Papeete, Tahiti to Balboa, Panama	76-84
10	Worzel, J. L., Bryant, W., et al.	1973	Galveston, Texas to Miami, Florida	85-97
11	Hollister, C. D., Ewing, J. I., et al.	1972	Miami, Florida to Hoboken, New Jersey	98-108

Volume No.	Authors	Date of Publication	Cruise Location	Drilling Sites
12	Laughton, A. S., Berggren, W. A., et al.	1972	Boston, Massachusetts to Lisbon, Portugal	111-119
13,Pt.1	Ryan, W. B. F., Hsü, K. J., et al.	1973	Lisbon, Portugal to Lisbon, Portugal	120-134
13,Pt.2	Ryan, W. B. F., Hsü, K. J., et al.	1973		
14	Hayes, D. E., Pimm, A. C., et al.	1972	Lisbon, Portugal to San Juan, Puerto Rico	135-144
15	Edgar, N. T., Saunders, J. B., et al.	1973	San Juan, Puerto Rico to Cristobal, Panama	146-154
16	van Andel, T. H., Heath, G. R., et al.	1973	Cristobal, Panama to Honolulu, Hawaii	155-163
17	Winterer, E. L., Ewing, J. I., et al.	1973	Honolulu, Hawaii to Honolulu, Hawaii	164-171
18	Kulm, L. D., von Huene, R., et al.	1973	Honoulu, Hawaii to Kodiak, Alaska	172-182
19	Creager, J. S., Scholl, D. W., et al.	1973	Kodiak, Alaska to Yokohama, Japan	183-193
20	Heezen, B. C., MacGregor, I. D., et al.	1973	Yokohama, Japan to Suva, Fiji	194-202
21	Burns, R. E., Andrews, J. E., et al.	1973	Suva, Fiji to Darwin, Australia	203-210
22	von der Borch, C. C., Sclater, J. G., et al.	1974	Darwin, Australia to Colombo, Ceylon	211-218
23	Whitmarsh, R. B., Weser, O. E., Ross, D. A., et al.	1974	Colombo, Ceylon to Djibouti, F.T.A.I.	219-230
24	Fisher, R. L., Bunce, E. T., et al.	1974	Djibouti, F.T.A.I to Port Louis, Mauritius	231-238
25	Simpson, E. S. W., Schlich, R., et al.	1974	Port Louis, Mauritius to Durban, South Africa	239-249

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26	Davies, T. A., Luyendyk, B. P., et al.	1974	Durban, South Africa to Fremantle, Australia	250-258
27	Veevers, J. J., Heirtzler, J. R., et al.	1974	Fremantle, Australia to Fremantle, Australia	259-263
28	Hayes, D. E., Frakes, L. A., et al.	1975	Fremantle, Australia to Lyttleton, New Zealand	264-274
29	Kennett, J. P., Houtz, R. E., et al.	1975	Christchurch, New Zealand to Wellington, New Zealand	275-284
30	Andrews, J. E., Packham, G., et al.	1975	Wellington, New Zealand to Apra, Guam	285-289
31	Karig, D. E., Ingle, J. C., Jr., et al.	1975	Apra, Guam, to Hakodate, Japan	290-302
32	Larson, R. L., Moberly, R., et al.	1975	Hakodate, Japan to Honolulu, Hawaii	303-313
33	Schlanger, S. O., Jackson, E. D., et al.	1976	Honolulu, Hawaii to Papeete, Tahiti	314-318
34	Yeats, R. S., Hart, S. R., et al.	1976	Papeete, Tahiti to Callao, Peru	319-321
35	Hollister, C. D., Craddock, C., et al.	1976	Callao, Peru to Ushuaia, Argentina	322-325
36	Barker, P. F., Dalziel, I. W. D., et al.	1977	Ushuaia, Argentina to Rio de Janeiro, Brazil	326-331
37	Aumento, F., Melson, W. G., et al.	1977	Rio de Janeiro, Brazil Dublin, Ireland	332-335
38	Talwani, M., Udintsev, G., et al.	1976	Dublin, Ireland to Amsterdam, The Netherlands	336-352
39	Supko, P. R., Perch-Nielsen, K. et al.	1977	Amsterdam, The Netherlands to Cape Town, South Africa	353-359

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40	Bolli, H. M., Ryan, W. B. F., et al.	1978	Cape Town, South Africa to Abidjan, Ivory Coast	360-365
41	Lancelot, Y., Seibold, E., et al.	1978	Abidjan, Ivory Coast to Malaga, Spain	366-370
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42,Pt.1	Hsü, K. J., Montadert, L., et al.	1978	PART I: Malaga, Spain to Istanbul, Turkey	371-378
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43	Tucholke, B. E., Vogt, P. R., et al.	1979	Istanbul, Turkey to Norfolk, Virginia	382-387
44	Benson, W. E., Sheridan, R. E., et al.	1978	Norfolk, Virginia to Norfolk, Virginia	388-394

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