1. INTRODUCTION AND EXPLANATORY NOTES[1]

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INTRODUCTION

The Middle America Trench transect off Guatemala was first recommended for study on the basis of earlier deep sea drilling experience at convergent margins, which showed that to differentiate among models of accretion, imbrication, erosion, or passive subduction at convergent margins, several conditions should be met: (1) Detailed age resolution is required to demonstrate stratigraphic repetition of a section or its absence; such resolution is easier to achieve in low latitudes where microfaunal diversity is greater than in high latitudes. (2) Oceanic basin sediments on the downgoing plate should be lithologically distinct from the slope deposits; glaciation in higher latitudes results in such a great influx of terrigenous sediments that distinction between sediments of different plates is virtually impossible. The low-latitude diversity, lesser terrigenous sediment source, and relatively rapid convergence rate (10 cm/yr, Molnar and Sykes, 1969) of the Central American Pacific Margin made this a desirable place to drill.

In the report of Seely et al. (1974), which includes multichannel seismic data and drill-hole information, a strong case was made for an imbricate thrust model of accretion for this convergent margin. The Guatemalan segment of the Middle America Trench has become widely accepted as the "type region" of such convergent margin tectonism. The virtues of the latitude diversity and low sedimentation made this area an obvious target for testing this model, and multichannel seismic reflector site surveys by University of Texas Marine Sciences Institute (Ladd et al., 1978; Ibrahim et al., 1979) led to the selection of a transect that emphasized the San José Canyon, where thin sediment cover would allow deeper penetration of the section.

The Middle America Trench was first drilled in 1979 during Leg 66 off Oaxaca, Mexico and Leg 67 off Guatemala as part of a broad effort to study the mechanics of plate subduction and continental accretion and erosion (Fig. 1). Although the legs are located along neighboring transects of the landward slope of the Trench, the scientists of the two cruises reached strikingly different conclusions about the role of accretion during subduction (Watkins, Moore, et al., 1982; Aubouin, von Huene, et al., 1982).

The Leg 67 scientific party (von Huene, Aubouin, et al., 1980) emphasized the passive tectonic character of the subduction zone. Their model required extensive mechanical decoupling to accommodate subduction of rough topographic features in the downgoing plate; they saw little evidence of an accretionary prism within the Guatemalan margin. The recovery of gas hydrates at three sites prevented drilling to landward-dipping reflectors, which had been presumed to be imbricate thrust slices near the middle of the Trench landward slope. The attempt to resolve the conflicting models of accretion and imbrication since the Tertiary (Seely et al., 1974) in an area that had become the classic "type region" for convergent margin accretion was therefore frustrated on Leg 67. The tantalizing evidence of lack of accretion or tectonism at the foot of the Trench (i.e., young terrigenous sediment fill over oceanic sediments of the subduction plate, no evidence of compressive deformation in the holes drilled against the Trench's landward slope, a normal stratigraphic succession of Cretaceous to Pliocene sediment in the slope section) made this area an even more obvious target for further drilling.

Leg 84 was recommended by the JOIDES Advisory Panels specifically to examine these tectonic and gas-hydrate problems. Further surveys with Seabeam (Aubouin et al., 1982) and deep tow instrumentation (Moore et al., 1982) supplemented the site surveys conducted by the University of Texas Marine Science Institute (UTMSI) for Leg 67, and UTMSI multichannel seismic reflection surveys off Costa Rica allowed selection of a site to be drilled on that slope.

Local bases of gas-hydrate reflectors (bottom simulating reflectors, or "BSR") were identified during reexamination of predrilling site survey data, and after enhancement and combination with refined temperature gradient information, the depth of the base of the gas hydrate could be identified. Drilling sites safely above the base of the gas hydrate were selected.

Our major objectives on Leg 84 were (1) to establish the age and structure of the continental framework that forms the landward slope of the Trench off Guatemala, and (2) to study the origin and occurrence of gas hydrate in the marine environment. In order to core above the base of any gas hydrate we had to drill on ridges or in eroded canyons where sediment cover is thinner than the calculated depth of the hydrate base. Sites along the UTMSI multichannel seismic record GUA-13 transect

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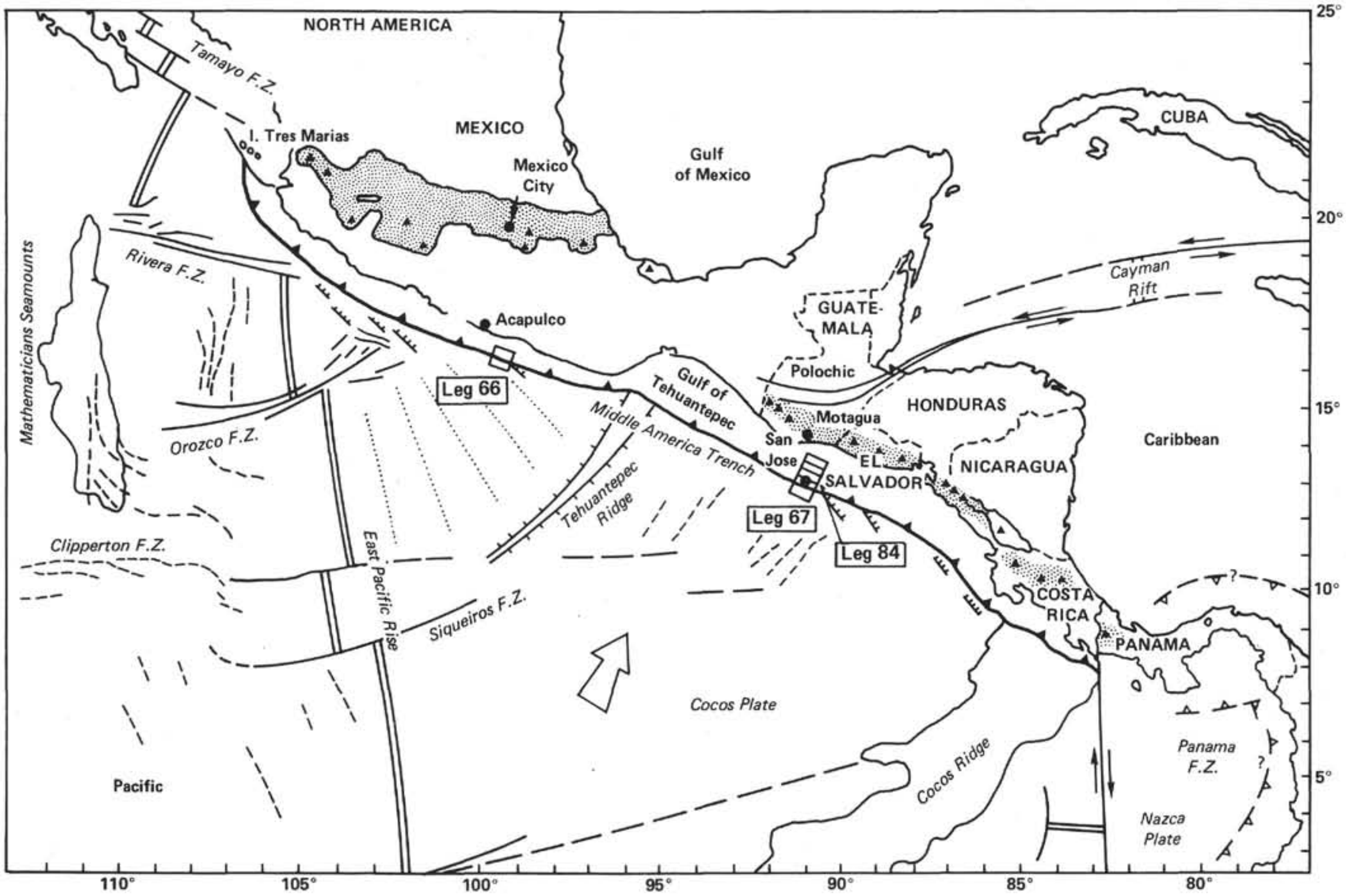


Figure 1. Sketch map of the Middle America Trench. Leg 84 rectangle shows the location of the Guatemala transect, and the smaller square represents Site 565 off Costa Rica.

down the San José Canyon were selected to meet these conditions, as well as one site along GUA-2 where the sediment cover over acoustic basement was thin (Site 566), and one site about 70 km west of the GUA-11 transect and 15 km west of the line published by Seely et al. (1974) on the upper slope of the Trench (Site 570). Here a basement high above the level of the base of hydrate is associated with a dipolar magnetic anomaly that has a steep gradient indicating a shallow anomaly-producing body. The single site on the lower slope off the Nicoya Peninsula of Costa Rica (Site 565) was drilled with the same objectives as those off Guatemala: to study the age and origin of the basement and the development of gas hydrate.

SUMMARY OF RESULTS

Figure 2 illustrates an interpretative block diagram of the Guatemalan continental margin in the area drilled during Legs 84 and 67. At the four sites off Guatemala where the bit penetrated through slope sediment (Sites 566, 567, 569, and 570), the basement consists of ophiolitic rock (serpentinized peridotite, metagabbro, metabasalt, metadiabase). The age of the sediment does not progress from younger at the base of the slope to older at the top, as occurs over the accreted complex off Mexico (Watkins, Moore, et al., 1982). As a consequence of drilling only on basement highs or through thin sediment cover, particularly along the San José Canyon where erosion could remove significant parts of the sediment section overlying basement, we did not recover the complete sequences that initially overlay the basement surface. At Site 566, sediment overlying basement is late Pleistocene, Pliocene, and late Miocene in Holes 566, 566A, and 566C, respectively. At Sites 569 and 570 the overlying slope sediment is early Eocene, whereas at Site 567 near the foot of the Trench the sediment over ophiolitic basement is Oligocene or perhaps Cretaceous. Thus the age of the sediment over basement gives only a conservative age of cover.

At Site 567 near the base of the slope, we drilled two holes only about 110 m from Leg 67 Site 494, which had come close to penetrating the subduction zone. We wanted to complete this drilling and recover a sequence of old rock in a setting at the front of the convergent margin to test the theory that the slope basement was an extension of the Central America framework. Although unsuccessful in reaching the subduction zone (a feat never accomplished by the Deep Sea Drilling Project in any active margin drilling), we interpreted the seismic record to show that the hole failed just 20 m from the top of subducting sediment. No Miocene accretionary prism exists along the base of the slope. The lack of deformation in slope deposits, the subduction of trench sediment with low shear strength, and the measurement of

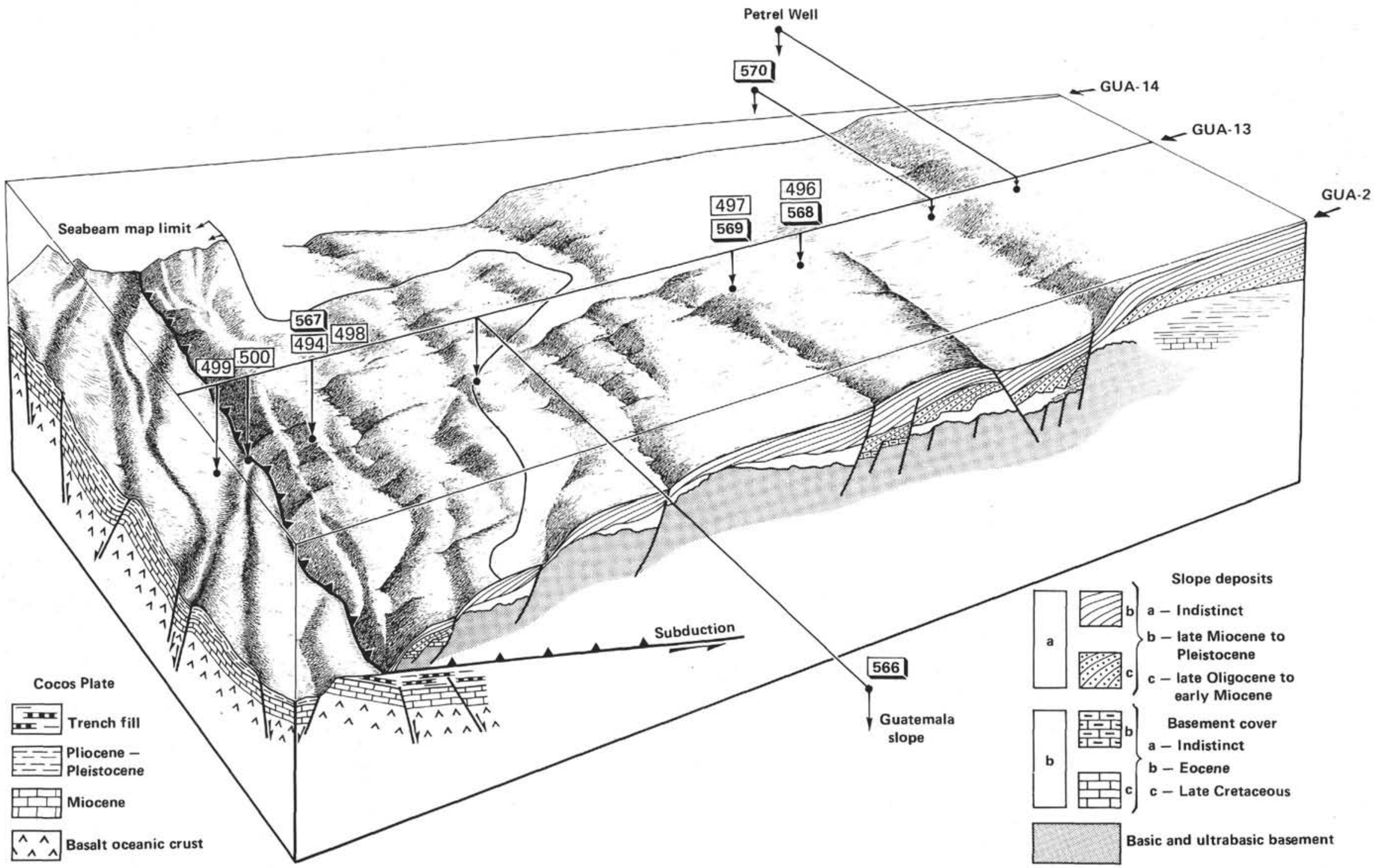


Figure 2. Block diagram showing convergent zone between the Cocos and Caribbean plates in the Leg 84 area. Morphology is reconstituted from *Jean Charcot* Seabeam data and GUA-2, GUA-13, and GUA-19 profiles of UTMSI (after Aubouin, von Huene, Baltuck, et al., 1982).

a bottom-hole pressure of 550 psi reflecting formation overpressure indicates that the upper and lower plates are highly decoupled across the subduction zone, a conclusion reached also by the Leg 67 shipboard party.

The Guatemala margin is underlain by tectonically disrupted ophiolitic rock. It is a nonaccretionary margin rather than a Neogene accreted complex; and it is an older, tectonized ophiolitic complex that faces the subducting Cocos Plate.

This material was emplaced prior to the present arc-trench tectonic system. Clastic rocks of the ophiolitic basement appear in the slope sediment, particularly at the slope base where debris flows contain large blocks of serpentinized peridotite. Using as a guide the geologic history developed from on-land studies in Costa Rica, Panama, and Guatemala and from the offshore Petrel Well drilled by Esso, the tectonic history of the Guatemala margin includes three major episodes:

1. Pre-Campanian or Maestrichtian thrusting of ultramafic rock over an ophiolitic complex. Initial tectonism could have started in the Late Cretaceous, and the sediment at the base of the slope could correspond to the Campanian–Maestrichtian sediment cover.

2. Strong Paleocene uplift documented by the Petrel Well and possibly immediately predating the early Eocene sediment recovered at Sites 569 and 570. This may have been a time of major emplacement of the ophiolite–Cretaceous sediment complex.

3. A strong Oligocene–Miocene uplift that left a sharp angular unconformity observable in seismic records across the edge of the shelf. The first thick hemipelagic slope deposits of the present tectonic setting developed during and after this event.

The first substantial layers of volcanic ash indicating development of the present arc–trench system did not appear until we reached late Oligocene sediment; from the ages of sediment over basement at Sites 569 and 570 we can say the ophiolitic rock of the Guatemalan margin was emplaced before the Eocene, and it is probably an extension of the complex Central American geologic framework.

Gas Hydrate at Site 570

Although Site 568 was designed to monitor the composition and distribution of gas hydrate (the site is located 1 km upslope from Leg 67 Site 496 along GUA-13—a site that had to be abandoned after a gas composition was encountered that suggested thermogenic components and gas hydrate), it was at Site 570 that we witnessed the most spectacular hydrate occurrence. Here gas hydrates were recovered from Core 22 (201 m) to the bottom of the hole in basement rock (Core 92; 402 m), and most spectacularly in Core 27 (249–259 m) in the form of a complete section of massive white hydrate. Gas hydrate decomposes rapidly under normal subaerial conditions, but the material here was sufficient in quantity (over 1 m was recovered) to survive cutting with the "super saw," photography under bright lights, and laboratory physical properties analyses designed for sediment and rock samples. Only the temperate house rules of the *Glomar Challenger* prevented jubilant shipboard scientists from finding yet more uses for the bubbling ice. Sufficient hydrate was secured in pressurized vessels for detailed shore-based physical and chemical analyses. Logging at this site contains the first demonstrated log response of cored gas hydrates in marine sediment and provides the first measurements of their *in situ* sonic velocity and density (Fig. 3).

EXPLANATORY NOTES

Leg 84 departed Balboa, Panama on 10 January 1982 and ended 26 February 1982 at Manzanillo, Mexico. During the 47 days at sea, the ship occupied one site off the coast of Costa Rica and five sites off the coast of Guatemala, drilled 11 holes, and steamed 3760 nautical miles.

Authorship

Authorship of the six site reports is shared collectively by Shipboard Scientific Party, ultimate responsibility lying with the two Co-Chief Scientists. All site reports follow the same general outline (authors responsible for each section are indicated in parentheses):

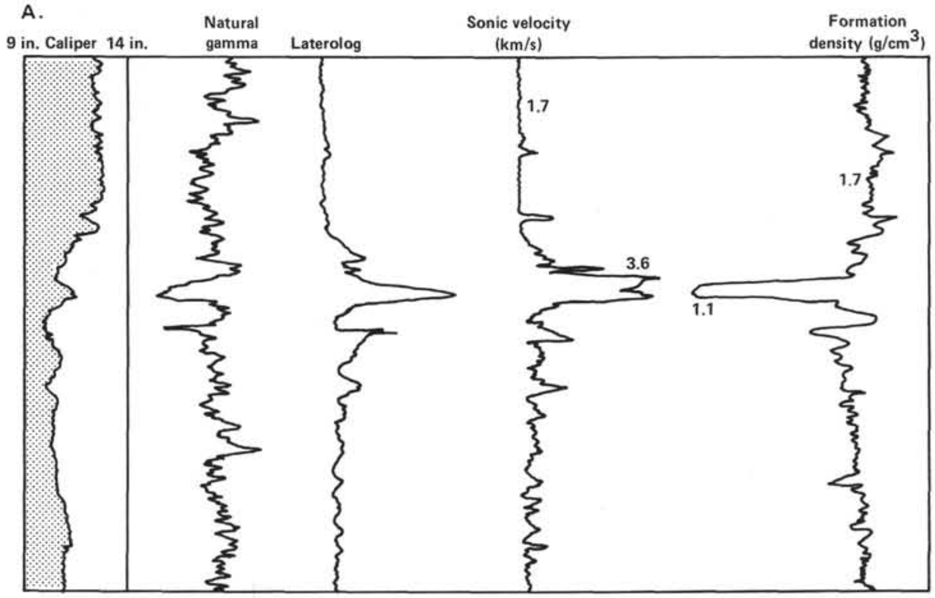
Site Summary Data and Principal Results	(von Huene and Aubouin)
Background and Objectives	(von Huene and Aubouin)
Operations	(Foss)
Lithologic Summary	(Baltuck, Arnott, Bourgois, Helm Ogawa)
Biostratigraphy	(Filewicz—nannoplankton; McDougall—foraminifers; Winsborough—diatoms)
Physical Properties	(Taylor)
Geophysics	(von Huene)
Paleomagnetics	(Leinert)
Organic Geochemistry	(Kvenvolden and McDonald)
Summary and Conclusions	(von Huene and Aubouin)

Shipboard Scientific Procedures

Numbering of Sites, Holes, Cores, and Samples

DSDP drill sites are numbered consecutively from the first site drilled by *Glomar Challenger* in 1968. A site number, slightly different from a hole number, refers to one or more holes drilled while the ship was positioned over one acoustic beacon. These holes could be within a radius as great as 900 m from the beacon. Several holes may be drilled at a single site by pulling the drill pipe above the seafloor (out of one hole), moving the ship 100 m or more from the previous hole, and then drilling another hole. The first (or only) hole drilled at a site takes the site number. A letter suffix distinguishes each additional hole at the same site. For example: the first hole takes only the site number; the second takes the site number with suffix A; the third takes the site number

A.



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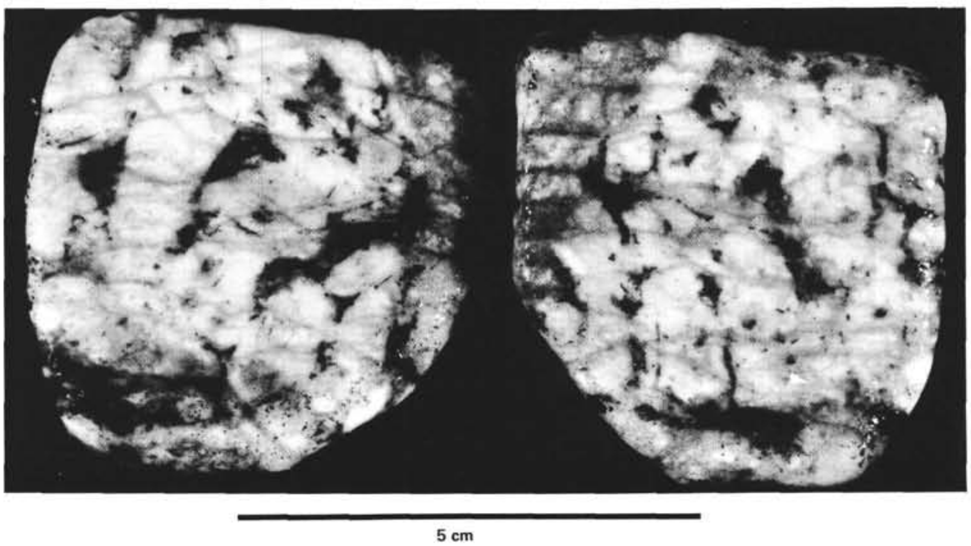

Figure 3. A. Physical properties of gas hydrate obtained during logging at Site 570. B. Split sample of massive hydrate from Core 27, Site 570.

with suffix B, and so forth. It is important, for sampling purposes, to distinguish the holes drilled at a site, because recovered sediment or rocks from different holes usually do not come from equivalent positions in the recovered stratigraphic column.

The cored interval is measured in meters below the seafloor. The depth interval of an individual core is the depth below seafloor at which the coring operating began to the depth at which the coring operation ended. Each coring interval is generally 9.7 m long, which is the nominal length of a core barrel; however, the coring interval may be shorter. "Cored intervals" are not necessarily adjacent to each other, but may be separated by "drilled intervals." In soft sediment, the drill string can be "washed ahead" with the core barrel in place, but not recovering sediment, by pumping water down the pipe at high pressure to wash the sediment out of the way of the bit and up the space between the drill pipe and wall of the hole. However, if thin, hard-rock layers are present, it is possible to get "spotty" sampling of these resistant layers within the washed interval, and thus have a cored interval greater than 9.7 m.

Cores taken from a hole are numbered serially from the top of the hole downward. Not included in this sequence is material recovered from a washed interval, which is assigned the prefix "H" to identify it as a wash core and a number corresponding to the washing episode (e.g., "H1" indicates the core contains material from the first washed interval in the hole).

Full recovery for a single core is normally 9.5 m of sediment or rock, which is in a plastic liner (6.6-cm I.D.), plus about a 0.2-m-long sample (without a plastic liner) in the core catcher. The core catcher is a device at the bottom of the core barrel that prevents the core from sliding out when the barrel is being retrieved from the hole. The sediment core, which is in the plastic liner, is then cut into 1.5-m-long sections and numbered serially from the top of the sediment core (Fig. 4). When full recovery is obtained, the sections are numbered from 1 through 7, the last section possibly being shorter than 1.5 m. The core-catcher sample is placed below the last section when the core is described, and labeled core catcher (CC); it is treated as a separate section (for sediments only).

When recovery is less than 100%, and if the sediment is placed in the top of the cored interval, then 1.5-m-long sections are numbered serially, starting with Section 1 at the top. There will be as many sections as needed to accommodate the length of the core recovered (Fig. 4); for example, 3 m of core sample in plastic liners will be divided into two 1.5-m-long sections. Sections are cut starting at the top of the recovered sediment, and the last section may be shorter than the normal 1.5-m length.

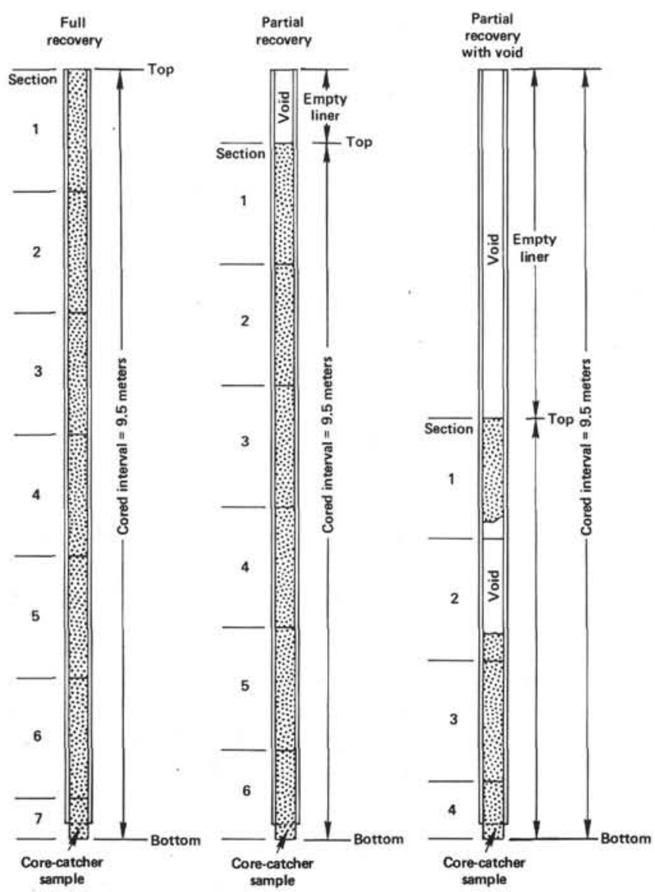

Figure 4. Conventions in cutting and labeling of Leg 84 core sections.

When recovery is less than 100%, the original stratigraphic position of the sediment in the cored interval is unknown; we conventionally attribute the top of the recovered sediment to the top of the cored interval. This is done for convenience in data handling, and for consistency. If the core is fragmented with less than 100% recovery, and if shipboard scientists believe that the fragments were not originally contiguous, then sections are numbered serially and the intervening sections are noted as void, whether the fragments as found were contiguous or not.

At Hole 567A, drilling time increased and recovery dropped significantly below Core 14, where serpentinite was first encountered in the hole. Cores 19 and 20 were retrieved after drilling two joints' lengths each. Mud flushing and sticking at Site 569 jeopardized the hole, and two cores (8 and 10) were drilled for two joints before the core barrel was retrieved to avoid sticking during wire trips.

A sample is designated by the interval in centimeters that it spans as measured from the top of the section from which it is taken. A full identification number for a sample consists of the following information: leg-site (or hole)-core-section, interval in centimeters from the top of the section. For example, the sample identification number "84-567A-5-2, 98–100 cm" means that a sample was taken between 98 and 100 cm from the top of Section 2 of Core 5, from the second hole drilled at Site 567 during Leg 84. A sample from the core catcher of this core is designated "84-567A-5,CC (8–9 cm)."

The depth below the seafloor for a sample numbered "84-567A-5-2, 98–100 cm" is the sum of the depth to the top of the cored interval for Core 5 (234.1 m) and the 1.5 m included in Section 1 and the 98 cm below the top of Section 2. The sample in question is located at 236.58 m sub-bottom, which in principle is the sample depth below the seafloor (sample requests should refer to a specific interval within a core section, rather than the depth below seafloor).

Conventions regarding the cataloguing of the hydraulic piston cores, pressure core barrels, and extensive core barrels are the same as those for the conventional rotary cores. Because the mud was quite stiff even near the sediment/water interface, very few cores were taken using the hydraulic piston corer (HPC) on Leg 84.

Handling of Cores

A core was normally cut into 1.5-m sections, sealed, and labeled; the sections were then brought into the core laboratory for processing. The following determinations were normally made before the sections were split: gas analysis, thermal-conductivity analysis (soft sediment only), and continuous wet-bulk density determinations using the Gamma Ray Attenuation Porosity Evaluator (GRAPE).

The cores were then split longitudinally into "working" and "archive" halves either by wire cutter or by "super saw." The contrast in appearance between cores cut by the two methods can be significant. Samples extracted from the "working" half included those for measurement of sonic velocity by the Hamilton Frame method, measurement of wet-bulk density by a GRAPE technique, carbon-carbonate analysis, measurement of calcium-carbonate percentage (carbonate bomb), geochemical analysis, paleontological studies, and other studies. When sufficiently firm, the archive half was washed on the cut surface to expose the sedimentary features. The color, texture, structure, and composition of the various lithologically different parts of a section were described on the standard visual-core-description sheets (one per section), and any unusual features were noted. A smear slide was made, usually at 50 cm if the core was uniform. However, more smear slides were often made for each area of distinct lithology in the core section. The smear slides were examined under petrographic microscope. The archive half of the core section was then photographed.

After the cores were sampled and described, they were maintained in cold storage aboard *Glomar Challenger* until transferred to the DSDP repository. Core sections that were removed for organic-geochemistry study were frozen immediately aboard ship and kept frozen.

Visual core descriptions, smear-slide descriptions, carbonate-bomb (% $CaCO_3$) determinations, and X-ray mineralogy (all done aboard ship) provide the data for the core descriptions in this volume. This information is summarized and sample locations in the core are indicated on the core-description sheets (Fig. 5).

Sediments and Sedimentary Rocks Core-Description Forms

Drilling Disturbance

Recovered rocks, particularly soft sediments, may be extremely disturbed. This mechanical disturbance is a result of the coring technique, which uses a 25-cm-diameter bit with a 6-cm-diameter opening for the core sample. Symbols for the disturbance categories used to identify soft and firm sediment are shown in Figure 5 in the column headed "Drilling Disturbance." The disturbance categories are defined as (1) slightly deformed: bedding contacts are slightly bent; (2) moderately deformed: bedding contacts have undergone extreme bowing (firm sediment is fractured); (3) very deformed: bedding is completely disturbed or homogenized by drilling, sometimes showing symmetrical diapirlike structure; (4) soupy: water-saturated intervals that have lost all aspects of original bedding; (5) breccia: indurated sediments have been broken into angular fragments by the drilling process, perhaps along preexisting fractures; and (6) biscuited: sediment is firm and broken into chunks of about 5- to 10-cm length.

Sedimentary Structures

In the soft, and even in some harder, sedimentary cores, it may be extremely difficult to distinguish between natural structures and structures created by the coring process. Thus the description of sedimentary structures was optional. Locations and types of structures appear as graphic symbols in the column headed "Sedimentary Structures" on the core-description form (Fig. 5). Figure 6 gives the key to these symbols.

Color

Colors of the core samples are determined using the Geological Society of America Rock-Color Chart. Colors were determined immediately after the cores were split and while wet and appear in the lithologic description of the core barrel sheets (Fig. 5).

Lithology

The graphic column on the core-description form is based on the lithologies and represented by a single pattern or by a grouping of two or more symbols (Fig. 7). The symbols in a grouping correspond to end-members of sediment constituents, such as clay or nannofossil ooze. The symbol for the terrigenous constituent appears on the right-hand side of the column, the symbol for the biogenic constituent(s) on the left-hand side of the column. The abundance of any component approximately equals the percentage of the width of the graphic column its symbol occupies. For example the left 20% of the column may have a diatom ooze symbol, whereas the right 80% may have a silty-clay symbol, indicating sediment composed of 80% mud and 20% diatoms.

Because of the difference in the length-to-width ratio between the actual sediment core and the graphic lithologic column, it is not possible to reproduce structures as they appeared in the core; in the graphic representation they are schematically represented true to their shape and position in the core but somewhat exaggerated in size, thickness (for beds thinner than 10 cm), or distinctness of outline. Voids less than 10 cm are not shown.

Smear-slide (or thin-section) compositions, carbonate content (% $CaCO_3$), and organic carbon content determined on board are listed below the lithologic description; the two numbers separated by a hyphen refer to the section and centimeter interval, respectively, of the sample. The locations of these samples in the core and a key to the codes used to identify these samples are given in the column headed "Samples" (Fig. 5). Locations and intervals of organic geochemistry (OG), interstitial water (IW), and physical property (PP) samples are given in the "Graphic Lithology" column.

Lithologic Classification of Sediments

The basic classification system used here was devised by the JOIDES Panel on Sedimentary Petrology and Physical Properties (SPPP) and adopted for use by the JOIDES Planning Committee in Mach 1974. Leg 84 shipboard scientists have modified this classification because of the dominant hemipelagic nature of the sediments recovered and the difficulty in accurately determining silt/clay ratios in smear slides.

This classification is descriptive rather than generic, and divisions between different types of sediment are somewhat arbitrary. We treat lithologic types that are not covered in this classification as a separate category termed Special Rock Types. A brief outline of the con-

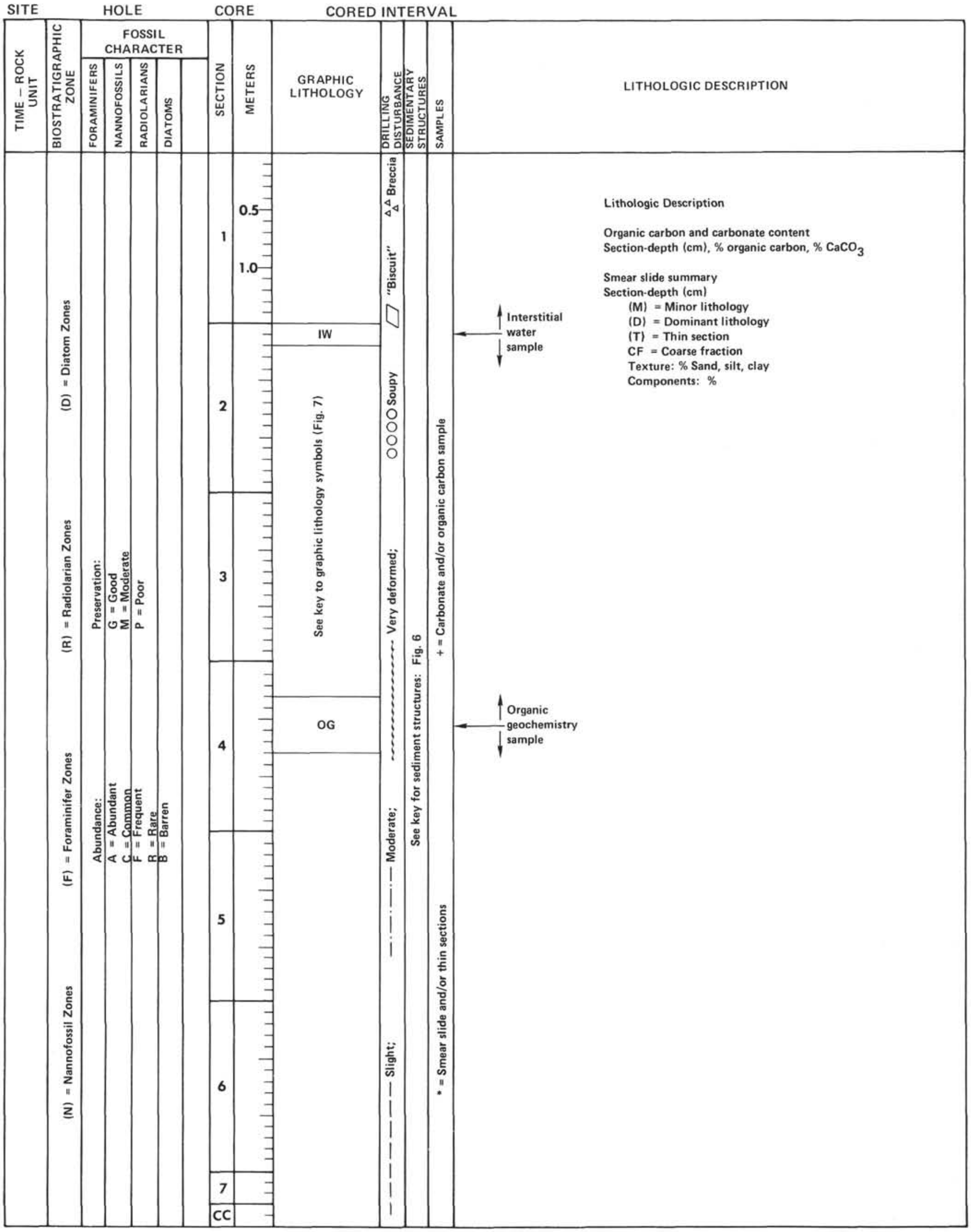

Figure 5. Sample core description form.

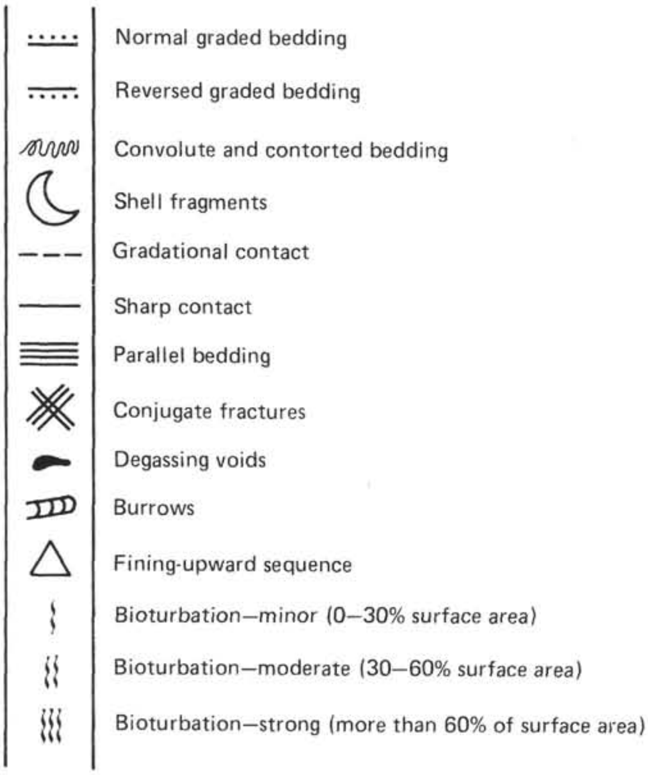

Figure 6. Symbols used in the "Sedimentary Structures" column.

ventions and descriptive data used to construct this classification follows.

Conventions and Descriptive Data

Composition and Texture

In this classification, composition and texture are the only criteria used to define the type of sediment or sedimentary rock. Composition is more important for describing sediments deposited in the open ocean, and texture becomes significant for hemipelagic and near-shore sediments. These data come principally from visual estimates of smear slides using a petrographic microscope. They are estimates of areal abundance and size components on the slide and may differ somewhat from more accurate analyses of grain size, carbonate content, and mineralogy (see Special Studies section). From past experience, we find quantitative estimates of distinctive minor components to be accurate to within 1 to 2%, but for major constituents accuracy is poorer, ±10%. All smear-slide estimates were done on board.

Where applicable we used one or several modifiers in naming the type of sediment encountered. In all cases the dominant component appears last in the name; minor components precede, with the least common constituent listed first. Minor constituents occurring in amounts less than 10% are not included in the name.

Induration of Sediments

We recognize three classes of induration or lithification for all sediments.

For calcareous sediments and sedimentary rocks, the categories (after Gealy et al., 1971) are (1) soft—ooze; has little strength and is readily deformed under pressure of finger or broad blade of spatula; (2) firm—chalk; partially lithified and readily scratched with fingernail or edge of spatula; (3) hard—limestone, dolomite, well-lithified and cemented, resistant or impossible to scratch with fingernail or edge of spatula.

For transitional carbonates, siliceous, pelagic, and terrigenous sediments, the three classes of induration are (1) soft—sediment core may be split with wire cutter; (2) firm—partially lithified but fingertip pressure leaves an indentation; (3) hard—cannot be compressed with fingertip pressure.

Types of Sediments and Compositional Boundaries

Pelagic Clay

Pelagic clay is principally authigenic containing pelagic deposits that accumulate at very slow rates. The class has often been termed brown clay or red clay, but because these are confusing as general terms we did not use them.

1. Boundary of pelagic clay with terrigenous sediments is where authigenic components (Fe/Mn micronodules, zeolites), fish debris, and so on, become common (more than 10%) in smear slides, indicating pelagic clay. Because the accumulation rates of pelagic clay and terrigenous sediments are very different, transitional deposits are exceptional.

2. Boundary of pelagic clay with siliceous-biogenic sediments is the point at which there is less than 30% siliceous remains.

3. Boundary of pelagic clay with calcareous-biogenic sediments is uncommon. Generally this facies passes from pelagic clay through siliceous ooze to calcareous ooze, with one important exception: at the base of many oceanic sections, black, brown, or red clays occur directly on basalt, overlain by or grading up into calcareous sediments. Most of the basal clayey sediments are rich in iron, manganese, and other metallic trace elements.

Pelagic-Siliceous-Biogenic Sediment

Pelagic-siliceous-biogenic sediment is distinguished from pelagic clay because the siliceous-biogenic sedient has more than 30% siliceous microfossils. Siliceous-biogenic sediments are distinguished from a calcareous category by a calcium carbonate content of less than 30%.

For a pelagic-biogenic-siliceous sediment with about 30 to 100% siliceous fossils, the following terminology is used: (1) soft—siliceous ooze (radiolarian ooze, diatomaceous ooze, etc., depending on the dominant fossil component); (2) hard—radiolarite, diatomite, chert, or porcellanite; (3) compositional qualifiers—diatoms and radiolarians may be the principal components, thus one or two qualifiers may be used. The order of the two modifiers in the terms is dependent on the dominant fossil type. The most dominant component is listed last and the minor component listed first.

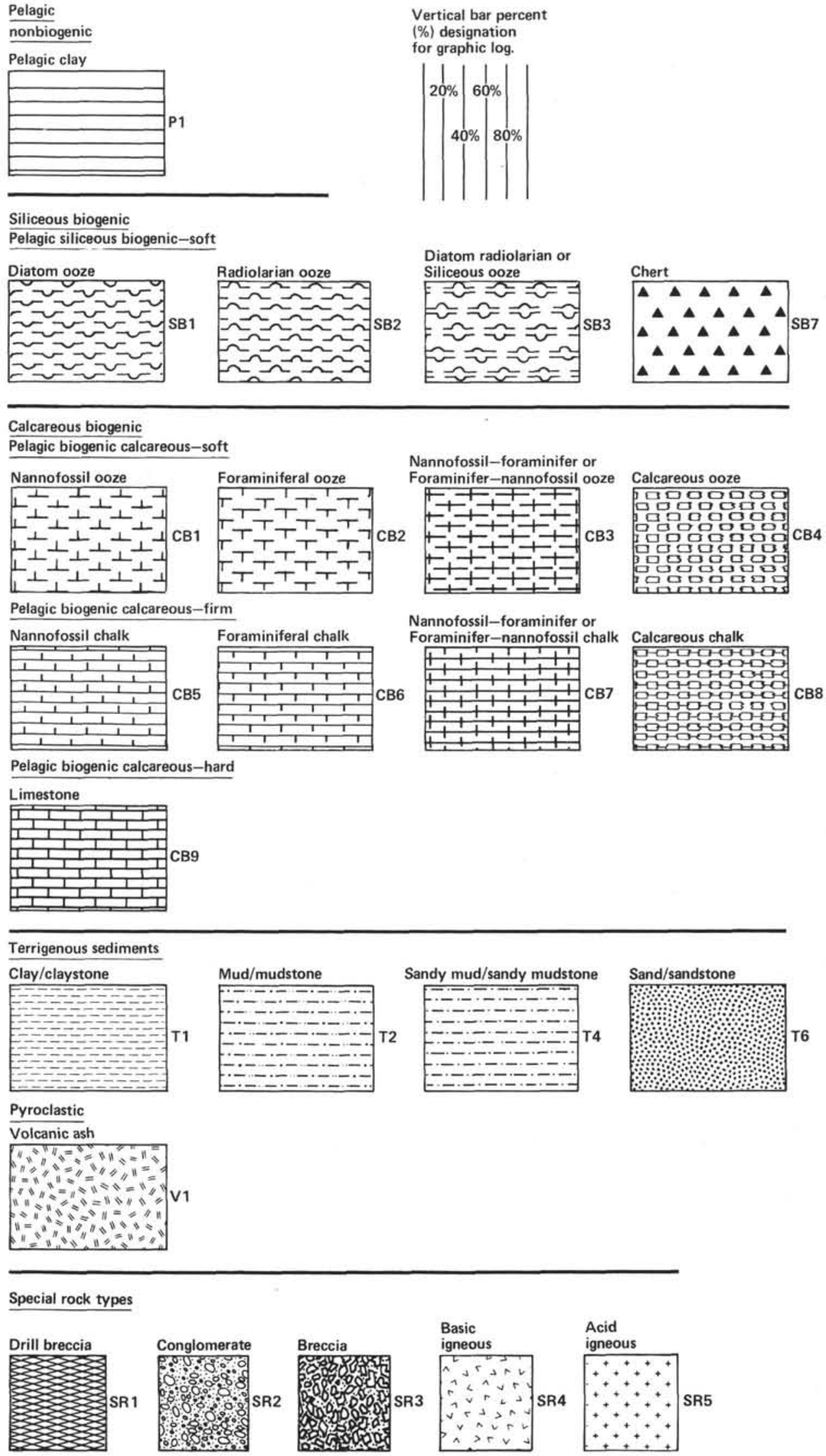

Figure 7. Symbols used in the "Graphic Lithology" column of the core-description form.

Pelagic-Biogenic-Calcareous Sediment

Pelagic-biogenic-calcareous sediment is distinguished by a biogenic $CaCO_3$ content in excess of 30%. There are two classes: (1) pelagic-biogenic-calcareous sediments that contain 60 to 100% biogenic $CaCO_3$ and (2) transitional biogenic-calcareous sediments, which contain 30 to 60% $CaCO_3$. These sediment types were not encountered on Leg 84.

For the pelagic-biogenic-calcareous sediment with 60 to 100% $CaCO_3$ the following terminology is used: (1) soft—calcareous ooze; (2) firm—chalk; (3) hard and cemented—limestone; (4) compositional qualifiers—if nannofossils and foraminifers are the principal components, then one or two qualifiers may be used.

The transitional biogenic-calcareous sediments with 30 to 60% $CaCO_3$ are termed marl or marlstone, depending on whether they are soft or hard.

Terrigenous Sediment

Terrigenous sediment is distinguished by a terrigenous component in excess of 30% and by siliceous and authigenic components each less than 10%. This is the most common sediment type encountered on Leg 84.

Sediments in this category are subdivided into textural groups by smear-slide estimation or grain-size analysis on the basis of the relative proportions of sand, silt, and clay. The size limits are those defined by Wentworth (1922); textural classification follows the triangular diagram (Fig. 8).

The transition between pelagic and terrigenous sediments is termed hemipelagic. This is the dominant type of sediment encountered during continental margin drilling. Hemipelagic sediments are distinguished by a terrigenous component in excess of 30%, a total nonbiogenic component in excess of 40%, and commonly by a biogenic silica content in excess of 10%. Besides the terrigenous component, hemipelagic sediments may be rich in biogenic silica (usually diatoms, because of coastal upwelling) and volcanic ash (predominantly along active margins).

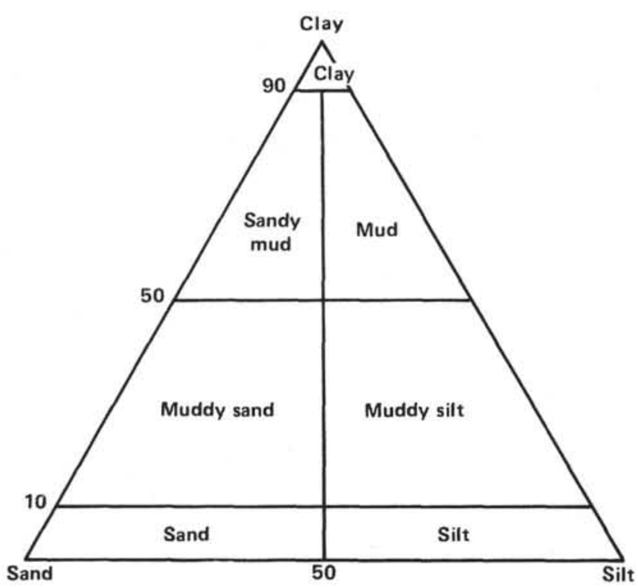

Figure 8. Terrigenous sediment classification used during Leg 84 (after Wentworth, 1922).

Components such as sand, diatoms, radiolarians, spicules, and ash, as well as more general terms "siliceous" and "calcareous" may be used as qualifiers to the original sediment description if their presence makes up 10 to 30% of the sediment. Within the textural group and the component group the modifiers are listed in order of increasing sedimentary abundance.

Volcanogenic Sediment

Pyroclastic rocks are described according to the textural and compositional scheme of Wentworth and Williams (1932). The textural groups are: more than 32 mm—volcanic breccia; 32 to 4 mm—volcanic lapilli and less than 4 mm—volcanic ash (tuff when indurated). The composition of these pyroclastic rocks are described as vitric (glass), crystalline, or lithic.

Sediments rich in ash are described in the following manner:

Ash (%)	Soft Sediment	Indurated
0–10	Mud	Mudstone
10–30	Vitric mud	Vitric mudstone
30–60	Muddy ash	Tuffite
>60	Ash	Tuff

Qualifiers

In general, sediments containing various constituents in the 10 to 30% range may be identified by the name of the sediment, for example, vitric diatomaceous mud or vitric muddy diatomaceous ooze. If more than one such qualifier is used, they are listed in order of increasing abundance in the sediment.

Biostratigraphy and Basis for Age Determination

During Leg 84 we recovered a variety of sediments ranging from a piece or two of chalk to turbidites to hemipelagic sediment draped over the Central American continental margin slope. The microfossils within these sediments were deposited over a span of time from the Late Cretaceous to the Recent. Calcareous benthic and planktonic foraminifers and calcareous nannoplankton were recovered in spotty concentrations within hemipelagic sediment cored at each of the sites, including those in the Trench axis. Their presence at great depth attests to rapid transport and burial.

The Leg 84 micropaleontologists used the zonal scheme of Vail and Hardenbol (1979) for planktonic foraminifers and Okada and Bukry (1980) for calcareous nannofossils in order to date the stratigraphic horizons and to reconstruct the paleoenvironmental histories for our drill sites (Fig. 9).

The following letters are used on core-description sheets to indicate fossil abundance:

A = abundant (many species and specimens)
C = common (many species, easy to make age assignment)
R = rare (enough for age assignment)

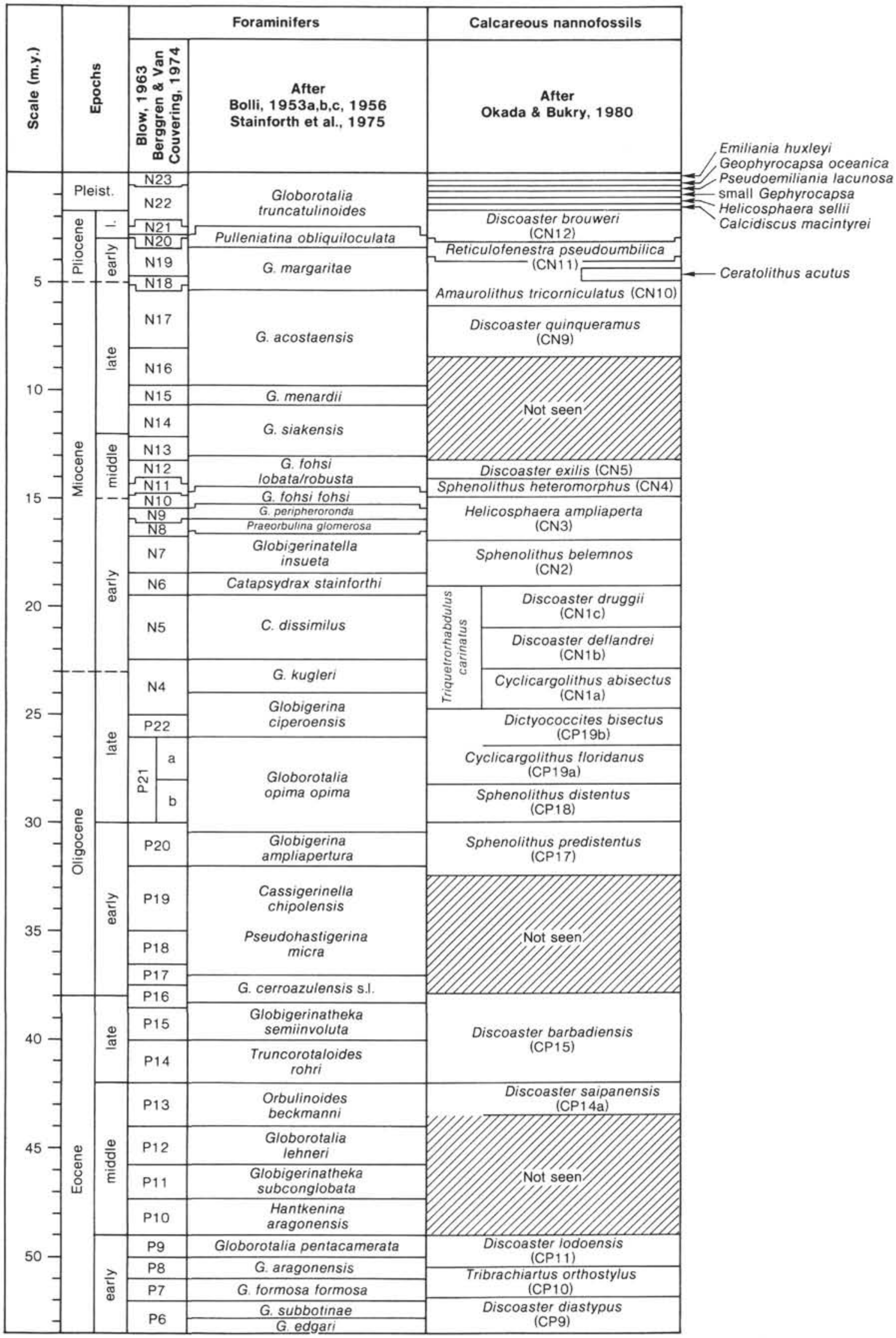

Figure 9. Biostratigraphic zonal scheme used in Leg 84 studies (adapted from Vail and Hardenbol, 1979, and Okada and Bukry, 1980).

T = trace (few species and specimens, not enough for age assignment)
B = barren

Letters used to designate fossil preservation are:
E = excellent (no dissolution or abrasion
G = good (very little dissolution or abrasion)
M = moderate (dissolution and/or abrasion and/or recrystallization very noticeable)
P = poor (substantial or very strong evidence of dissolution and/or abrasion and/or recrystallization).

Physical Properties—Procedures

A thorough discussion of physical properties is presented by Boyce (1976) with respect to equipment, methods, errors, correction factors, and problems related to coring disturbance. Only a brief review of methods employed on Leg 84 is given here.

Velocity

Compressional wave velocity was measured on the Hamilton Frame velocimeter by timing a 400-kHz pulse between two transducers and by measuring the distance across the sample with a dial gauge. Measurements were made at laboratory temperature and pressure. Sediments were removed from the core and trimmed carefully to form two parallel surfaces to ensure good contact with the transducer heads. Water was used to make acoustical contact between the sample and the transducers.

Calibration of the velocimeter consisted of making numerous measurements through lucite, aluminum, and brass standards of varying thicknesses to obtain a calibration constant for each of 3 μs/cm settings on the DSDP Tektronix 485 oscilloscope used to make the traveltime measurements. This calibration constant reflects the position picked by the operator as representing the first break from horizontal of the sonic signal.

GRAPE Density

The Gamma Ray Attenuation and Porosity Evaluator (GRAPE) was used to determine wet-bulk density based on the attenuation of gamma rays by the sample. Boyce (1976) discusses the theoretical aspects of this process in detail. During Leg 84 GRAPE was used in two modes: (1) continuous GRAPE, in which most sections of the core were irradiated; continuous "corrected" wet-bulk density (relative to quartz) was plotted on an analog graph; and (2) two-minute GRAPE, in which the gamma count through a small piece of the core was measured for two minutes, followed by a similar count through air and/or a quartz standard.

Continuous GRAPE

Prior to running each core through the device, an aluminum standard was measured. A density of 2.60 Mg/m^3 was assigned to the 6.61-cm (diameter) aluminum standard analog record, and a density of 1.0 Mg/m^3 to the 2.54-cm (diameter) aluminum standard analog record. Linear interpolation of the GRAPE analog data between these values yielded an "empirical" wet-bulk density of the sediment sample in the core.

Two-Minute GRAPE

For two-minute GRAPE calculations,

$$\rho_{bc} = \frac{\ln(I_0/I)}{d\ \mu qtz},$$

where I_0 = two-minute gamma count through air, I = two-minute gamma count through the sample, d = gamma-ray path length through the sample (2.5 cm), ρ_{bc} = corrected bulk density, and μqtz = quartz attenuation coefficient determined daily by measuring through a quartz standard. Then, assuming a 2.65 Mg/m^3 grain density,

$$\rho_b = 1.068\ (\rho_{bc} - 1.128) + 1.025$$

and

$$\phi(\%) = \frac{100\ (2.65 - \rho_b)}{1.675}$$

where ϕ = porosity.

Boyce (1976) estimates ±5% accuracy for continuous GRAPE data and ±2% for two-minute GRAPE data. In practice, it was found that the error on Leg 84 determinations seemed to be higher, owing in part to the highly disturbed nature of many of the cores and in part to errors in gamma-ray travel-path determinations (resulting from the extremely gassy and friable nature of the sediments). However, good agreement exists between the GRAPE data from selected portions (as just described) of nearly every section and the gravimetric method.

Gravimetric Technique

Samples of approximately 20 cm^3 were selected to provide maximum coverage of all sediments and rock materials obtained. These chunks of material were weighed in air and immediately afterwards were weighed submerged in distilled water. Subsequently the samples were dried for at least 24 hr. in an oven set at 110°C, then cooled in a dessicator and weighed again. This process provided measures of water volume, sample volume, and weight. Computations for wet-bulk density, water content, and porosity were then carried out using the following relationships:

1. Wet water content (%) =
$$\frac{100[(\text{wt. wet sediment}) - (\text{wt. dry sediment})]}{(\text{wt. wet sediment})}$$

2. Salt corrected wet-water content (%) =
(wet-water content) × 1.0363 (assumes salinity = 35‰)

3. Wet-bulk density (Mg/m^3 =
$$\frac{(\text{wt. wet sediment in air})}{(\text{wt. wet sediment in air}) - (\text{wt. sediment submerged})}$$

4. Porosity (%) =
$$\frac{(\text{wt. evaporated water})}{(\text{wt. wet sediment} - \text{wt. sediment submerged})}$$

Gravimetric and two-minute GRAPE results are quite comparable, and in only a few instances are the gravimetric determinations affected by loss of material during the submerged weighing processes.

Vane Shear

A Soil Test hand-rotated Torvane was utilized to determine undrained shear strength of clayey sediments. The Torvane was rotated at a rate yielding a 360° revolution in approximately 10 s. All vane measurements were made with the vane axis oriented parallel to bedding on the split core and in the least disturbed sections. Measurements were discounted when cracking of the sediments was observed, indicating failure by fracturing instead of by shear, or when interbedding of mudstone interfered in obtaining suitable samples for this measurement. Results are generally reproducible within ±15%.

Penetrometer

A Soil Test hand-held penetrometer was occasionally used as a measure of unconfined compression strength. These results were obtained simply as a comparative measure of strength. These were measured in least disturbed sections and in the direction parallel to bedding as well.

Paleomagnetic Techniques

Remanent magnetization of sediment and rock samples is measured with a Digico balanced fluxgate rock magnetometer (spinner magnetometer), calibrated frequently with a shipboard standard. The sensitivity of the magnetometer was greatly improved by tuning the fluxgate magnetometer and replacing the analog to digital converter in the Digico M16V computer, reducing the noise level to under 5×10^{-8} emu/cm^3.

Samples for paleomagnetic analysis are taken from unconsolidated and semiconsolidated sediments in the upper parts of the cores by inserting plastic 2.5-cm cubes into the split sections. In more lithified samples from deeper levels, cylindrical samples of 2.5-cm diameter are taken from the split core sections with a diamond corer ("minicore drill"). An orientation is marked with an arrow in the uphole direction on every sample before removal from the split core section. When inclined bedding is encountered, the inclination of the bedding plane is carefully measured against the plane along which the core is split.

Shipboard Inorganic Geochemical Measurements

Aboard ship, analyses for carbon-carbonate, pH, alkalinity, salinity, calcium, magnesium, and chlorinity are conducted routinely.

Interstitial waters are routinely analyzed for pH, alkalinity, salinity, calcium, magnesium, and chlorinity. Sediments are squeezed using a stainless steel press; the water collects in plastic syringes and is then filtered through 0.45-m, 1-in. millipore filters. Interstitial waters collected with the *In Situ* Water Sampler are filtered through 0.4-m, 13-mm filters prior to analysis.

A Corning Model 130 pH meter and a Markson combination electrode are used to determine pH. The pH meter is calibrated with 4.01 and 7.42 buffer standards; all readings are originally in millivolts and are later converted to pH. All pH measurements are made in conjunction with alkalinity measurements.

Alkalinities are determined potentiametrically. Five to ten mil samples are first tested for pH, then titrated with 0.1 *N* HCL. Near the end-point, acid is added in 0.1-ml or 0.005-ml increments, and the millivolt readings noted for each increment. The exact end-point is then calculated using the Gran Factor method (Gieskes and Rogers, 1973).

Salinity is calculated from the fluid refractive index, as measured by a Goldberg optical refractometer, using this expression:

$$\text{Salinity (‰)} = 0.55 \times \Delta N$$

where ΔN is the refractive index multiplied by 10^4. The refractometer's calibration is checked periodically using IAPSO seawater standard and deionized water.

Calcium is determined by titrating a 0.5-ml sample with EDTA (sodium salt) using GHA as an indicator. To sharpen the end-point, the calcium-GHA complex is extracted into a layer of butanol. No correction is made for strontium, which is also included in the result.

Magnesium is determined by titrating a buffered 0.5-ml sample to an Ereochrome Black-T end-point, using EDTA as a titrant. This method analyzes all alkaline earths, including calcium, magnesium, strontium, and magnesium; concentrations are obtained by subtracting the calcium (which includes strontium) from this analysis.

Chlorinity is determined by titrating a 0.1-ml sample (diluted with 1-ml deionized water) with silver nitrate to a potassium chromate end-point.

Methods and equipment are checked and standardized at each site using IAPSO standard seawater. As a further check, a surface seawater sample is also analyzed and archived. This sample is also used to test for possible drill-water contamination of the interstitial water samples.

Carbonate Bomb

Percent $CaCO_3$ is also determined on board ship by the "Karbonate Bombe" technique (Müller and Gastner, 1971). In this simple procedure, a sample is powdered and treated with HCl in a closed cylinder. Any resulting CO_2 pressure is proportional to the $CaCO_3$ content of the sample. Application of the calibration factor to the manometer reading (× 100) yields percent $CaCO_3$. Percent error can be as low as 1% for sediments high in $CaCO_3$, and in general an accuracy of about 2 to 5% can be obtained.

These data are presented on the core-description sheets. The sample interval is designated by two numbers: the section number, followed by the top of the centimeter interval. For example, a sample from Section 2, 11 to 12 cm, with 90% calcium carbonate will be represented on the core-description sheet as "2, 11–12 (90%)."

Shipboard Organic Geochemical Techniques

A major objective of Leg 84 was to study the origin and occurrence of gas hydrates in oceanic sediments.

Sediment samples of full round cores (labeled KVE) approximately 5 cm long were recovered for extraction of gases into helium headspace as described by Kvenvolden and Redden (1980) and the subsequent analysis of portions of the headspace by gas chromotography. Similar samples (labeled MCL) were taken for shore-based analyses, and 10-cm^3 samples taken for analyses by pyrolysis and fluorescence techniques.

In addition to the headspace analyses, gases were obtained directly from gas pockets that developed as sediment separated in the core liner as a result of gas expansion. Gas pockets were sampled by means of a hollow punch with a valve to prevent immediate gas release, and vented through the valve into standard 20-ml evacuated containers (vacutainers) and analyzed on the ship by gas chromotography.

Shipboard pyrolysis studies used the Rock-Eval to obtain a hydrogen index (HI) and oxygen index (OI), and the shipboard CHN analyzer was used to measure total carbon and nitrogen at Site 567.

Solid pieces of hydrate were placed in pressure devices consisting of a 23-cm^3 sample holder, a gauge to monitor the increasing pressure as the sample decomposes, and a sampling part with septum. These devices were used on solid pieces of ice and hydrate recovered at Sites 565, 568, and 570.

At Site 568 a pressure core barrel was deployed three times to recover pressurized cores from which gas samples were to be taken. Methods and PCB performance are described in the Organic and Inorganic Geochemistry sections of the Site 568 report, this volume.

Photography

Sets of color and black and white negatives of whole cores are available for consultation. In addition, negatives in black and white for close-up documentation of special structures are archived at DSDP.

Obtaining Samples

Potential investigators who desire to obtain samples should refer to the DSDP-NSF Sample Distribution Policy. Sample request forms may be obtained from the Curator, Deep Sea Drilling Project, A-031, University of California at San Diego, La Jolla, California 92093. Requests must be as specific as possible: include site, core, section, centimeter interval within a section, and the volume of sample required.

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