Dean et al 1985

1985

CLASSIFICATION OF DEEP-SEA, FINE-GRAINED SEDIMENTS

WALTER E. DEAN, MARGARET LEINEN, AND DORRIK A. V. STOW

Made in United States of America
Reprinted from JOURNAL OF SEDIMENTARY PETROLOGY
Vol. 55, No. 2, March 1985

CLASSIFICATION OF DEEP-SEA, FINE-GRAINED SEDIMENTS[1]

WALTER E. DEAN
U.S. Geological Survey
P.O. Box 25046, DFC, MS 940
Denver, Colorado 80225

MARGARET LEINEN
Graduate School of Oceanography
University of Rhode Island
Narragansett, Rhode Island 02882

AND

DORRIK A. V. STOW[2]
Grant Institute of Geology
University of Edinburgh
Edinburgh EH9 3JW, Scotland

ABSTRACT: Most deep-sea sediments contain one or more biogenic components and one dominant nonbiogenic component, usually clay or silty clay. We present a descriptive classification scheme in which deep-sea, fine-grained sediments are placed within a three-component system of calcareous-biogenic, siliceous-biogenic, and nonbiogenic components. In a three-step procedure the user assesses whether the dominant component is biogenic or nonbiogenic, whether the dominant biogenic component is siliceous or calcareous, and what the relative abundances of the biogenic components are within limits of 10, 25, and 50%. The terminology proposed is that commonly used by many sedimentologists, with some refinements and greater precision in the use of terms.

INTRODUCTION

Most deep-sea sediments can be described within a three-component system that consists of calcareous-biogenic, siliceous-biogenic, and nonbiogenic endmembers, the latter being composed mainly of terrigenous siliciclastics within the silt- to clay-size range. The ability to distinguish subtle differences between the relative proportions of these three components, within a stratigraphic sequence that otherwise appears to be homogeneous, can pose important implications in interpreting past changes in organic productivity, oceanic circulation patterns, carbonate compensation depth, and so forth (for example, van Andel et al. 1975; Diester-Haass and Schrader 1979; Gardner et al. 1984). This three-component system is recognized in most classifications of deep-sea sediments, including the one devised by the JOIDES Sedimentary Petrology and Physical Properties Panel (SP4), which is most widely used within the Deep Sea Drilling Project (DSDP) community. This classification (hereinafter referred to as the JOIDES classification) was adopted by JOIDES in 1973, and, although never formally published separately, it appears in one form or another in the introductory chapters of most DSDP Initial Reports volumes since Leg 38; it appears in its entirety in the introduction to the Initial Reports volume for Leg 42, Part 2 (Ross et al. 1978).

Sedimentologists who must rely on classification schemes to describe the actual composition of a sediment (or rock) as precisely as possible have found that it is difficult in practice to use the JOIDES classification for two reasons. First, sediments that contain intermediate mixtures of calcareous-biogenic, siliceous-biogenic, and nonbiogenic components are not clearly defined by the JOIDES classification. Second, sediments that contain siliceous-biogenic components are classified differently from those that contain calcareous-biogenic components. Davies et al. (1977) computerized the JOIDES classification in an attempt to standardize DSDP shipboard smear-slide data, but it also failed to define classification subdivisions for all possible mixtures of three components.

The need for a more uniform and more completely defined deep-sea sediment classification was recognized almost as soon as the JOIDES classification was put into use by DSDP. The evolution of our classification began on Leg 75 of DSDP off southwest Africa where sediments containing siliceous-biogenic, calcareous-biogenic, and nonbiogenic components are common. Two of us (Dean and Stow) as shipboard sedimentologists found that we could not use the JOIDES classification for those three-component sediments and modified the JOIDES classification accordingly for use on Leg 75 (Hay et al. 1984). The Leg 75 classification was then submitted to the JOIDES-SP4 panel for consideration. JOIDES-SP4 sent the proposed classification to 28 sedimentologists for review. While the classification was out for review, two of us (Dean and Leinen) had the opportunity to test the classification again during rapid recovery of hydraulic piston cores (HPC) aboard the *Glomar Challenger* on Leg 89 in the western Pacific, and Leg 92 in the central South Pacific. The Leg 75 classification was refined and improved by the Leg 89 shipboard scientists. The present classification is the result of further modification of the Leg 89 classification, taking into account review comments by 19 sedimentologists who responded to the JOIDES-SP4 review request.

The purpose of this report is to present the resulting classification scheme for deep-sea sediments. This classification is, as far as possible, symmetrical and consistent

[1] Manuscript received 30 May 1984; revised 24 September 1984.
[2] Present address: Geology Department, University Park, Nottingham NG7 2RD, England.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 55, NO. 2, MARCH, 1985, P. 0250–0256

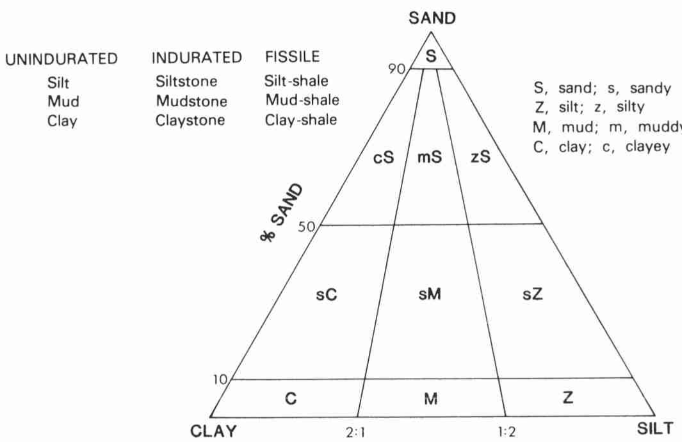

FIG. 1.—Textural classification of clastic sediments (from Folk 1980).

within the confines of the three main components, preserves the spirit and intentions of the JOIDES classification, is easy to understand and use, and provides simple, precisely defined names for sediments of intermediate compositions.

SEDIMENT CLASSIFICATION

Measurement of Components

The basic framework of our classification is the three-component system of calcareous-biogenic, siliceous-biogenic, and nonbiogenic components. In practice, measurements of abundance of these components usually are made by estimating the abundance of components in smear slides of the sediment. We are aware that such measurements are semiquantitative at best, but this method does provide a reasonable *estimate* of the sediment composition and provides the equivalent of a field description of the sample.

Nonbiogenic components are classified entirely on the basis of texture (sand, silt, and clay) according to Folk's (1954 and 1980) classification (Fig. 1). The term *clay* is used for any material <4 μm in size without regard to composition or origin (hence, terms such as *pelagic clay* do not appear in our classification). Size can be determined by estimation in smear slides aboard ship. We have found that subtle but significant differences in amounts of silt and clay often can be distinguished by this method. Visual smear-slide estimates should be modified, where necessary, by any subsequent, more quantitative composition and size analyses.

Many deep-sea sediments that consist mainly of nonbiogenic components, particularly those found closest to continental margins, are mixtures of silt and clay. Some sedimentologists prefer to call such a sediment *mud* (for example, Stow 1981). However, we agree with Folk (1980, p. 28) that it is "worthwhile to make an attempt, if at all practicable, to estimate this (silt : clay) ratio," because information of possible genetic significance can be lost by lumping the two size groups together as *mud.* For example, in basinal areas close to continental margins, the distinction between a sediment that is predominantly silt and one that is predominantly clay may be the distinction between a sediment deposited by distal turbidites and one deposited by pelagic or hemipelagic processes.

In most deep-sea sediments, $CaCO_3$ is derived mainly from the remains of calcareous plankton (Foraminifera and calcareous nannoplankton). Several rapid, easy, and precise methods are available for measurement of percent $CaCO_3$. The "carbonate bomb" method (Müller and Gastner 1971) is particularly useful for shipboard measurements, and provides a rapid check of smear-slide estimates. It has been our experience that the sum of smear-slide estimates of each calcareous-biogenic component usually is within ten percent of the measured percent of $CaCO_3$.

The percentage of biogenic SiO_2 (opal) can be measured (for example, Leinen 1977; DeMaster 1981), but this determination is much more time-consuming than that for $CaCO_3$ and usually cannot be done easily aboard ship. This is a more critical determination, however, because siliceous-biogenic components (diatoms, radiolaria, and silicoflagellates) are large and porous, and it has been our experience that smear-slide estimates tend greatly to overestimate the percentage of biogenic opal (compare percentages of total siliceous-biogenic components and biogenic SiO_2 in Fig. 2). This can lead to some serious errors, particularly if the volumetric smear-slide estimates are used for gravimetric calculations such as computing mass accumulation rates.

Because smear-slide estimates are preliminary, we have used broad boundaries of 10, 25, and 50% for our classification. Basically, we are asking that the user evaluate whether a component is greater or less than "about a tenth," greater or less than "about a quarter," or greater or less than "about a half" of the sediment.

Rules for Using the Classification

On the basis of the above philosophy of component estimation, we now outline the basic rules for using the classification. In the examples that follow in the text and in illustrations, capitalization of sediment names is intended for emphasis; it does not imply that sediment names be capitalized.

Rule 1.—More than 50% of a component or group of components (for example, total siliceous biogenic or total calcareous biogenic) determines the main name. Main names are determined as follows:

a) *Nonbiogenic:* If the total of nonbiogenic components is greater than 50%, the main name is determined by the dominant size(s) (Fig. 1). Examples of nonbiogenic main names are CLAY, SILT, SAND, and so forth.
b) *Biogenic:* If the total of biogenic components (siliceous plus calcareous) is greater than 50%, the main name is OOZE, modified by the name(s) of the dominant biogenic component(s).

Rule 2.—Twenty-five to 50% of a component qualifies it for *major-modifier* status. Major modifiers are as follows:

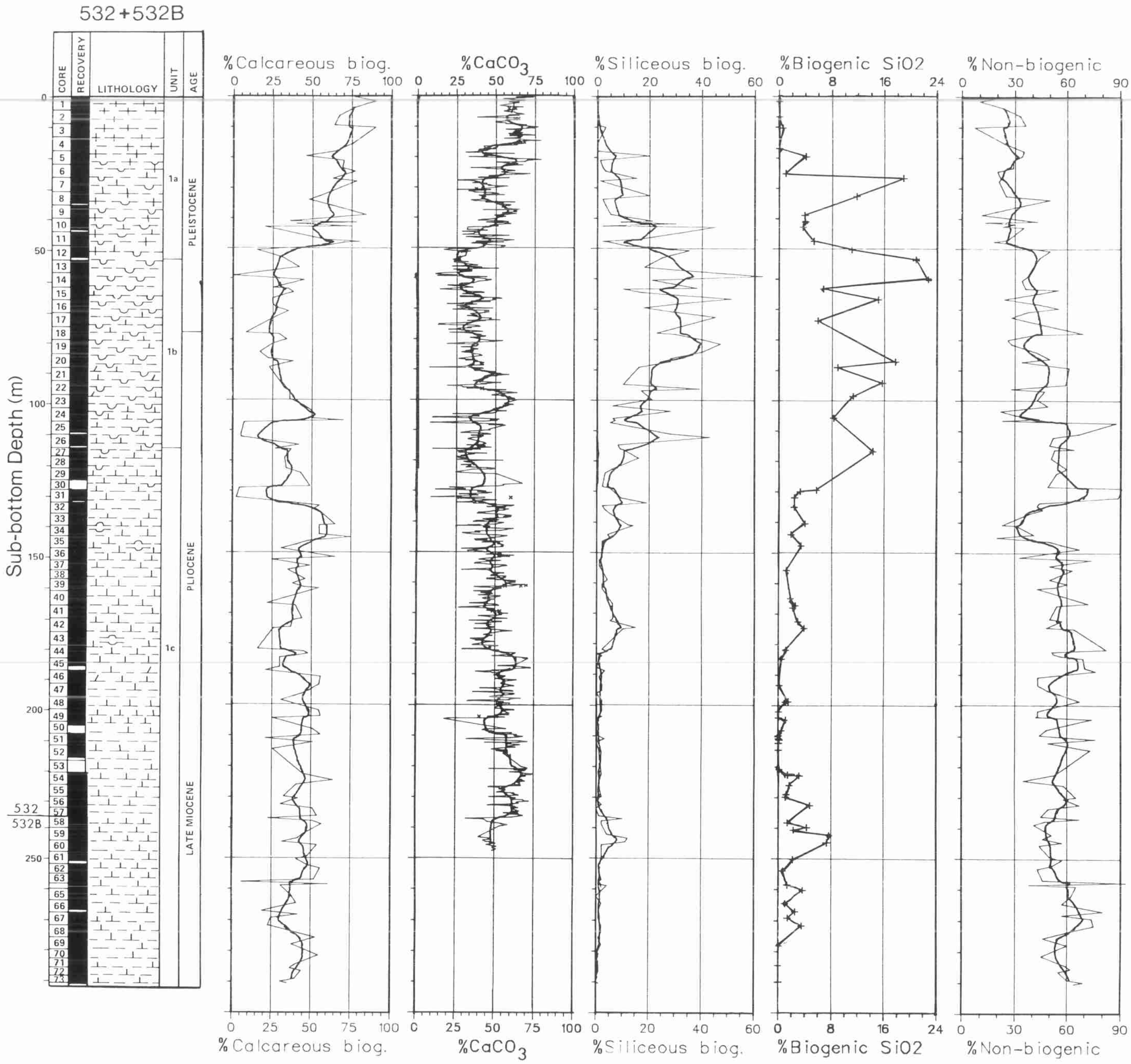

FIG. 2.—Lithology, percent total calcareous-biogenic components, percent $CaCO_3$, percent total siliceous-biogenic components, percent biogenic SiO, and percent total nonbiogenic sediments in samples of sediments from DSDP Holes 532 and 532B, eastern Walvis Ridge, South Atlantic Ocean. Data for calcareous-biogenic, siliceous-biogenic, and nonbiogenic components are from smear-slide estimates in Hay et al. (1984). Data for percent $CaCO_3$ are from Gardner et al. (1984). Data for percent biogenic SiO_2 are from Dean and Parduhn (1984).

a) *Nonbiogenic:* The main modifiers are SILTY, CLAYEY, SANDY, and so forth (Fig. 1).

b) *Calcareous biogenic:* The main modifiers are NANNOFOSSIL, FORAMINIFER, or simply CALCAREOUS (but it is best to be more specific when possible).

c) *Siliceous biogenic:* The main modifiers are DIATOM, RADIOLARIAN, or SILICEOUS (again, it is best to be as specific as possible).

Rule 3.—Ten to 25% of any sediment component qualifies it for *minor-modifier* ("-bearing") status.

Rule 4.—Major and minor modifiers are listed in order of increasing abundance to the left of the main name. Some examples are the following:

a) Sixty percent nannofossils, 30% foraminifers, 5% radiolarians, 5% clay = FORAMINIFER NANNOFOSSIL OOZE.

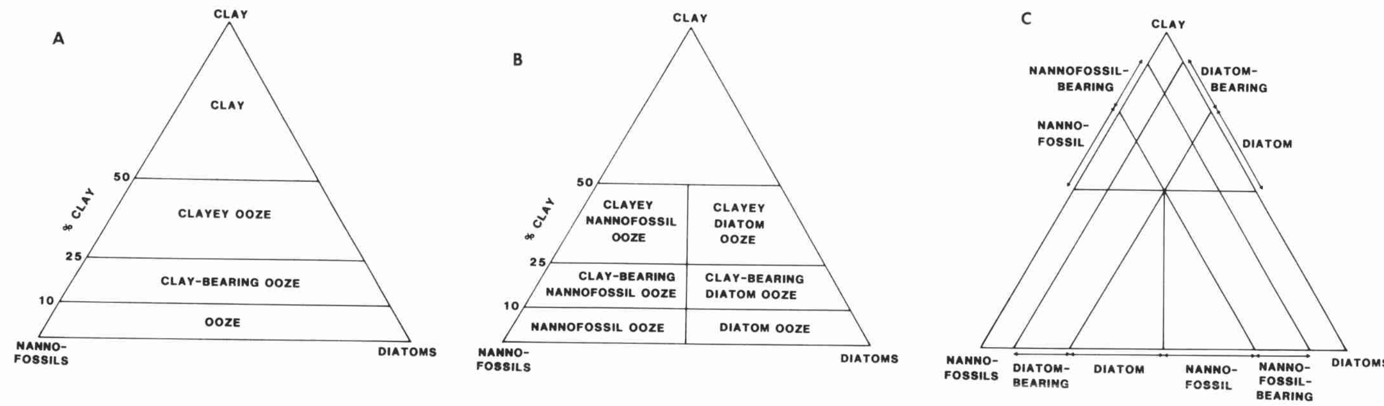

FIG. 3.—Diagrammatic illustrations of the three steps in using the sediment classification described in this report. For purposes of illustration, the total nonbiogenic component is clay, the siliceous-biogenic components are diatom remains, and the calcareous-biogenic components are nannofossil remains. A) Step 1—determining the abundance of nonbiogenic components (clay in this example) relative to the total of all biogenic components. B) Step 2—determining the abundance of siliceous-biogenic components relative to calcareous-biogenic components. C) Step 3—determining the relative abundances of siliceous-biogenic and calcareous-biogenic components within limits of 10, 25, and 50%.

b) Forty percent nannofossils, 35% foraminifers, 15% radiolarians, 10% clay = CLAY- and RADIOLARIAN-BEARING FORAMINIFER NANNOFOSSIL OOZE.
c) Thirty percent foraminifers, 15% radiolarians, 30% sand, 25% silt = RADIOLARIAN-BEARING FORAMINIFER SILTY SAND.
d) Forty percent diatoms, 30% nannofossils, 30% clay = CLAYEY NANNOFOSSIL DIATOM OOZE or NANNOFOSSIL CLAYEY DIATOM OOZE.

Steps in Using the Classification

Now that we have outlined the basic rules of the classification, we will go through the logical steps in using the classification. To illustrate the steps, we will use a three-component sediment in which the nonbiogenic components are more than 90% in the clay-size range, the calcareous-biogenic components consist of more than 90% nannofossils, and the siliceous-biogenic components consist of more than 90% diatoms. Although this three-component sediment may seem rather simple, particularly for a near-shore sediment, it is fairly typical of many deep-sea sediments. In fact, many deep-sea sediments are basically two-component sediments (for example biogenic $CaCO_3$ and clay).

Step 1.—Does the clay (the total nonbiogenic component in our example) constitute more than 50% or less than 50% of the sediment? If it is more than 50%, the main name of the sediment is CLAY; if it is less than 50%, the main name of the sediment is OOZE (Fig. 3A). If the clay is less than 50%, is it more or less than 25%? Is it more or less than 10%? If clay is between 25 and 50%, the sediment is a CLAYEY OOZE; if clay is between 10 and 25%, the sediment is a CLAY-BEARING OOZE; and if clay is less than 10%, the sediment is simply an OOZE (Fig. 3A).

Step 2.—Which are most abundant, the siliceous or the calcareous biogenic components (diatoms and nannofossils in our example)? If the sediment is an OOZE (i.e., total biogenic components > 50%), the answer to this question determines the main name as either a DIATOM OOZE or a NANNOFOSSIL OOZE, appropriately modified by CLAYEY or CLAY-BEARING depending upon how much clay is present (Fig. 3B).

Step 3.—The final step in using the classification is to determine the relative abundances of the biogenic components within the 10, 25, and 50% limits. This determines the major- and minor-modifier status of the components (Fig. 3C). Steps 1 and 2 may have determined, for example, that a sediment is a NANNOFOSSIL OOZE, but is it a DIATOM NANNOFOSSIL OOZE (diatoms between 25 and 50%), a DIATOM-BEARING NANNOFOSSIL OOZE (diatoms between 10 and 25%), or simply a NANNOFOSSIL OOZE (diatoms < 10%)? This third step also determines the modifiers for a sediment that consists of more than 50% nonbiogenic components (clay in our example), and completes the names for all pigeonholes in the three-component classification scheme (Fig. 4).

Some Alternate Terms

The classification scheme described in this report provides well-defined pigeonholes with names within a three-component framework. Some users may wish to substitute other terms, either because of a sense of euphony or because of long-standing usage. For example, some people object to the use of "-bearing" as a minor modifier, either because they don't like the sound of it, or because they feel that it implies lower percentages of the component than 10 to 25%. We believe, however, that, when defined, it provides a clear distinction between, for example, a "diatom-bearing nannofossil ooze" and a "diatom nannofossil ooze," both of which might be classified as a "diatom nannofossil ooze" or, even more vaguely, as a "diatomaceous nannofossil ooze" by other classification schemes. We, therefore, recommend adhering to the well-defined modifier terminology even though it can sound stilted at times.

It is with some personal regret that the term *marl* does not appear in our classification for a clayey calcareous sediment. To quote one of our reviewers: "The term 'marl' is an excellent word, with a wonderful history dating back to the earliest days of our science; it should not be abandoned. It has been abused and misused, but so what?" Few terms spark more polarized reactions than the term *marl*. In our original classification scheme (Hay et al. 1984), we included the term *marl* and proposed the term *sarl* for the siliceous equivalent (for example, diatom clay and clayey diatom ooze). However, those who had a quarrel with *marl* simply snarled at *sarl*. To avoid controversy, we therefore eliminated both terms from our classification. Sedimentologists undoubtedly will continue to use terms such as *marl* and *mud* as convenient field or shipboard terms. However, if quantitative measurements of $CaCO_3$ and grain size are available, we urge that more precise terms be used.

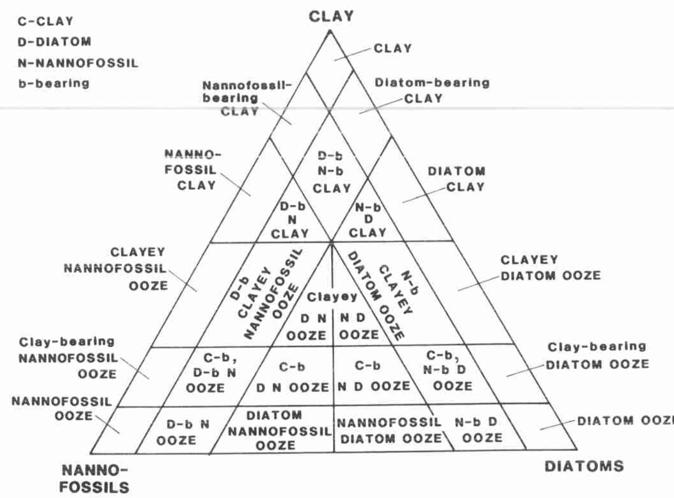

FIG. 4.—Diagrammatic illustration of an example of the complete three-component classification using clay, diatoms, and nannofossils as the three end members, and following the three steps outlined in the text and in Figure 3.

DEGREE OF INDURATION

Recognizing stages in the degree of induration of a sediment can provide valuable insight into the processes of diagenesis and lithification. For carbonate sediments, a three-fold induration scale (soft, firm, and hard, equivalent to ooze, chalk, and limestone) has been used for many years (for example, Heath and Moberly 1971). No such scale exists for noncarbonate sediments; they are either sediment or rock. The general criteria for recognizing the three stages of induration in carbonate sediments are as follows:

Soft (ooze): Has little strength and is easily deformed with the blade of a spatula.
Firm (chalk): Partly indurated ooze; can easily be scratched or deformed with the edge of a spatula blade.
Hard (limestone): Completely cemented rock.

For nonbiogenic sediments (mostly silt and clay), it is probably sufficient to retain the two-fold induration scale of sediment and rock (identify the suffix -stone following the main sediment name if the sediment is indurated but not fissile, or -shale if the sediment is indurated and fissile; Fig. 1).

For siliceous sediments, however, we believe that there is a need for a classification of sediment of intermediate induration equivalent to chalk for carbonate sediments. Because *diatomite* commonly is used as a good working field term for a partly indurated, uncemented sediment composed mainly of diatom frustules, we recommend that the terms *diatomite* and *radiolarite* be used for the equivalent of chalk for sediments that contain more than 30% diatoms and radiolarians, respectively. Hard, lithified siliceous sediments are *porcellanite* and *chert*. Porcellanite usually is dull, white, fairly porous, and the dominant silica phase is opal-CT (for example, Kastner et al. 1977; Hein et al. 1978). Chert, in contrast, generally is lustrous, has conchoidal fracture, and is much denser and harder than porcellanite; but most important, the dominant silica phase is cryptocrystalline quartz (Hein et al. 1981). These two siliceous rock types cannot always be distinguished in hand specimen but can be distinguished by X-ray diffraction and thin-section observations.

OTHER SEDIMENT AND ROCK TYPES

Our classification covers the majority of sediment and rock types likely to be found in deep-sea areas. A few other, less common types are worth mentioning, however, and still other sediment types probably can be dealt with through existing classifications.

Volcanogenic Sediments

Volcanogenic sediments may consist of primary volcanic minerals (volcanic glass, feldspar, pyroxene, volcanic rock fragments, opaque minerals, and so forth) or secondary minerals (for example, smectites, palagonite, zeolites, palygorskite, and silica minerals) (Vallier and Kidd 1977). Volcanogenic sediments are found as distinct beds only when deposited by air fall after a large eruption, or, more commonly, when deposited by downslope transport (turbidites and debris flows) on volcanic edifices (for example, the Line Islands, Schlanger et al. 1976; Hess Rise and the Mid-Pacific Mountains, Vallier and Jefferson 1981), in adjacent basins (for example, the Nauru Basin, Moberly and Jenkyns 1981), or near continental volcanic sources. Much wind-borne volcanogenic sediment is masked by biogenic components and (or) terrigenous components, and is recognized mainly by the presence of characteristic minerals in smear slides or on X-ray diffractograms.

If volcanogenic components comprise more than ten percent of a sediment, we suggest that the term *ash* be used following the same rules as for other components; that is, 10–25% ash in a sediment is *ash-bearing*; 26–50% ash is *ashy*; and more than 50% ash determines the main name as *ash*. The lithified equivalents are *tuff-bearing*, *tuffaceous*, and *tuff*. *Hyaloclastite* is a fragmental rock that forms when a fluid lava is quenched quickly and shatters as it contacts seawater, resulting in broken pieces of basaltic glass (Williams and McBirney 1979).

Ferromanganese Sediments

In smear slides, ferromanganese sediments generally appear as iron oxide-rich clays, and (or) may have an abundance of ferromanganese micronodules. Because hydrated oxides and hydroxides of iron and manganese are good adsorbers of certain trace elements, particulary the transition elements, they have often been referred to as "metalliferous" sediments. However, we recommend that this term not be used unless chemical analyses, at least of Fe, Mn, and some conservative, detrital element such as Al, are available. In keeping with our classification scheme, we recommend that iron-bearing or ferromanganese-bearing be used as modifiers when these components comprise more than ten percent of the sediment, and that ferromanganic be used as a modifier when these components constitute more than 25 percent of the sediment.

Zeolitic Sediments

In smear slides, zeolites appear as clear, euhedral crystals with high optical relief. They are authigenic, hydrous aluminosilicates and are usually found in slowly accumulating, deep-sea clay deposits, or in deeply buried volcanogenic deposits. The most common zeolites in deep-sea sediments are *phillipsite* and *clinoptilolite,* with phillipsite usually being the most abundant in deeper, older strata. Zeolites commonly are associated with ferromanganese oxides, smectite-rich clays, palagonite, and with primary or secondary volcanogenic minerals. We recommend that zeolite be considered as a sedimentary component like other components described above. Sediments containing 10–25% zeolites would then be zeolite-bearing and those containing 26–50% zeolites would be zeolitic.

Some sediment components may be present in amounts of less than ten percent but may be of particular economic importance, or may be indicators of depositional or diagenetic envrionments. Depending on the purpose of the study, volcanic ash, iron and manganese oxides, and zeolites might be in that category. Other environmentally sensitive components are phosphate, organic carbon, glauconite, pyrite, siderite, and so forth. For example, it might be more important for the purposes of a particular study that a sediment contains five percent organic carbon than the fact that the sediment is a diatom-bearing silty clay. Terms such as "organic-carbon-rich clay" or "pyritic clayey nannofossil ooze" probably will continue to be used in particular studies, but should be defined as precisely as possible.

SUMMARY

Deep-sea, fine-grained sediments are classified on the basis of a three-component system of calcareous-biogenic, siliceous-biogenic, and nonbiogenic components. Relative amounts of the components are estimated from smear slides within limits of 10, 25, and 50%. Any component with a concentration of 10–25% is given minor-modifier or "-bearing" status. Any component with a concentration of 26–50% is given major-modifier status, and the most abundant component determines the main sediment name. If the dominant component is nonbiogenic, the main name is determined by the dominant size(s). If the total of biogenic components is more than 50%, the main name is "ooze," modified by the name(s) of the dominant biogenic component(s).

ACKNOWLEDGMENTS

We greatly appreciate the comments, suggestions, and ideas on classification of deep-sea sediments that we have received either formally or informally from numerous colleagues. Shipboard sedimentologists from DSDP Legs 75 and 89 who helped to develop the classification "under fire" of rapid HPC core recovery were M. Baltuck, E. J. Barron, J. A. Haggerty, R. Moberly, J. G. Ogg, S. O. Schlanger, R. E. Schallreuter, and J. M. Whitman. The JOIDES-SP4 panel, and particulary its chairman, George deVries Klein, obtained numerous reviews, many of which were very thorough and involved a considerable amount of time and effort on the part of the reviewers. Those JOIDES-SP4 reviewers who responded were W. H. Berger, H. Chamley, D. M. Curtis, S. E. Calvert, J. E. Damuth, L. J. Doyle, J. V. Gardner, G. R. Heath, D. A. Johnson, R. B. Kidd, I. N. McCave, F. McCoy, H. Okada, N. Pisias, D. K. Rea, M. Sarnthein, C. Sancetta, Tj. H. van Andel, and H. B. Zimmerman. Additional comments were provided by H. C. Jenkyns, D. J. W. Piper, and J. Thiede. Our thoughts on siliceous sedimentary rocks have been influenced by the recommendations made at a recent Penrose Conference on Siliceous Sediments.

REFERENCES

Davies, T. A., Musich, L. F., and Woodbury, P. B., 1977, Automated classification of deep-sea sediments: Jour. Sed. Petrology, v. 47, p. 650–656.

Dean, W. E., and Parduhn, N. L., 1984, Inorganic geochemistry of sediments and rocks recovered from the southern Angola Basin and adjacent Walvis Ridge, Sites 530 and 532, Deep Sea Drilling Project Leg 75: Initial Reports of the Deep Sea Drilling Project, v. 75, U.S. Government Printing Office, Washington, D.C., p. 923–958.

DeMaster, D. J., 1981, The supply and accumulation of silica in the marine environment: Geochim. Cosmochim. Acta, v. 45, p. 1715–1732.

Diester-Haass, L., and Schrader, H.-J., 1979, Neogene coastal upwelling history off northwest and southwest Africa: Marine Geol., v. 29, p. 39–53.

Folk, R. L., 1954, The distinction between grain size and mineral composition in sedimentary rock nomenclature: Jour. Geology, v. 62, p. 344–359.

———, 1980, Petrology of sedimentary rocks: Austin, TX, Hemphill Publishing Co., 182 p.

Gardner, J. V., Dean, W. E., and Wilson, C., 1984, Carbonate and organic-carbon cycles and the history of upwelling at DSDP Site 532, Walvis Ridge, South Atlantic Ocean: Initial Reports of the Deep Sea Drilling Project, v. 75, U.S. Government Printing Office, Washington, D.C., p. 905–921.

HAY, W. W., SIBUET, J.-C., ET AL., 1984, Initial Reports of the Deep Sea Drilling Project, v. 75: U.S. Government Printing Office, Washington, D.C., 1,303 p.

HEATH, G. R., AND MOBERLY, R., 1971, Cherts from the western Pacific, Leg 7, Deep Sea Drilling Project: Initial Reports of the Deep Sea Drilling Project, v. 7, U.S. Government Printing Office, Washington, D.C., p. 991–1007.

HEIN, J. R., SCHOLL, D. W., AND BARRON, J. A., 1978, Diagenesis of late Cenozoic diatomaceous deposits and formation of the bottom simulating reflector in the southern Bering Sea: Sedimentology, v. 25, p. 155–181.

HEIN, J. R., VALLIER, T. L., AND ALLAN, M. A., 1981, Chert petrology and geochemistry, Mid-Pacific Mountains and Hess Rise, Deep Sea Drilling Project Leg 62: Initial Reports of the Deep Sea Drilling Project, v. 62, U.S. Government Printing Office, Washington, D.C., p. 711–748.

KASTNER, M., KEENE, J. B., AND GIESKES, J. M., 1977, Diagenesis of siliceous oozes—I. Chemical controls on the rate of opal-A to opal-CT transformation—an experimental study: Geochim. Cosmochim. Acta, v. 41, p. 1041–1059.

LEINEN, M., 1977, A normative calculation technique for determining opal in deep-sea sediments: Geochim. Cosmochim. Acta, v. 41, p. 671–676.

MOBERLY, R., AND JENKYNS, H. C., 1981, Cretaceous volcanogenic sediments of the Nauru Basin, Deep Sea Drilling Project Leg 61: Initial Reports of the Deep Sea Drilling Project, v. 61, U.S. Government Printing Office, Washington, D.C., p. 533–548.

MÜLLER, G., AND GASTNER, M., 1971, The "Karbonate-Bombe," a simple device for determination of the carbonate content of sediments, soils, and other materials: Neues Jahrb. Mineral. Monatsh., v. 10, p. 466–469.

ROSS, D. A., NEPROCHNOV, Y. P., ET AL., 1978, Initial Reports of the Deep Sea Drilling Project, v. 42, pt. 2: U.S. Government Printing Office, Washington, D.C., p. 13–15.

SCHLANGER, S. O., JACKSON, E. D., ET AL., 1976, Initial Reports of the Deep Sea Drilling Project, v. 33: U.S. Government Printing Office, Washington, D.C., 973 p.

STOW, D. A. V., 1981, Fine-grained sediments: Terminology: Quart. Jour. Eng. Geol. London, v. 14, p. 243–244.

VALLIER, T. L., AND JEFFERSON, W. D., 1981, Volcanogenic sediments from Hess Rise and the Mid-Pacific Mountains, Deep Sea Drilling Project, Leg 62: Initial Reports of the Deep Sea Drilling Project, v. 62, U.S. Government Printing Office, Washington, D.C., p. 545–558.

VALLIER, T. L., AND KIDD, R. B., 1977, Volcanogenic sediments in the Indian Ocean, *in* (J. R. Heirtzler, ed.) Indian Ocean geology and biostratigraphy: Am. Geophys. Union, Washington, D.C., p. 87–118.

VAN ANDEL, TJ. H., HEATH, G. R., AND MOORE JR., T. C., 1975, Cenozoic history and the paleoceanography of the central equatorial Pacific Ocean: Geol. Soc. America Memoir 143, 134 p.

WILLIAMS, H., AND MCBIRNEY, A. R., 1979, Volcanology: New York, Freeman, Cooper, and Co., 397 p.