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THE ENCYCLOPEDIA OF SEDIMENTOLOGY

Edited by

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ENCYCLOPEDIA OF EARTH SCIENCES, VOLUME VI

The ENCYCLOPEDIA *of* SEDIMENTOLOGY

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PREFACE

The *Encyclopedia of Sedimentology* is a comprehensive, alphabetical treatment of the discipline of sedimentology. It is intended to be a reference book for sedimentologists, geologists, and others who come in contact with sediments. In the broadest sense, this group includes most of the world's population because over 75 percent of the earth's surface is covered with sediments and sedimentary rocks. The book should be particularly useful, however, to petroleum and coal geologists, soil scientists, hydrologists, archaeologists, and other professionals in related fields.

Sedimentology is a broad and growing discipline (see *Sedimentology; Sedimentology—Yesterday, Today and Tomorrow*) that has seen the publication of several new texts and innumerable more specialized volumes in the last decade. We could not hope in this encyclopedia to cover the field in depth; but in breadth—from *Microbiology in Sedimentology* to *Radioactivity in Sediments* to *Martian Sedimentation*—we intend to provide readers with basic information and to direct them to more specialized literature.

Some attempt has been made to define terms and to adhere to definitions in this volume, but an encyclopedia is *not* a dictionary. It is a compendium of knowledge, and in some instances there are differences of opinion and in choice of terminology among the people who practice sedimentology. Nor is an encyclopedia a symposium volume; although we have tried to present an up-to-date book, controversial issues or new and untested ideas are not emphasized in an encyclopedia. The reader should be aware, however, that each entry may reflect the individual outlook of an author, from a broad, international spectrum of contributors. Partly for this reason, there are numerous entries that overlap in their coverage. The extensive cross-referencing should allow the reader to note differences in opinion or in approach. We hope that this diverse coverage will enhance the usefulness of the volume.

Literature

It is customary in the encyclopedia series to provide a list of basic references that would complement the volume. Below is a list of only some of the most recent fundamental sedimentology texts and older reference books. Books marked with an asterisk (*) contain comprehensive reference lists.

*Bathurst, R. G. C., 1975. *Carbonate Sediments and Their Diagenesis.* Amsterdam: Elsevier, 658p.

Berner, R. A., 1971. *Principles of Chemical Sedimentology.* New York: McGraw-Hill, 240p.

*Blatt, H., Middleton, G., and Murray, R., 1972. *Origin of Sedimentary Rocks.* Englewood Cliffs, N.J.: Prentice-Hall, 634p.

*Boswell, P. G. H., 1933. *On the Mineralogy of Sedimentary Rocks.* London: Murby, 393p.

Carozzi, A., 1960. *Microscopic Sedimentary Petrography.* New York: Wiley, 485p.

Carver, R. W., ed., 1971. *Procedures in Sedimentary Petrology.* New York: Wiley, 458p.

*Englehardt, W. V., 1977. *The Origin of Sediments and Sedimentary Rocks.* Stuttgart: E Schweizerbart'sche, New York: Halsted, 359p.

*Friedman, G. M., and Sanders, J. E., 1978. *Principles of Sedimentology.* New York: Wiley, 700p.

*Füchtbauer, H., 1974. *Sediments and Sedimentary Rocks 1.* Stuttgart: E. Schweizerbart'sche; New York: Halsted, 464p.

Garrels, R. M., and Mackenzie, F. T., 1971. *Evolution of Sedimentary Rocks.* New York: Norton, 397p.

Hatch, F. H., Rastall, R. H., and Greensmith, J. T., 1971. *Petrology of Sedimentary Rocks,* 5th ed. New York: Hafner, 502p.

Krumbein, W. C., and Pettijohn, F. J., 1938. *Manual of Sedimentary Petrography.* New York: Plenum, 549p.

Krumbein, W. C., and Sloss, L. L., 1963. *Stratigraphy and Sedimentation,* 2nd ed. San Francisco: Freeman, 660p.

Kukal, Z., 1970. *Geology of Recent Sediments.* Prague: Czech. Acad. Sci., 490p.

*Milner, H. B., 1962. *Sedimentary Petrography,* 2 volumes. New York: Macmillan, 643p and 715p.

*Pettijohn, F. J., 1975. *Sedimentary Rocks,* 3rd ed. New York: Harper & Row, 628 p.

*Pettijohn, F. J., Potter, P. E., and Siever, R., 1972. *Sand and Sandstone.* New York: Springer, 618p.

*Reineck, H.-E., and Singh, I. B., 1973. *Depositional Sedimentary Environments.* New York: Springer, 439p.
Selley, R. C., 1976. *An Introduction to Sedimentology.* London: Academic Press, 408p.
*Shrock, R. R., 1948. *Sequence in Layered Rocks.* New York: McGraw-Hill, 507p.
*Strakhov, N. M., 1967, 1969, 1970. *Principles of Lithogenesis,* 3 vols. (translated from 1962 Russian edition) New York: Consultants Bureau; Edinburgh: Oliver & Boyd, 245p, 609p, and 577p.
Twenhofel, W. H., 1950. *Principles of Sedimentation.* New York: McGraw-Hill, 673p.
*Wilson, J. L., 1975. *Carbonate Facies in Geologic History.* New York: Springer, 417p.

Three major journals deal exclusively with sedimentology:

Journal of Sedimentary Petrology (1931), sedimentological journal of the Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma.
Sedimentary Geology (1967), international journal of pure and applied sedimentology, published by Elsevier, Amsterdam.
Sedimentology (1962), journal of the International Association of Sedimentologists, published by Blackwell, Oxford.

Other journals that emphasize sedimentology include:

Bulletin of the American Association of Petroleum Geologists
Bulletin of Canadian Petroleum Geology
Clays and Clay Minerals
Deep-Sea Research
Estuarine and Coastal Marine Science
Geochimica et Cosmochimica Acta
Geologie en Mijnbouw
Lethaia
Limnology and Oceanography
Lithology and Mineral Resources
Lithos
Marine Geology
Maritime Sediments
Palaeogeography, Palaeoclimatology, Palaeoecology
Senckenbergiana Maritima

The American Association of Petroleum Geologists publishes a series of *Memoirs,* and the Society of Economic Paleontologists and Mineralogists, *Special Publications;* both societies produce reprint series, short-course notes, and various other publications. A comprehensive series of volumes entitled *Developments in Sedimentology* is published by Elsevier. The *Initial Reports of the Deep Sea Drilling Project* contain a wealth of information. A particularly valuable reference is *GEO Abstracts E: Sedimentology,* which attempts to abstract all papers in sedimentology, in six issues a year.

Organization and Style

Major entries, for example *Limestones,* appear alphabetically. If the reader does not find an entry where expected, it is best to consult the Index. Most articles are extensively cross-referenced, both in the body of the text and at the end of the reference list for each entry. The abbreviation q.v. (*quod vide*), for example "flow regimes (q.v.)," is used to indicate that an entry by that title appears in the volume. Cross-references to other volumes in the Encyclopedia of Earth Science Series are also included. The following is a list of published and planned volumes:

I: Oceanography
II: Atmospheric Sciences and Astrogeology
III: Geomorphology
IVA: Geochemistry and Environmental Sciences
IVB: Mineralogy
V: Petrology
VII: Paleontology
VIII: World Regional Geology, Part 1: Western Hemisphere
VIII: World Regional Geology, Part 2: Europe and Asia
VIII: World Regional Geology, Part 3: Africa and Middle East
IX: Stratigraphy
X: Structural Geology
XI: Pedology
XII: Soil Science
XIII: Applied Geology
XIV: Petroleum Geology
XV: Beaches and Coastal Environments
XVI: Natural Resources and Energy Conservation
XVII: Snow, Ice and Glaciology
XVIII: Geohydrology and Water Supply
XIX: World Ore Deposits
XX: Ore Genesis and Metallogeny
XXI: Mining and Mineral Resources
XXII: Volcanoes and Volcanology
XXIII: Geophysics
XXIV: History of Geology

Each entry is followed by a list of references.

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There may be references included that are not cited in the text, but that may lead the reader to additional, more detailed information.

Abbreviations in the volume include:

i.e. (*id est*) = that is
e.g. (*exempli gratia*) = for example
≈ = approximately
μ (mu) = micrometers (S.I. abbreviation has now been established as μm)
B.P. = Before Present (1950)
m.y. = million years
‰ = parts per thousand
ppm = parts per million
< = less than
> = greater than

Standard abbreviations are used for measures of length, area, and volume. An attempt has been made to use the metric system whenever possible. Where definitions are involved, metric equivalents are usually given in parentheses. Some tables, figures, and maps, however, retain the English system of measurement; the following conversion tables may, therefore, be useful:

Metric to English Units—Equivalents of Length

1μ = 0.001 mm = 0.00004 in
1 mm = 0.1 cm = 0.03937 in
1000 mm = 100 cm = 1 m = 39.37 in = 3.2808 ft
1 in = 2.54 cm
12 in = 1 ft = 0.3048 m
1 cm = 0.39370 in
1 km = 0.62137 mi
1 fathom = 1.8288 m
1 nautical mile = 1.85325 km
1 statute mile = 1.60935 km = 5280 ft

Square Measures

1 acre = 43560 ft^2 = 0.0015625 mi^2
1 yd^2 = 0.836127 m^2
1 mm^2 = 0.00155 in^2
1 cm^2 = 0.155 in^2 = 0.0011 ft^2
1 m^2 = 10.764 ft^2
1 km^2 = 0.3861 mi^2
1 in^2 = 6.452 cm^2
1 ft^2 = 0.09290 m^2 = 929 cm^2
1 mi^2 = 2.59 km^2

Cubic Measures

1 gal (UK) = 4.5461 liters = 1.201 gal (US)
1 liter = 0.22 gal (UK) = 0.264 gal (US)
1 gal (US) = 3.7854 liters = 0.83 gal (UK)
1 in^3 = 16.387 cm^3
1 ft^3 = 0.0283 m^3
1 mi^3 = 4.1681 km^3
1 mm^3 = 0.000061 in^3
1 cm^3 = 0.061 in^3
1 m^3 = 35.315 ft^3
1 km^3 = 0.24 mi^3

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Over half of the contributors reviewed other manuscripts in the volume, and many agreed to write second or third (or more) entries. Among them the following deserve special mention: Arnold Bouma, Wolfgang Berger, Benno Brenninkmeyer, Robert Carver, John Conolly, Gerald Friedman, Peter Gascoyne, David Jablonski, David Kinsman, David Krinsley, Curt Olsen, Richard Orme, John Sanders, Daniel Stanley, Diana Thurston, and Karl Wolf. Many thanks are due to Gerard Middleton and Donn Gorsline, whose untiring assistance and moral support were invaluable to the completion of this volume. Charlotte Schreiber began the editorial work on this volume and continued to help in later stages; many of her contributions were incorporated into larger articles, and she deserves extra credit.

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A

ABRASION pH

Abrasion pH is defined as the pH of a slurry produced by grinding a mineral in a small quantity of water (Stevens and Carron, 1948). To determine abrasion pH, soft minerals that do not absorb large quantities of water are abraded on a wet streak plate, and hard minerals, or minerals that absorb water, are ground in an agate mortar with a few drops of water. Indicator papers or solutions are used to find the pH of the resultant slurry. Stevens and Carron investigated the abrasion pH of 280 minerals and suggested that abrasion pH, ranging from 1 to 12, is a valuable tool for field identification of minerals.

Abrasion pH is dependent on hydrolysis of the mineral tested. Minerals that can be considered to be salts of strong acids and strong bases give nearly neutral (7) abrasion pH values; minerals consisting of relatively passive cations and highly active anions (iron sulfate minerals) give low abrasion pH values; and carbonates give very high values. The effect is strongly dependent on the quantity of water added to the crushed mineral and on solute concentration of the water added.

According to Stumm and Morgan (1970) the phenomenon of abrasion pH is explained in general by electrical double-layer theory and specifically by the Gouy-Chapman theory. Because the broken surfaces of a silicate mineral are negatively charged and, when in contact with water, hydrated, the hydrogen ion concentration at the surface of the mineral may be quite different than the concentration in the bulk of the surrounding water. The difference between pH at the surface and in the bulk of the surrounding fluid can be estimated from the Gouy-Chapman theory.

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Cross-references: ***Authigenesis; Diagenesis; Silicification; Sulfides in Sediments; Weathering in Sediments.*** Vol. IV A: *Abrasion pH.*

ABYSSAL SEDIMENTARY ENVIRONMENTS

Abyssal pertains to the marine environment of the deep sea having depths >1000 m. The outstanding features of the abyssal province are the broad spatial expanses and the great ranges of depth. The boundaries between the overlying bathyal region and the underlying hadal realm are somewhat gradational and indistinct. Bruun (1957) describes the boundary between the bathyal and abyssal zones as coinciding with the 4°C isotherm, which is also a faunal boundary. In the Atlantic Ocean the 4°C isotherm occurs at 2000 m, while in the Indian and Pacific Oceans it occurs between 1000 and 1500 m. The lower limit of the abyssal region is probably about 6000 m, which means that a vertical range of 4000 m exists for the abyssal environment. The area between 2000 and 6000 m covers 76% of all the area of the oceans, or more than half the surface of the globe. In a recent endeavor to describe the abyssal environment, Menzies et al. (1973) assert that the bathyal/abyssal boundary cannot be established at a constant depth (the 2000 m isobath) or at a constant temperature (the 4°C isotherm). They hypothesize that the zone oscillates, depending on water masses and bottom currents. They suggest a bentho-abyssal scheme of zonation, based upon faunal composition.

Although there is some controversy regarding the boundaries of the abyssal zone, agreement exists concerning its physical characteristics. There is no solar light, so that no photosynthesis is possible. Bruun (1957) observes that the food supply of the abyssal zone is not plentiful but that actual depth is of less importance than the proximity of productivity zones at the surface. The fauna are carnivores and detritus feeders. The hydrostatic pressure is tremendous, rising with depth at the rate of 1 atm/10 m and resulting in the wide range 200-600 atm. Small variation in salinity has been observed in the abyssal zone; an average figure is 34.8‰, with a variation of 0.2‰. The temperature of the water is uniformly low, from 4°C to -1°C. There is ample circulation in the open ocean to supply well aerated water from deep vertical movements in the high latitudes.

The bottom topography of the province consists of abyssal plains, submarine channels and fans, and abyssal hills. Abyssal plains occur at the base of a continental rise, where turbidity flows transport clastic material in suspension, erode and redeposit bottom sediments, and produce the smooth stratification and remarkably flat surfaces (slopes $<1{:}1000$) characteristic of abyssal plains.

The assortment of sediment types that have been observed in the abyssal province suggest that a description of abyssal sedimentation should emphasize the factor concerning the extreme depth of water, not the processes of deposition. The nature of abyssal sedimentation is influenced by the foregoing environmental factors. The greater part of the abyssal floor is covered with a soft bottom of deep-sea red clay, while biogenous ooze is found on the rises. Suspended terrigenous sediments, carried by wind, water, or ice, settle with extreme slowness, so that all matter soluble in sea water has been removed, leaving only ferric oxide and aluminum silicate, the main constituents of red clay. Similarly, as skeletal parts of planktonic tests settle, the most fragile parts are dissolved, leaving the larger, more resistant ones. Calcareous oozes of foraminifera and coccolithophores occur at depths <4000 m, and pelagic red clays are found at the greater depths, the boundary between them determined by the position of the calcite compensation level (see *Pelagic Sedimentation*). Siliceous oozes of radiolarian and diatomaceous skeletal parts are prevalent beneath the high productivity regions of surface waters of high latitudes and the Equatorial Pacific. Sediment cores raised from abyssal plains give evidence of the action of turbidity currents in sedimentation processes of the abyssal plains. Shallow-water foraminifera, graded quartz sand, gray clays, and silts have been observed interbedded with deep-sea red clay (Heezen and Laughton, 1963). Sediments of cosmic and volcanic origin, including ash and pumice, and coarse rock detritus, rafted by ice and sometimes by the roots of plants, may settle to the abyssal floor; and secondary deposits, including authigenic zeolites and manganese nodules, are also found there. In summary, the extreme depth of water and the spatial expanse of the abyssal marine environment account for the variety of sediment types that reach the deep abyss and accumulate there.

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Cross-references: *Hadal Sedimentation; Pelagic Sedimentation; Red Clay; Siliceous Ooze; Submarine (Bathyal) Slope Sedimentation; Turbidity-Current Sedimentation.* Vol. I: *Abyssal Hills; Abyssal Plains; Abyssal Sediment (Thickness); Abyssal Zone.*

ABYSSAL SEDIMENTATION

Abyssal sedimentation occurs in the deep ocean basins, generally at depths >2000 m. Included within its scope are the standard parameters of sedimentation: provenance, transportation, deposition, and diagenesis.

Abyssal sedimentation can be subdivided in a variety of ways, none of which is wholly satisfactory or universally accepted. A simple division based upon deep-sea sedimentary processes, into pelagic sedimentation, authigenesis, and sedimentation involving near-bottom and gravity-driven density currents, is used here. Pelagic sedimentation (q.v.), a loosely but widely used term, occurs slowly by settling of particles through the water column. Authigenesis (q.v.)

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