

Sedimentary Rocks

SECOND EDITION



SEDIMENTARY ROCKS

by

F. J. PETTIJOHN

PROFESSOR OF GEOLOGY
THE JOHN HOPKINS UNIVERSITY

SECOND EDITION



HARPER & BROTHERS NEW YORK

SEDIMENTARY ROCKS

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Printed in the United States of America

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Library of Congress catalog card number: 56-11820

SEDIMENTARY ROCKS

HARPER'S GEOSCIENCE SERIES

Carey Croneis, Editor

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Editor's Introduction to the First Edition

PETTIOHN's *Sedimentary Rocks* is the seventh in Harper's Geoscience Series. Our editorial suspicion is that it will become one of the more useful of the many textbooks on various of the fundamental aspects of geology. Of all these aspects, none is more central than the general process of sedimentation, and none is more important than the product of that process—the sedimentary rocks.

Dr. Pettijohn himself regards this volume as an "elementary treatment" of the subject. Students and colleagues are likely to agree that this is something of an understatement. For although *Sedimentary Rocks* presents none of the exhaustive topical treatments characteristic of the average monograph, it does nonetheless include essentially all major subjects in its field. In a certain real sense, however, the volume is elementary, for the author has taken pains to make the presentation of even the most complex concept simple, direct and clear.

Although the author has made no attempt to prepare a complete bibliography, approximately seven hundred carefully selected papers are cited. Well over one hundred useful tables are also included in the text, with which are incorporated general photographs, line drawings and photomicrographs. For the average reader the latter, numbering 104, are likely to prove especially helpful. Not only have the sections been chosen with care, but the photomicrography displays a high order of perfection. In this text the sedimentary rocks portrayed are not merely illustrated—they are illuminated.

But if the illustrative material commends itself to students, the text may be equally appreciated, for it is as sharply focused as are the photographs. The fifteen chapters which cover almost the entire gamut of sedimentary rock topics thus require less than 200,000 words—very few of them superfluous.

Dr. Pettijohn, for nearly twenty years a member of the Department of Geology at the University of Chicago, has recently become the third editor of the *Journal of Geology*. Like its first and second editors—Thomas Chrowder Chamberlin, and his son, Rollin T. Chamberlin—Dr. Pettijohn

has devoted much of his research activity to the study of the pre-Cambrian sediments. But he has also found time to train many of the country's active students of modern as well as ancient sedimentation. All of these, among them Dr. William C. Krumbein, have contributed indirectly to this present volume; and yet it is these very researchers who may especially welcome its publication. This is true because *Sedimentary Rocks* was written to fill a long-felt need for a single-volume guide "to the observation, classification and interpretation of these deposits both in outcrop and as hand specimens."

Although Dr. Pettijohn's book may serve as a useful compendium for many professional geologists, both in and out of the field of sedimentology, the volume was designed chiefly as an aid in teaching. In this important area *Sedimentary Rocks* may well have wide use because of the philosophy of material presentation. As will be noted, the author has limited himself in the treatment of the processes of sedimentation and has devoted considerable space to analysis of the properties of rocks. Students particularly should appreciate this direct approach—and especially will they later appreciate the fact that he has been preoccupied with common rocks and structures, which they will actually see in the field, rather than with rare specimens and rare sedimentary phenomena commonly observed only in textbooks.

The style of Dr. Pettijohn's *Sedimentary Rocks* will be found refreshing in its vigor. He is not given to ambiguous or tentative explanations. He has not followed the all too common procedures of merely cataloguing unrelated observations, or listing conflicting interpretations without expressing judgment. In fact, in a recent letter, Dr. Pettijohn has written, "I have advanced some generalizations as though they were better established than they really are since I thought such treatment . . . stimulating and interesting. . . ." It seems probable that this type of text "treatment" characteristic of *Sedimentary Rocks*, will indeed prove stimulating and interesting, not alone to students but to their teachers.

CAREY CRONEIS

Beloit, Wisconsin

Editor's Introduction to the Second Edition

THE second edition of Dr. Pettijohn's *Sedimentary Rocks* requires little editorial comment. The author's Preface suggests the important changes and improvements which characterize the largely rewritten present volume. Moreover, the editorial prediction concerning the widespread use and influence of the first edition—a prediction which, typically, Dr. Pettijohn deprecated—has been so completely confirmed that additional comment regarding the modernized version of *Sedimentary Rocks* would be superfluous. It is appropriate to point out, however, that since the first edition was published, Dr. Pettijohn has become Professor of Geology at The Johns Hopkins University; and that, not surprisingly, recognition of his contributions to the study of rocks has been demonstrated in many ways—among them his election to the Presidency of the Society of Economic Paleontologists and Mineralogists.

CAREY CRONEIS

The Rice Institute
April 14, 1956

Preface to the First Edition

THE chief interest of the geologist is the lithosphere—primarily the rocks of the lithosphere. His chief goal is to elucidate the natural history of these rocks, which constitute the sole record of the history of the earth itself. This history is reconstructed primarily from the study of the *sedimentary rocks*. This volume is intended, therefore, to be a guide to the observation, classification, and interpretation of these deposits both in outcrop and as hand specimens. It should serve also as a textbook in courses which have such an objective.

The author's aim is to write a book which will tell the user something about *sedimentary rocks* rather than *sedimentation*. A book which treats largely of the so-called processes of sedimentation, cannot of itself be of direct use to the geologist who must deal, not with process, but with the product—namely, rocks. Moreover, an adequate treatment of the processes of sedimentation—such as the fluid transport of sediments—would require another volume. Hence, in order to make this book practical and keep its contents within reasonable bounds, much of what is ordinarily considered “sedimentation” is omitted. Many of the transient phenomena, especially those of sediment transport, interesting and important as they are, leave no record and can best be left out. Even those which leave an imprint can be but briefly reviewed.

Likewise, the mechanics of sediment analysis—the measurement of particle size, microscopic determination of the mineral composition, and the like—are not included. Analytical methods have been treated in detail elsewhere and some knowledge of these procedures is assumed. Though methods as such are excluded, the properties of sedimentary deposits need some discussion, because upon these is based any interpretation of origin and any system of classification and nomenclature. Hence the first part of this volume is given over to the properties of the sedimentary rocks. Many analytical methods, moreover, are appropriate only for unconsolidated materials. Few sedimentary rocks so qualify—thus recourse to thin-section studies must be the main basis for investigation rather than the exception. The student, therefore, should have a working knowledge of the methods of micropetrology.

In this volume, the author has included much new data acquired by

quantitative methods of analysis. These methods, which largely are a product of the last two decades of research, have yielded significant information which needs to be digested and organized in usable form. The writer has attempted to do this and to describe and interpret sedimentary rocks in the light of these newer researches. Rapid as the advances have been, more remains to be done than has so far been accomplished. This became evident as compilation of this work proceeded. Gaps, of larger or smaller size, in our knowledge appear everywhere. The author has pointed out many of these gaps in the hope that someone will undertake to fill them upon seeing the need.

There is notable overemphasis in the literature both of rare rocks and rare structures to the neglect of the common rocks and structures. The author has tried to strike a better balance in this volume.

The student of rocks, especially the beginner, can turn to no better source of instruction than the rocks themselves. Certainly the subject of sedimentary petrology should be pursued only if a well-collected representative set of specimens and thin sections is at hand. No course in this subject can be considered adequate unless accompanied by a well-organized program of laboratory work on such materials.

References to the literature are freely given. No attempt has been made, however, to make the bibliography complete. An attempt was made to provide a "working bibliography." For the most part the citations are to the large, more comprehensive works and to those with modern outlook. As is likely with any compilation covering a diverse field, some important references may have been inadvertently omitted.

A general work, such as this, is necessarily a compilation from many sources. A conscientious effort has been made to credit such sources. The contributions of the author, if any, lie in the direction of organization and classification, proper emphasis and balance between the various topics, and the choice of bibliographic items. It is inevitable, however, that some materials are not duly credited for one can never truly say how much is original and how much is unknowingly borrowed from fellow workers. The author is in heavy debt especially to Paul D. Krynine with whom he has had many stimulating discussions. He is likewise indebted to his colleagues at the University of Chicago—especially his former student and co-worker, W. C. Krumbein.

The preparation of this book has been made possible by the willing assistance and coöperation of many individuals and organizations. The author gratefully acknowledges the assistance of William Schmidt who took most of the photomicrographs and of Alfred Harris, D. J. Lehmer and Robert Nanz for preparation of most of the drawings. He is indebted also to those individuals and organizations that have permitted reproduction of published

drawings or photographs or have supplied some of the needed illustrations. Specific acknowledgment of such has been made at appropriate places in the text. So also is the author indebted to those former students and others who, over a period of years, have send him many rock specimens the photo-micrographs of which form the bulk of the illustrative matter of this text. Special thanks are due M. Macgregor, Assistant Director of the Geological Survey of Great Britain for a collection of Scottish graywackes; N. A. Riley of the University of Chicago for an excellent suite of Arbuckle rocks; Ada Swineford of the Kansas Geological Survey for numerous specimens from Kansas; and P. D. Krynine of Pennsylvania State College for much Pennsylvania material. F. F. Grout, J. H. C. Martens, and Ada Swineford were kind enough to loan the author certain thin sections for photographic purposes.

The writer is indebted to N. A. Riley who read parts of the manuscript and made many suggestions. Finally the author wishes to express his appreciation of the many helpful criticisms of Carey Croneis who as editor had the task of reading the whole volume. Dr. Croneis made many constructive suggestions and in general greatly facilitated the preparation of the manuscript for publication.

F. J. PETTIJOHN

Chicago, Illinois
August, 1948

Preface to the Second Edition

NEARLY ten years have elapsed since the manuscript for the first edition was completed. This decade has seen a flood of papers dealing with sediments and sedimentary rocks. Some, like those dealing with turbidity currents, have revolutionized our concepts of marine sedimentation and have made necessary a new interpretation of many sedimentary textures and structures. Others, such as those describing the plotting of vector properties and the making of paleocurrent maps and the quantitative measurement and mapping of sedimentary facies, provide new methods for the solution of the problems of paleogeography. The experimental work on the chemical precipitates and the complementary field studies of these deposits, and of the iron-bearing sediments in particular, have added much to our understanding of the origin of the chemical sediments. These new concepts and observations, as well as many others have made necessary the rewriting—not revision—of the first edition.

The author is convinced of the soundness of the geological science and believes that the study of rocks is most fruitfully advanced by a study of the rocks themselves. “. . . knowledge of theoretical interpretations is of no scientific value unless it is allied with (a) knowledge of the phenomena to be interpreted, and (b) knowledge of the evidence upon which the interpretations are based” (Doris L. Reynolds). The emphasis remains, therefore, on the geology of the sedimentary rocks.

The reader familiar with the first edition will note minor rearrangement of parts, a considerable increase in the number of references, collection of these into classified bibliographies at the ends of chapters or at other appropriate places. Rearrangement of the plate materials has made possible a net increase in the number of photographs. Many new line-drawings have been added; at least half of all those used are new.

The task of rewriting *Sedimentary Rocks* was a formidable one. It would not have been possible without the assistance of many persons. The author is especially indebted to John Spurbeck of The Johns Hopkins University and to William F. Schmidt of the University of Chicago for many of the new photographs, and to Philip W. Choquette for most of the new drawings. Others who have contributed photographs include H. L. James of the

U.S. Geological Survey, F. B. Van Houten of Princeton University, and W. L. Stokes of the University of Utah. The author is grateful to Gertrude Steffe and Mae Ann Stevens for typing the manuscript. The author also acknowledges with thanks the aid of Carey Croneis of Rice Institute and Editor of Harper's Geoscience Series for his assistance and encouragement in the preparation of both the old and the new editions.

F. J. PETTIJOHN

July, 1956

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Introduction

GEOLOGY is primarily history—a history of the earth. Petrology has to do with the history of rocks and sedimentary petrology¹ is concerned with the history of the sedimentary rocks. Stratigraphy also has to do with geologic history. The primary task of stratigraphy is to ascertain the order of superposition of the strata at any given place and then to integrate the local geologic column thus constructed with the geologic columns of other places—places isolated or removed from one another. In short, the task of stratigraphy is to determine the temporal sequence of the strata the world over. This may be a difficult job; even the order of superposition is not easily determined in areas of complex structure, especially in the absence of fossils.²

At the present time, however, the composite geologic column is pretty well worked out—except, of course, for the Precambrian for which there is at present no world-wide rock or time scale. Students of sedimentary rocks are now turning to another and more difficult task, namely, reading the geologic history of a bed, the geologic age of which has been worked out by the stratigrapher. Although this is not a new task, it is one which is receiving renewed attention and is being attacked with new tools.

The history of any given bed involves determination of the source rocks and the source area from which the sediment came, or, in a word, its *provenance*. It involves also an understanding of the mechanism of *dispersal* of the residues formed in the source regions and the direction and distance of

¹ Miscalled “sedimentation”; also designated “sedimentology” (Wadell, 1932, 1933; Twenhofel, 1932; Goldman, 1950; Hough, 1950; Lohse, 1951; Doeglas, 1951).

² Shrock’s book, *Sequence in layered rocks*, well illustrates the effort and ingenuity that may be required to establish the correct stratigraphic order.

transport and the area or petrologic province over which these materials were spread. Germane to the history of a sediment is a reconstruction of the *environment* of deposition—the physical and chemical milieu in which the materials accumulated. And finally the history involves those changes or modifications which the sediment underwent after deposition including internal physical and chemical rearrangements and the resultant *lithification*.

Not only is it of interest to determine what happened to a particular bed or layer, but the geologist is interested also in the long-time trends which may be a clue to the chemical and physical evolution of the earth's crust. About these secular trends little is known—it is not even known certainly whether or not there are any such trends.

THE ORIGIN OF SEDIMENTS

The origin and accumulation of sedimentary rocks might, at first thought, seem relatively simple. Sands and muds are seen to form and be carried by the rivers from the continents into the sea. The origin of sedimentary rocks, unlike that of many igneous and all metamorphic rocks, is apparently open to inspection and study. Unfortunately the matter is not so simple. Not all of the formative processes can be seen. The diagenetic changes, in particular, which include intrastratal solution, cementation, formation of concretions, and so forth, cannot be readily observed. Neither can the turbidity currents responsible for the transport, deposition, and structures of many marine sediments. The formation of many chemical sediments has never been seen. And so, as in the case of most other rocks, the history must be reconstructed from the geologic record—the effects produced by processes no longer operative. The “effects” are primarily the textures, the structures, and the minerals of the deposit in question. This, then, is the proper task of sedimentary petrology: to go to the rocks and read the record and thereby unravel the natural history of the rock.

The task of interpreting the history of a sedimentary rock is much more complex than that of an igneous or metamorphic rock. This follows from the more complex character of sedimentary rocks. Failure to understand this complexity comes about in part by the conventional separation of rocks into the traditional three categories—igneous, sedimentary, and metamorphic. The sediments, in fact, belong to *all three groups*. This vital and fundamental concept was well understood by Grabau (1904) but seems largely to be forgotten by his successors, who lump together rocks of fundamentally different origins merely because they were formed at or near the earth's surface at “relatively low temperatures and pressures.”

As noted by Grabau, there are two fundamentally different groups of rocks,