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and their sub-surface diagnosis

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LONDON
CHAPMAN AND HALL

First published in 1970
by Chapman and Hall Ltd
11 New Fetter Lane, London EC4P 4EE
Reprinted 1972, 1973
Reprinted as a Science Paperback 1976
Second Edition, revised 1978

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ISBN 0-412-27310-1 (Hardback)
ISBN 0-412-25730-0 (Science Paperback)

Printed in Great Britain at the University Press, Cambridge

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British Library Cataloguing in Publication Data

Selley, Richard C.
Ancient sedimentary environments and their sub-surface diagnosis.—3rd ed.
1. Sedimentation and deposition 2. Rocks, Sedimentary
I. Title
551.3'04 QE571

ISBN 412-27310-1
ISBN 0-412-25730-0 Pbk

Preface to the first edition

In this book I have attempted to show how the depositional environments of sedimentary rocks can be recognized. This is not a work for the specialist sedimentologist, but an introductory survey for readers with a basic knowledge of geology.

Within the last few years environmental analysis of ancient sediments has been enhanced by intensive studies of their modern counterparts. Thus Geikie's dictum 'the present is the key to the past' can now be applied with increasing accuracy. While an understanding of Recent processes and environments is critical to the interpretation of their ancient analogues, it is beyond the scope of this book to describe these studies in detail. I have, however, attempted to summarize the results of this work; detail being sacrificed in the interest of brevity. Inevitably, this has led to a tendency to generalize; I have tried to counteract this by providing bibliographies of studies describing Recent sediments.

The economic importance of environmental analysis of ancient sediments is increasing. With the world expected to consume as much oil and gas in the decade 1970–80 as has been produced to date, the search extends increasingly to the more elusive stratigraphically controlled accumulations.

Similarly environmental analysis has a part to play in locating metallic ores in sediments whose geometries are facies controlled.

The book begins with a discussion of the classification of sedimentary environments and an evaluation of the methods which may be used to identify them in ancient deposits.

Each subsequent chapter describes a particular depositional environment, beginning with a summary of its characteristics as seen on the earth's surface at the present time. This is followed by a description of an ancient case history whose origin is then deduced. A general discussion of the problems of identifying the environment in ancient sediments comes next, and each chapter concludes with a brief review of its economic significance.

Neither the selection of environments nor the discussion of economic aspects is intended to be comprehensive. I hope, however, that there are sufficient examples to show how the environment of a sedimentary rock can be determined and some of the ways in which sedimentology can be used in the search for economic materials. The discussions of the economic aspects of the various environments are heavily biased in favour of the oil industry at the expense of mining, hydrogeology, and engineering geology. This is no accident. The oil industry is the largest employer of sedimentologically oriented geologists and has done more to advance and apply sedimentology than any other branch of industrial geology.

Critical readers will notice that metres, feet, kilometres, and miles are used indiscriminately throughout the book. Since the oil industry refuses to go metric, the student must quickly learn to correlate the two systems. A conversion scale is included in the first figure.

January, 1970
Tripoli, Libya

RICHARD C. SELLEY

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Preface to the second edition

I began to write the first edition of this book after spending nearly ten years at university studying and teaching how to diagnose the depositional environments of sedimentary rocks where they crop out at the earth's surface.

The first edition was written during the first three months of my five-year sabbatical in the oil industry. From then on a very large part of my time has been spent learning how to diagnose the environments of sediments from bore holes in the sub-surface. This is a far more challenging occupation for there are fewer data, the techniques are quite different, and the economic implications may be immense.

The new edition reflects this experience. The introductory chapter includes a discussion of the techniques of sub-surface facies analysis, and subsequent chapters discuss the criteria by which each environment may be recognized in the sub-surface.

Most of the chapters have been modified in one way or another; sections on modern environments have been expanded and some of the case histories have been extensively modified and, for the Captain 'reef', completely rewritten.

I have updated the bibliographies, but since the sedimentology part of GeoAbstracts show that some 20 000 papers have been published in this field since the first edition, I may well have missed one or two important papers. I apologize to the reviewers, for experience has taught me that the unquoted seminal papers are inevitably their own.

August, 1977
Imperial College, London

RICHARD C. SELLEY

Preface to the third edition

I wrote the first edition of this book at a very impressionable age. I had just completed nine years of university research on the environmental interpretation of sediments, and had started work for an oil company. The first edition was thus concerned with the interpretation of sedimentary environments from outcrop, from an aesthetic stance, with no thought of vulgar commercial applications.

I wrote the second edition after spending several years learning how to interpret the depositional environment of sediments in the subsurface and in trying to apply this knowledge to petroleum exploration. Thus the second edition was expanded to include sections on the use of geophysical well logs in subsurface facies analysis.

Within the last few years seismic geophysical surveying has improved tremendously. A whole new field has developed, loosely termed seismic stratigraphy, which applies sedimentary concepts to the interpretation of seismic data. Today seismic surveys may delineate channels, deltas, reefs, submarine fans, and other deposits. In this edition I have included sections on the seismic characteristics of the various sedimentary facies. I have also expanded sections on metalliferous sedimentary deposits, and on recent environments. New case histories have been introduced and I have attempted the impossible task of updating the bibliographies.

September, 1984
Imperial College, London

RICHARD C. SELLEY

Acknowledgements

Any textbook, by its very nature, is parasitic on previously published work. This is probably more true of this book than many others due to its case history approach.

I am, therefore, extremely grateful to the authors of the various case histories who allowed their work to be pirated in this fashion, who criticized portions of the manuscript, and who generously supplied photographs. These include J. R. L. Allen, A. H. Bouma, J. D. Collinson, A. Hallam, A. J. Jenik, J. F. Lerbekmo, N. D. Newell, M. D. Picard, H. G. Reading, D. J. Stanley, W. F. Tanner, G. S. Visher, R. G. Walker, and R. J. Weimer.

Correct opinions and environmental interpretations are attributable to the authors of the case histories. Errors of fact and interpretation are due to me.

My colleagues at the Oasis Geological Laboratory, particularly Dr J. Hea and D. Baird, suggested numerous improvements to the manuscript. Thanks are also due to Oasis Oil Company of Libya Inc. for permission to publish.

I am extremely grateful to Professor J. Sutton and the Imperial College authorities who granted me leave of absence to retire from the academic hurly-burly to the peace and quiet of the oil industry to write this book.

R.C.S.

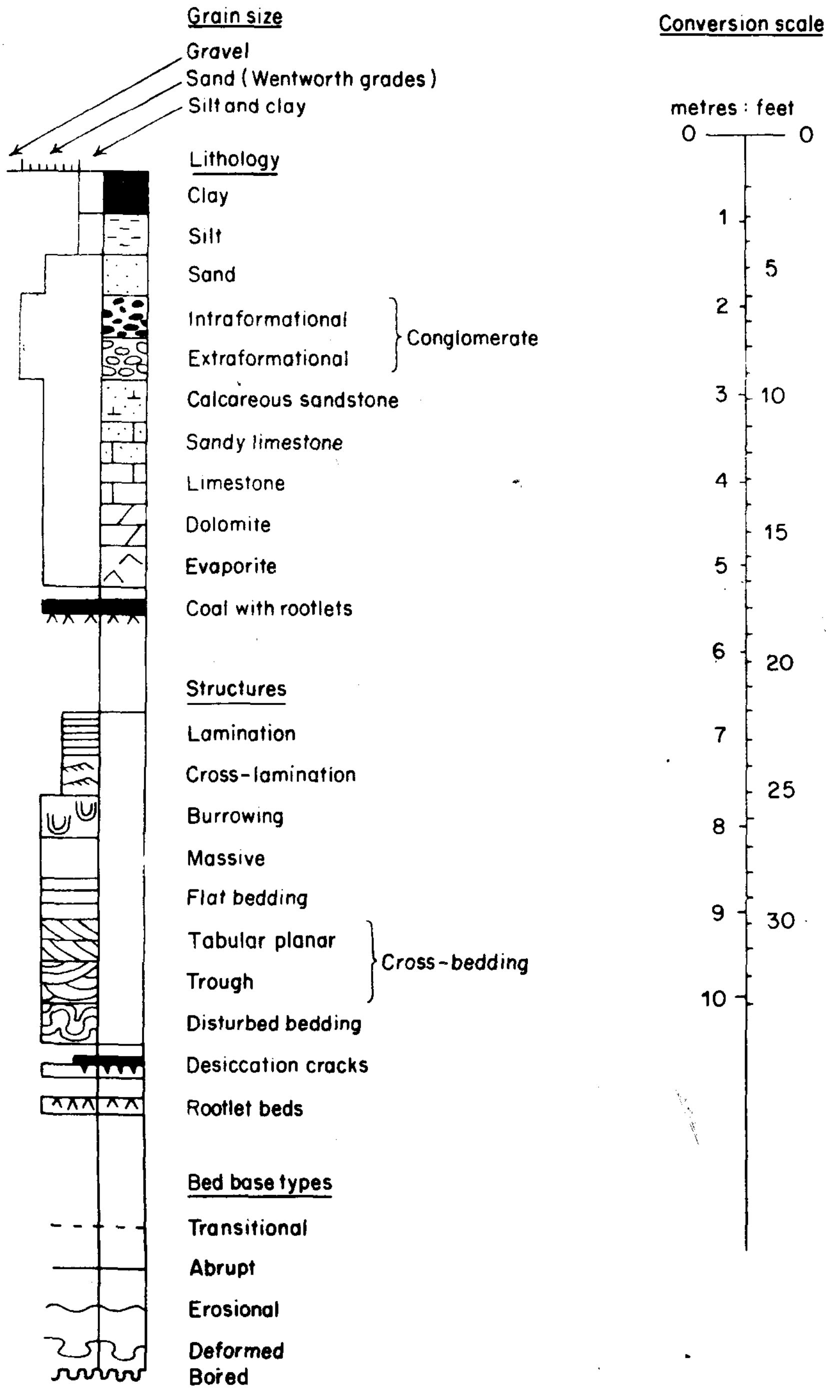

Figure 0.1 Detailed measured rock sections, illustrated throughout the book, ar[e] drawn using the above key. Note that grain size is drawn increasing to the left s[o] as to correlate with wireline logs.

Contents

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1 Introduction

SEDIMENTARY ENVIRONMENTS AND FACIES

A sedimentary environment is a part of the earth's surface which is physically, chemically, and biologically distinct from adjacent terrains. Examples include deserts, river valleys, and deltas.

The three defining parameters listed above include the fauna and flora of the environment, its geology, geomorphology, climate, weather, and, if subaqueous, the depth, temperature, salinity, and current system of the water. These variables are tightly knit in dynamic equilibrium with one another like the threads of a spider's web. A change in one variable causes changes in all the others.

Numerous deserts, lakes, deltas, reefs, and other environments are found all over the present-day face of the earth suggesting that there are a finite number of sedimentary environments. This statement must be qualified though by noting that no two similar environments are ever exactly alike, and that different environments often merge imperceptibly with one another across the face of the earth.

A sedimentary environment may be a site of erosion, non-deposition, or deposition. As a broad generalization, sub-aerial environments are typically erosional while sub-aqueous environments are mostly depositional areas. Some environments alternate through time between phases of erosion, equilibrium, and deposition. River valleys are a case in point.

Erosional environments generally occur in dissected mountain chains, and to a lesser extent along rocky shores. They are not preserved in the statigraphic record and we can only infer their past existence from adjacent detrital formations.

Equilibrial or nondepositional environments occur both on land and under the sea. Many deserts are equilibrial surfaces on which there is neither erosion nor net deposition. The wind may transport sand in eolian dunes, but these bed forms often migrate across scoured bedrock or gravel surfaces. Similarly many continental shelves are equilibrial surfaces where there is neither erosion nor net deposition taking place, though as with deserts, tidal sand waves may migrate across scoured rock or lag gravel sea floors. Equilibrial environments also occur in deep oceanic environments. Here the sedimentation rates may be so slow that the rate of solution of sediment particles may keep pace with deposition. Equilibrial environments, like erosional ones, do not actually deposit detritus. They are commonly preserved in the stratigraphic record as unconformities. Because the rock beneath an equilibrial surface is generally very well cemented they often generate velocity contrasts with the overlying strata and thus may show up as reflecting surfaces on seismic surveys.

The third type of sedimentary environment is the depositional one. It is the depositional sedimentary environment which is actually preserved in the stratigraphic record in the form of sedimentary facies.

A *sedimentary facies* is a mass of sedimentary rock which can be defined and distinguished from others by its geometry, lithology, sedimentary structures, palaeocurrent pattern, and fossils.

The consensus of geological opinion is that there are a finite number of sedimentary facies which occur repeatedly in rocks of different ages all over the world. Comparison with Recent sediments suggests that these can be related to present-day depositional environments. As with their Recent counterparts, therefore, no two similar sedimentary facies are ever identical, and gradational transitions between facies are common.

A sedimentary facies is the product of a depositional environment, a special kind of sedimentary environment. One of the main problems of determining the origin of ancient sediments is that, though essentially reflecting depositional environments, they also inherit features of earlier erosional and non-depositional phases. Consider for example an old river channel. The profile of the stream bed reflects an erosional environment, the infilling sediment reflects the nature of the source rocks and the hydraulics of the current which transported (as well as deposited) the sediment, while rolled bones and wood are derived from non-depositional environments outside the channel. It is only the sedimentary structures (and palaeocurrents) which unequivocally indicate the depositional environment.

These concepts of sedimentary environments and facies are summarized in Table 1.1. A more detailed review of the concepts of environments and facies, and their historical evolution, will be found in Selley (1982, pp. 255–266).

Table 1.1. The relationship between sedimentary environments and sedimentary facies.

CAUSE ——————→ EFFECT

Process			
Physical	SEDIMENTARY ENVIRONMENT	Erosional	Geometry
Chemical		Non-depositional	Lithology
Biological		Depositional → SEDIMENTARY FACIES	Sedimentary structures
			Palaeocurrents
			Fossils

It is very important to distinguish a sedimentary environment from a sedimentary facies. There is no problem in identifying the environment of Recent sediments. A sand sample collected from a beach today is, by definition, a beach sand. When studying ancient sediments, however, it is best to classify them into facies on a purely descriptive basis; it is unwise to give them environmental names. Thus one should talk of pebbly channel sand facies, flysch facies, and so on, rather than of fluviatile facies or turbidite facies.

Many attempts have been made to classify both Recent sedimentary environments and ancient sedimentary facies (e.g. Pettijohn, 1957, p. 610; Krumbein and Sloss, 1959, p. 196; Visher, 1965; Potter, 1967; Shelton, 1967; and Crosby, 1972).

The classification of depositional environments used in this book is unique, but owes much to previous ones (Table 1.2). It is put forward not as a final statement of environments but as a foundation on which to base the case histories discussed in subsequent chapters.

Table 1.2. A classification of depositional environments. Like all classifications this one contains several deficiencies and inconsistencies which are inherent due to the complexity of environments. Note particularly that eolian deposits can form on the crests of barrier islands: deltas can build into lakes as well as seas; reefs occur in fresh, as well as sea water.

Continental	Fluviatile	Braided Meandering
	Lacustrine	
	Eolian	
Transitional (Shorelines)	Lobate (deltas) Linear	Terrigenous Mixed carbonate: terrigenous Carbonate
Marine	Reef	
	Shelf	
	Submarine channel and fan	
	Pelagic	

Recent sedimentary environments can generally be divided into sub-environments. For example, a linear shoreline is often composed of a complex of barrier islands, lagoons, and tidal flats lying between alluvial and shelf major environments. Ancient sedimentary facies can be divided in a similar manner into sub-facies which can often be attributed to sub-environments.

RELATIONSHIP BETWEEN FACIES, SEQUENCES AND STRATIGRAPHY

Sedimentary environments occur side by side across the earth in a predictable manner. Thus for example, an alluvial flood plain may merge into a tidal flat, which may pass laterally via a lagoon into a barrier island and so to the open sea. As the sea level rises and falls the shoreline may transgress and regress the continental environment. The result of this process may be the deposition of a series of conformable facies with gradational vertical transitions. This important relationship between facies and environments was first noted by Walther (1894), and is now known as Walther's Law. This may be stated

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