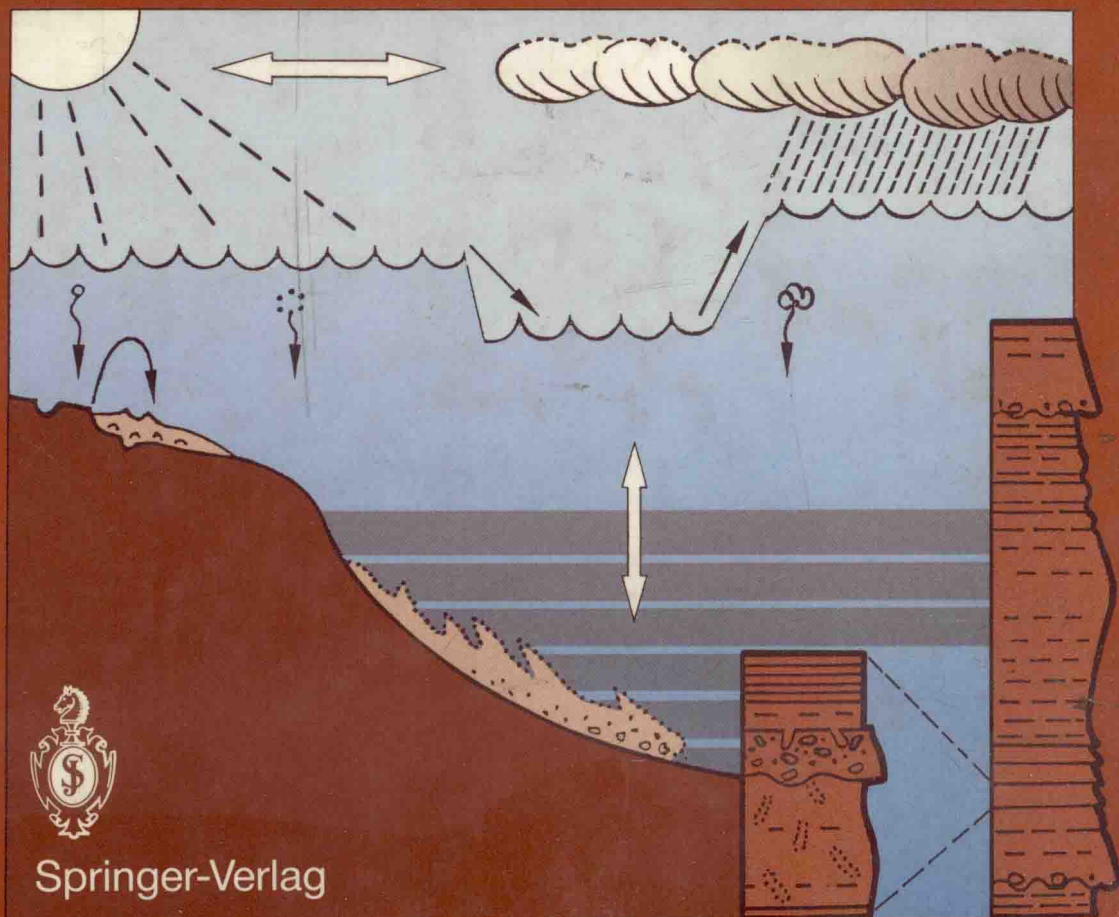


G. Einsele · W. Ricken · A. Seilacher (Eds.)

Cycles and Events in Stratigraphy



Gerhard Einsele
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Cycles and Events in Stratigraphy

With 393 Figures

Springer-Verlag
Berlin Heidelberg New York
London Paris Tokyo
Hong Kong Barcelona
Budapest

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ISBN 3-540-52784-2 Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-52784-2 Springer-Verlag New York Berlin Heidelberg

Library of Congress Cataloging-in-Publication Data. Cycles and events in stratigraphy / Gerhard Einsele, Werner Ricken, Adolf Seilacher, eds. p. cm. Includes bibliographical references and index. ISBN 3-540-52784-2 (alk. paper). — ISBN 0-387-52784-2 (U.S.: alk. paper) 1. Geology, Stratigraphic. 2. Geology — Periodicity. I. Einsele, Gerhard. II. Ricken, Werner. III. Seilacher, Adolf. QE651.C9 1991 551.7—dc20 91-11656

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Printed in Germany

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Typesetting: International Typesetters Inc., Makati, Philippines
32/3145-543210 — Printed on acid-free paper

Preface

Earth's history is recorded in her strata. Each stratum is a historical accretion event. It may retain evidence of millions of subevents, but normally the stratum is the lowest level of coherent historical resolution, and the succession of strata thus constitutes the succession of links in the chain of history, as recognized by Steno.

Descriptive and *chronological* stratigraphy are concerned with sets of strata grouped into lithic or biotic units: with recognizing, describing, and naming them, and with mapping them in space and time. This work has established the framework of historical geology.

New insights were reached when seismic profiling brought to view the subtleties in the geometric relationships of stratal packages, and when the *sequence stratigraphy* thus defined turned out to be widely correlated, suggesting that transgressive-regressive events were driven by a global dictator – eustatic oscillation. While the level to which this correlation may be relied upon is debated, and while the mechanisms continue to be controversial, sequence stratigraphy has emerged as a major new branch of our science.

Event stratigraphy in a narrower sense is concerned with the individual strata and their substance. Progress in geophysics, geochemistry, geobiology, and other fields is providing ever-improving means of reading the information inherent in the stratum. Normally, a lithic unit is composed of hundreds or thousands of strata of a few kinds, recording a regime in which certain events occurred over and over again. Regimes recording the recurrent deposition of turbidites or of tempestites find their match in presentday settings, but others do not: for example, formations in which sediments with normal bottom fauna alternate with black shales devoid of benthic fossils record regimes in which whole seas became anaerobic time after time – a kind of regime which nowadays occurs only at the local level.

Beyond this lie the rare events, such as strata showing global isotope anomalies or geochemical signatures such as enrichment in iridium, which bespeak environmental shocks of global extent, events of sorts beyond human experience (but not necessarily beyond our abilities to decipher). Event stratigraphy teaches us that the Earth has not always been as it is today; and event stratigraphy is thus challenged to decipher the nature, extent, and cause of such deviations.

In this endeavor, a special concern is that of timing. Oscillatory or more complex cyclic repetition are the rule in stratigraphic sequence. To what extent are these randomly timed, to what extent the products of programmed processes? The

world of our experience is rigorously structured by the alternation of night and day and of summer and winter, imposed by our planet's orbital characteristics. Random variations such as those of war and peace and those of the stock market are superimposed. The annual cycle is imprinted in stratigraphy at the level of varves, and the question arises as to whether stratigraphic cyclicity at larger scales may also have been driven by larger-scale cycles, such as the Earth's precession, the variation in obliquity, the cycles of orbital eccentricity, and the oscillation and revolution of the Solar System in the Milky Way Galaxy.

There is no doubt about the existence of these cycles (indeed, there may be others), but there is diversity of opinion as to whether they have left their imprint in sediments, and whether this imprint can be sifted out from the stochastically generated oscillations and cycles, and from diagenetically superimposed features. This is the special concern of *Cyclostratigraphy*.

The response of Pleistocene glaciation to the orbital variations has already been firmly established, and Pleistocene stratigraphy is being tied increasingly to the detailed proxy record of global ice flux provided by the oceanic oxygen isotope record, with potential time resolution to the 10^4 year level. The possibility of achieving such time resolution in the more distant past opens new horizons to stratigraphy. Orbital forcing patterns through the ages would also shed much new light on the functioning of climatic and oceanic regimes, and might well provide new data on the changes in length of day and other orbital features.

Some of the questions about events, changing regimes, and cycles were asked long ago, but the focus on deciphering individual beds in successive strata and of visualizing the nature of such ancient regimes, by combined sedimentology and paleontology, is comparatively recent. It can now be cast in the framework of sequence stratigraphy, and is now drawing strength from increasing involvement of geochemistry and geophysics. The specter of the enormous numbers of strata in the record is being laid to rest by the computer. We stand on the threshold of a new stratigraphy.

The predecessor volume, *Cyclic and Event Stratification*, approached some of these problems by means of individual case studies. The success which it enjoyed led Publisher and Editors to plan this successor volume, with somewhat broadened scope and an attempt to provide more overview. The proof of a book is in the reading, and this one will be read extensively.

San Pedro, December 1990

Alfred G. Fischer

Cycles and Events in Stratigraphy follows a precursor volume, *Cyclic and Event Stratification*, which was published in 1982 as a result of a workshop held in Tübingen. That volume contained essentially case studies dealing with three major topics of marine environments: rhythmic marl-limestone sequences, sandy and calcareous tempestites, and bedding phenomena in black shales. Although translated also into Russian and Chinese, *Cyclic and Event Stratification* was out of print within a few years.

Since then, knowledge about, and general interest in bedding features and cyclic sequences have increased considerably. New concepts and techniques have become available. Encouraged by friends and colleagues, we therefore felt it appropriate to present the state of the art in a new book, instead of just preparing a revised edition of the first volume. *Cycles and Events in Stratigraphy* has a much wider approach than the first volume. A total of 62 experts present reviews and concepts of various aspects of stratification. Most of these papers were discussed during a second international meeting held in January 1989 in Tübingen.

The principal changes are twofold: the new book for the most part presents review articles illustrated with conceptual figures, and covers a much wider range of topics than did the former volume. It describes not only a larger variety of marine bedding features, including gravity mass flows, siliceous sediments, phosphorites, shallow water carbonate, and glacio-marine cycles, but also stratification phenomena in lacustrine sediments, coal cycles, and tephra layers on land and below the sea. Scales range from annual varves to larger, mainly sea-level controlled sedimentary sequences. Secondary effects, such as biological response and feedback mechanisms, trace fossil tiering, and diagenetic overprinting, are also presented, as well as special techniques in timing and correlating cyclic and event bedding phenomena. A limited number of chapters were reserved to address only particularly interesting case studies. Most of the contributions are newly written, only one chapter has been taken from the first volume, but in a completely revised version. In spite of changes in authorship and treatment of much wider aspects, the book maintains the old dualism between cyclic and event signals in the stratigraphic record and extends it to the level of sequence stratigraphy.

We gratefully acknowledge the excellent contributions by all of the authors, as well as the advice and help from countless other colleagues. The secretaries of the Geological-Paleontological Institute in Tübingen, Marlis Lupold, Margot Pilopp, and Helga Wörner, helped with the typing, and Hermann Vollmer did the drafting for not only our own, but other chapters as well. Werner Wetzel made some of the photographic reductions. Linda Hobert of Albany, NY, and Susanne Borchert of Tübingen, had the difficult task of editing the language for the non-native English speaking authors. Marie-Luise Starke compiled the tremendous number of references from all articles to a single list. From the very beginning of this project, we enjoyed the close and fruitful cooperation with Dr. Wolfgang Engel and the Springer-Verlag.

This book addresses graduate students as well as professionals in geology, sedimentology, stratigraphy, and paleontology. Presenting concept-oriented reviews, it is expected to close the gap between the conventional text book and the standard symposium volume published for a small insider group of specialists. We hope that, in spite of any shortcomings, this book will contribute to keeping alive the discussion on the exciting field of dynamic stratigraphy.

Tübingen, December 1990

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Cycles and Events in Stratigraphy – Basic Concepts and Terms

G. Einsele, W. Ricken, and A. Seilacher

1 Introduction

One of the most conspicuous features of sedimentary rocks is their stratification. Caused by various periodic and episodic processes, as well as by biologic and diagenetic overprints, such stratification commonly exhibits a distinctive kind of rhythmicity, due to regularly alternating beds or a repetition of larger units which are referred to as depositional cycles. Rhythmic and cyclic sequences occur worldwide in presumably every environmental and stratigraphic system. Several textbooks have summarized the knowledge and concepts of rhythmic stratification (e.g., Merriam 1964; Duff et al. 1967; Elam and Chuber 1972; Schwarzacher 1975; Einsele and Seilacher 1982; Berger et al. 1984), and many books on facies analysis deal with this subject. In the meantime, our knowledge and techniques have increased considerably, and more geologists, sedimentologists, stratigraphers, and paleontologists appear to be interested in rhythmic and cyclic stratification than in earlier years.

The basic subjects addressed in this book include: (1) The description of depositional processes and associated overprints forming various beds, which may be grouped into cyclic and episodic stratification types; and (2) the description of the ordering of beds into a hierarchical pattern of smaller cycles and larger sequences. However, before such concepts are presented in Parts I and II of this Volume, some very basic introductions to the subjects dealt with here and some clarifications regarding terminologies used are given in this first chapter. In the following, these introductory remarks start with comments on the types of beds treated in this book.

2 Types of Beds Addressed in this Book

The basic sedimentological unit addressed in this book is the laterally traceable bed (Fig. 1). Smaller and larger sedimentary structures are not discussed in this book, including small-scale ripples, larger trough cross beds, larger sand and carbonate bodies, etc. The typical bed addressed in this book is defined as a three-dimensional body of relatively uniform composition, as compared to the underlying or succeeding beds. Compositional characteristics include primary chemical-mineralogical and structural properties, biological aspects, and diagenetic structures. Bed thicknesses can vary from a few centimeters to several meters, representing various time spans ranging from seconds to several 100 ka. Thicknesses of 5 to 40 cm are common, but