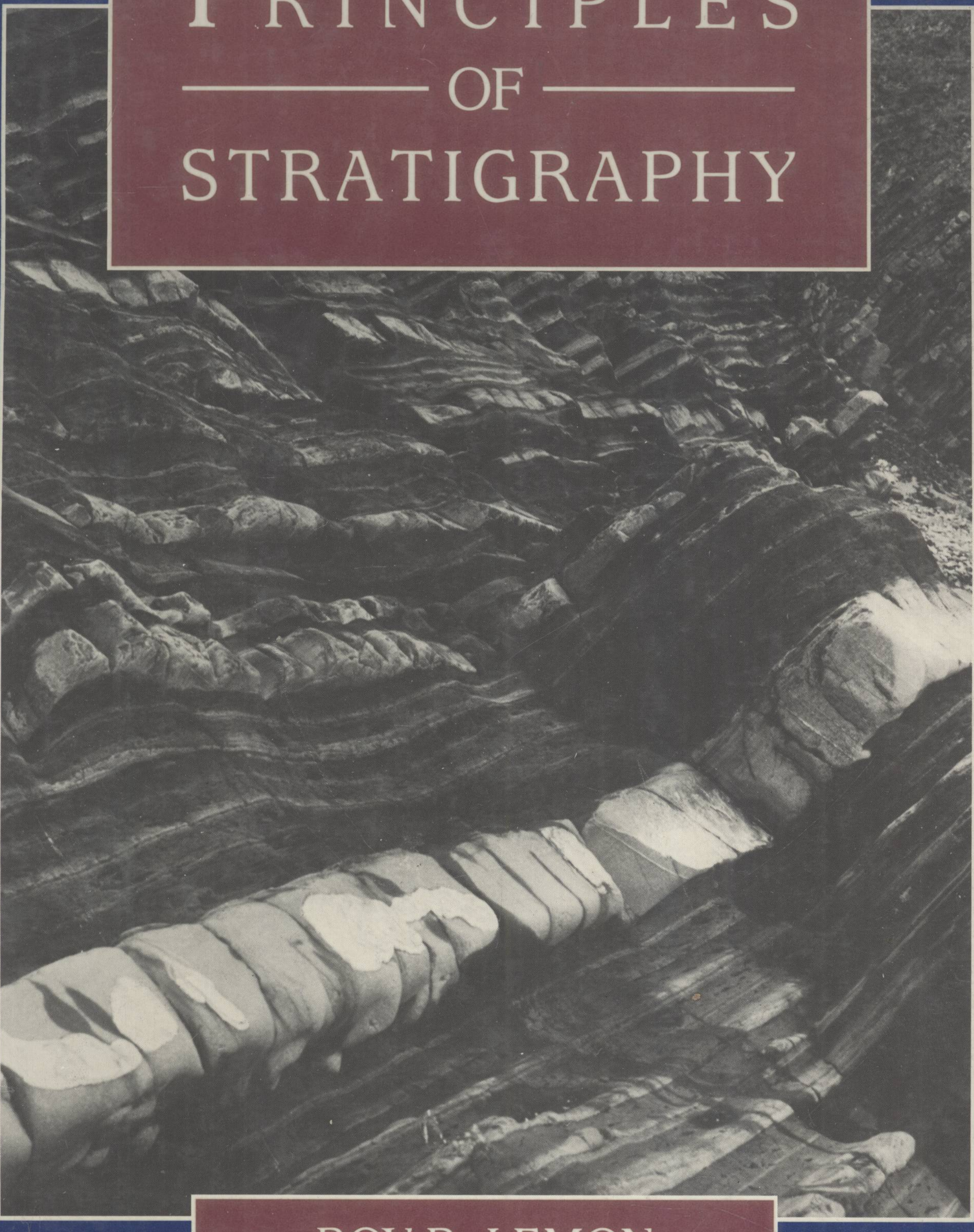
PRINCIPLES OF STRATIGRAPHY



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PRINCIPLES OF STRATIGRAPHY

To Mary and Chris

PREFACE

Stratigraphy lies at the core of any geology curriculum because no investigation of earth history can proceed far without some grasp of stratigraphic principles. Stratigraphy is concerned with stratified rocks as the repository of a record of past events. It deals with sediments and sedimentary rocks, sedimentary environments, and fossils, and with the ways they can be described in terms of passing time. It provides the means of piecing together a calender so that world geologic records can be brought together into a coherent whole. The field of stratigraphy is broad. This causes considerable divergence of opinion as to what should or should not be included in a stratigraphic text. One of the earliest major texts was Grabau's great work published in 1913, and it is clear from a perusal of the contents that the author considered that virtually every topic from the atmosphere to vulcanicity should be embraced. Later texts emphasized the sedimentological aspects of stratigraphy, as did, for example, the classic work by Krumbein and Sloss published in 1950. Since that time, surprisingly few textbooks in stratigraphy have appeared, and virtually all of them have strongly stressed lithostratigraphy. On the other hand, the study of sediments and sedimentary processes also has evolved rapidly and has seen a considerable growth in the number of texts available; nearly a dozen new ones have appeared in the past ten years. Because the stratigraphic record is contained within sedimentary successions, it is obvious that no treatment of stratigraphy would be complete without some explanation of this topic. In the present text, however, I have ventured to reduce those portions dealing with sediments and sedimentary rocks, as such, to a minimum. This approach is in no way intended to downgrade the importance of sedimentology, but merely to recognize that that field is itself increasingly served by its own separate literature. This treatment also emphasizes the fact that modern stratigraphy deals with magnetic stratigraphy, seismic stratigraphy, and an increasingly sophisticated numerical biostratigraphy. These topics are at least as important as those in the field of sedimentology and accordingly should be given considerable weight in a stratigraphy text.

The key role of biostratigraphy in all stratigraphic investigations is recognized by the special emphasis placed on this topic. Modern stratigraphy would be impossible without biostratigraphic control, and this justifies a more in-depth study of fossils than is found in more orthodox stratigraphic texts. Topics such as the geographic dispersal of fossils, the species concept, and mass extinctions are discussed. Also examined is the impact of the new approach to evolutionary theory in which punctualism is apparently replacing the gradualistic model and, in the process, explaining many puzzling features of the biostratigraphic record.

An adequate understanding of the subsurface data obtained from the many logging tools now available, and from seismic surveys, is also essential in stratigraphic studies. Because a large number, perhaps the majority, of geology graduates working in stratigraphy are in industry, much of their work will be based upon subsurface information.

Finally, at the ends of the geologic column are the Quaternary and Precambrian which, perhaps unexpectedly, have one thing in common: many of the so-called "normal" stratigraphic procedures cannot be applied to them. The special problems of Quaternary stratigraphy are accordingly dealt with in Chapter 15. Chapter 16, the closing chapter, ventures into what for many stratigraphers is a *terra incognita*. Attempts have been made to sort out Precambrian stratigraphy only relatively recently. Because we are here dealing with some seven-eighths of earth history, it is clearly a topic of immense importance with great opportunities for future work.

It is important to recognize the fact that, largely as a result of stratigraphic studies, the traditional uniformitarian view of earth history is being modified. It is clear, for example, that both in the accumulation of sediments and the evolution of life forms, the record speaks of constant interruptions, both of minor and major, literally earth-shaking, dimensions. Although some of the recent discoveries have raised important controversies yet to be completely resolved, some awareness of these ongoing discussions should be part of modern stratigraphy.

This text should stand in a corequisite relationship to those in the parallel fields of sediments, sedimentary rocks, and sedimentation. Within the geology program curriculum, it is expected that stratigraphy would, perhaps at the sophomore or junior level, occupy one semester and sedimentology another. Both areas could be covered simultaneously in corequisite courses, or alternatively, one would be the prerequisite of the other. Which should come first is open to debate and is, perhaps, not too important.

Acknowledgments

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PART ONE
TIME AND THE TIMEKEEPERS

VERY LITTLE CAN BE SAID ABOUT STRATIGRAPHY WITHOUT REFERENCE TO THE TIME dimension. It is the record of sequential events that is of primary interest; so to gain some understanding of the relationship of sediments to time, and of the way geologic time is measured, are essential first steps. Perhaps the most prominent characteristic of the stratigraphic record is its lack of continuity, so it is with periodicity in earth history that this account begins.

1
TIME AND SEDIMENTS

There's something damn funny about the stratigraphical record.

Derek Ager

1.1 INTRODUCTION

So far as there is a written record, our modern understanding of rock strata can be said to begin with the writings of Nils Stenson, or as he is better known, Nicolaus Steno, a seventeenth-century Danish physician in the court of the Duke of Florence. Steno's studies of the rock strata of northern Italy were published in 1669 in a book that truly can be labeled as the first to deal with stratigraphic principles. Steno's observations of sedimentary rocks and their contained fossils led him to conclude that the land once had been covered by the sea and that layers of rock had formed by deposition of bed upon bed. The sequential ordering of beds from the oldest at the base to the youngest at the top of the succession followed what Steno called the *law of superposition.* A second law, which he labeled the *law of original horizontality,* was based on the observation that, although rock strata are to be seen often in an inclined attitude, they originally had been deposited in a horizontal position. A third law, that of *original continuity,* explained why strata exposed on one side of a valley could be seen also on the other. The implication here was that the edges of the strata seen in an outcrop must have been exposed by the breaking and removal, or the wearing away, of strata. In other words, the strata had once extended continuously across the area; the valley was, in fact, the result of their removal by surface agents of erosion. Steno's three laws are fundamentally simple and seem very obvious to us today. What is astonishing, perhaps, is that these first recorded observations occurred so late in history and that it had taken so long for a reasoned comment on the origin of sedimentary strata. It is very difficult to believe, for example, that the resemblance between sand deposits in a river or on a beach, and layers of sandstone in a cliff face, had not been noted by many people since the beginning of history. The lack of any written record of such observations during the hundreds of years before Steno's time can be explained only by assuming that no one was sufficiently interested! The origins of this lack of interest are not hard to find.

Much of what scholars were beginning to discover about the physical world during the seventeenth-century was, in fact, a rediscovery of many things known during the flowering of Greek science some fifteen hundred to one thousand years earlier. This promising beginning of science had come to an end, most scholars agree, with the destruction of the great library at Alexandria in the fifth century A.D. Probably the last in the great tradition of Greek scientists was Hypatia; her death in A.D. 415, at the hands of followers of Archbishop Cyril (who later was made a saint!), generally is accepted as marking the beginning of the so-called Dark Ages. During the thousand years that followed, and under the growing influence of Christianity, scholarship turned in a new direction. Intellectual debate dealt largely with the philosophical and mystical and was directed toward the spiritual rather than the real world.

Steno's law of superposition is the basis for what has come to be called "layer cake stratigraphy," in which each layer of sediment was laid down only to be immediately buried by the next layer above. This is what Ager (1981) called the "gentle rain from heaven" concept, in which at all locations and, more or less, at all times sediment is supposed to sift down from above. There is nothing intrinsically wrong with any of these ideas—the mistake lies in taking them too literally and applying them too widely. We can come to a proper understanding of the sedimentary record only if we realize that sometimes the processes do operate in this way and sometimes they most definitely do not. It is quite clear, for example, that sediment accumulation is not continuous over long periods of time. Even in deep-ocean sediments there are gaps in the record marking intervals of nondeposition or erosion, whereas in shelf and platform areas there is more gap than record. Most typically, the intervals of nonrecorded geologic time exceed by many times those time intervals for which there is a sedimentary record. This is what Charles Darwin referred to as the "imperfection of the geologic record." Also, implicit in an understanding of sediments and sedimentary rocks is the idea that the individual layers of sediment were deposited over a span of time and that the thickness of each layer is related in some way to the length of time it took to form. At a most elementary level of understanding, this is simply the "hourglass" idea. It is quite true that, other things being equal and under uniform conditions, 10 m of sediment will probably take twice as long to accumulate as 5 m. Time and sediment thickness are linked sometimes. In deep-sea cores, for example, quite reliable ages can be estimated by extrapolation of thicknesses downward on the basis of measured thicknesses higher in the core where there are some biostratigraphic or other age indicators. Actually, of course, there exists a tremendous variability in sedimentation rates. Sir Archibald Geikie in 1886 described large fossil trees (some of them more than 12 m tall) in their positions of growth (Fig. 1.1) and rightly concluded that the sandstone entombing them had accumulated before they had had time to rot away. At the other extreme, on certain parts of the ocean floor, sediments may accumulate at a rate of only 1 mm per 1000 years.

FIGURE 1.1
Sediment accumulation can be extremely rapid, as seen at this Pennsylvanian section in Nova Scotia, where a large tree trunk was buried in sediment before it had time to rot away. (Photograph courtesy of the Geological Survey of Canada, Ottawa.)

1.2 EPISODIC NATURE OF THE STRATIGRAPHIC RECORD

Balance between Deposition and Erosion

On many present-day marine shelves the bottom sediment consists, for the most part, of a transient veneer of clastic material, ranging from sand in the shallower areas to silt-size and finer material in deeper or more sheltered areas. One of the most important differences between shallow- and deeper-water regions is the frequency with which the bottom sediment is disturbed by wave or current action. In relatively shallow water—above what is called **wave base**—normal (fair-weather) wave action keeps the bottom sediment stirred up and in a state of constant shifting to and fro. Ripple marks, sand waves, submerged bars, and other features constantly form and reform. Below wave base, bottom sediment is moved less frequently, but is still shifted occasionally by storm waves and tidal currents. Obviously, the frequency of this disturbance bears a direct relationship to the depth of the water and/or the energy input to the water column. In such environments, where sediments are eventually disturbed again, it is difficult at first to understand how any accumulation of shallow-water sediment can ever be formed and permanently preserved. The fact that sediments are preserved is due to several factors. Probably the most important is that the shallow shelves and platforms are slowly sinking. Causes of such sinking will be discussed in a later section. Thus, there will be a net accumulation of sediment, no matter how much redistribution takes place in the short term.

It is important to examine some of these short-term processes and local influences because they have a profound effect on the kind of sediment that is eventually preserved. Despite the essentially ephemeral nature of shallow-water sediments, there are numerous ways in which net accumulation does occur:

1. In the case of finer sediments, particularly clays, there is a natural cohesiveness—once deposited, fine sediments are relatively difficult to erode and reentrain.
2. Plants and benthic animals often play an important role as sediment-trapping devices by reducing current velocity at the sediment–water interface (Fig. 1.2). Other

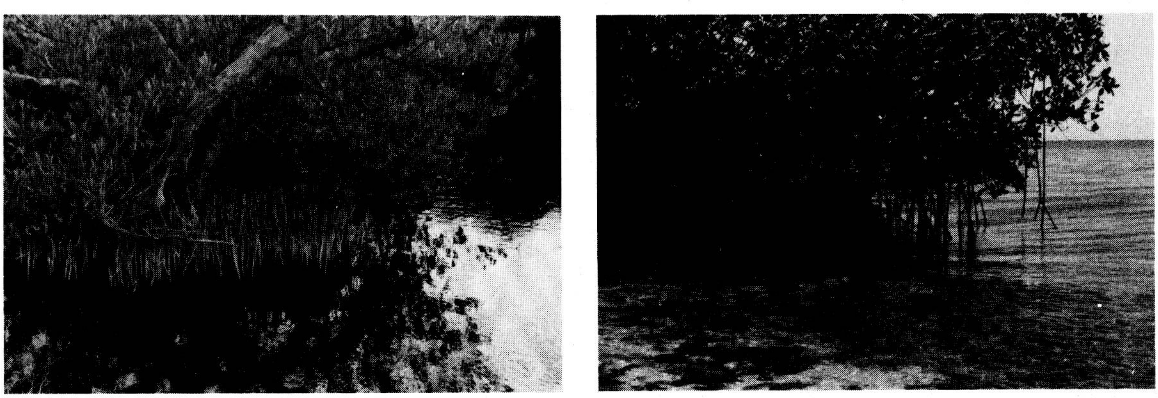

FIGURE 1.2
A. Red mangroves (*Rhizophora mangle*) are effective in stabilizing and entrapping sediment in the supratidal zone. B. Black mangrove (*Avicennia germinans*) with nematophores growing up out of the water.