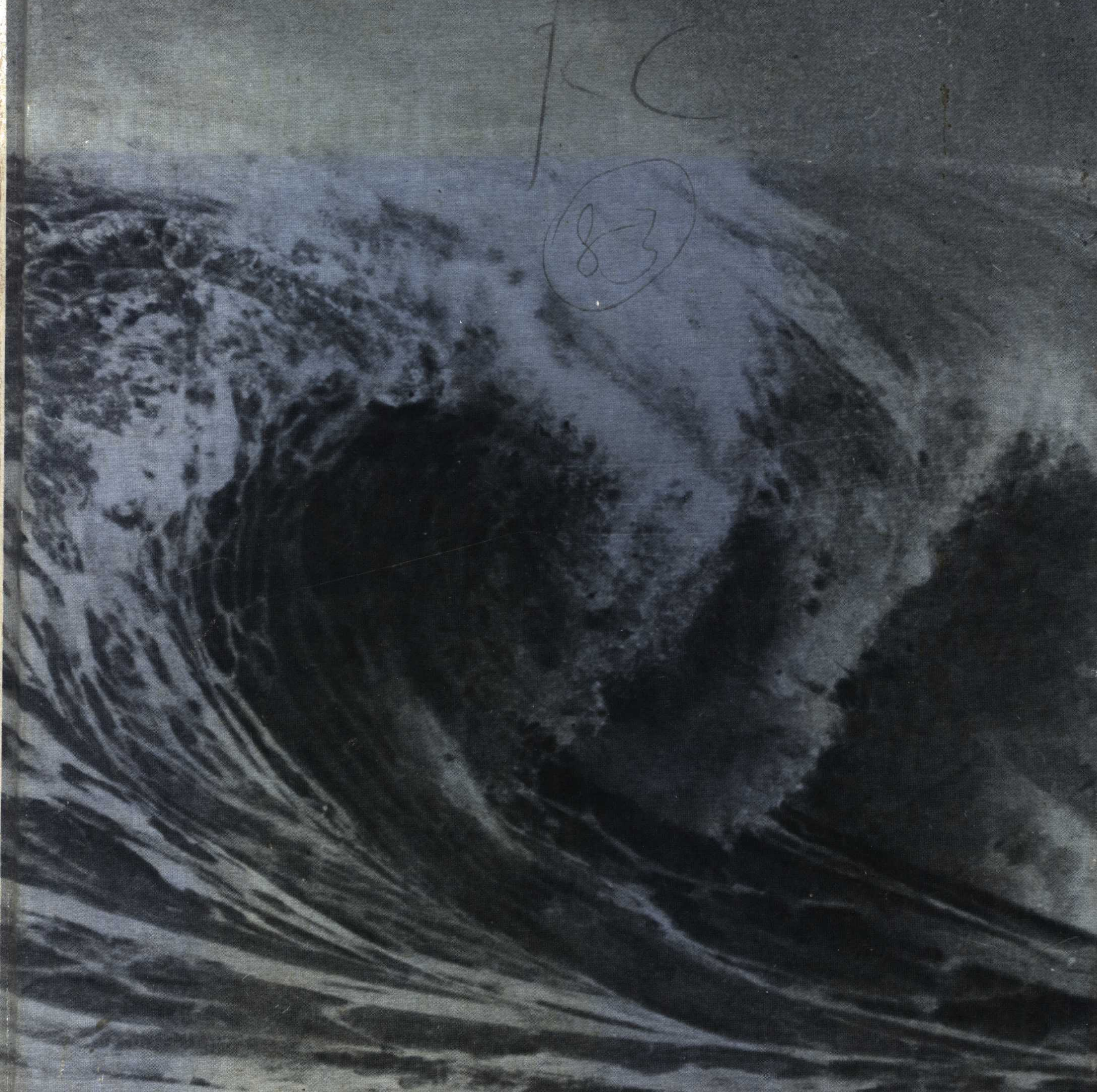
OCEAN SCIENCE

KEITH S. STOWE



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PREFACE

This book was developed as an introductory text for college students having little background in the sciences. Most of these students will not be pursuing technical careers, and this course may be one of our last opportunities to share with them the intrigue and excitement of science in general, or that of oceanography in particular. I have written this book with the idea that we might be able to use this opportunity to impart to students something that will continue to enrich their lives long after details have faded from their memories.

It is the overriding purpose of this book to convince the students that the world around them is neither chaotic nor irrational. There are good reasons for things being the way they are, and most of these reasons are easily understood through everyday examples and common sense. It is hoped that the student will develop an appreciation for the curiosity of the scientists, who are constantly probing and scrutinizing the world about them, and an appreciation of our optimism that we will find and understand the reasons behind what we observe.

My motivation for writing this book was that I felt that the several books that were accurately written in terms of describing the properties and behaviors of the oceans tended to be somewhat lacking in their explanation of the *causes* of these phenomena. Without the organizing framework provided by an understanding of the underlying causes, the student tends to become lost in a forest of details. It is doubtful that many of these particulars would otherwise be retained very long past the appropriate exam date. Even worse, the student may develop a misconception of what oceanographic research is all about. The student may see it as some irrational search for data and details rather than seeing that these data are merely a tool used toward the more profound goal of a basic understanding of nature.

For this reason, I have tried in this book to answer not only "what?" but also "how?" and "why?" The causes of the ocean's various properties and behaviors are usually understandable in terms of our everyday experiences—in a coffee cup, the kitchen, a bathtub, the sky, and so on. These explanations constantly would be reinforced by the students' experiences throughout their lifetimes. In addition to retaining their understanding of the oceans, it is hoped this might also help the students master other problems they might encounter, which are not covered in this book. Hopefully, it would leave the student with the impression that most natural phenomena have simple explanations that can be understood easily, without scientific sophistication. With this attitude the students would be more eager to question and probe the world around them, and in this way develop a first-hand appreciation for what science is all about.

The content of the book is sufficient for a one-semester introductory course, with most of the customary topics being introduced. The ordering of these topics was arrived at after much experimentation in the author's own classes, and with the help of others who have taught the subject. However, the chapters are fairly independent, so their order may be changed and some topics may be omitted, if desired, without risk of impeding student comprehension of subsequent topics. An exception is that an understanding of the material in Chapter 8 should be achieved before tackling that in Chapter 9.

At the end of each chapter are many questions. In general, there is at least one question for each paragraph in the text. The answers to most questions can be found in the text and in the same order as the questions are numbered. That is, the answer to Question 3, for example, can be found after the answer to Question 2, and before the answer to Question 4.

The large numbers of questions reflects the author's feeling that many students can learn more from a paragraph if they are actively looking for answers to questions within it. In my own course, I give students added incentive by letting them know that the overwhelming bulk of test material will come from the answers to these questions. Some of the more thought-provoking questions are assigned for homework.

In writing the book I received considerable help from several colleagues. I am particularly indebted to Lawrence Balthaser, who patiently answered innumerable questions, read over much of the original manuscript, and offered many helpful suggestions for improvement. I am also grateful to Raymond Bauer, David Chipping, Kenneth Hoffman, David Roach, and to my students for their help and encouragement, and my apology to my wife and two sons for the time this book has taken from them.

Keith S. Stowe

CONTENTS

1 INTRODUCTION

The most unique feature of the earth is its oceans. Among other things, they are responsible for life. They cover most of the earth, and so quite naturally they have a lot to tell us.

People who study the oceans are called oceanographers, and the various fields within oceanography are frequently placed into the four broad categories of geology, chemistry, physics, and biology. Of course, the oceans are much too complex to allow their study to be neatly categorized. Some important aspects of oceanographic studies that cannot be placed easily into one of these categories include geophysics, biophysics, nutrition, petrology, anthropology, meteorology, and pharmacology, just to name a few. In fact, some of oceanography involves studies outside the realm of the pure sciences, such as history, law, or sociology. In short, describing a person as an "oceanographer" may say very little about what he or she actually does for a living.

One result of the complexity and diversity of the field is that it is impossible in one course, or even in a finite number of courses, to teach all there is to know about the oceans. An author or teacher who would claim to do so should be as suspect as one who would purport to explain all there is to know about life. No one is qualified to make such a claim. This book concentrates on the scientific aspects of oceanography, and gives an overview of the fields of study receiving the greatest attention.

Although it would be a most welcome by-product, the primary objective of this book is not to relay information. It is rather to foster an attitude that will hopefully remain long after the details in this book are forgotten. As a course in history may allow us a deeper appreciation of various social institutions, or a course in art or music may allow us new enjoyment of these expressive forms, a course in the sciences should offer us a new way of looking at our world for greater appreciation of it.

The world is a masterpiece. Every scene is more beautiful than the finest painting, and every piece displays an intricacy and harmony finer than Beethoven's best. The more we ask how something is made, how it works, or how it evolved, the more we are in awe of the magnificence of nature. This is the beauty that science teachers would like their students to appreciate. It is everywhere, and its enjoyment requires no scientific sophistication. The inquisitiveness of a child is all it takes to turn our everyday world into a magical kingdom.

In this particular book, the vehicle is the study of oceanography. Hopefully, the student will be able to catch glimpses of how personally rewarding this inquisitive attitude can be.

A. OVERVIEW

We begin our studies in this chapter with a brief history of the earth. Our own lifetimes are very short in comparison, and so we must change our perspective if we're going to study events in the evolution of the earth, such as the formation of continents or the birth and death of oceans. That is followed by a brief history of oceanographic exploration as a prelude to our own study of the oceans.

We begin in Chapter 2 with a study of the earth in general. We will study how oceans evolve, and how the continents arrived at their present configuration. We will get a feeling for the excitement of a revolution of ideas about our earth, which has happened in the past two decades.

Then we'll look at the ocean bottom in Chapter 3. We'll see what is beneath those features appearing at the surface, and what the ocean would look like with all the water removed. We'll find it has a complex and exciting geography, much of which reflects geological processes studied in the preceding chapter.

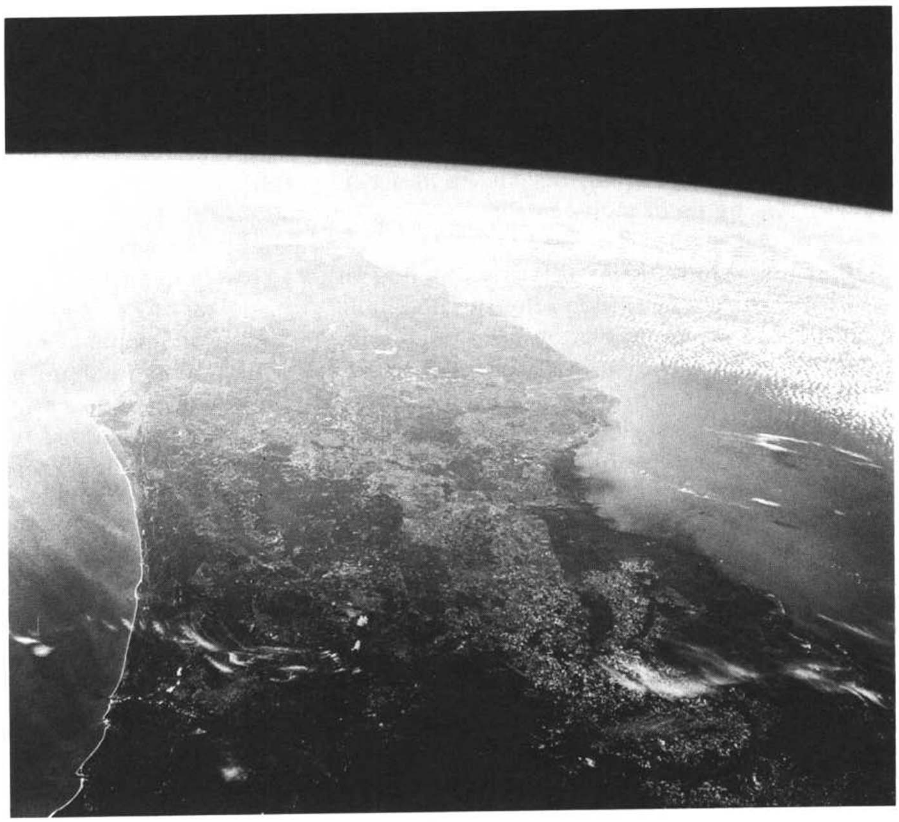


Figure 1.1 *View to the south across Florida, taken by the crew of Appolo 9. On the horizon it can be seen that the atmosphere is very thin in comparison to its lateral extent. The same is true of the oceans. Because the two are in contact over such a large area, the behaviors of the atmosphere and the ocean are intimately interrelated.*

In Chapter 4, we'll examine the sediments covering the ocean bottom. We'll study the weathering of rocks and the formation of sedimentary deposits from them. We'll also see that skeletons of organisms are a large component of the sediment in many areas, and we'll learn of sediments from other, less likely sources as well.

After this study of the ocean bottom and the earth beneath, we turn our attention toward the seawater that fills the basins. We'll ask where it came from, and what magical properties it has that make the earth such a pleasant place to live. We'll also study the salts, what they are, where they came from, and what role they play in important chemical and biological processes.

The behaviors of the ocean and atmosphere are strongly interrelated. This is because they interact across a surface of contact that is enormous in comparison to their volumes. (See Figure 1.1.) In fact, the ratio of surface to volume (or area to thickness) for each is roughly that of a sheet of paper. For this reason, the behavior of neither ocean nor atmosphere can be understood without reference to the other.

In Chapter 7 we study the weather and how the ocean controls our climate. In the following two chapters we study the circulation of the ocean and atmosphere. The first of these deals mostly with overall effects, such as how the earth's rotation causes peculiar behavior in large-scale motions of wind and water, and how this, combined with solar heating, drives the atmospheric circulation. In the next chapter, we zero in on ocean currents, including those driven by wind and those driven by gravity. Chapter 10 deals with the circulation in estuaries.

Our study of waves ranges from the tiny capillary waves we make when blowing on hot soup to the gigantic tides that span entire oceans. Much of the chapter concentrates on the familiar wind-driven waves that toss us about in the surf. The larger, more destructive tsunamis are also investigated.

Waves end their short lives on beaches, which are familiar recreation areas. In Chapter 12 we ask questions such as, "What can beaches be made of?" "Why isn't the sand quickly washed to sea?" and "What causes the various beach features we see?"

Chapters 13 and 14 study life in the oceans. The first examines plants and plant productivities, on which the entire biological community depends. General questions are asked about the overall livelihood and biological welfare of the area, irrespective of what particular organisms live there. Then we look at more specific things, such as how a cell functions and what are some problems that marine organisms must deal with. We look at the various types of marine organisms, from the tiniest one-celled plants to the gigantic whales, and we look at patterns in the distribution of marine creatures.

Finally, we look at ocean resources. Those who expect the oceans to solve our world hunger problem will be disappointed, but some things can be done to help alleviate the suffering. Also, we will see that the ocean does have a wealth of mineral and energy resources, although we must yet learn how to extract them economically, in most cases.

B. PERSPECTIVE IN TIME

The earth condensed from a cloud of interstellar gas and dust (Figure 1.2) about 4.6 billion years ago, along with the sun and the rest of our Solar System. Throughout virtually all of this time, the earth and her oceans have gone unmolested by humans. We appeared only very recently. With curiosity appropriate to our "newborn" status here, we are vigorously probing this fascinating world.

We are wise enough to know that what we see today is a result of what has happened in the past. To understand our present world, we must also probe its history.

For very short-term changes, this is an easy task. For example, we are familiar with the disappearance of beach sand in the winter and its reappearance in the summer. Similarly, the extension of a river delta is observed within a lifetime. However, with regard to long-term changes, we are essentially taking a snapshot in time, and in that snapshot we're looking for clues regarding the evolution and behavior of the earth and its oceans.

We find our ability to comprehend our earth's history falls far short of

Figure 1.2 *M16 and the Nebula of Serpens. The Solar System was born of a region such as this.*

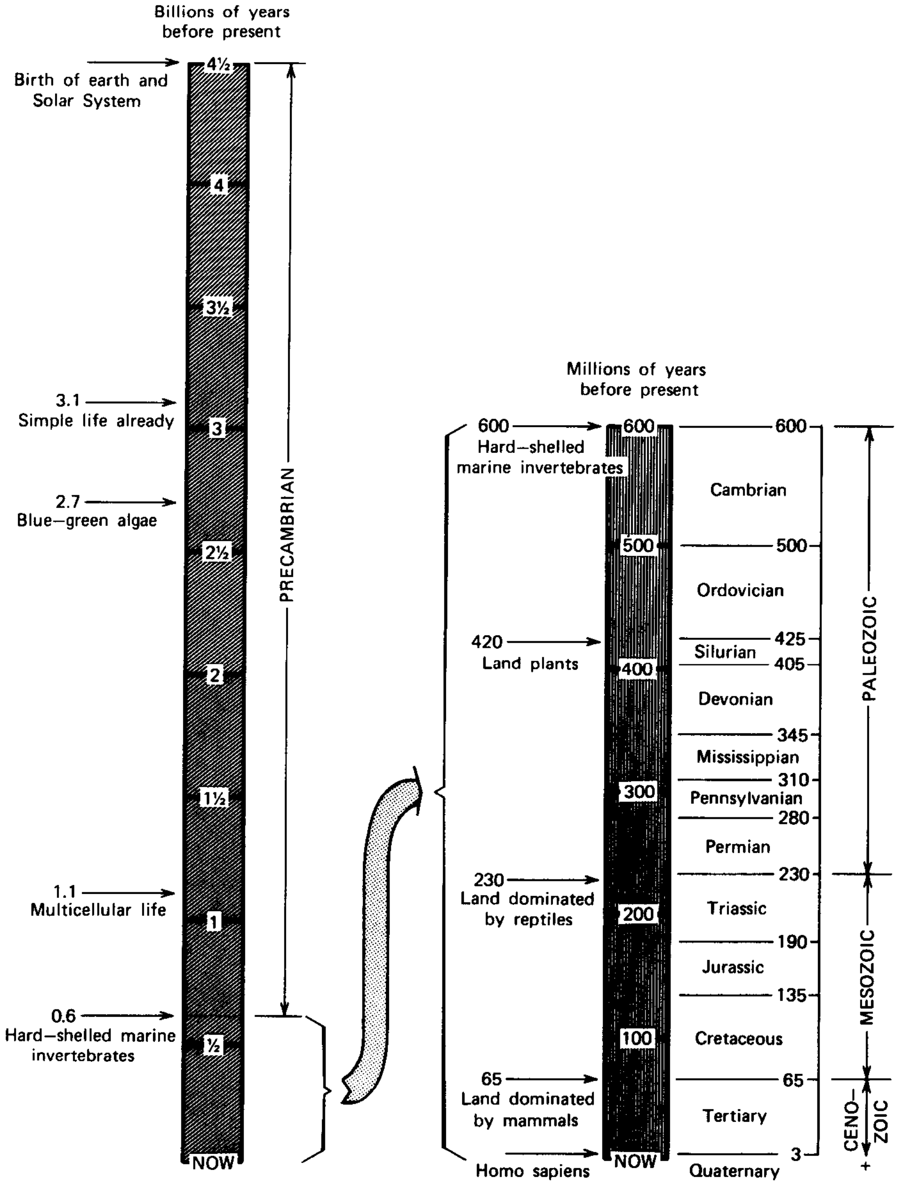


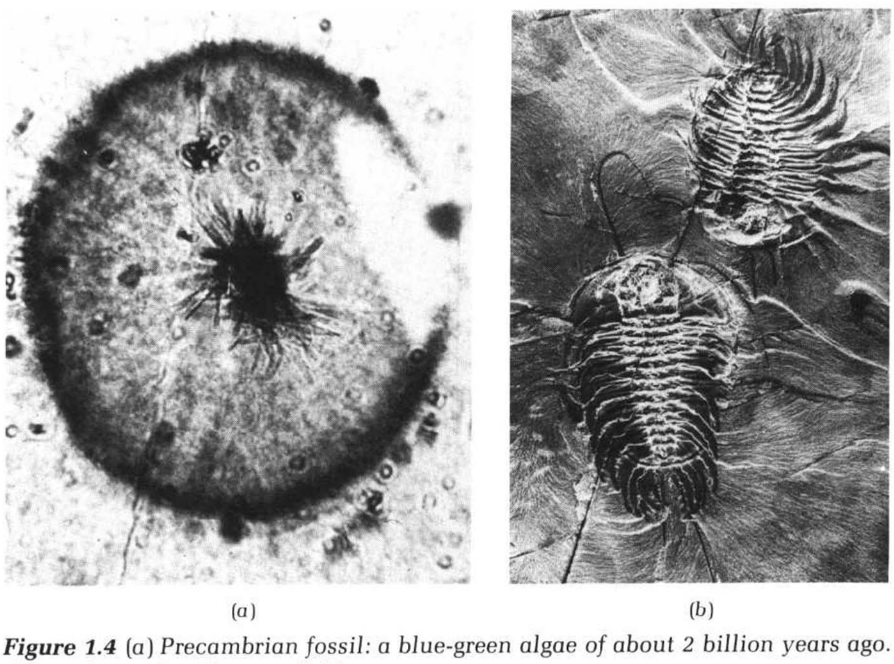
Figure 1.3 *The development of life on earth.*

our desire. The average person travels a significant fraction of the earth's circumference during his or her lifetime, yet we have difficulty in comprehending even the distance across one continent. Much greater is our difficulty in comprehending the earth's evolutionary time scales, since our lifetimes, and even the entire history of humankind, is such a minute fraction of the history of the earth.

It is relatively easy to demonstrate that the earth is quite alive geologically. Dating a typical rock on the ocean bottom yields an age of a few hundred million years at most. A glance at Figure 1.3 will convince you that the age of such a rock is only a few percent of that of the earth itself, giving us a feeling for the rate at which oceans are being created and destroyed. The Atlantic Ocean, for example, has been around much longer than most species of mammals, but not as long as the reptiles.

For the first 90% of the earth's history, any life that existed was oceanic. We have found the remains of single-celled marine organisms from 3.1 billion years ago, so life here must be at least as old as that. Blue-green algae (Figure 1.4*a*) existed as early as 2 billion years ago. Several digs have found the remains of multicellular organisms from about a billion years ago.

Rather suddenly (on geological time scales), many forms of hard-shelled invertebrates began to appear in the oceans about 600 million years ago. This marked the beginning of the Cambrian Period. The entire 4 billion years of earth history previous to this is called the Precambrian, but since the beginning of the Cambrian, many relatively short time divisions have



(*a*) (*b*)

Figure 1.4 *(a) Precambrian fossil: a blue-green algae of about 2 billion years ago. (b) Cambrian fossil: two trilobites.*