PHYSICAL GEOLOGY

Robert J. Foster

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Robert J. Foster
San Jose State College

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Preface

This book is designed for both geology majors and general education students. Many physical geology courses are taken by both groups in spite of the different needs of the two. This book attempts to help with one of the resulting problems—terminology or jargon.

The geology major must learn the language of geology if he is to continue his studies, but the general education student resents having to memorize terms. This resentment is one reason many of today's students reject courses. Each instructor must decide both the topics and the terminology needed for his students. A brief examination of current texts shows that at least in geology there is little consensus in terminology used. This book attempts to help the problem by using as few terms as practical in the narrative. Instead, at appropriate points other terms and concepts are noted in gray boxes. In this way, an instructor can choose which, if any, of these are to be used by his students. Many of the terms used in the narrative could also have been eliminated, and they reveal the author's prejudices.

Most of this book is a slightly revised version of part of *General Geology*. Recent work, especially in ocean-floor spreading, continental drift, and the space program, required rewriting several chapters. That book covers both physical and historical geology and is written for the general education student. Its use in many physical geology courses, including courses for majors, suggested that the modifications described above would make it useful to a much wider audience.

Because this book attempts to provide a broad overview, many topics are covered that do not always appear in survey courses. When some of these topics are omitted, the thoughtful student recognizes that the story is not complete, and the instructor is made aware of this by the questions asked. Although this book attempts to present a modern, conventional view of geology, not all instructors will agree with its viewpoints, especially on controversial subjects. These subjects are avoided in some texts because any viewpoint presented will offend some instructors. However, if an instructor disagrees with the text, he should lecture on the topic and present his own interpretation. This may force the student to think through and analyze both viewpoints and so serve to develop the student's critical thinking. In any case it is easier to lecture on a topic with which the student is already familiar. In the same way those areas in geology that are still not understood are noted with no attempt to gloss them over. In understanding the earth, it is just as important to realize what is not known as it is to learn the facts that are known. The thoughtful student deserves no less.

The first part of this book covers minerals and rocks so that they can be introduced in the early laboratory periods if the course has required a laboratory. Most laboratory courses begin with these topics, and this commonly forces the instructor to use the chapters in the text in a different sequence than the author intended. This forces an undue hardship on the student. In many laboratory courses the emphasis is on identification and naming. To this should be added the interpretation of rocks as stressed in this text.

The sequence of topics progresses from materials, such as minerals and rocks, to processes and appeals to students in laboratory and nonlaboratory courses. Every part of geology is related to every other part so there is no best sequence of topics. To show the interrelationships among the various topics, frequent cross-references appear in the text. These references help the student to see these relationships and keep his interest high on the initial reading. They also facilitate using the chapters in a different sequence, and they greatly aid in study and review for the final examination.

The Supplementary Reading listed at the end of each chapter stresses *Scientific American* articles, especially those available separately, and books published in paperback editions. Such readily available, inexpensive materials may encourage more outside reading. The chapter-end questions are mainly simple factual questions that will help the student to review and test his retention. Some, however, are thought questions that may help him to see beyond the text. In a few cases some points not specifically covered in the text are covered by the questions.

It is impossible to mention everyone who aided me in my writing. M. Grant Gross, SUNY, Stony Brook; E. G. Ebbighausen, University of Oregon; William Quaide, NASA, Ames Research Center; and Robert L. Rose, San Jose State College, have been especially helpful. My wife, Joan, did the line drawings. In addition, she did most of the proofreading and undertook other onerous editorial tasks. Many other people and agencies helped me to gather the photographs and other illustrations.

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Chapter 1

Why study the earth?
Scope of geology
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Introduction

Why study the earth?

Geology is the study of the earth. That we live on the earth is reason enough to study it. The more that we know about our planet, especially its environment and resources, the better we can understand, use, and appreciate it. To man the earth is the most important body in the universe.

In the broader view, however, the importance of the earth shrinks. At least three other stars, and possibly as many as eight, are thought to have planets. Even with our largest telescopes we cannot see these other planets, but we infer their existence from the wavering motions of the stars. The earth is a medium-sized planet orbiting a medium-sized star. Thus the earth appears to be an average planet. However, the earth is unique in having abundant water, exemplified by the oceans, and an atmosphere that can support life. The earth's surface temperature, controlled largely by its distance from the sun, makes these features possible, and these features, in turn, make life possible on the earth. The development and history of life are important aspects of historical geology. The space program has also revealed that the earth is unique in having a magnetic field. The earth's magnetic field, for reasons that will be discussed later, is believed to be caused by a liquid iron core that is also believed to store the energy that causes the formation of such surface features as mountain ranges. These features, which, as far as we know, are unique to the earth, are central to the processes of erosion and deformation of the earth's surface that are the main aspects of physical geology. Thus geology is in large part the study of the consequences of the earth's unique features.

Geology has contributed a great deal to civilization both intellectually and economically. Among the great concepts gained from geological studies are an understanding of the great age of the earth, and the development of an absolute time scale. Geology differs from most other sciences in that it is concerned with absolute time. Time appears

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in the equations of physics and chemistry, but these sciences are generally concerned with rates of change, and the time is relative—not absolute. Geologic time extends back almost five billion years to when the earth formed. Thus geology is concerned with immense lengths of time when measured against human experience. It is difficult to comprehend the lengths of time involved in geologic processes, but this must be done to appreciate geology fully. (See Fig. 1-1.)

Another important point learned from geology is that constant change, both biological and physical, has been and is occurring on the earth.

The origin and development of life is part of geology. It is closely related to the history and development of the earth's surface and thus cannot be separated from the physical history of the earth. Geology shows that, in the broadest sense, all life is related. Biologists share this

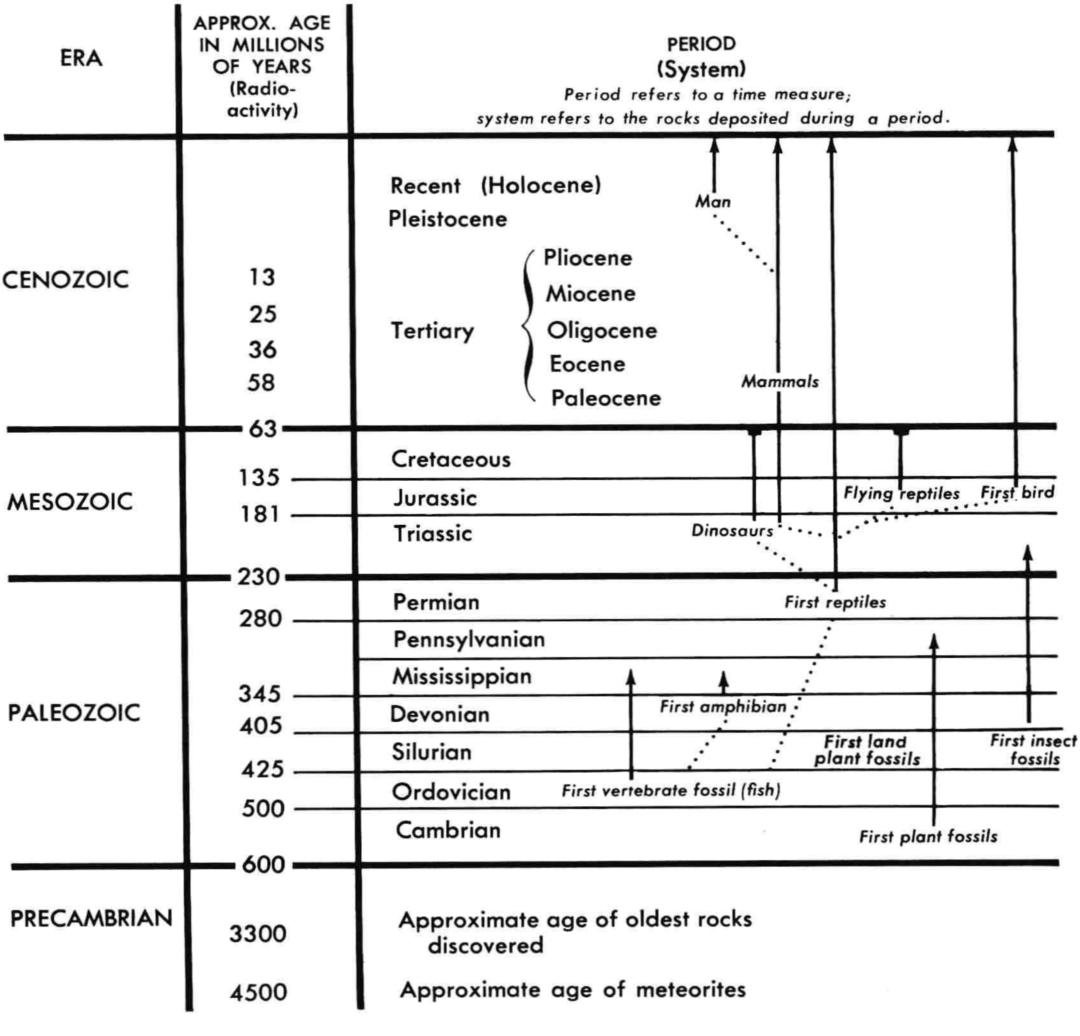

FIG. 1-1. *The geologic time scale. Shown to the right is a very simplified diagram showing the development of life. Not included on the diagram are many types of invertebrate fossils such as clams, brachiopods, corals, sponges, snails, etc., which first appeared in the Cambrian or Ordovician and have continued to the present. This figure is discussed in Chapter 18.*

concern with life, but much of the evidence is geologic in nature. Thus geology and biology overlap in part. Historical geology, as this aspect is called, is not included in this book.

There are only a few fundamental laws in geology. The most important of these were recognized by the ancient Greeks, but because men were not yet ready to accept them, they were forgotten and had to be rediscovered. The fundamental principle that underlies most of geology is simply that the present processes occurring on the earth have occurred throughout geologic time. Thus ancient rocks can be interpreted in terms of present processes.

The economic contributions of geology to civilization show that in many ways, too, geology is a very practical science. Geologic knowledge is used to locate and to exploit our mineral resources. Except for water and soil, all mineral resources, such as sand and gravel, petroleum, coal, and metals, are non-renewable. Once mined they are gone, and new deposits must be found. Geologists have discovered the deposits of metal and energy-producing minerals on which our civilization is based. We take these things for granted now; but a hundred years ago, when the West was opening up and the industrial revolution was occurring, these mineral deposits were being discovered at a rapid rate and geologists were the most influential scientists of the day. At this time, too, the principles of geology were being formulated.

Today mineral resources still occupy many geologists, but geologists are also concerned with other economic problems, such as urbanization. The development of large cities has resulted in the building of large structures, such as tall buildings and dams. Geology helps in designing foundations for these structures. Examples of both large and small structures that have failed through neglect of simple geologic principles, easily understood by elementary students, are common. (See Fig. 1-2.) Dams fail because they are built near active faults or on porous

FIG. 1-2. *Landsliding at Point Firmin, California. Geologic studies can prevent losses such as this. Spence air photo.*

foundations. During their first rainy season, new highways are washed out or blocked by landslides. Homes built on hillsides are destroyed by landslides and mudflows. Geologists have also recognized the need for earthquake-resistant structures in some areas and have helped in their design.

Scope of geology

Geology is concerned with both the processes operating in and on the earth, and with the history of the earth including the history of life. In the broadest sense, geology includes the study of the continents, the oceans, the atmosphere, and the earth's magnetic and radiation fields. Clearly, this scope is too broad for any one scientist, so geologists generally, but not exclusively, limit themselves to the solid earth that can be studied directly. Other specialties have developed to study the other aspects of the earth. Geophysicists study the deep parts of the earth and its fields, mainly by indirect methods; oceanographers study the hydrosphere; and meteorologists study the atmosphere.

Even with this restriction, geology is a very broad field. Most geologists specialize in one or more facets of geology, much as engineers specialize in various fields of physical science such as electronics or construction. However, geology is even broader than engineering because it encompasses both physical and biological science.

Mention of a few of the specialties in geology will illustrate. Those who study minerals and rocks need specialized training in chemistry and physics, as does the geochemist who is concerned with chemical processes in the earth. Those who study fossils must be trained in biology of plants and animals, both vertebrate and invertebrate, so that they can interpret the age and environment of fossils. Those who study deformed rocks must know mechanics. Ground water and petroleum geologists must be familiar with hydrodynamics. A complete listing would be very long, but these examples will illustrate the point. All of these specialties overlap somewhat, and, no matter what his specialty, a geologist must be familiar with all facets of geology.

Geologic methods

Geology is based mainly on observations and seeks to determine the history of the earth by explaining these observations logically, using other sciences such as physics, chemistry, and biology. Only a small part of geology can be approached experimentally. For example, although the important use of fossils to date or establish contemporaneity of rock strata is based on the simple, basic principle that life has changed during the history of the earth, this principle could not be established experimentally; it was the result of careful observations and analyses over a long period of time by many people of varied backgrounds.

Geologic problems are many, diverse, and complex; almost all must be approached indirectly, and in some cases, different approaches to the same problem lead to conflicting theories. It is generally difficult to test a theory rigorously for several reasons. The scale of most problems prevents laboratory study; that is, one cannot bring a volcano into the laboratory, although some facets of volcanoes can be studied indoors. It is also difficult to simulate geologic time in an experiment. All of this means that geology lacks exactness and that our ideas change as new data become available. This is not a basic weakness of geology as a science, but means only that much more remains to be discovered; this is a measure of the challenge of geology.

Reasoning ability and a broad background in all branches of science are the main tools of the geologist. The geologist uses the method of multiple working hypotheses to test his theories and to attempt to arrive at the best-reasoned theory. This thought process requires as many hypotheses as possible and the ability to devise ways to test each one. Not always is it possible to arrive at a unique solution—but this is the goal. In the sense that the geologist uses observation, attention to details, and reasoning, his methods are similar to those of fictional detectives.

The most important method used by the geologist is to plot on maps the locations of the rock types exposed at the earth's surface. The rocks are plotted according to their type and age on most geologic maps. (See

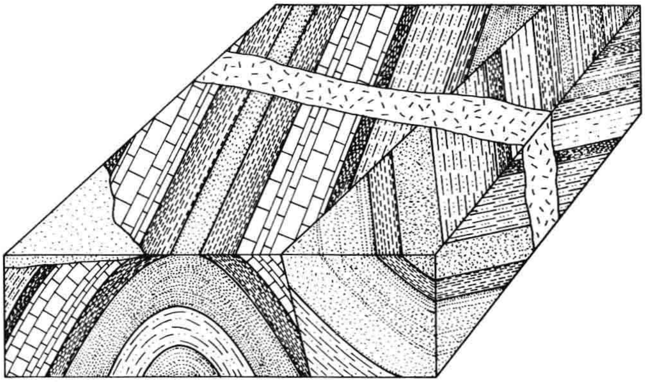

FIG. 1-3. *Block diagram showing a geologic map with cross-sections on the sides. A geologic map shows the distribution of rock types on the surface. From such maps, the history of an area is interpreted.*

Fig. 1-3.) From such maps it is possible to interpret the history of the area. The early geologists had to make their own base maps, and work in a remote area was very difficult in many cases. Now, excellent base maps produced from aerial photographs are available for most areas. Much geologic mapping is done directly on either black and white or color aerial photographs, which have proved to be unexcelled for accurate location of rock units. In addition, the outcrop pattern of the rock units generally shows well on air photos. (See Fig. 1-4.) Radar images that show the surface beneath thick forest cover now extend the use of aerial photographs into such areas. (See Fig. 1-5.) Helicopters and jeeps have

FIG. 1-4. *Vertical aerial photograph of folded rocks in Wyoming. Erosion has etched out the differences in resistance of the various rock layers. Such a photo is essentially a geologic map of the area. Photo from U. S. Geological Survey.*

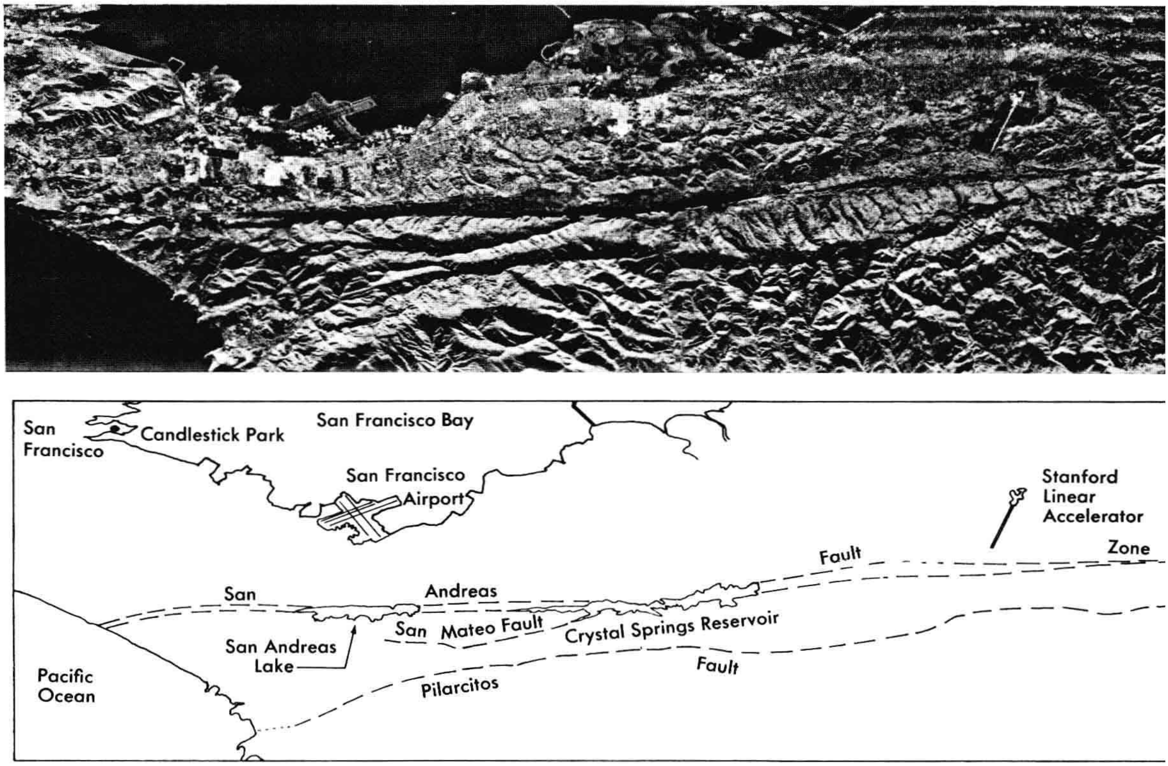

FIG. 1-5. *Radar images. A. San Francisco Peninsula. Unlike conventional aerial photos, radar images can be obtained in cloudy weather or even at night. The radar penetrates the vegetation and reveals the actual surface. The bottom (west) part of this area has thick redwood forests. From U. S. Geological Survey in cooperation with NASA and Westinghouse Electric Co.*

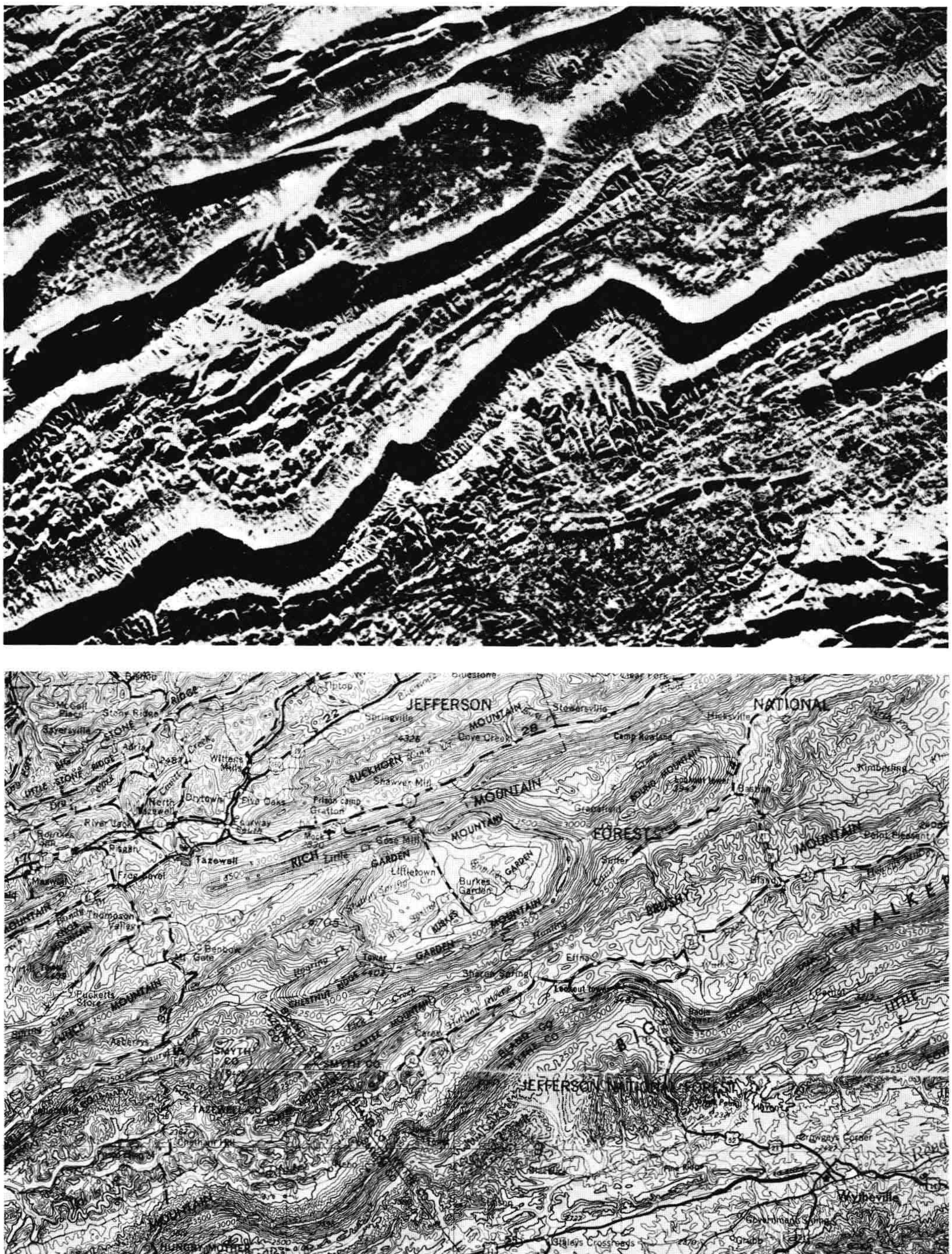

FIG. 1-5. *(cont.) Radar images. B. Appalachian Mountains in western Virginia. The structures of these folded rocks are well shown. Courtesy of Raytheon Company, Autometric Facility.*

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