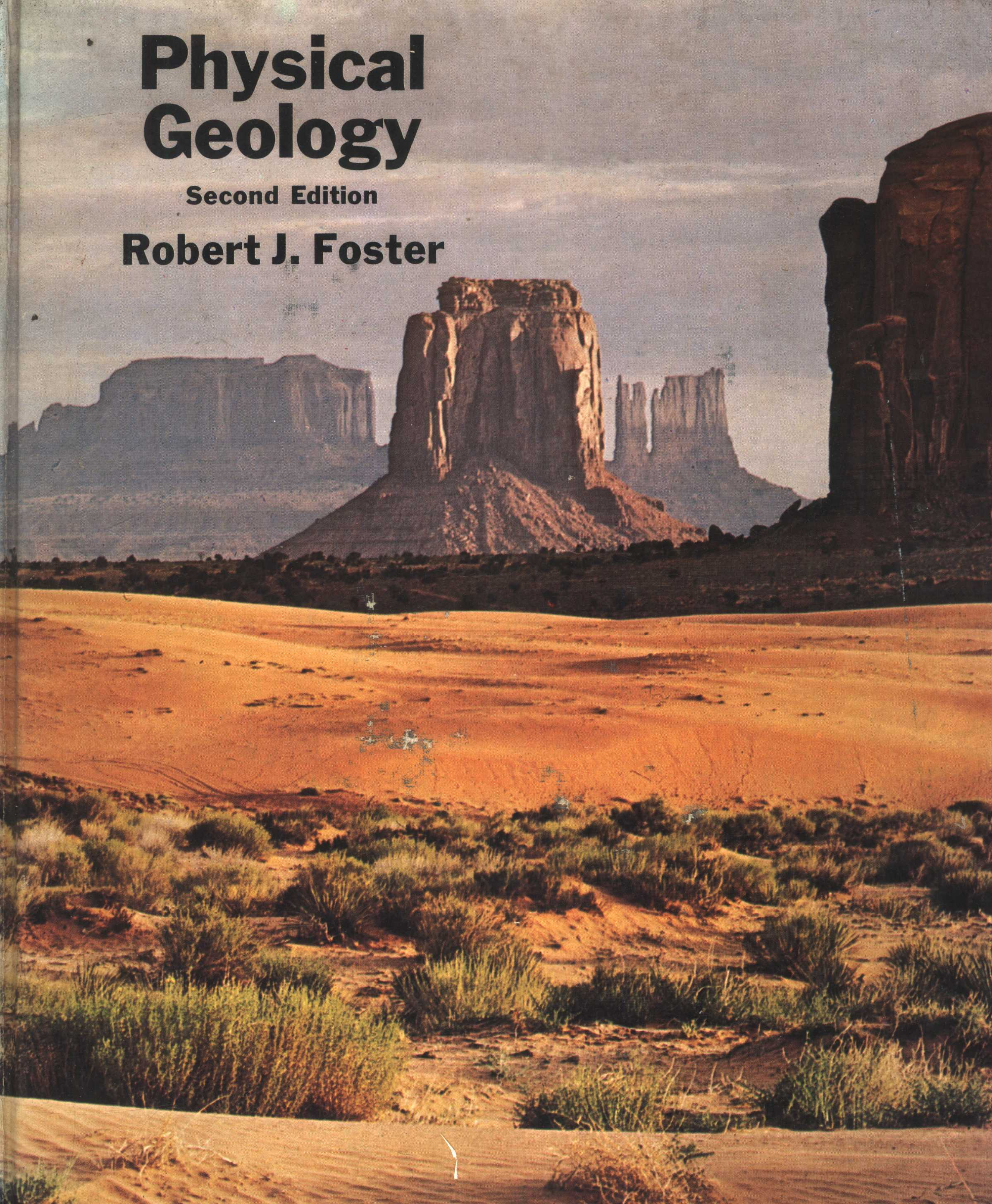
Physical Geology

Second Edition

Robert J. Foster



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Robert J. Foster

San Jose State University

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Preface

This revision was undertaken in an effort to make this book more interesting and more useful to the student. Most of the features of the first edition have been retained.

Many chapters have been updated or rewritten. Many of these changes were dictated by the revolution in geologic thinking brought about by recent advances in the theories of sea-floor spreading and continental drift.

To make the book more interesting and more timely, geological aspects of environment have been added in every chapter. This will help the student see better the many ways that geology affects our lives. If today's students understand the environment, they may be able to make our earth a better place on which to live. Brief historical summaries have been added to many chapters to help the general education student see the development of science as part of the overall intellectual development of man and to help the geology major better understand the development of geologic concepts. Hopefully, the addition of environment and history will help to humanize geology. A summary of principles has been added at the end of each chapter to help students to focus their study.

As in the first edition, this revision begins with minerals and rocks so that they can be introduced in the early laboratory periods if the course has a required 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 from what the author intended. In some courses this forces an undue hardship on the student. In many laboratory courses the emphasis is on identification and naming. To these should be added the interpretation of rocks as stressed in this text.

The Supplementary Reading listed at the end of each chapter stresses *Scientific American* articles, especially those available separately, and books available in paperback editions. Such readily available, inexpensive materials may encourage more outside reading. The end-of-chapter questions are mainly simple, factual questions that will help the student to review and test his retention. Some, however, are thought-provoking 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.

Many new illustrations, especially photographs, have been added. This increase in the number of examples will help to make the principles clearer and the book more interesting. I am grateful for the generous response of many people to my requests for the photographs.

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An Introduction

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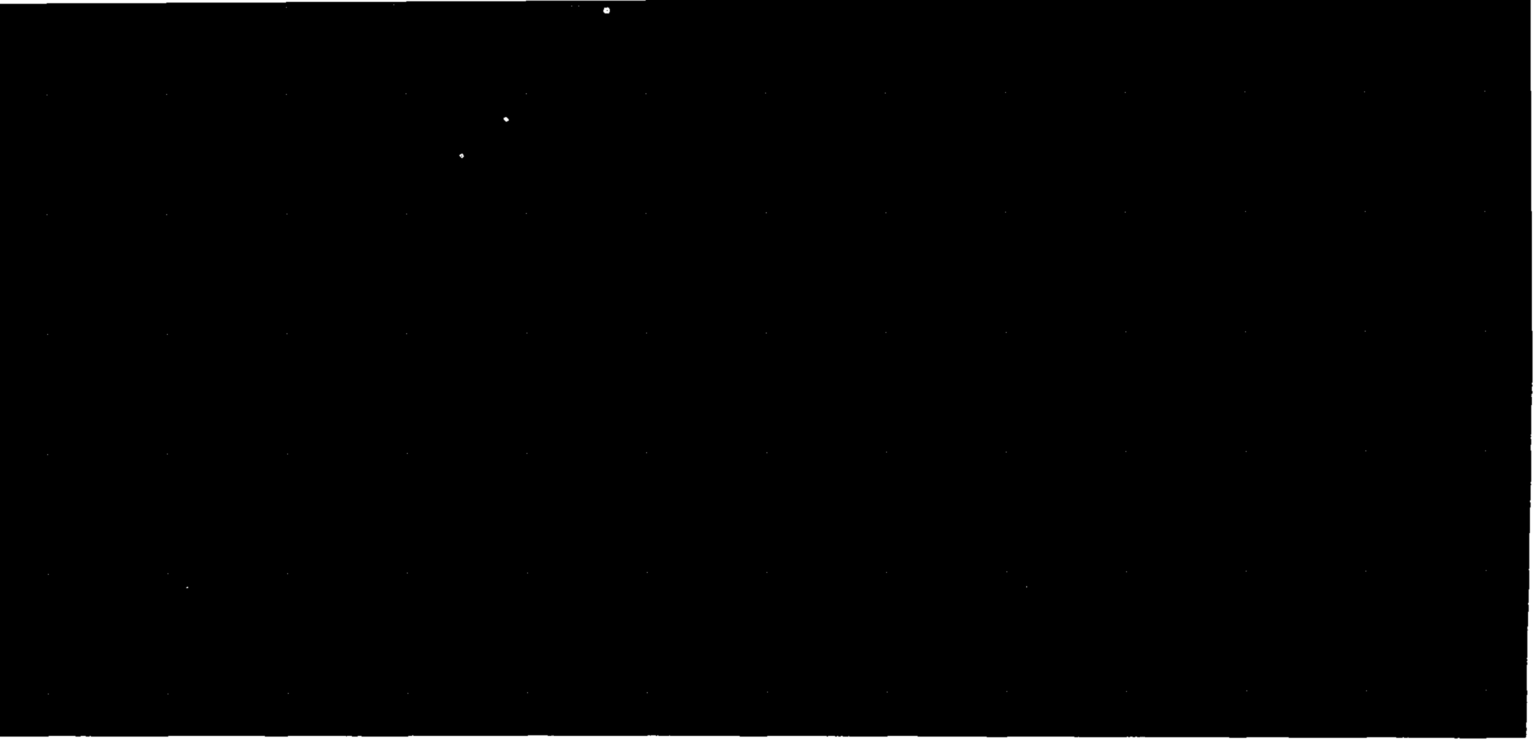


Why Study the Earth?

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, at least in the solar system, 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 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 among the planets so far studied 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 may also store the energy which 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 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 5000 million 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.)

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

A group photo showing members of Hayden Survey taken at Red Buttes, Wyoming, August 24, 1870. In about a ten-year period, the Hayden Survey explored most of the Rocky Mountains geologically. The early geologic surveys of the west resulted in many concepts that helped the development of the science of geology. This scene contrasts sharply with today's space program, which is one of today's geologic frontiers. Photo by W. H. Jackson, U. S. Geological and Geographical Survey of the Territories.

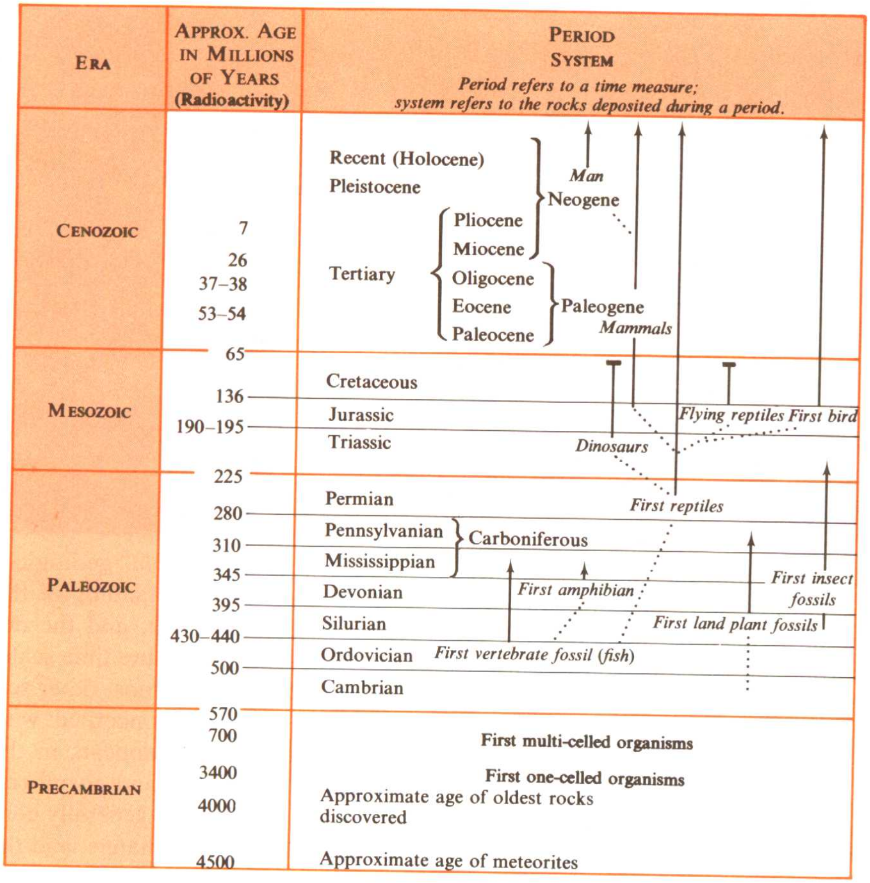


Figure 1-1. The geologic time scale. Shown to the right above is a very simplified diagram showing the development of life. Not included on the diagram are many types of invertebrate fossils such as clams, brachiopods, corals, sponges, snails, etc., which first appeared in the Cambrian or Ordovician and have continued to the present. This figure is discussed in Chapter 17.

present processes.

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 concern with life, but much of the evidence is geologic in nature. Thus geology and biology overlap in part.

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 the study of mineral resources is of utmost importance, 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 foundations. During their first rainy season, new freeways 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. These and many other geological aspects of our environment will be described.

Scope of Geology

Geology is concerned both with 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.

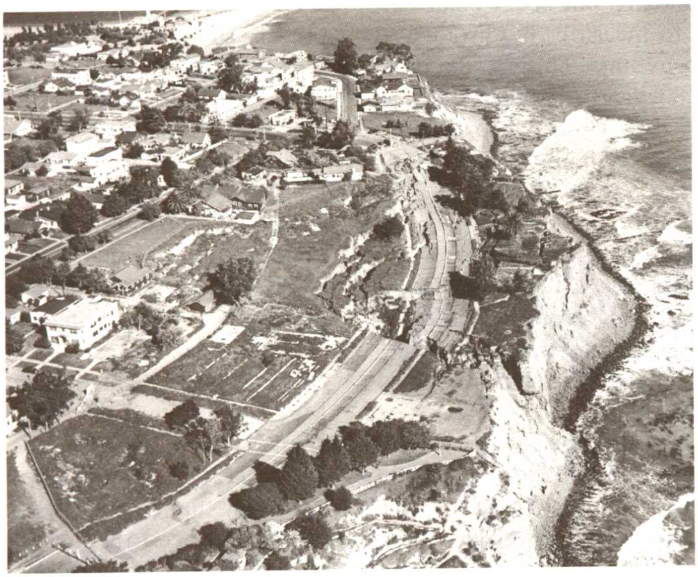


Figure 1-2. Landsliding at Point Firmin, California. Geologic studies can prevent losses such as this. Spence air photo.

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 meterologists 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. 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.

Discovering the Earth's Place in the Universe

The science of geology developed around the end of the eighteenth century, but long before then, the earth's place in the universe was explored. In many early civilizations, the priests kept track of the movements of the sun, moon, and planets relative to the stars. This was of practical value, as well as religious, because it led to the development of calendars and prediction of such events as eclipses. The Greeks went further and developed a system to explain the motions of the heavens. This was the first big step in finding the earth's place in the universe.

The work of the Greeks was summarized in 140 A.D. by Ptolemy. In the Ptolemaic system, the earth was at the center of the universe and all of the other objects in the solar system—the sun, moon, and planets — revolved around the earth. Although not all of the earlier Greeks would have agreed with this system, the great advantage of Ptolemy's work was that it could be used to predict future movements of the sky. Thus, it was of great use in astrology and navigation. Columbus and the early explorers used the Ptolemaic system.

The first important challenge to the idea that the earth and man's place was at the center of the universe came at the Renaissance about 1400 years after Ptolemy. Putting the sun at the center and having the planets revolve around the sun made a much simpler system in the sense that fewer motions are necessary. This system was published posthumously in 1543 by Nicholas Copernicus. Moving man away from the center created a controversy that raged for a hundred years because proof of the earth's daily rotation and yearly revolution came much later. The main advantage of the Copernican system over the Ptolemaic system was that it was simpler. Both had many inaccuracies in prediction. In the early part of the seventeenth century, Johannes Kepler, using data collected by Tycho Brahe, was able to describe the motions of planets and showed that Copernicus was basically correct.

Galileo Galilei, an Italian, was a contemporary of Brahe and Kepler. He worked in many fields, but only parts of his studies of astronomy and mechanics will be mentioned. In 1609, Galileo built one of the first telescopes and used it to observe the heavens. He saw things that no man had ever seen before, and many of his observations could not be explained by the Ptolemaic system. He announced his discoveries in two books but was later forced to recant by the Inquisition. As a result, he had to spend the last years of his life in virtual house arrest. It was during this period that he carried out many of his experiments in mechanics, experiments which later helped Newton.

Isaac Newton, an English physicist, using the work of Kepler and Galileo, discovered the laws of mechanics and of gravity. He worked out these laws about 1664 and published them in 1686. It was then possible to understand why the planets orbit the sun. This discovery profoundly influenced eighteenth century thought, and it was widely believed that almost everything could be explained by Newton's laws. It was not until the early part of the twentieth century that Einstein showed that Newton's laws do not apply in all situations.

Thus by Newton's time, the earth's place in the sun's family was established. The distance to the sun, 93 million miles, was measured in 1672. But where is the sun in the universe? New instruments, especially big telescopes, had to be built before this question could be answered and man's place in the universe known, if indeed it can ever be fully known.

The first step out of the solar system was to measure the distance to some nearby stars. This was not done until 1838 when Bessel measured the very small change in angle to a nearby star, as the earth moves from one side of its orbit to the other. This geometric method can only be used to an angle of 0.008 second of arc which corresponds to a distance of 400 light-years. Beyond this distance the angle is too small to measure accurately. The closest star is about 4 light-years away.

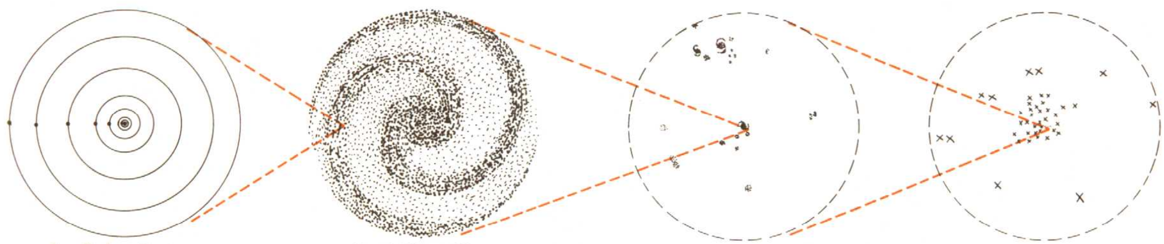
It was not until the early twentieth century that greater distances could be measured. During much of the nineteenth century, spectroscopic analysis was developed and applied to starlight. In 1911, Ejner Hertzsprung in Holland and H. N. Russell in the United States noted that there is a relationship between spectral type and absolute brightness of a star. The absolute brightness can be calculated from the apparent or measured brightness for those stars whose distance is known. It then became possible to calculate the distance from the apparent brightness of any star whose spectral type is known, because from the spectral type, one knows the absolute brightness.

The size of the known universe was growing rapidly, but for the most part, the distances measured were to stars in our galaxy, the Milky Way. (All of the stars seen with the naked eye are within our galaxy, although some more distant objects such as the Andromeda galaxy can be seen without a telescope.) During the nineteenth century, astronomers noted many objects whose light was soft and fuzzy. By 1850, several spiral galaxies had been noted, but their nature was in doubt. In 1908, some stars were resolved in some of these objects, suggesting that they might be vast groups of stars like the Milky Way. It was not until 1925, when the new 100-inch telescope at Mount Wilson became available, that Edwin Hubble was able to report that these objects were composed of many stars. Objects the size of the Milky Way, so distant that they appear to be stars except in the largest telescopes, reveal a universe whose size is beyond comprehension. The diameter of the Milky Way itself is 80,000 light-years.

In 1912, Henrietta Leavitt made a discovery that enabled measurement of the distance to a galaxy. She observed that there is a relationship between the brightness and the period of a type of variable star called a Cepheid. Using this, as well as other methods, the size of the known universe quickly expanded to over a 1000 million light-years. The total number of galaxies may be as great as 100,000 million.

Perhaps the most astonishing thing revealed was Hubble's discovery in 1929 that all of these galaxies are moving away from us — that is, the universe is expanding. The further away a galaxy, the faster it is receding from us. This motion is measured from the *red shift,* a movement of the lines in a galaxy's spectrum toward the red. This change in frequency is similar to the change in pitch of a train whistle as the train moves away from the listener.

Thus, in about 500 years, man's perception of the earth has changed from its being the center of the universe to its being a small planet orbiting an average star in one of perhaps 100,000 million galaxies. (See Fig. 1-3.) Research continues in astronomy, and new, strange objects (qua-



A. Solar System

Innermost circle represents Earth's orbit around sun. Other circles represent orbits of Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. One light-year is approximately 1600 times the distance from the sun to Pluto.

B. Milky Way.

Distance from the center of the galaxy to the sun is 30,000 light-years, 48 million times the sun – Pluto distance. The center to the edge of the galaxy is 40,000 light-years, 64 million times the sun – Pluto distance.

C. Local Group.

The Local Group of galaxies extends about 3 million light-years away, 75 times the distance from the center of the Milky Way to its edge. The sizes of the galaxy symbols are greatly exaggerated.

D. Universe of galaxy groups.

Large X's represent large groups of galaxies; smaller x's, small groups. Dashed circle approximately 500 million light-years away from center.

Figure 1-3. The earth's place in the universe.

sistellar objects—QSO's) have been discovered. Some of these QSO's emit radiowaves, and some have very large red shifts, suggesting very high velocities and perhaps great distances. These objects, or others yet to be discovered, may again change our ideas on man's and the earth's place in the universe.

Exploring the Earth

Concurrent with finding his place in the universe, man also explored his own planet. The Crusades, which lasted from 1095 to 1291, marked the end of the Dark Ages. In the Crusades, the Europeans discovered that the people of the near east were in many ways more advanced than the Europeans. Marco Polo also described much more advanced peoples in the far east. He returned to Venice about 1300 after a trip, mainly overland, to China and India and wrote a book describing the things he had seen. Although he attracted much interest, he was not widely believed because few people thought that the Orient could be more advanced than Europe. At this time very little was known of the world outside of Europe, although missionaries had ventured into Africa and Asia. Marco Polo's journey and the Crusades were the first step in awakening Europeans to the world around them.

Some attempts at systematic exploration began during the first half of the fifteenth century. Portuguese captains under the direction of their ruler Henry the Navigator (1394–1460) sailed further and further along the African coast. The age of exploration, however, began with the fall of Constantinople to the Turks in 1453. This severed the trade route to Asia and left Europe with no source of silks or spices. They could do without the silk but they had to have spices. The price of spices rose sharply, adding a commercial incentive to the existing religious and political reasons for finding a route to Asia.

Spices were very important at that time because in the winter Europeans had almost nothing to eat except pickled meat. They had no fodder crops, so each fall most of the cattle were slaughtered and pickled. Without spices this was a very dreary diet.

The great voyages of exploration began in 1492 with Columbus. He sailed west, hoping to reach the Indies. This was the first time anyone had ventured into the Atlantic far away from the coast. One reason for this reluctance to leave the sight of land was the lack of knowledge of navigation. Columbus used a plumb bob and a quadrant to sight stars and could find his latitude from sighting the North Star, but with his equipment even this was difficult in a wave-tossed ship. He had only an hourglass to measure time, so he was unable to find his longitude with any accuracy. He thought that he had reached the Indies because he believed that the earth was much smaller than it is.

After Columbus came the other great explorers. In 1497 Da Gama sailed around Africa to India. Balboa discovered the Pacific in 1513 and was the first of the Spanish Conquistadors to explore the Americas. In 1519 Magellan sailed around

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