chapter 1

The Roots of Earth Sciences

Because scientific inquires and discoveries are and have always been affected by history, a retrospective view of the historical development of the earth sciences seems a good place to begin our discussion of the planet Earth. While this historical survey is necessarily brief—this is, after all, a *Little Book*—it will establish the foundations of modern earth science and introduce important thinkers and scholarly developments.

Classical Scientific Thought

Prior to and even after 600 B.C., most ancient Greeks used mythology to explain the natural world. Then, around 630 B.C., an important intellectual and methodological shift began to occur. Thales, a Greek and the first recorded Western philosopher, began to use a different kind of reasoning as he coupled his own speculations with observations and mathematics. Among other things, Thales claimed that all of the Earth's matter was made of water and, furthermore, that the Earth was a sphere and not a disk, as was widely believed at the time. About 50 years later, Pythagoras, another Greek philosopher, claimed that the Sun and the Moon also were spheres, and that Mercury and Venus rotated around the Sun. Controversial at the time, this notion of a heliocentric (Sun-centered) system foreshadowed the view of the world that would be established by Copernicus almost 2000 years later.

Around 450 B.C., Herodotus, who was not only a famous Greek historian but may also be considered one of the first sedimentary geologists, observed that the Nile slowly enlarged its delta, and that this deposition process took an extremely long time. About 100 years later, the great philosopher Aristotle wrote some 400 treatises, many of them on physics and biology. Around the year 200 B.C., Eratosthenes at Alexandria's Greek University calculated the exact circumference of the Earth by observing the length of the Sun's shade in two different locations at fixed times. In A.D. 150, Ptolemy, considered the last great classical astronomer, returned to the geocentric view of the world. He argued that the Earth had to be at the center of the Universe, and that the Sun, Moon, and stars revolved around it in very complex "epicycles." After Ptolemy, the scientific knowledge that the Greeks had developed was largely forgotten, and Roman pragmatism limited further developments in the natural sciences.

The Copernican Revolution

Near the end of the Middle Ages, the natural sciences experienced a revival, and a number of discoveries were made that have had profound effects on our understanding of the Universe and our planet. This new era of scientific discovery was initiated by Nicolaus Copernicus in the sixteenth century. In his most famous work, *De revolutionibus orbium coelestium*, which was published shortly before his death in 1543, he outlined the heliocentric system in which the Earth and the visible planets revolve around the Sun. In the early 1600s, Johannes Kepler, a German astronomer who was greatly influenced by Copernican teachings, formulated laws of the planets' movements around the Sun based on very exact observations by his contemporary and teacher Tycho Brahe. About the same time, Galileo Galilei, the great Italian physicist, observed the orbiting planets and four of Jupiter's moons with a simple, self-made telescope. These and other observations convinced Galileo that the Copernican view was true. As a result of these convictions, he had to defend his theories against ecclesiastical authorities in Rome who believed that Copernicus's teachings were dangerous to the faith. Under threats of torture, at an age of 70 years, Galileo renounced his opinion. Ultimately, it took the Church more than 300 years to tolerate the Copernican view of our Solar System. Over 50 years after Galileo's trial, another of the science's most famous sons, Sir Isaac Newton, published his most renowned work, *Philosophiae naturalis principia mathematica.* In it, he developed a substantial physics-based foundation to Kepler's laws and outlined his own theories of motion and gravity. Looking back at the great achievements from Copernicus to Newton, we can see a true revolution in scientific thinking that most convincingly marked the transition from the Middle Ages to modern times. No longer were the study of old philosophers, like Aristotle, or a literal citation of biblical text considered the ultimate goal of research. Instead, exact physical observations and rational deduction opened up the time of enlightenment and a new view of the world.

From Physics and Philosophy to Geology

Improved telescopic observations toward the end of the eighteenth century convinced researchers that our Solar System was only part of a much larger unit of stars, called the Milky Way galaxy. Although both René Descartes and Emanuel Swedenborg had attempted to describe stellar nebulae and their role in the Universe, only the German philosopher Immanuel Kant combined Swedenborg's ideas and Newton's physics to create the first substantial nebula theory. However, Kant's explanation, published in 1755, contained a number of physical problems. In 1796, a French scientist named Pierre-Simon Laplace expanded Kant's ideas, proposing that our Solar System originated as a large, swirling nebula that slowly cooled and contracted into its present form. At the beginning of the nineteenth century, Carl Friedrich Gauss of Göttingen, Germany, combined magnetic observations with new mathematical tools to prove that the Earth's magnetic field originated in its deep interior. This important break-through could explain a great number of observations, from polar lights and the poles themselves to the functioning of compasses. No mystical magnetic mountains were needed anymore. One hundred years after Gauss's deductions, several branches of geophysics, including paleomagnetism and archeomagnetism, opened completely new fields in geophysics and geology.

New physical, chemical, and seismological data were collected toward the end of the nineteenth century, but an exponential increase in knowledge of the structure and interior of our planet started only in the twentieth century. Seismology took the lead and was able to decipher many of the mysteries of the Earth, such as the existence and the shape of the metallic core, the huge silicate mantle, and the thin crust. From the sporadic observations of earthquakes with huge (but primitive) seismometers to the development and installation of modern digital seismometer arrays all over the world, one century witnessed great change.

Geological knowledge developed more or less parallel to the physical discoveries. Around the mid-sixteenth century, scholars began to question the biblical conclusion about the age of the Earth. In 1556, Georgius Agricola used his knowledge of mining and metallurgy to explore geologic strata and thermal gradients. More importantly, Agricola began classifying minerals more systematically and is credited with first applying chronology to the discussion of rock formations. Then, in the eighteenth century, both Abraham Gottlob Werner and James Hutton helped lay the basis for modern geology, developing systems for describing minerals, rocks, and strata that are still used today. Werner, a rather dogmatic *neptunist* (from the Roman god Neptune, ruler of all waters), argued that nearly all rocks originated from a series of chemical precipitations and depositions formed by the water that covered the Earth. He was partly right, at least regarding the origin of sedimentary rocks.

At the beginning of the nineteenth century, Nicholas Desmarest, a French government employee, argued that many rocks had to be of igneous origin, namely the basalts in France's *Massif Central.* He and his followers, among them Hutton who was the most prominent researcher, were called the *vulcanists*, or *plutonists* (after the Roman god Pluto, the smith and ruler of the deep fire). They were, correctly, convinced that deep intrusions and many igneous rocks had their ultimate origin at great depth and were similar to volcanic rocks. During the nineteenth century, the controversy between plutonists and vulcanists on one side and neptunists on the other quickly faded. A new research technique, the identification of rocks and the correlation of strata by fossils, laid the basis for modern geology.

At this time, Alexander von Humboldt, a German explorer, observed rocks, strata, and biological species around the world and found interesting correlations. Von Humboldt can be considered a forerunner of the great pioneer of the biological and geological sciences in the second half of the nineteenth century, Charles Darwin. Darwin's travels led him to many parts of the world, and, in a grand synthesis of all his observations, he wrote *On the Origin of Species* and put forth his renowned concept of natural selection. Darwin developed a new understanding of the evolution of life, based on careful investigations of fossils in rocks. His remarkable intellectual leaps laid the foundation of paleontology, linked biology and geology, and greatly advanced studies of the development of animals and humans.

The Age of the Earth

As the astronomical and physical explanations of mysterious celestial and terrestrial phenomena became more known in European universities at the beginning of the eighteenth century, some animosities between theology and science began to develop. Both astronomers and neptunists postulated an age of at least 75,000 years for the origin of the Earth, while some interpreters of the Bible insisted on an age of 4000 to 14,000 years. In fact, around 1654, the Irish Archbishop James Ussher claimed that the Earth was created on October 26, 4004 B.C.

A major break-through occurred in 1860, when the eminent physicist William Thomson Kelvin calculated an age of 25 million years. Kelvin based this estimate of the Earth's age on internal heat flow, which he considered a remnant of the molten stage of the Earth. Later, he adjusted his age calculation multiple times, upward to a maximum of 100 million years. Charles Darwin, who based his estimate on the development of several species, dated the Earth at even 300 million years, but later—under attack from many geologists at various conferences in Great Britain—reduced the number to 100 million years. Most nineteenth-century geologists, observing the slow sedimentation rates in rifts and depressions, estimated an age of 80 to 100 million years.

Then, in 1896, Antoine Henri Becquerel discovered the phenomenon of radioactivity, the geological significance of which was recognized by Pierre and Marie Curie as a new and important source of the Earth's heat. The Curies had first studied radium salts and found a steady flow of heat. Later, they found more heat-releasing radioactive elements. As a result, it was recognized that the Earth's heat was not only coming from a "molten stage" but also from the radioactive elements, mainly uranium, thorium, and potassium.

Shortly thereafter, Ernest Rutherford, a British physicist, became the leading researcher of radioactivity and atomic structure. He studied various radioactive elements and calculated the origin of rocks based on the decay of radioactive elements. The age of these rocks and, consequently, the age of the Earth were surprisingly large. In 1904, he seems to have even convinced old Lord

Kelvin. In fact, in a talk he gave where Kelvin was in the audience, he said that his incorrect age estimates were compatible with Kelvin's early remark, "provided that no new sources of heat were discovered."[1] From this research, new estimates of the age of the Earth started with 500 million years, but continuous improvement in scientific techniques steadily increased that number. Finally, in the middle of the twentieth century, a value of 4600 million years was established, and today the age of the Earth is no longer the subject of major controversy.

Through the long process of theoretical and experimental research, the physical age determination of minerals, rocks, and strata developed into one of the most intensive and successful fields of geology. Today, so-called *isotope geology* is applied to dating rocks on the Earth and from the Moon and is fully integrated into general geology. It stands as an example for the fact that only a combination of physical and geological reasoning makes up the framework of earth sciences.

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[1] Anthony Hallam, *Great Geological Controversies* (New York: Oxford University Press, 2nd ed. 1990), 101.