CHAPTER ONE

Sleuthing the Past

Four and a half billion years, the number that represents the current estimate of the age of Earth, is so large, so far outside of our normal, everyday experience that it is difficult to comprehend. If a piece of string an inch long represents one year, for example, then a 6-foot length is about equivalent to the average lifetime of a U.S. citizen. The length of a string representing all of recorded history would be slightly more than half a mile, but a string representing 4.5 billion years would be 71,023 miles long and would wrap around Earth nearly three times!

If a period of time measured in billions of years is difficult to grasp, the implications of such a temporal abyss are even more elusive. Think of all the things that have happened during your lifetime, and then try to imagine how many things might have happened everywhere in the Universe in 4.5 billion years. Stretches the mind, doesn't it?

As staggering as these numbers may seem, the evidence clearly shows that Earth's age is, in fact, 4.5 billion years and the Universe, including our Milky Way Galaxy, is about three times older. Yet humans are relatively recent inhabitants of the planet, the merest of specks on a timeline of Earth's history, and we have witnessed only an infinitesimally small percentage of what has happened since Earth formed. How, then, can scientists peer back through vast reaches of time, figure out so many things about the history of Earth and the Universe, and determine an age for Earth with an accuracy of better than 2%? It's a good question, and it deserves a good answer.

What Is Science and How Does It Work?

Although people have probably wondered about the mysteries of nature for millennia, science is a relatively recent field. Prior to the seventeenth century, most civilizations attempted to understand the physical world by appealing to religion. Things that appeared to be mysterious—such as eclipses of the Sun, lightning storms, diseases—were attributed to actions of the gods and often viewed with superstition and fear. The scientific and intellectual revolution that characterized the Age of Enlightenment, which developed in the seventeenth and eighteenth centuries in Western Europe, changed that dramatically. The leaders of this movement—including Kepler, Galileo, Bacon, Descartes, Newton, Boyle, and Lavoisier, to name a prominent few—began to seek an understanding of the physical world through observation, experiment, and the careful formulation of logical conclusions. In doing so, they freed the intellect from the bondage of medieval theology, made curiosity about nature legitimate, and invented what we know today as science.

Twentieth-century science is a vast, complex, and often daunting enterprise conducted by scientists working for universities, governments, and businesses. Scientists are the caretakers of an enormous system of knowledge that has accumulated and evolved over several centuries, and it is being constantly modified, corrected, and expanded. The purpose of some scientific work is to answer specific questions about matters of immediate importance. What are the long-term effects of certain chemicals on the human body? How can batteries be made that will make electric automobiles practical? How can cancer be prevented?

Much of the efforts of scientists, however, are directed simply at expanding our understanding of nature. Science is the activity of thousands of curious people who want to discover how nature works. Science does not exist, however, just to provide amusement and employment for scientists. On the contrary, even basic research that may seem to have no immediate application is of immense value to society. The extensive pool of accumulated scientific knowledge, to which new discoveries are constantly being added, is a valuable resource for others who seek to develop new products, solve technological problems, and improve our living conditions.

Like most organized forms of human activity, science has rules. Just as in baseball, the rules of science define the boundaries of the playing field and the types of moves and strategies allowed in the game. The rules of science are not written down in a formal code, in the manner of civil law or the rules of baseball, but there is an extensive body of literature about them, and they are well understood and carefully followed. They were developed and are followed out of necessity, because without them science would not advance.

The rules are quite simple, and you use some of them every day without realizing it. For example, when you go to bed tonight you fully expect that the Sun will rise tomorrow morning. In arriving at this conclusion you have used inductive reasoning, that is, the drawing of general conclusions from specific observations, one of the primary tools of science. Let's briefly explore some of the more important rules of science, especially as they apply to the processes of probing into the mysteries of the past.

THE SUBJECT IS NATURE

This is probably the most important rule of all, for it determines what questions scientists can and cannot ask (and answer) and provides the fundamental basis for understanding scientific conclusions. Failure to understand this rule is one of the primary reasons that science is so often perceived to be at odds with other fields of intellectual endeavor, especially religion. Put simply, science involves the study, description, and classification of nature and natural processes. It deals only with the world of physical phenomena. Politics, art, baseball, and affairs of the human spirit, such as religion and philosophy, are not included because these are subjects with which science simply is not equipped to deal.

This is not to say that science does not overlap with other disciplines. On the contrary, science commonly peeks and pokes into any field where its unique methods of investigation might bring clarification. Science can explain the physics of a curve ball, but not why baseball is so popular. Science can explain why the mixture of certain colors produces other colors, but not why we find a painting by Rembrandt or Van Gogh so beautiful. Science can determine the age of the Shroud of Turin (A.D. 1325 ± 65 years) but has nothing to offer on its religious significance.

Science has a unique role in finding natural explanations for things regarded by some as mysterious—flying saucers revealed as electrical discharges and ordinary rocket launches, supposed paranormal phenomena exposed as fraud, "creation science" revealed as thinly disguised religious apologetics. This restriction to nature and the neglect of other matters does not mean that science is either inferior or superior to other fields, only that it is different. Its limitation should not be considered either a weakness or a strength, but merely an essential attribute. All it means is that science has its limits, just as there are limits to the size of a football field and the diameter of a golf ball.

Because science deals solely with observable phenomena that occur in the physical world, there are some questions that science can answer and others it cannot. Science can be expected to provide a reasonable estimate for the age of Earth and to describe the sequence of physical events that sculpted the world we now inhabit. But it cannot answer the questions of why we exist, who created the Universe, or even if there was a "who" involved in the process. If those questions have answers, they must come from the fields of religion and philosophy, not science.

CAUSE AND EFFECT

The premise that for every effect there must be a cause may seem so obvious that it appears unnecessary to state it, but it is the very basis for asking questions about nature. The law of cause and effect has been observed to be true in so much of our experience that it is only reasonable to assume it holds for all of nature and for all time. It tells us that for every observable condition, it is profitable and worthwhile to seek a rational and natural cause, and that without understanding the cause, one can never really understand the effect. Perhaps more fundamentally, it says that answers to questions about nature do exist, and that there is every chance that we can find them if we are clever and persistent enough. Scientists presume that there is a reason for everything that can be observed in nature, and, conversely, that nothing happens in nature without there being a rational cause that can eventually be determined by the careful application of experiment, observation, and inductive reasoning.

EXPERIMENTS DEMYSTIFIED

A frequent barrier to understanding how scientists decipher the past is a common misconception of the definition and role of the experiment in science. Most people realize that experiments play an important role in scientific discovery. Many think of an experiment, however, exclusively as a test that can be done in the laboratory and repeated at will. If this is so, they ask, then how can scientists experiment with the past to discover what happened? Sometimes the question takes a slightly different form. Since there were no people millions of years ago to observe and record events as they occurred, how can scientists confidently say what happened so long ago?

Webster's dictionary defines an experiment as "a test or trial of something; specifically, any action or process undertaken to discover something not yet known or to demonstrate something known." The key word here is *process*. Included within this definition are three distinct types of experiments, each involving a different process. The real-time experiment is the familiar one. Common in physics and chemistry, the real-time experiment involves repeatability at will and the careful control of, and the ability to vary, experimental conditions. An example is an experiment to determine the temperature at which a particular type of rock melts. The scientist melts samples of the rock in the laboratory and carefully measures the melting temperature. By varying some of the conditions of the experiment, the scientist can determine how the melting temperature is affected by pressure, the presence of different amounts of water, and so forth. Any step of the experiment can be repeated at any time by anyone who desires to question or verify the results.

In the derived or historical sciences, including geology and astronomy, a second type of experiment, the observational experiment, is common. This type of experiment depends on observing the effects produced by both past and present natural events. The experimental conditions cannot be varied at will by the scientist, as they can in the real-time experiment, but an observational experiment can be repeated by different observers, at different localities, and at different times in order to verify results. The type of observation can also be varied. Consider an experiment to determine the climate at some particular time in the past. If a large proportion of the rocks formed during that time are identical to the deposits of modern glaciers, and the fossil plants and animals preserved in the rocks of that time resemble modern forms that today live only in cold climates, then the scientist would conclude that the climate in the region when the rocks formed was probably cold. Others could check the results at any time by repeating the scientist's original observations and by adding new observations from other localities.

The third type of experiment, the thought experiment, takes place solely within the mind and is an exercise in pure logic. The conditions can be varied at will and the experiment is repeatable, but there are no physical measurements or observations. This type of experiment involves formulating an imaginary but plausible set of initial conditions, and following the resulting sequence of events and their effects through to their logical conclusion within the confines of the relevant natural laws. Albert Einstein often conducted thought experiments in his research on relativity. One well-known example is his experiment involving twins, one of whom embarks on a round-trip journey to a nearby star at a speed approaching that of light. Einstein's theory of special relativity requires that time slows down for anything traveling at a velocity near the speed of light. The result is that the traveling twin observes that his trip takes less than a day, whereas the twin on Earth observes that his brother has been gone for decades. Both twins age according to their own frame of reference, and at the completion of the trip the twins are no longer the same age. Although this experiment was done entirely in Einstein's mind and involved no physical measurements, the results can be verified at any time by anyone with a sufficient knowledge of physics.

All three types of experiments are equally valid and powerful tools of science, and often two or even three will be brought to bear on a single topic of research. But it is the observational experiment, combined with the law of cause and effect and sometimes assisted by real-time experiments, that is the key to discovering the history of Earth, the Solar System, and the Universe. Thus, it is not necessary to have been there in order to reach valid conclusions about past events in nature, even though the events may have occurred millions or billions of years ago.

NO MAGIC, PLEASE

While the law of cause and effect encourages scientists to seek causative agents to explain the existence of observable effects, there are limitations on the kinds of explanations that are acceptable. A fundamental premise of science is that natural laws do not change with time. We presume that the laws describing the properties and behavior of matter and energy today operate everywhere in the Universe and have operated throughout the history of the Universe. Where scientists have in the past thought that some anomaly was defying the laws, they later learned that they had not been examining the anomaly properly or that the original law was inadequate—and then understanding of the scientific law changed accordingly.

If natural laws are constant and predictable, then it follows that supernatural agents may not be invoked in science; magic, witchcraft, or intervention by a supreme being are excluded as possible causes. This does not mean that a supreme being does not exist or that Earth was not created by some miraculous event, only that such an explanation is forbidden in the world of science. Why is this? If science were not restricted to natural explanations, there would be little reason to seek them, for everything could instead be explained easily by calling upon supernatural acts. Admittedly this would save a lot of effort and expense, but it would also result in a rather unpredictable and useless science. Science takes as one of its starting points the premise that nature is decipherable, and that it is reasonable and profitable to ask questions about the history of the Universe, including the age of Earth.

SIMPLIFY, SIMPLIFY

Science always seeks and adopts the simplest of all possible answers that are consistent with the facts, unless there is good reason to do otherwise. It is easy to make up complicated explanations, but scientists learned long ago that the most efficient way to proceed is to find the simplest explanation and add complexity only when required to satisfy specific observations.

One of the primary objectives of science is to find new unifying laws and ordering principles (theories) to explain and describe complex phenomena. Examples are the laws of thermodynamics, which explain the relationships between heat and various other forms of energy; the law of conservation of momentum, which explains the resistance of bodies to changes in motion; the theory of evolution, which accounts for the observation that organisms change over time; the theory of relativity, which explains important relationships between mass, energy, space, time, gravity, and motion; and the theory of plate tectonics, which accounts for the motions of Earth's outer layers. Scientific laws and theories are discovered by the application of inductive reasoning to generally small sets of observations.

Consider the sunrise. If you expect the Sun to rise tomorrow, you have probably reached that conclusion by the application of observation, induction, and simplification, even though you may not have realized you were applying scientific reasoning to the results of an observational experiment. In our short lifetimes, we observe only a very small percentage of the trillion or so sunrises that have occurred on Earth. How, then, can we be so confident that tomorrow's sunrise will arrive on schedule? The key is logical consistency. Sunrises occur with such regularity and predictability that it is reasonable to presume that they will continue for the foreseeable future. Even the fact that the time of sunrise varies from day to day and from one location on Earth to another, or the knowledge that several billion years from now the Sun will consume its available energy and cease to function as it does now, does not shake our confidence because even those changes are predictable. Our experience has convinced us that the simplest conclusion—that the Sun will rise again tomorrow whether or not we are here to see it—is the most profitable because it is the one most likely to be correct.

We can also use inductive reasoning and simplicity in arriving at conclusions about the history of Earth. On the basis of observations we make today, and presuming the constancy of natural laws, we arrive at reasonable conclusions about events in the past, making them no more complicated than is necessary to account for the facts at hand. This process is responsible for the success of the historical or observational sciences, like geology, where real-time experimentation often is intrinsically impossible. For example, on the basis of our observations of sunrise—including the written historical record, which confirms that the phenomenon occurred throughout human history, and the fossil record, which shows that photosynthetic plants existed hundreds of millions of years ago—are we not entitled to conclude that sunrise has occurred regularly over all of geologic time? The answer is yes, unless there is some evidence to the contrary. Any other conclusion would be more complicated than necessary and would be inconsistent with the principle of the constancy of natural laws. It would also make scheduling of tomorrow's activities extremely difficult.

Consider, as another example, sand dunes. Numerous observations have shown that the sand grains found in modern dunes have surface characteristics unique to wind-blown sand. In addition, the sand in dunes is deposited in a sequence of inclined and curved layers, called cross-bedding, that is distinctly different from the cross-bedding found in sand deposited by water. If ancient rocks in which the sand shows all of the characteristics of sand in modern dunes are found, what is the logical conclusion about the origin of these rocks? By now you probably have the idea.

ANYONE CAN PLAY

Science is a game that is open to anyone who wishes to play and will agree to abide by the rules. One of the premises of science is that observations and experiments must be reproducible by others, and every result is subject to verification. This means that science is nonauthoritarian. No individual, committee, organization, or government dictates which conclusions are valid and which are not, and no conclusion or observation is accepted as scientific unless it is made and expressed in such a way that it can be confirmed by anyone who is able to repeat the process. This also means that conclusions are accepted as valid only by the consensus of knowledgeable scientists. There are no votes and no official pronouncements. Each scientist makes those decisions on his or her own. When a large majority of scientists are convinced that some finding is valid, then that finding becomes accepted by the scientific community more or less automatically, and it will be the working model until it is disproved or shown to be inadequate.

There are, to be sure, individual scientists and scientific organizations that are listened to more carefully than others because of their expertise and reputations for excellence. The U.S. National Academy of Sciences, for example, has a reputation for conducting studies on issues using panels of experts and a rigorous review process. As a result, their reports are taken very seriously by the scientific community and by the U.S. government. Some individual scientists are recognized as authorities in their fields because of the quality and depth of their research, knowledge, and experience. The reasoning and conclusions of these scientists may carry more weight than those of others. Anyone is free to disagree, publicly or privately, with any of these authorities, but if one does so, he or she should have some better data or more insightful reasoning to back up the objections.

Several things make scientific research fun. One is the thrill of discovery. Another is the excitement of competition. Competition is also why science is self-correcting and is a field in which there is a significant disincentive to cheat. No scientist can exclude others from a field of inquiry, so there are invariably many scientists working on similar things. If it appears that one scientist has discovered something important, it is a sure bet that others will take up the same or similar research path, check the results, and either confirm, extend, or disprove the discovery. To confirm or improve the finding is fun because one then becomes part of the discovery. It is also great fun to recognize what others have overlooked, and it is much less embarrassing for a scientist to correct his or her own mistakes publicly than to have someone else do it. What this all means is that important findings are checked and rechecked, sometimes over a period of many years, and that mistakes are eventually discovered and publicly revealed. Science is self-correcting by design and is continuously changing as new knowledge is acquired.

NOTHING IS FOREVER

A final attribute of science that often causes confusion and misunderstanding by nonscientists is that everything science discovers is considered by scientists to be tentative. This is why scientists often use so many qualifiers when asked to explain some recent finding or conclusion to the public. This situation is not helped by some of the words scientists use—words like hypothesis, law, and theory—to describe the structure of science. The confusion comes because the general public uses these words somewhat differently than scientists do. *Hypothesis* is probably the least misunderstood. A scientific hypothesis is a tentative model advanced to explain some usually incomplete set of observations. Nonscientists use the term similarly. Often a scientist will advance several hypotheses to explain the same set of observations. Next, these hypotheses are tested to see which ones hold up and which need to be discarded as unworkable.

The terms *law* and *theory*, however, are sources of considerable confusion. A scientific law is a concise statement of a relationship between phenomena that is invariable under a given set of conditions. Laws often have a simple mathematical expression, such as $E = mc^2$, which describes exactly the relationship between energy (E), mass (m), and the speed of light (c), but there are also laws that do not. The law of superposition, so important in geology and first articulated by the Danish physician and naturalist Nicolaus Steno in 1669, simply states that in any undisturbed sequence of sedimentary strata, any individual stratum is older than the one above it and younger than the one below.

But scientific laws are not always as inviolable as the word implies. Sometimes they are proved wrong and discarded. Sometimes they are proved wrong but still used under certain conditions. Newton's law of gravity is a good example of the latter. It has a simple mathematical expression that treats gravity as a kind of force that attracts bodies toward each other. Although this works in a wide variety of situations and is still commonly used, it is not exactly true. Newton's law fails when very large masses, like stars and galaxies, are involved. Albert Einstein's theory of general relativity reveals that gravity is not a force but instead that mass causes curvature in space. As a result, objects are not actually attracted to each other, but instead they fall toward each other because of the curvature, much like two eggs roll to the bottom of a bowl. Relativity accounts for the observations that a clock runs more slowly (time slows down) in the presence of large masses compared with negligible masses, and it also explains why light, which has no mass, is deflected by large gravitational fields. There are other consequences and observations that Newton's law does not account for but that the theory of general relativity does. When appropriate, however, scientists still use Newton's law because it is a lot easier calculation to make and accurate enough for everyday situations on Earth.

Perhaps the most misunderstood term is *scientific theory*. To many nonscientists, a theory is nothing more than an idea, a guess, a belief, or a hypothesis. To a scientist, however, a theory is one of the most powerful statements that science can make about how the natural world works. A scientific theory is a logical and unifying structure of ideas that accounts for a large body of observations and, therefore, explains something important about nature. Examples are the theories of special and general relativity, the theory of evolution, and the theory of plate tectonics. Much of physics does not make any sense unless viewed within the framework of relativity. The theory of evolution and the theory of plate tectonics have the same importance to biology and geology, respectively. A theory is the closest that science can come to the "truth." This is why scientists were so upset when President Ronald Reagan said that evolution was "only a theory." He was equating an important scientific theory, for which there is convincing evidence and that is universally accepted by knowledgeable scientists, with a hypothesis or a guess, and he was dead wrong.

Despite the confidence scientists have in current theories and laws, none of them is absolutely guaranteed to endure. Science arrives at its description of nature by a series of increasingly better approximations. New findings may modify scientific facts, laws, and theories and lead to new and quite different conclusions from those previously thought to be true. Occasionally, when overwhelming evidence is brought to bear, a whole field of science may undergo a revolution of sorts—a "paradigm shift." The discovery of atomic structure around the turn of the twentieth century did that for chemistry and physics, just as the discovery of plate tectonics in the 1960s did for geology and Charles Darwin's 1859 descent with modification, now known as the theory of evolution, did for biology.

Revisiting the Inquiry

I have now answered the questions posed at the beginning of the chapter and shown, I hope, that it is not unreasonable for scientists to presume to answer the question about the age of Earth. It is merely an exercise in the application of inductive reasoning to careful observations of the present-day world and applied to the past on the presumption that there is a consistency and predictability to natural laws. It is also the result of the dogged and necessary premise that miracles or supernatural agents do not play any direct role. As I will show, the currently accepted age for Earth is a conclusion based on a breadth and depth of evidence that, at present, can be interpreted in no other rational way. The data, the reasoning, and the conclusions are so persuasive in this case that no serious scientist believes that the age so calculated could be dramatically in error. This does not mean that the age of 4.5 billion years is absolutely and forever firm. Future findings may cause scientists to revise the number slightly, or perhaps even drastically, but for now it is the best and only reasonable conclusion that science can offer. By the time you finish reading this book, I think you will agree it is a fair one.

Why Bother?

It is likely that humans have wondered about the age and origin of their surroundings since they first developed the capacity for abstract curiosity. How and when was the world created? Theologians, philosophers, and scientists have been searching for satisfying answers to these questions for thousands of years. Only within the last half century, however, has the age of Earth been known with any reasonable degree of certainty. Even then, the answer emerged only after centuries of thought, observation, and experimentation.

Why bother? Two reasons come immediately to mind. The first is philosophical. History makes it abundantly clear that people have struggled with the question of their place in the Universe since the beginning of organized thought. Was the Universe created by a god specifically for us, or are we a minor result of natural processes shaping a Universe of unimaginable dimensions over seemingly infinite time? Clearly, there is a certain comfort and security in the former explanation, and throughout most of recorded history, Western thought has focused on the idea that *homo sapiens* is central to a grand and purposeful plan conceived by a supreme being. Until Copernicus, Galileo, Kepler, and their successors showed otherwise, it was universally held that Earth, and by implication humankind, was at the very center of the Universe. Even after man discovered that his place in the Universe was not geometrically central, he still clung to the belief that his timing was. Indeed, some creationists still prefer to believe that the Universe was created specifically for humans and that creation predated the debut of humans by only a few days.

We now know, of course, that Earth revolves about a rather ordinary star located among billions of similar stars in a rather ordinary galaxy that occupies an ordinary position among billions of other galaxies in the Universe. Humankind is neither located in the center of the Universe, nor the center of the Milky Way Galaxy, nor even in the center of the Solar System. We also know that we humans are newcomers on the scene, having appeared so recently that our existence occupies but a fleeting moment in the vast span of time since the Universe began. Thus, knowledge of the age of Earth and its surroundings puts our lives in perspective and gives us all a better idea of our physical place in the Universe.

The second reason is scientific. We have always sought information about our physical surroundings to satisfy our curiosity and to add to the pool of scientific knowledge from which we draw both intellectual and material satisfaction in the form of new ideas, new understandings, new directions for future research, new technology, and new inventions. Thus, the age of Earth is simply one more interesting thing to know in the array of information that scientists have gathered in the quest for an increasingly accurate description of the Universe. Curiosity may well have killed the cat, but there can be no doubt that the curiosity of scientists has immeasurably enriched us all in numerous ways.