namely that living systems incorporate innumerable instances of non-functioning bits and pieces whose presence is explicable on historical evolutionary grounds but not in terms of *ab initio* design. The final chapter is by a Christian believer who argues against the attempt to make intelligent-design theory a part of science.

This last set of chapters provides a good, brief overview of the intelligent-design movement.

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Tales from the Underground: A Natural History of Subterranean Life by David W. Wolfe. Perseus Books, 2002. 221 pp. $18.00 (paper). ISBN: 0-73820-679-2.

This book is an engaging and fascinating look at discoveries concerning the nature of underground life. Some of the revelations are profound enough to radically change our intuitive perception of ourselves and our place in the world. The narrative contains just about the right degree of technical content. Except for the last chapter of the book, Wolfe's treatment is balanced and factual. The style is easy, and the book is a little difficult to put down at times. There are two primary messages to be derived from the text. The first is that all life on Earth depends on soil and crustal organisms; the second is that all life on Earth is interconnected and interdependent.

Chapter 1 deals with the origin of life. This is one of the great unanswered questions in science to which we do not have a clue. By 3.5 billion years ago, life was present on Earth, and perhaps earlier, although the evidence for organisms older than 3.5 billion years is highly problematic. The early Earth was an inhospitable environment. The lack of free oxygen in the atmosphere meant there was no ozone layer to absorb ultraviolet radiation. In an offhand letter, Charles Darwin speculated in 1871 that life began in a "warm little pond". Ten years later, Darwin remarked that the problem of explaining life's origin was *ultra vires*, or beyond the powers of science at the present time. The Miller-Urey experiments of 1951 resurrected Darwin's "warm little pond" and created a sensation. Miller, a graduate student of Urey, mixed hydrogen, ammonia, methane, and water in a beaker and passed electric sparks through it. He found that this simple process created amino acids. By the 1980s, it was apparent that the composition of the primitive atmosphere was not like that used in the Miller-Urey experiments. Biologists discovered that the most basic living unit, the cell, was not simple at all, but an incredibly complex machine. This led Fred Hoyle to remark that the expectation that life could be created by swirling chemicals together in a test tube was similar to the expectation that a Boeing 747 could be assembled by a tornado passing through a junkyard. The intelligent design school continues to enjoy the greatest renaissance since the publication of Paley's *Natural Theology* in 1835. Wolfe presents the latest idea, that clay particles served as a matrix on which organic molecules arranged themselves. The idea is fascinating, but barely a beginning. Wolfe shows considerable insight when he remarks that the "scaffolding" upon which life was built has probably long since vanished.

In Chapter 2 we are treated to a visit to a gold mine in South Africa, three kilometers deep. Here, in a vein of carbon, are found microbes at population densities between 100,000 and 1,000,000 organisms per gram. These so-called extremophiles exist at temperatures of 140°F (60°C), and derive their energy from a variety of metabolic pathways. We learn that science has documented the existence of an organism that can survive at temperatures of 235°F (113°C) and thrive at an optimum temperature of 223°F (106°C). Following Thomas Gold, Wolfe does a back-of-the-envelope calculation of the total mass of underground microbial life and concludes that the total biomass of subsurface life likely exceeds that of above-ground life. It is we who are extreme; it is the body of the Earth, not the skin, that is the true home of life. The most interesting of our subterranean cousins are the lithotrophs, literally "rock eaters". We are introduced to SLiMES: Subsurface Lithotropic Microbial Ecosystems. In a fractured basalt aquifer in the northwestern United States, lithotrophs facilitate the rock weathering process. As the basalt slowly decomposes, it releases hydrogen gas. Free hydrogen and dissolved carbon dioxide are used by lithotrophs as energy sources, with methane being the primary metabolic product. The ultimate basis of life is not necessarily photosynthesis after all: a variety of metabolic pathways are possible.

Chapter 3 is largely the story of Carl Woese. It was Woese who, working in virtual isolation, determined the true "tree of life" from RNA sequences. In 1976, Woese identified an entirely new kingdom: the archaea. Today, it is widely accepted that there are three main divisions of living things: bacteria, eukarya, and archaea. All plant and animal life is but a very small division of the entire world of life. For a long time, humans have been able to acquire a profound sense of their insignificance by contemplating astronomical distances or geologic time. We now have a biologic equivalent. Wolfe described the initial reaction of the scientific community to Woese's results:

> Most microbiologists simply ignored the mountain of evidence for a three-domain tree of life that he had so painstakingly put together. They refused to believe that this scientist, working on his own for years examining tiny bits of bacterial rRNA, was really on to something. Some openly criticized Woese's work, scoffed at his conclusions, and warned his supporters that they were jeopardizing their own careers by associating with him.

When Wolfe asked Woese how he coped with rejection, the answer surprised him. Woese responded by saying that he considered it appropriate for science to move cautiously.

Chapter 4 is devoted to a discussion of the nitrogen cycle. The most interesting piece of information here is that all life on Earth depends on a small group of bacteria and archaea with the unique ability to turn free atmospheric nitrogen into a form that can be metabolized. These nitrogen-fixing organisms enter into a unique symbiotic relationship with the root systems of legumes, enriching not only the legume with nitrogen, but also the soil. Even the Romans knew the advantages of crop rotation, alternating legumes with grains. In the beginning of the twentieth century, the world's entire supply of nitrogen consisted of guano deposits (bird feces) in Chile. The deposits were on the verge of exhaustion when a German chemist, Fritz Haber, invented a process of creating ammonia from free nitrogen gas. The Haber process continues to be the single method of producing nitrogen fertilizer. Haber died in 1934, but his discovery continues to feed perhaps as much as one-third of the world's population.

There is another surprise found in Chapter 5. Ninety percent of all plants have a symbiotic relationship with soil fungi. The fungi have filaments that are much smaller than the finest root hairs, and they are more efficient than plant roots at absorbing water and other nutrients from the soil. In return, the plant provides the fungus with sugars it produces by photosynthesis. This symbiotic relationship explains why truffles cannot be cultivated: they depend on the presence of tree roots. The message to be obtained is the interdependence of living things.

Naturally, no book on the underground would be complete without a discussion of earthworms (chapter 6). Charles Darwin studied worms for forty years. In one of his long-range experiments, he spread a layer of chalk over a grassy field. Returning twenty-nine years later, he dug a trench and discovered that the deposition of vegetable mold at the surface by earthworms had buried the chalk six inches (15 centimeters) deep. Today the beneficial role of earthworms is well understood. Over a year they typically transport twenty to thirty tons of soil per acre from below ground to the surface. Before Darwin's studies, earthworms were largely regarded as pests.

"Germ Warfare" is the title of chapter 7. Soils contain a few pathogenic organisms. Perhaps the most feared of these is the microorganism that causes tetanus, *Clostridium tetani. Clostridium tetani* is ubiquitous in soils throughout the world. Although there are typically less than 100 cases a year of tetanus in the United States, the disease is still widespread in less developed parts of the world. The course of the infection is agonizing for the victim. The infectious bacterium releases a neurotoxin that causes muscle contractions severe enough to tear muscle tissue and fracture vertebrae. In the most severe cases, the victim's body takes on a severe backward bow. The soil is also the source of many antibiotics used to treat disease. Of chief historical importance is the antibiotic streptomycin, discovered by Selman Waksman in 1943. Prior to his discovery, Waksman had been warned by a senior colleague that there was no branch of science of less practical value than soil microbiology.

The last two chapters of this book were my least favorites. Chapter 8 is devoted to a discussion of the devastation that human development has inflicted on prairie dogs, burrowing owls, and black-footed ferrets. Wolfe points out that the prairie dog is essential to the ecology of the American plains. It is fascinating to learn that Wyoming once contained a prairie dog town 100 miles (161 km) long, or that Texas had one that covered 25,000 square miles (64,750 square km). This is all well enough; most of us can appreciate the virtue of conservation. The last chapter (titled "The Good Earth") is where the text occasionally lapses into Rachel-Carson–type hysteria. On page 171, Wolfe claims that in the case of land denuded of vegetation "several tons of topsoil can be washed from a one-acre field in a single rainstorm". I wouldn't dispute this, but certainly this would be the extreme upper limit for a steeply sloping surface. On page 182, Wolfe falsely states that atmospheric concentrations of carbon dioxide have been nearly constant for tens of thousands of years. He then says that the concentration of carbon dioxide is rising at an "alarming rate". Broad, sweeping generalizations unsupported by a critical discussion of the scientific evidence are not to my taste. This is not to say that environmental problems are not a concern. The issue is whether the approach is one that is balanced, quantitative, and factual; or emotional, qualitative, and alarmist.

In summary, I enjoyed reading this book and learned a lot from it. The book is at its strongest in the first seven chapters which are largely devoted to factual discussions of the science of the underground.

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Life Is a Miracle: An Essay Against Modern Superstition by Wendell Berry. Washington, DC: Counterpoint, 2000. 153 pp. $21.00 (cloth). ISBN 1582430586. $14.00 (paper). ISBN 1582431418.

As modern biology pursues the question "What is life?" from the point of view of a preordained answer "Life is a machine", Wendell Berry offers the alternative possibility that "Life is a miracle": It is an alternative perfectly consistent with a scientific perspective within which there remains, and will always remain, a timeless mystery.

I think Niels Bohr captured this thought as a scientific reality many years ago: "In every experiment on living organisms there must remain an uncertainty as regards the physical conditions to which they are subjected and the idea suggests itself that the minimum freedom we must allow the organism will be just large enough to permit it, so to say, to hide its secrets from us. On this view, the very existence of life must in biology be . . . [like the quantum action] taken as a basic fact that cannot be derived from ordinary mechanical physics." (Bohr, 1933: 458)