It is unfortunate that advocates of new and interesting research methods like embodied cognitive science feel compelled to support their own research program by, in part, denigrating approaches already in use. We should not abandon the other methods of modern cognitive science simply because the use of autonomous agents has shown early success in accounting for sensorimotor behavior. This is not the first time that a rebellious group that met with some initial success in understanding cognition attempted to expand the reach of their methodology to all of cognitive science. The dawn of the cognitive revolution in the 1950s witnessed the development of powerful computer programs like the General Problem Solver (whose architecture is similar in spirit to that of Deep Blue). This work led to predictions that artificially intelligent systems based on these methods would soon outstrip human intelligence. The failure of these overly optimistic prognostications should remind us that no single method is going to solve all of the remaining mysteries of cognitive science. Let us hope that it does not take another five decades to understand this lesson about intelligence.

BOOKS: ASTROBIOLOGY

All Alone After All?

Christopher P. McKay

Are we alone? This question guides the fundamental quest of astrobiology. Certainly interest in the field has surged in recent years, and there is an eager expectation in both the scientific community and the public that somehow we will soon obtain an answer. Lacking data, we guess at where to look and what we might find. But, as geologist Peter Ward and astronomer Donald Brownlee point out, it's important to clarify the "we" in the target of our search. "We" could refer to any life, to animal life, or to intelligent communicative beings. For each target, our search strategy and the expected results might be very different. The rare Earth hypothesis put forward in *Rare Earth* posits that microbial life is common but complex (animal) life is rare. The authors comb through all the aspects of what makes Earth a home for complex life: from deep within its interior, to the solar system, and beyond to the galaxy itself. For each factor they make the case (if not always convincingly) that the situation of our Earth is optimal for the development of complex life. It seems we do live in the best of all possible worlds after all.

For the first three billion years of Earth's history, our planet was populated only by simple microbial life. This pattern, we all agree, is the one most likely to be repeated on other planets. Maybe a shortened version of it even occurred next door, during Mars' early history. Why are we so confident that microbial life is widespread? The arguments in *Rare Earth* are the standard ones: Organic matter is common in the universe. The formation of many biologically important molecules is easily achieved in chemical reactions. The catalytic RNA molecule appears to be a suitable halfway point between proteins and DNA. And, most importantly, it all happened so quickly here on Earth, why not elsewhere as well.

Rare Earth
Why Complex Life Is Uncommon in the Universe
by Peter D. Ward and Donald Brownlee

Copernicus (Springer-Verlag), New York, 2000. 361 pp. ISBN 0-387-98701-0.

Much has been made recently about microbial life in extreme environments, and *Rare Earth* follows suit. But that emphasis is mistaken. Life on Earth is not very tough at all. No life form has yet been found that can grow or reproduce without liquid water. This restricts life to a fairly narrow range of temperatures, –20° to 120°C. By cosmic standards, that's a narrow habitable zone. Despite the rhetoric, recent work in extremophiles has not changed our understanding of the limits to life. The list of life's boundaries from 20 years ago is identical to the current one except that the upper temperature limit has moved from 100° to 113°C. What has expanded is our understanding of the ecology of life in environments difficult for humans to access. Accompanying this has been an increased comprehension of possible liquid water environments on early Mars, subsurface Mars, and Europa.

Nevertheless, I too believe microbial life is widespread. But in the back of my mind there are two uncomfortable facts. The first is that we have only one example of life, evolution, and intelligence. From this we can conclude that such events are not impossible, but any assessment of their probability is uncertain at best. The second is that we currently have no good evidence of any life beyond Earth. The infamous martian meteorite has whetted our appetite for evidence of life but not satisfied it.

The transition from microbial life to complex life (animals) is the key step. Factors that could influence this include a long-lived stable star, a Jupiter to scatter planetesimals throughout the solar system in just the right way, a Mars to perhaps provide the initial seed for life, a large Moon to stabilize the climate, just the right amount of water and carbon to provide for a stable biosphere but not overwhelm it, and, most importantly, plate tectonics. Plate tectonics emerges as the hero in the life story of Earth: "It may be that plate tectonics is the central requirement for life on a planet...." Subduction, volcanism, and plate motions recycle the planet both biologically and chemically and control the temperature. (It is sobering to remember that just 40 years ago plate tectonics was an unbelievable hypothesis.) If plate tectonics is the hero in the epic Ward and Brownlee recount, then meteor and comet impacts, which threaten to wipe out complex life at regular intervals, are the villains.

How do we discover how common life is? how common complex life is? how common intelligence is? By searching as widely as we can. Searching the skies for signals or artifacts of intelligent beings, searching the nearby planets for evidence of a second genesis of microbial life, and searching the nearby stars for habitable planets. We should let our quest be guided by our theories of life and evolution, but we should try not to be constrained by them—they may be wrong. In this spirit, *Rare Earth* provides a sobering and valuable perspective in just how difficult it might be for complex life and intelligence to arise.

BROWSINGS

CREDIT: P. HARDY/FROM L. SZYRMA'S "LETTERS FROM THE PLANETS," *CASSELL'S FAMILY MAGAZINE* (1887)

Worlds Without End. The Historic Search for Extraterrestrial Life. *R. A. S. Hennessey.* Tempus, Charleston, SC, 1999. 160 pp. $29.99, £18.99. ISBN 0-7524-1450-X.

Hennessey chronicles the major developments in pluralist theories, from ancient Greece to modern television. His samples of imaginative illustrations of life elsewhere in the universe include Paul Hardy's 1887 depiction of martian fauna (above).

The author is in the Space Science Division, Mail Stop 245-3, Moffett Field, CA 94035, USA. E-mail: cmckay@arc.nasa.gov