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BOOK REVIEW

The Origin and Nature of Life on Earth

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A review of **The Origin and Nature of Life on Earth: The Emergence of the Fourth Geosphere** by Eric Smith and Harold J. Morowitz, Cambridge University Press, Cambridge, 2016, pp. xxiv + 677. Scope: monograph, £29.99, ISBN 978-1-107-12188-1 (Hardback). Level: professional researchers in multidisciplinary science.

We now know a great deal about the nature of life on Earth. We understand how it functions and, in many cases, how it can be modified; but how it arose here in the first place remains an enduring mystery. It is well-established that life in some form, probably akin to bacteria, was already flourishing about 3.8 billion years ago, i.e. almost as soon as the young Earth had cooled enough for it not to be cooked. Once life had appeared, it is not difficult to envisage how the combination of random mutation and Darwinian evolution (survival of the fittest) has brought us and the Earth to where we are today. There remain some notable residual problems, e.g. the seemingly improbable appearance of the complicated eukaryotic cell which forms the building blocks for the higher forms of life like plants and people but, in a rough-and-ready kind of way, the story seems clear and convincing. Unfortunately, however, no evidence remains about how the process got started.

The most widely-accepted picture is probably that based on the notion of a "primeval broth" in puddles or lakes or oceans, a watery liquid containing complex organic molecules created by the ultra-violet radiation from the Sun acting on inorganics, there being no ozone layer in the early atmosphere to filter out the ultra-violet. Eventually, a random event resulted in a self-replicating molecule. This most primitive form of life is no longer around, having been replaced by fitter forms that competed more effectively for nutrients. It is widely thought that an RNA-based world, in which heredity as well as protein synthesis was based on RNA, preceded the advent of DNA for holding the heritable information. The difficulty about this general picture is that it depends on the occurrence of an event that is assumed to be highly improbable but which nonetheless clearly took place quite quickly, while the still-hot Earth was very young.

One possible explanation of the appearance of life at such an early stage is that it came from elsewhere in accordance with the panspermia theory espoused by Wickramasinghe and others. In this case, the problem of the origin of life still remains, of course, but displaced to elsewhere in the Universe. However, but it can be argued it arose somewhere with vastly bigger volumes of primeval broth and far more time in which an improbable event could occur. The other possible explanation is that the life-forming event is actually not as improbable as conventionally assumed.

Eric Smith and (the late) Harold Morowitz adopt a radically different approach, one that they developed together at the Santa Fe Institute over many years of collaboration. Rather than considering the spontaneous appearance of a self-replicator in a highly improbable random event, and its subsequent propagation, they propose that the biosphere arose through a sequence of

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non-equilibrium phase transitions, and that its development was virtually inevitable because life provided chemical paths that facilitated the conduction away of surplus energy, thereby relieving pressure or stress in the system. It was only after or during the transition from geochemistry to biochemistry that individuation occurred, bringing Darwinian possibilities. Thus they reject any formal definition of life in terms of ability to evolve.

The authors advance many detailed arguments to persuade the reader of the plausibility and correctness of these ideas which, understandably, has required a big book. The opening chapter sets the perspective where life is to be considered as a planetary phenomenon, best viewed as the fourth geosphere (after the atmosphere, hydrosphere and lithosphere) and encompassing a new kind of order for matter and energy. It summarises the main arguments that are to follow. The discussion of the Earth's beginnings in the second chapter leads to an overview of life as we know it. This leads on to a consideration of geology and geochemistry and, in particular, the energy flow from the Sun and radioactive heating in the planetary interior leading to highly nonequilibrium conditions in the mantel and on the surface. Chapters 4 and 5 focus on metabolism, the hierarchy of biology, the emergence of ribosomal translation of peptides, genetic code, bioenergetics, and cellularization. Thus the first five chapters describe relevant aspects of life and the World as we know them (or can reconstruct them in the past). Building on this solid base, Chapter 6 considers how biochemistry and the biosphere may have emerged from geochemistry, including the probable significance of hydrothermal vent systems, and discusses the advent of the ribosome. Phase transitions as paradigms of emergence are treated in Chapter 7, including discussions of large fluctuations, transitions under equilibrium and non-equilibrium conditions, information theory and error correction. The final chapter brings everything together and adds thoughts about modularity and its importance for efficiency in hierarchical complexity, the emergence of individuality, ecosystems, and the nature of the living state. There is an Epilogue to set the book in context, 912 references and an extensive index.

It is carefully and thoughtfully put together, with pains taken to distinguish new ideas from what is considered generally well-established and agreed and (apart from there being too many too-long sentences, for my taste) is very well written. But I remain agnostic about the correctness of the central hypothesis, of life having arisen almost inevitably because it was needed to provide chemical paths and associated energy flows for the relief of planetary stress. Life is surely not an inevitable consequence of this chemical energy flow, which can also occur in inanimate materials. In a thermodynamic analogy, heat from a hot thermal reservoir can flow via a Carnot engine to a cold reservoir producing useful work; but it can also flow there directly and uselessly, merely increasing the entropy of the Universe. Like the Carnot engine, life can indeed take advantage of the energy flow, but it is not obvious to me that it is needed for the flow to occur.

The authors' description of the nature of life, and the breadth and sweep of their vision, are among the strongest features of the book. They range freely over science including e.g. chemistry, biology, physics, geochemistry, complex systems, nonlinear dynamics, and pattern formation. There are numerous fascinating insights and asides and there are copious footnotes. I was particularly struck, for example, by their comment that

> "...the most durable pattern of all – core metabolism – consists of the roles of the most fleeting entities – the core metabolites. Yet this dynamical order is arguably the oldest fossil on Earth."

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