nism, base-substitution mutations occur at a frequency of $\sim 10^{-11}$ to 10^{-9} per nucleotide site per cell division.) The importance of epigenetic inheritance for evolution remains open. How common it is, generally, and the ratio of the two timescales, in particular, are going to be critical.

For an evolutionary biologist the most intriguing part of the book is a radical conjecture alluded to earlier, long advocated by Newman. According to it the role of physics in biology goes well beyond the familiar one of constraining the range of possible outcomes. The conjecture amounts to saying that living matter is more 'matter' than 'living'. It states that aspects of biological form and structure may have physical explanations as opposed to explanations based on the cumulative accumulation of mutations of small effect that occurred by chance. Spatio-temporal patterns within and among cells, the major evolutionary transition from single-celled to multicellular life and subsequent events in the evolution of multicellular organisms may have originated – at least in part – by self-organization. The physical and biochemical properties of single cells, along with their behaviours, could have predisposed them spontaneously to build multicellular morphologies of particular kinds. An illustration would be the segregation of cells into coherent sub-groups during development, which can be compared to the phase separation of two fluids with different surface tensions.

A spatial pattern that arose by self-organization could be stabilized by subsequent genetic change via the Baldwin effect. The scope for adaptation by natural selection would not be eliminated. But adaptation would amount to the fine-tuning of an outcome whose broad direction was set by physical principles. Self-organization may have been meaningful in another situation, not examined here: self-organized networks of reciprocal interactions may have seeded the evolution of social behaviour. Considering that cultural evolution proceeds largely along Lamarckian lines, it would have been interesting to see an exploration of the consequences.

Darwin lacked an understanding of the nature of heredity. He had neither read Mendel's paper nor drawn the correct conclusions from his own experiments on crossing plant varieties. He was unable entirely to discard the possibility that traits acquired during a lifetime could be inherited, or that use and disuse could lead to the heritable modification of organs. But an inner voice seems to have persuaded him that Lamarck's views on evolution could not be correct. Advances in genetics, cell and developmental biology have opened our minds to the many and varied routes that evolution can take. To say that much of this was foreseen by Lamarck is anachronistic. The motivation seems to be to restore to him the honour that is his due. True, he has been unfairly derided for being wrong; indeed the attacks began immediately after his death with an insulting eulogy by the palaeontologist Cuvier. Still, a scientist's contributions should not be judged by asking whether subsequent developments show that they pointed in the 'correct' direction. The right question to ask is how original and interesting the contributions were at the time they were made and to what extent they stimulated others. Lamarck does not require posthumous rehabilitation on either count.

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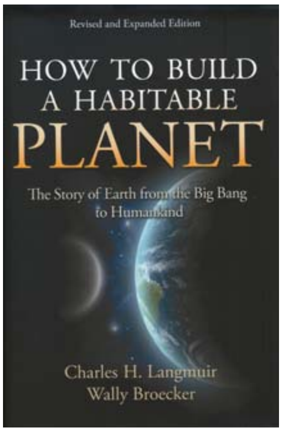

How to Build a Habitable Planet: The Story of Earth from the Big Bang to Humankind. Charles H. Langmuir and Wally Broecker. Princeton University Press, 41 William Street, Princeton, New Jersey 08540. 2012. 718 pp. Price: US$ 39.95. ISBN-978-0-691-140063.

In 1985, Wally Broecker gifted us with a brilliant account of the origin and evolution of the Earth in his book *How to Build a Habitable Planet*. This 291 page book was more like a gripping novel, but was packed with state-of-the-art scientific information and has served not only the earth sciences community, but many other inquisitive minds. Almost three decades later, a thoroughly updated second edition of this book has been presented by Langmuir and Broecker. This book covers diverse topics over 21 chapters from the Big Bang and Star formation, synthesis of elements and molecules, to planet formation and differentiation, plate tectonics and mantle convection to the ocean and atmosphere, surface processes on the Earth to origin and evolution of life, impacts of humans on the Earth to the search for extra-terrestrial life. These diverse topics are held together by a 'systems approach', i.e. how different parts of the planet influence one another and their relationship to the Solar System and the universe.

The first chapter provides a thoughtful introduction to reductionism – its power and limitations in explaining natural phenomena, chaos, self-similarity, feedback mechanisms and other characteristics of natural systems. This is followed in the subsequent four chapters by a journey through time, from the Big Bang and Galaxy formation, synthesis of elements in stars, formation of molecules, to the formation of planets. Chapter 6 switches gears and discusses about radioactive dating and is more technical than the preceding chapters. Age of the Earth and bulk meteorites are discussed along with concepts of half-life and the isochron technique. The concept of extinct radionuclides and their significance in understanding events in the first few million years of our Solar System is also briefly described. Interesting trivia is provided regarding early age estimates of the Earth – from the seventeenth century estimate of Bishop James Ussher, who calculated that the world was created in 4004 BC, to that of the nineteenth century physicist Lord Kelvin, who argued that the Earth was no more than 40 million years old. This is followed by a discussion of differentiation of the Earth into core, mantle and crust, other planetary bodies in our Solar System such as planetary satellites, asteroids, comets and impact events.

After the first eight chapters, the stage is set to zoom into our Earth and discuss why our particular planet became habitable. The authors argue in chapter 9 that for life of any complexity to develop on a planet, the surface environment must have the right conditions. In particular, abundant liquid water sustained over billions of years is a prerequisite, and greater greenhouse gas concentrations in the early atmosphere would have kept surface temperatures warm in spite of a 'faint young Sun'; a tectonic thermostat involving the carbon cycle controlled the high CO_2 concentration in the atmosphere by locking them in carbonates and the Earth's magnetic field shielded us from deadly cosmic rays. Surface conditions on the Earth are also a manifestation of the movement of plates and their interaction. That certain parts of the Earth are more prone to earthquakes and active volcanism occurs along a belt, is a direct manifestation of plate tectonics which in turn is linked to internal circulation in the Earth's mantle. The interplay of the solid Earth, liquid oceans and the atmosphere helps to buffer conditions of our habitable planet. These topics are discussed in chapters 10 through 12.

Origin and evolution of life is discussed in chapters 13 and 14. The authors argue that life can be treated as a natural consequence of planetary evolution; all complex life points to a common ancestry once the evolutionary pathway is traced back, whereas the chemical resemblance of the composition of life to that of our Sun suggests that the basic ingredients for life are widely abundant. Yet, why life originated and that too only on Earth remains unknown, but it is clear that certain planetary conditions have made it possible. In chapter 15 the authors describe the co-evolution of life and the planet in terms of a planetary fuel cell. Life forms have changed over time with evolution and so have the requirements to sustain life. Origin of life required reducing conditions prevalent in the earliest Earth, whereas modern life forms require oxidizing conditions and free O_2. The discovery of oxygenic photosynthesis not only increased life's access to solar energy by obtaining hydrogen and electrons from the water molecule, but also resulted in the buildup of oxygen in the atmosphere which, in turn, permitted development of multicellular life. The transition from a reduced to oxidized surface is closely linked to geochemical cycles and in chapter 16 the authors argue that the 'ultimate source of surface oxidation is the plate-tectonic geochemical cycle'. Evolutionary changes in life further facilitated this process by creating conditions that enhance habitability. On the other hand, catastrophic events like impacts, flood-basalt volcanism and other forms of naturally-induced climate change allowed 'evolutionary innovations' by destroying long-term stability. These are discussed in chapters 17 and 18.

There is life and then there is 'intelligent' life. The rise of *Homo sapiens* and their influence on planet Earth is discussed in chapters 19 and 20. The rapid rise of human beings to become the dominant species on the planet in 0.0015% of the time since birth of the planet is an immense stress not only on our planet, but its other inhabitants. The authors point out that 'In very recent times, ...*Homo sapiens* has changed the entire course of Earth's history' and that 'planetary evolution now depends on our behaviour'. Their argument is based on how we humans have plundered our fossil energy reserves which took millions of years to form, dammed our rivers, polluted the lakes and oceans, cut down trees and destructed other life forms in a short time-period.

The last chapter poses the question of habitability elsewhere in the universe and our current efforts to better answer that. Our understanding of building a habitable planet is based on a single datapoint, which is our planet Earth. However, is the Earth as well as our Solar System really unique? The position of the planet around a star controls whether it can evolve with liquid water, a pre-requisite for life. If life is really a planetary phenomenon as argued by the authors, it is expected that some planet around some other star must also have life. Technological innovations as well as new astronomical methods in the last decade have allowed identification and characterization of extra-solar planets, which is a first step in the identification of habitable planets elsewhere in the universe.

Carl Sagan said 'Somewhere, something incredible is waiting to be known'. Langmuir and Broecker provide a coherent account of some of the incredible aspects of our planet and its surroundings, and inspires us to know more. This book has seamlessly incorporated all the recent discoveries and our improved understanding of construction and operation of the Earth, the only known habitable planet. Although this 718 page book is over twice as long compared to the first edition, it is still a comfortable read both for earth scientists as well as non-specialists. The diverse topics dealt with have been skillfully stitched together and each chapter provides lucid descriptions, logical discussions and a nice summary. This book could be an useful text for undergraduate students in earth sciences and with necessary supplements, could also be used for advanced courses in earth sciences.

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