ORIGINS OF LIFE

An improbable journey

Adrian Woolfson enjoys two studies on microbial life's trek towards complexity.

In 1676, the Dutch merchant and amateur scientist Antoni van Leeuwenhoek submitted an essay to the Royal Society of London detailing a singular discovery. This was the world of unicellular organisms, which he observed using a self-designed microscope. Three hundred years later, Leeuwenhoek's "animalcules" were shown to hold the secret to the evolution of complex life on Earth.

In his imaginative and beautifully written *The Vital Question*, evolutionary biochemist Nick Lane defines a genealogy that links the descendants of the Cambrian explosion — the first appearance of morphologically complex animals in the fossil record, about 540 million years ago — to the simple organisms that preceded them. In so doing, he persuades us that comprehending the structure, function, behaviour, genetics and evolution of microorganisms is necessary for a deep understanding of complex life, and of the processes that undermine it, including diseases and ageing. This visceral insight into the largely uncharted expanses of microbial existence could also form the basis of a predictive science enabling us to speculate about the nature of potential life on other planets.

Biophysicist Paul Falkowski's entertaining, easy-to-read and historically rich *Life's Engines*, meanwhile, uses the work of microbiologist Carl Woese to trace complex life back to its three lines of descent: bacteria, archaea and eukaryotes. By studying the RNA sequences of ribosomes — the cellular machines that make proteins — Woese was able to show that Charles Darwin was correct in suggesting that all life arose from a single, now-extinct, common ancestor.

It remains unclear how and when life first originated on Earth, but we know that the first unicellular organism emerged between 3.6 billion and 2.7 billion years ago, giving rise to bacteria and archaea, which have no nucleus or other sub-cellular organelles. The evolutionary engine of life then seems to have got stuck, idling along at the unicellular level for another 2 billion to 3 billion years. Falkowski explains how unicellular organisms, although morphologically challenged, managed to perfect the basic biochemical 'engines' that would power all forms of life on Earth. According to Lane, the stagnation occurred because the molecular motors that drive the biochemistry of bacteria and archaea were unable to cross the energetic threshold necessary for the evolution of complex form. This energetic constraint on life is the central focus of *The Vital Question*.

THE EVOLUTIONARY ENGINE **GOT STUCK,** IDLING ALONG AT THE **UNICELLULAR LEVEL.**

It derives, Lane explains, from two principal design features that all living things use to power themselves. The first is the use of high-energy molecules of ATP, the chemical currency of energy transfer. The second is the idiosyncratic 'chemiosmotic' force, which moves protons and facilitates the continuous generation of ATP. Both Lane and Falkowski describe these molecular processes compellingly. Although adequate to power single bacteria-sized cells, the method constrains the allowable surface-to-volume ratio of a living cell. Lane argues, however, that around 1.5 billion years ago this energetic constraint was overcome by an improbable endosymbiosis event: an

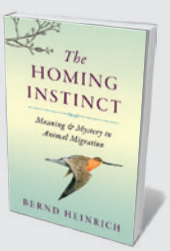
The Vital Question: Why is Life the Way it is?
NICK LANE
Profile: 2015.

Life's Engines: How Microbes Made Earth Habitable
PAUL G. FALKOWSKI
Princeton Univ. Press: 2015.

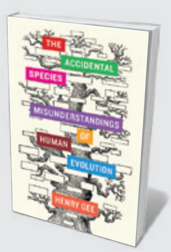
ancestral archaean host engulfed a small population of symbiotic bacteria, resulting in the first eukaryotic cell, the forebear of complex life.

Lane recounts how over time, the engulfed bacteria jettisoned most of their genes that were unrelated to energy production; these were either lost permanently or relocated to the cell nucleus. There they continued to fulfil their original functions, or formed the raw material for the evolution of new genes with unexpected roles, such as transcription factors — proteins that bind to DNA. This allowed embryonic stem cells to be patterned in three-dimensional space. What remained of the imbibed bacteria, with their pared-down genomes and surrounding membranes, became energy-generating mitochondria. The acquisition of these organelles enabled eukaryotic cells to expand their volume by up to 15,000 times that of the average bacterium, and to support a genome around 5,000 times larger. Lane's important realization is that this also gifted eukaryotic cells with about 200,000 times more energy per gene than the average prokaryotic cell. This over-cranking of the evolutionary engine allowed for the development of a baroque diversity in the nature and extent of cellular gene and protein expression.

Although readily accommodated by classic Darwinian evolutionary theory, the horizontal, sudden and co-operative nature of Lane's evolutionary narrative differs from the incremental, vertical and competitive ▶



The Homing Instinct: Meaning and Mystery in Animal Migration
Bernd Heinrich MARINER *2015*
Erudite naturalist Bernd Heinrich attributes the instinct for migration to an affinity for 'home', from beavers' skilful dam-building to the joyful dance of Alaskan cranes returned to their nesting pond. (See Joel Greenberg's review: *Nature* **508,** 317; 2014.)



The Accidental Species: Misunderstandings of Human Evolution
Henry Gee UNIV. CHICAGO UNIVERSITY PRESS *2015*
Nature's palaeontology editor, Henry Gee, condemns the idea that our species is the pinnacle of evolution, arguing that traits prized as uniquely human, such as creativity, are not. (See Tim Radford's review: *Nature* **503,** 34–35; 2013.)

features of the more canonical one. As elegant as the details underpinning the thesis seem, it is occasionally hard to distinguish between fact and speculation. Lane has, nevertheless, made a bold and commendable attempt to sketch out a highly challenging scientific issue for a general audience. In so doing, he has reaffirmed the importance of a largely overlooked area of basic research, and has generated testable hypotheses about the origins of complex life.

Falkowski covers some of the same details of the evolution of microbes and their contribution to complexity, including the historical origins of the concept of endosymbiosis. However, his focus is primarily on how microorganisms have made Earth habitable, perhaps most notably with the development of oxygen-generating photosynthesis by cyanobacteria. This leads him to touch on humanity's potential to undermine Earth's systems.

History has shown how modifications to microbial biochemistry affect global geophysical processes. For example, following 200 million to 300 million years of photosynthesis by ancient microorganisms, oxygen became a significant component of Earth's atmosphere, increasing ozone levels, reducing the greenhouse effects of gases such as methane and leading to one of the most extensive glaciations in the planet's history. Humanity's interference with natural biological processes risks damaging Earth in ways that cannot be predicted.

What is clear is that a deep understanding of how complex life originated will provide insights into human biology and the nature of disease processes. It may also enable the generation of forms of life unconstrained by the contingent processes that locked life into its current trajectory. Life as we know it may eventually be supplanted, perhaps one day even being viewed as a primordial soup that facilitated the emergence of silicon-based existence. ■

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VIROLOGY

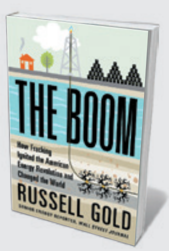
Journal of the plague years

Mark Dybul applauds the latest chapter in an account of a life at the leading edge of HIV research and policy.

Virologist Peter Piot's *AIDS Between Science and Politics* is a terrific follow-up to his highly acclaimed memoir *No Time to Lose* (W. W. Norton, 2012). It demonstrates the deep intellectual lessons of a lifetime at the cutting edge of science and politics. Piot's narrative ranges from his thrilling, on-the-ground experiences in remote regions of Africa as a young scientist and member of the team that identified Ebola, to the high-altitude reflections of his years as executive director of the Joint United Nations Programme on HIV/AIDS (UNAIDS).

Three messages underpin the book's nine chapters. One is that the HIV epidemic generated an unprecedented local and global response, recast many development and health paradigms, and ultimately triggered treatments that have saved millions of lives. The second is that progress was made only when various scientific disciplines, on-the-ground implementation strategies and politics were aligned. And the third? That AIDS is not over.

This Changes Everything: Capitalism vs the Climate
Naomi Klein ALLEN LANE *2015*
Unafraid to name and shame fossil-fuel junkies hooked on a billion-dollar industry, Naomi Klein investigates capitalism and climate change. She sees the global crisis as a potential spur to positive action, as happened with the women's rights movement. (See Nico Stehr's review: *Nature* **513,** 312; 2014.)



The Boom: How Fracking Ignited the American Energy Revolution and Changed the World
Russell Gold SIMON AND SCHUSTER *2015*
Journalist Russell Gold traces the rise of fracking, a tale of innovation and investment — such as ex-oilman Aubrey McClendon's 260,000 land acquisitions in Texas's Barnett Shale. (See Chris Nelder's review: *Nature* **508,** 185; 2014.)