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Book review

Life's Early Years

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A review of J. William Schopf, *Cradle of Life: The Discovery of Earth's Earliest fossils*, Princeton University Press, Princeton NJ, 1999, xiv + 367 pp. (Pb) ISBN 0-691-08864-0

Iris Fry, *The emergence of Life on Earth: A Historical and Scientific Overview*, Rutgers University Press, 2000, ix + 239 pp. (Pb) ISBN 0-813-52740-6, (Hb) ISBN 0-813-52739-2

Philosophy of biology has broadened its horizon considerably over the last 10 years. While issues at the core of evolutionary biology – the role of fitness in evolutionary explanations, the levels of selection, adaptationism, the nature of species – remain focal to the field, interests both within evolutionary biology as well as those beyond it have diversified significantly in recent years. Examples of the latter kind are: the exploration of the presuppositions and implications of the Human Genome Project; a reawakened interest in the nature of life and the idea of artificial life; a consideration of the relationship between life and mind (including historical forays into the 19th-century, when this issue was of more salience than it has been for most of the 20th-century); and a rethinking of "genetics and development", driven largely by developmental systems theory. In general terms, philosophers have played both critical and constructive roles with respect to all of these issues, not only often engaging with biologists but also providing further food for thought about the scope and limits of the philosophy of biology itself.

Earlier work in the philosophy of biology did depart significantly from the dominant conceptually-driven, "rationally reconstructive", and global approaches that then dominated general philosophy of science. However, accompanying the more recent increased bandwidth of attention has been a second-wave of naturalization that constitutes a closer approximation of the ideal of making the philosophers indistinguishable from the biologists, at least when the latter are addressing fundamental issues in biology. The books under review here discuss the origin and early (Precambrian) history of life, and though neither is by an author whose primary training is philosophical, the issues that they raise will be of interest to philosophers of biology participating in this second wave of naturalization. Representing the "general reader" genre, they employ an expository style that make them accessible to a wide, interdisciplinary audience, and so avoid the chief problem faced by otherwise impressive, recent books in the field, such as Lily Kay's *Who Wrote the Book of Life?* and Michael Ghiselin's *Metaphysics and the Origin of Species*. For all their sophistication, such books are essentially unavailable to many of the biologists whose work is being evaluated and interpreted because of the specialized language each uses. The books by Fry and Schopf have their own hazards, as we will see, but readability is not one of them.

Iris Fry teaches history and philosophy of biology at Tel Aviv University and at the Technion-Israel Institute of Technology in Haifa. She was trained in chemistry and biochemistry before moving into philosophy and exploring Kant's teleology. Fry's book falls into two main parts: the first focusing on early work on the origin of life (roughly until the end of the 19th century), the second taking up more recent work, beginning with that of Alexander I. Oparin and J. B. S. Haldane from the mid-1920s, but gathering experimental energy only with the Stanley Miller studies in the 1950s. The origin of life has always been a focal point for consideration of the significance of human life. As far back as tribal memories reach, human cultures have floated hypotheses about the mechanisms involved in the initiation of life in general and especially human life. These tribal memories, embedded in mythological and religious contexts, provide an enhancement of motivation, but also a confounding of discussion about such matters.

The disjunction between the two major parts of Fry's book – the "historical" and the "contemporary", represents a striking gap in the efforts of biologists to provide mechanistic answers to fundamental questions. Fry's discussion of the gap, however, appears sketchy, particularly in light of James Strick's (2000) recent study of the debates and the correspondence among the participants in the controversies of the 1860s and 70s. As a mechanistic understanding of the course of life on Earth began to be constructed in the 19th century, intellectual energy focused on the pas de du of some indisputable giants of the century. The details of the convoluted interactions between the followers of Pasteur and Darwin have long been obscured by the disciplinary myths constructed about the germ theory, spontaneous generation and evolution. A truce, apparently constructed primarily by T. H. Huxley and his "X Club", suspended the major religious, disciplinary and nationalistic interests and quieted the turmoil over the origin of life for a time. The truce relegated the problem of the origin of life from the arena of scientific investigation to a remote and practicably unapproachable mystery in the dim origins of the planet. The Huxley strategy was successful in making evolution acceptable to Victorian sensibilities, even though it was disastrous to the careers of those, such as Henry Bastian, who were attempting laboratory investigations at the time. The strategy may also have delayed a renewed mechanistic approach to the problems.

The story of the construction of the disciplinary myths about spontaneous generation is even today a shock to one's naive faith in the disinterest of the scientific establishment and the objectivity of scientific judgment. The strategy was successful in putting to sleep both theoretical and experimental approaches to biogenesis for several generations. They awakened only fitfully from time to time, usually in out of the way places where the discipline of the authorities was weakened.

Though Fry did not have access to Strick's analysis, she (2) views part of the rationale for including overtly historical material as a gesture towards the sort of externalist views that have, sometimes in extreme form, prevailed within the social studies of science. For the most part, her book presents about as clean an *internalist* view as one is likely to produce, particularly in the second half of the book where the disciplinary myths have not yet precipitated out of low consensus discourse. Even in Chapter 4, however, in her discussion of the debate between Pasteur and Pouchet over spontaneous generation, she points both to Pasteur's religious views and his experimental flirtation with the formation of organic compounds from crystalline structures. She observes the discrepancies and tensions between these and his public position on spontaneous generation. She could have also drawn attention to Huxley's earlier speculations about the vitality of marine precipitates (*Bathybius*) in connection with his later adamant rejection of recent neobiogenesis.

Eventually, however, though Henry Bastian did not live long enough to participate in the enterprise, experimental studies of the origin of life came back into fashion. Alexander I. Oparin (1924) from his distant Russian outpost spelled out a plausible mechanistic account for the origin of life from inorganic precursors. Oparin survived to observe laboratory investigations of biosynthesis from inorganic elements. The new studies were encouraged by the more authoritative speculations of the brilliantly independent J. B. S. Haldane, and by the increasing understanding of the physical conditions on neonascent Earth.

Fry's last two chapters are independent of the major dichotomy of her book. Chapter 13 presents her assessment of many of the issues raised in the previous accounts, and includes some consideration (200–215) of "creationism" in the context of scientific studies. The long last chapter, one quarter of the book's length, deals with rising interests in astrobiology, taking up recent, topical discussions of the possibility of life on Mars and the search for extraterrestrial intelligence. (Apart from the soon-to-be launched *International Journal of Astrobiology* from Cambridge, note also the "Insight" section on astrobiology in *Nature* 409: 1079–1122.)

Given the structure of Fry's book, one might think that the speculations of Oparin and Haldane constitute the decisive moment, after the philosophical dust from the spontaneous generation debates had settled, when scientifically-grounded work could begin. Oparin and Haldane moved beyond Darwin's dreamy visions of sparks in warm ponds of organic soup and began a serious consideration of the geochemical conditions present on the early planet. Fry (65) views the exclusion of contemporary spontaneous generation as a necessary precursor for the beginning of experimental work. She does not consider, because she was unaware of its mode, how the dogmatic exclusion of the possibility of modern spontaneous generation may have delayed experimental approaches. Closure on spontaneous generation in the discourse of the 1870s was, it seems, achieved at a considerable cost.

By the time biologists again directed attention to the origin of life, not only had cosmologists established some boundary conditions about the environment of early Earth, but life was beginning to be understood in much clearer detail. The studies of Gregor Mendel had been lost in the speculative proliferation of "biological atoms" that fogged the 19th century. The modern microscopes of the last quarter of the 19th century allowed the visualization of real biological organelles that behaved in remarkable and discernible patterns. When mendelism was rediscovered in 1900, Mendel's biological determinants could be immediately associated with microscopically visible cellular elements. And within a decade the new science of genetics was moving to a junction with Darwinian evolution. J. B. S. Haldane, along with Ronald Fisher and Sewall Wright, was a major force in building the "modern evolutionary synthesis", and that synthesis informed and directed his inquiries about life's origins. The subsidence of vitalistic thinking and the serious establishment of mechanistic experimental inquiry finally allowed biology to escape from the truce constructed by Huxley.

Mechanistic origin studies eventually made it into the laboratory with Stanley Miller's celebrated demonstration of the synthesis of organic compounds, especially amino acids, from simple inorganic compounds in reactions energized by electric sparks in the reducing mix that simulated the postulated atmospheric conditions on the prebiotic Earth. Many consider these experiments by a stubborn graduate student in Harold Urey's Chicago laboratory to have provided the starter's gun for a new experimental era. More serious consideration requires that we recognize the relevance of the philosophical atmosphere within which these experiments evoked an immediate and enthusiastic response. The "auxiliary assumptions" needed to connect the experiments to the hypothesis being tested were complex indeed, and epistemically far less secure than are commonly encountered in scientific activities. But the experiments validated a growing list of disconnected assumptions about the primitive Earth and about the nature of Life. And the experiments in turn triggered a cascade of corollary assumptions in a kind of epistemic domino effect. The renewed debates, now expressed in more concrete terms about the primacy of proteins or nucleic acids, are still unresolved, but the mechanisms are accepted as knowable in terms of modern achievable laboratory conditions. The origin of life is no longer a remote mystery to be dealt with by a waving of hands. Fry clearly and evenhandedly recounts the theories and the evidence adduced in the dialectic discourse that continues in modern molecular biology's most interesting pots abrewing.

Fry's account is not limited to the laboratory, however, but engages the initial impulse to an understanding of the significance of human existence. Although we have not achieved the synthesis of life in the laboratory, biologists realize much better the complex task of generating a viable genetic system from scratch, and they have a firmer estimate of the short time required for life to become a pervasive presence on Earth. The multitudes of diverse habitats provided by the young planet provide a special challenge to anyone hoping to find the particular concatenation of circumstances essential for life's emergence. Few biologists are driven to postulate a miraculous intervention, but some are driven to despair of finding the appropriate combination of compounds and physical conditions critical to ignite the spark. Though cosmologists and geochemists have sampled cosmic debris and have made enormous advances in defining the conditions prevailing at our planet's origin, they cannot fully describe all the local conditions on fetal Earth or provide solid generalizations about planetary geochemistry.

The controversies over the mechanisms and sequences of basic events in the origin of life should not be considered as a reflection of the inability of the scientific process eventually to achieve resolution. The current lack of consensus concerning fundamental natural events is only superficially similar to the conflict that roiled sensibilities in the late 19th century. The questions are being raised and differences are being resolved in a fundamentally altered epistemic landscape.

An interesting adjunct to the discussions about how life originated is the reprise on the question of where. Theories of panspermia were espoused in the 19th century, and probably much earlier, to suggest that life did not in fact originate on Earth, but came prepackaged in some way from somewhere else in the universe. Even with modern mechanistic and molecular approaches, the difficulties of defining appropriate conditions for the emergence of living systems from inorganic media have led sophisticated modern theorists (Crick 1981; Hoyle and Wickramasinghe 1981) to revisit the notion that life originated somewhere other than Earth, and was transported here as "seeds". Some of these speculative ventures seem to be derived from recognized genres of science fiction, and may indeed be merely tongue-in-cheek capers. Their contribution to current mechanistic considerations is largely to raise the probability of a possibly very rare random event, by allowing it to take place at any place-time in an infinite universe. The theoretical exercises add piquancy to the analysis of meteorites and tension to planetary exploration. Fry treats these fugues with respect and gives them serious consideration. Some of the value of such excursions derives from the ease with which they challenge firmly held assumptions, e.g. about such things as the survivability of spores in the hostile conditions of outer space. Modern studies of extremophilic life forms on Earth also encourage us to revise our notions about the robustness of life, and the likelihood of a panspermic origin to life.

The excitement and contention over these fundamental biological and philosophical issues will likely continue in this high pressure – low consensus ferment for some time to come. Iris Fry is a dependable guide for the paths taken thus far in a pilgrimage toward understanding as old as humanity.

J. William Schopf looks at some of these same issues from a distinctive perspective. Schopf is currently a professor of paleobiology at UCLA, and has enjoyed a distinguished career as an explorer of the traces of microbial life in ancient rocks. He joined the pioneering efforts of Stanley A. Tyler, Elso S. Barghoorn, Boris V. Timofeev, and others in developing and exploiting the technology required to visualize convincingly the microscopic relics of the life that flourished before the advent of eukaryotic organisms 2–3 billion years ago. Those studies have provided an important addendum to our understanding of the early history of life. The time during which life has existed on Earth is effectively doubled, and its gestation time drastically reduced. Life came into existence within a few hundred million years of the planet's origin, in a mere eye blink of geological time.

The book is both an informal history of micropaleontology and a professional autobiography. The story is told with verve, and is lavishly illustrated with photographs and diagrams. The reader is entertained with accounts of excursions to far corners of the Earth and encounters with international personalities. A notable example is the description of a visit with A. I. Oparin to the home of the Spanish surrealist painter Salvador Dali. Some readers will be entertained by these biographical forays, others will find them minor (if annoying) diversions; some may view them as self- indulgent distractions from the fascinating set of issues at the core of the book – the early history of life on Earth.

Schopf begins with a pair of chapters that describe the shift in thinking about the history of life both caused and mandated by the development of paleobiology. He also introduces many of the personalities that animated the early years as the discipline acquired fineness and respectability. In Chapter 3 he provides an accessible overview of the whys and hows of hunting ancient microfossils, structured around a "Top Ten" list of frequently asked questions about the search for the remains of ancient life. Chapters 4–6 take the reader through material that Fry also discusses, including the theories of Oparin and the Miller-Urey experiments. Schopf is most comfortably at home in Chapters 7 through 9 where he focuses on the stromatolitic fossil record and its significance for understanding the early life of the planet. It is the intellectual core of the book, and the part that philosophers of biology are likely to find most interesting.

The story told by Schopf, in contrast to that told by Fry, is that of an insider, someone who knew both Oparin and Miller professionally and personally. While it has the excitement of back-slapping beerhall storytelling, it avoids many of the complexities of both the historical record and the contemporary state of play in the discipline. One result of Schopf's first-person narrative style is that he presents issues as more settled than they are, and the development of the science appears more unidirectional than it in fact has been. Schopf is a skilled popular salesman of his discipline's accomplishments, and his fluent exposition is understandably marked with the stigmata of the lecture hall. The writing is in a headlong journalistic style with breezy descriptions and memorable aphoristic summaries. The lecture style does not fare so successfully in written prose, however. The load of cliches soon becomes burdensome: "if it's not broken, don't fix it", "rare as hens' teeth", "potential smoking gun", "needle in a haystack", "give a black-eye", etc..

More troublesome than his stylistic roughness is the superficiality of Schopf's understanding of biological mechanisms and of the implications of the vastly expanded history of life that his efforts have helped reveal. Unlike his sophisticated explanations within micropaleontology, his expositions on biological evolution more generally are simplistic. He glosses over details important to a full appreciation of both the significance and the limitations of fossil evidence regarding the history of life. A few examples will have to suffice.

The history of life, in Schopf's paleontological perspective, finds primitive microbes (prokaryotes) already well established and diversified in the oldest surviving sedimentary rocks from almost 3.5 billion years ago. He perceives no significant differences between the earliest forms available and their modern counterparts still thriving over three billion years later. The first "evolutionary" events occurred very quickly, before the first fossil microbes were preserved. Because he observes no changes in the fossils of these organisms after they first appear, Schopf concludes (e.g., 197–201) that the organisms have not changed in significant respects.

Following the establishment of the first life forms, the next big evolutionary disjunction in the fossil record is the appearance of modern cells (eukaryotes) 2.0–2.5 billion years ago. These organisms were initially unicellular (eukaryotic protists) and, like the prokaryotic protists before them, quickly stabilized in a number of distinctive morphological types. The evolutionary events at the base of the eukaryotes, like those at the start of the prokaryotes, occurred too quickly and left relics too fragile for an evolutionary sequence to be recovered in the fossil record. Indeed, it is difficult to reconstruct the evolutionary tree even with the sophisticated tools for molecular phylogeny. Their identical use of informational macromolecules (DNA, RNA and protein) make it certain that the eukaryotes were derived from prokaryotic precursors, but the fossil record does not tell us how this innovation was achieved. What is clear is that all eukaryotes bear complicated new biological inventions not manifested in any obvious way in the prokaryotes that have been studied. The innovations include the eukaryotic chromosome with its histone spools for packaging and deploying large amounts of DNA; the proteins spun into the microtubules making up the mitotic apparatus and the distinctive motor organelles; and the evolutionary new membrane packaging systems which potentiate, among other things, intracellular separation of particular metabolic functions.

Once the eukaryotic radiation had occurred, no major novelties were apparent in the fossil record again until higher plants and animals (differentiated multicellularity) appeared another 1.0–1.5 billion years later. The multicellular radiation occurred recently enough, and the organisms were large enough, that paleontological studies provided the first convincing evidence for the idea of evolution, and they still constitute the major basis for constructing evolutionary trees for the later stages of evolution. Schopf's explanatory gloss over the fossil record, however, provides the major difficulty within his account. Two major problems need to be mentioned.

The first is his use of biological terms in ways that blur common and technical definitions. The most critical of these is "sex". Biologists have long considered the essence of sexuality to be the combination of genetic material from diverse sources. Sex in this sense is commonplace in the modern prokaryotic world, though it is not visible in the fossil record. Indeed, sexual recombination was not demonstrated in prokaryotes until the 1940s. We now recognize a multiplicity of mechanisms for transferring genetic material from organism to organism in prokaryotes: DNA-mediated transformation, specialized and generalized transduction by means of bacterial viruses, sexduction mediated by F-factors, etc. Only rarely, however, do bacteria engage in whole genome combinations and recombinations; prokaryotic sex is largely piecemeal. Nevertheless, the sharing of genetic diversities in different individuals is a critical supplement to the mutational variety arising in an individual line of descent. Genetic sharing (sex) is almost certainly nearly as old as life, a critical factor in the engine of evolution from the beginning.

The novelty of sex as it is manifested in eukaryotes does not lie in a new-found exploitation of the power of genetic recombination, as Schopf (246–251) says, but rather in the novel eukaryotic delimitation of the population within which genetic materials may be combined. Genetic material is often transferred between highly distinctive bacteria, as for example in clinical settings, where a gene conferring antibiotic resistance may move among bacteria assigned to different genera. Some limitations on genetic sharing certainly exist among prokaryotes, but these are far less restrictive than the limitations in eukaryotes. The naked selfish gene has the capacity to act much more independently as a selective target and evolutionary element in bacteria than in higher organisms.

One can argue that species, in the sense of more or less fully closed gene pools, came into the evolutionary record only with the eukaryotic state, half way through the evolutionary story. The origin of "species" in the sense of the modern evolutionary synthesis is roughly simultaneous with the origin of the eukaryote. Though this is not an appropriate place to elaborate on details of evolutionary genetics, we should point out that the limitation on the sharing of genetic diversity brought with it the possibility of constructing more complex highly integrated genomes, as "coadapted gene complexes".

The other biological term that Schopf uses in a misleading way is "clone". Just as "sex" gains its "looky-here" value from shadows cast in tabloid headlines and across the Oval Office, "clone" evokes a Scottish sheep named Dolly, and the vision of some capitalist billionaire making more of himself. But in general biological discourse, cloning refers simply to the process of making genetically identical copies of a biological entity: a gene, a cell, or an organism. The ability to make copies was the first requirement for something that aspired to be called "living". Replication (cloning) and mutation were the foundations of life, undoubtedly assisted by recombination (sex) throughout the prokaryotic aeons and beyond. Mitosis and meiosis, that came with the eukaryotes, represent a more precise process of multiplying a more complex genetic entity. To suggest that eukaryotes perfected "the art of cloning", as Schopf does (243), however, is at best extremely misleading.

Our other complaint about Schopf's evolutionary discourse has to do with his faith in the evidence for his eyes. To Schopf, "seeing is believing", and something not seen is something we have no reason to believe. The application of this perspective to the fossil record drives Schopf straight into the arms of the punctuationists in their perennial dialectic with the uniformitarians. In each of Chapters 7 and 8 Schopf expounds on the theme of evolutionary stasis, under the rubric "the Volkswagen Syndrome", rejecting the possibility that paleontological stasis masks underlying cellular developments over evolutionary time. Schopf entertains the possibility of the Volkswagen Syndrome applying in the case of the long lag between the appearance of eukaryote microbes and the invention of multicellular organisms, as well as to that separating the earliest fossil records of microbes in stromatolites from their prokaryotic descendants that are our comtemporaries. Because he sees little in the fossil record in these long intervals, he decides that "Evolution's Goal is to Avoid Evolving" (246). Besides meshing himself inadvertently in the teleological tangles of "goals" in evolution, Schopf overestimates the resolving power of the new techniques in micropaleontology, even as he cautions about the inevitable lacunae in the fossil record.

Although evolutionists have long considered "stabilizing selection" – a necessary pruning of harmful mutations – to be a significant factor in evolutionary dynamics, no one has elevated stasis to the preeminent principle of biological evolution. The primary challenge to incipient life forms was not to resist change, but to accommodate to the almost unimaginable challenges posed by the environmental vicissitudes of primitive Earth that cosmologists are now describing in more detail and with greater confidence: the battering of a constant rain of meteors, the molten rock flowing from incendiary volcanoes, the rising and falling of mountain ranges, the boiling, freezing and drying seas, the changing atmospheric gases shifting from hydrogen and helium to nitrogen and oxygen.

More seriously, confusing morphological conservation with genetic and physiological stability, Schopf thrusts himself into the middle of another interesting controversy. Recent studies in the molecular phylogeny of eukaryotic protists demonstrate that morphological species usually consist of many genetically isolated "cryptic species". Even when living or stained, much less when petrified, individuals of these cryptic species are morphologically indistinguishable. At the molecular level, however, they can often be easily separated. Molecular chronometry indicates that they have been evolutionarily distinct for many millions of years. A set of cryptic species may all look like Volkswagens, but they go to different places, and have different energy sources, and different fuel budgets. Given that this is true in the current microbial world, much of which even microbiologists are just beginning to see, it is likely true of microbes during the perhaps 1.5 billion years of life prior to the advent of the nucleus. Schopf's fixation on the sketchy but important fossil evidence denies him access to the range of biological evidence relevant to an accurate picture of the whole of Precambrian life.

The significance of cryptic eukaryotic species has been challenged since they were first described in detail (Sonneborn 1957). Ernst Mayr, attempting to consolidate the authority of the modern synthesis, found himself uncomfortable with the cryptic species of the ciliated protozoan *Paramecium*, as well as with Sonneborn's refusal to give Latin binomials to species that could (at that time) be distinguished only by mating tests with living reference strains. According to Schloegel (1999), Mayr adopted a role similar to that of Huxley in the previous century. He designed a similar tactic of ad hominem disparagement to blunt challenges to an evolutionary synthesis that solidified too early to include the microbial world.

The consequences of this arbitrary social management of a scientific enterprise, as in the case of spontaneous generation, are not easy to assess. As one can argue a benefit for delaying laboratory studies of the origin of life, one can also argue a benefit for delaying the incorporation of microbial evolution into the modern synthesis. Yet disputes over the nature of the microbial world, such as that between Mayr (1998) and Woese (1998), raise broader issues about the early history of life that are perhaps of interest in the current context.

For example, consider Mayr's resistance to Woese's proposal of three domains (Woese's term) or empires (Mayr's term) of life. Central to Woese's proposal is the distinction within the prokaryotes of *eubacteria* from *archaebacteria*; the claim that the *Archaea* are more closely related to eukaryotes than either is to the *Eubacteria*; and the consequent rejection of the phylogenetic reality of the "domain" of prokaryotes. In favor of the established dichotomy between prokaryotes and eukaryotes as marking the major evolutionary division in life, Mayr appeals to general claims about what he calls "Darwinian taxonomy", such as evolution being "an affair of phenotypes" (1998: 9722), extremely dubious on independent grounds. Like Schopf, Mayr's epistemology here has a blunt empiricist feel to it, and like Schopf, he minimizes the significance of the fact that three-quarters of the history of life is a history lacking the multicellular, eukaryotic life forms whose middle-sized descendants, such as ourselves, have been the focus for both folk and scientific biology alike until very recently. One of the ironies in Schopf's views here is that while his work on stromalitic fossils has been one of the prime bases for shifting our views of just how old life is on the planet, his broader epistemological and biological views have leave him with little to say about its nature over the 1.5 billion years separating its origin from that of the eukaryotes.

The diversity within the microbial world has recently been defended with some force by Pace (1997). Also in recent years, the relevance of cryptic eukaryotic species to questions of global biodiversity has been made clear (Finlay et al. 1996), even though many taxonomists ignore the cryptic species within the commonly described morphospecies. The continued coexistence of multiple cryptic species over many millions of years suggests that they are adapted to different ecological niches, even though, for example, four or five sibling species of the *Tetrahymena pyriformis* complex (a ciliated protozoan) have been isolated from a 10 ml. sample of water taken from a sandy beach on Lake Michigan, or from a river bank in Malaysia. The principle of ecological exclusion makes it unlikely that these persistent separate gene pools occupy the same niche, though one cannot always specify the nature of the niche. That there are real ecological niches for cryptic species is strongly supported by the recent observation (Darling et al. 2000) that one of the several cryptic species of an oceanic foraminiferan is found in separate populations in subpolar seas at both ends of the Earth.

The number of eukaryotic genetic species may be greater by at least two orders of magnitude than current estimates allow. (Some whole contemporary branches of protists are known only from informational molecules taken from samples of soil and sea.) The fine-grainedness of the environmental niche mosaic is likely underestimated by a similar scale. We cannot know how significant this misunderstanding may be for an assessment of the effects of global warming on the survival of amphibians, mammals and birds. One can derive some comfort, perhaps, from the expectation that the adaptive skills of some of cryptic species of most of the morphological species give them high odds for lasting another billion years.

Finally, a comment needs to be made concerning Schopf's allusions to the philosophy of science (particularly epistemology) and the sociology of scientific practice. No expositor of science today can manage to ignore totally the concerns of metascientists, but Schopf's reflections manifest an unusual naivete with respect to these increasingly influential disciplines. He notes, for example (265) "It is no coincidence that practically all the pioneers belonged to the power elite, a status that upped the odds for acceptance of their views". This comment is strangely discordant with his lionization of A. I. Oparin whose theoretical explorations of the conditions required for biogenesis on early Earth were at least eased because of his location in revolutionary Russia, far from the hegemony of the power elite of western biology. A few pages later (268) Schopf considers "dead-wrong" breakthroughs in science and asks: "How does science guard against such errors? There is one style that can always be counted on, 'Science by Facts'. Here claims are accepted only if they are thoroughly tested, debated and validated by the extended scientific community." Any tension between these commonplace assertions concerning the ways of science in society is ignored (or perhaps not even recognized), and there is no attempt to sophisticate either claim in a way that might make them of interest to philosophers and sociologists.

The contrasts between these books by Fry and Schopf may evoke some consideration from the reader. Both authors attempt to communicate the status of scientific advance in an area of persistent popular interest. Their styles of exposition are different and probably reflect the circumstances under which the accounts were first constructed. Schopf writes as a popular speaker performing before a lay audience after having his accomplishments proclaimed in a generous introduction. Fry writes in a more pedantic classroom style, apparently for an audience under some obligation to take the exposition seriously. Both authors attempt to reach beyond the boundaries of their technical expertise (and certainly beyond ours). Fry, as an historian of science, is obligated not only to be competent in the disciplines of historiography but also to be firmly grounded in the materials and practices of the relevant sciences. Schopf is not required to possess such disciplinary breadth as a scholar in micropaleontology, even though a student of microfossils must have considerable understanding of planetary cosmology, geophysics and biochemistry. He is tempted, however, to reach beyond the strict limitations of the academic discipline in which he is an acknowledged master, and to make plenary judgments in scholarly disciplines he knows only at a considerable distance, particularly microbiology and the philosophy of science.

The challenge of popular exposition lies in part in the sheer volume of technical information generated by the scientific engine, according to the scientometrician de Solla Price, doubling every 15 years for some 300 years. The scientific community has adjusted to the plethora of information by fragmentation. The fragmentation necessary to maintain competence within smaller scientific domains makes broader excursions more difficult and forays into adjacent disciplines more hazardous. Complicating the task of the synthesizer is the social construction of the authoritative spokesperson. The pronouncements of eminent scholars are respected even when they stray beyond their acknowledged boundaries. Nobel laureates are expected to (and often do) pass judgment on social and political issues that have little relevance to their specialized knowledge, just as basketball players and golfers are paid large sums to endorse products they may never use.

While scholars attempting comprehensive understanding and public enlightenment should be encouraged, the standards of performance in such exercises should be held high. To be successful in cross-disciplinary syntheses the chief virtue required is humility, and the besetting sin is hubris. Avoiding dullness is not enough.

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