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A Proposal Concerning the Origin of Life on the Planet Earth

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Summary. The widely accepted Oparin thesis for the origin and early evolution of life seems sufficiently far from the true state of affairs as to be considered incorrect. It is proposed that life on earth actually arose in the planet's atmosphere, however an atmosphere very different from the present one. Because of an extremely warm surface, the early earth may have possessed no liquid surface water, its water being partitioned between a molten crust and a fairly dense atmosphere. Early preliving systems are taken to arise in the droplet phase in such an atmosphere. The early earth, which resembled Venus then and to some extent now, underwent a transition to its present condition largely as a result of the evolution of methanogenic metabolism.

Key words: Oparin Ocean – Origin of Life – Evolution – Runaway greenhouse – Photosynthesis – Methanogenesis

It is a basic tenet of biology that living systems have arisen from non-living ones. This process, which involves the "evolution" of a simple initial system to states of greater and greater complexity, of increasing organization, is not fundamentally understood. The first plausible rationalization of such an "evolutionary" process was formulated by Oparin and Haldane in the 1920s and '30s. Although it has been modified, refined, and extended in the intervening 50 years, the essential features of the original Oparin Ocean thesis still form the basis for the accepted explanation of the origin and early evolution of life (Oparin, 1924; Haldane, 1929; Urey, 1951; Miller, 1953).

A priori it would seem unlikely that an hypothesis conceived in the near total absence of relevant facts – as was certainly the case regarding the origin of life in the 1930s – would turn out to be correct in its details. The only question seems to be whether its basic features are sufficiently close to the truth that the model can serve as a useful guide for experimentation – i.e., can be refined by conceptual successive approximations into a correct model – or whether the model is sufficiently far from the true state of affairs that it eventually misdirects experimentation, obscurs understanding, and so must be replaced as the guiding paradigm. In either case the critical

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posing of alternatives serves a useful, defining function. It is my contention that the Oparin Ocean thesis is indeed incorrect in its basic assumptions and so its major conclusions. The present communication is a summary critique of the thesis and an outline of what I feel to be a more acceptable rationale for the origin and early evolution of life.

In brief, the modern version of Oparinism sees the origin of life starting with the planet earth initially, or very soon, surrounded by a moderate, anaerobic atmosphere containing appreciable amounts of volatile forms of the crucial elements C, O, H, N, and S. Organic synthesis is effected in such an atmosphere through the action of ultraviolet light and/or electrical discharge. The compounds so produced ultimately end up, and so accumulate, in the planet's hydrosphere, which eventually becomes a moderately concentrated organic "soup". In this Oparin Ocean, or in relation to it – e.g., adsorbed on clay sediments, on its surface, or in locales where concentration by eutectic freezing or drying has occurred – further reactions take place that produce compounds of greater complexity, and so polymers and other aggregates of biological interest (Miller and Orgel, 1974; Kenyon and Steinman, 1969). The emergence of cellular organization is seen to have its beginnings in coacervate phase separations or some alternative form of encapsulation – e.g., "proteinoids" or micro-pockets in sediments (Oparin, 1924; Miller and Orgel, 1974; Kenyon and Steinman, 1969; Fox, 1965). The ultimate outcome of this increasing complexity is somehow the emergence in the ocean of a primitive type of organism whose metabolism is anaerobic and completely heterotrophic (Oparin, 1957; vanNiel, 1946). Evolution from this stage onward becomes a series of crises, as the newly evolved organisms deplete the oceanic store of energy rich compounds. These crises are met initially by the evolution of biochemical pathways – backwards, one step at a time – to produce the depleted essential monomers and so on from their still available precursors, and ultimately by evolution of photosynthesis as oceanic stores of all organic compounds become negligible (Miller and Orgel, 1974; Oparin, 1957; Horowitz, 1945).

The Oparin thesis should be questioned because it evolves life in what is basically a non-biological way, and a way in which the living systems that emerge are but peripherially connected to the processes giving rise to them. Ultraviolet light, electrical discharge, and so on, are non-biological energy sources; they are in fact destructive of biological systems. The postulated series of events – the formation of starting compounds in the upper atmosphere, their gradual accumulation and further reaction in (and in relation to) the hydrosphere, followed eventually by the "explosion" into life – is a highly unidirectional course. To the biologist, accustomed as he is to rapid biocycles of elements, compounds, and organisms, such a scenario feels alien. Moreover, life is not an inevitable consequence of this scheme; the Oparin Ocean would go on turning out organic molecules, creating complexity, whether or not life ever arose, whether or not it arose and soon thereafter died out (for failure to evolve in time the postulated properties that make it self-sustaining). Most of all, perhaps, this scheme is unappealing because the life that arises is basically destructive of the organization that preceded it; it does not in itself contribute to the build-up of chemical complexity on the planet (until photosynthetic organisms finally evolve).

It should also be noted that the course of experimentation in prebiotic chemistry is a *de facto* rejection of Oparinism. Basic biochemical reactions by and large are dehydrations; they cannot reasonably happen in an ocean. As experimentation has progressed the prebiotic chemist has found it necessary to invoke increasingly severe, dehydrating primitive environments in order to effect primitive syntheses – which environments are always viewed somehow as adjuncts to the Oparin ocean. These ptolemaic revisions of Oparinism should be recognized for what they are, and the question put squarely: It is not a matter of how to modify Oparinism, but whether to replace it.

In simplest terms the basic postulate governing the origin of life appears to be this: the manner in which life arises is fundamentally the same as the ways in which life maintains itself and evolves after its appearance. Prebiotic evolution is not a collection of special conditions, a peculiar dynamics whose essence is discarded and replaced by another dynamics, other conditions, once life arises. Preliving states must possess the basic attributes of living ones, for these attributes are not properties of "living organisms" *per se*; they are characteristics of a general process of transformation of energy into organization. On this assumption the role of sunlight in prebiotic times is more than to warm the planet; visible range radiation must indeed be the primary energy source for prebiotic synthesis. Centers for the absorption of visible light are the focal points for prebiotic chemistry, for prebiotic organization. This initial simple organization is in turn subsumed by, is the focal point for, more complex organization, and so on. Thus the first living organisms to emerge would not be the clostridia-like heterotrophs the biologist has grown to expect from Oparinism. The first cells develop from sources of, not from the sinks for, prebiotic biochemistry; the earliest organisms would, therefore, be autotrophic and photosynthetic. (Were more than one type of organism to arise initially – i.e., a full-blown ecology were to arise – then obviously only some of these need be photosynthetic or fully autotrophic.)

The crux of the origin problem lies in the initial state and subsequent physical evolution of the primitive earth, and the times during this process at which the critical events leading to the first living systems occurred. Recent advances in our understanding of the geology and geologic history of the earth (greatly aided by exploration and study of the Moon and Venus) and comparable advances in our understanding of the early evolution of living systems, together give us for the first time some useful limits on, some faint picture of, what the primeval scenario might have been.

As recently as 20 years ago the biologist believed life to be a relatively recent arrival on the planet, the first cells arising, say, a mere one billion years ago. This view reflected both the fact that the macroscopic fossil record becomes scant to nonexistant prior to 600 million years ago, as well as the prejudice that evolution of a cell must have involved a series of highly improbable events – a euphemism for miracles – and so took a long time. With the discovery and study of microfossils and with the capacity to determine ancient evolutionary relationships among organisms from properties of their extant descendants, this picture has changed completely. The oldest known sedimentary rocks – 3.4 billion years – contain what are almost certainly fossil bacteria; the oldest known limestones – 3.1 billion years – contain stromatolites, i.e., fossilized algal mats (Noll and Barghoorn, 1977; MacGregor, 1940). Whether this evidence signifies the presence of blue green algae at these early times as has been suggested, is a moot point, but that it signifies the presence of at least some photosynthetic bacteria is almost certain. Assuming then that photosynthetic sublines of bacteria existed three and a half billion years ago, how much further back in time did the common ancestor of all ordinary bacteria exist? And how much further back than that did the universal common ancestor exist – i.e., the progenitor of the common ancestors of ordinary bacteria, of archaebacteria, and of the eucaryotic cell (Woese and Fox 1977)? It has now become easy to rationalize the existence of life on this planet at least four billion years ago. Thus we are faced with the very real question of whether the origin of life on this planet virtually coincided with the origin of the planet itself. If so, then the origin of life can no longer be perceived as an improbable happening – requiring a series of unlikely and so protracted events, or the slow accumulation of compounds in a primeval ocean. Neither can it be seen as occurring on a planet very like the earth today.

The generally accepted notion of the state of the primeval earth has undergone a comparable turnabout. Since the 1940s it was believed that the earth formed by a relatively cold accretion process and was surrounded by a highly reduced atmosphere (Urey, 1951; Miller and Orgel, 1974; Kenyon and Steinman, 1969). [The latter idea was discarded in favor of one in which the planet formed without appreciable atmosphere, yet developed a less reducing but still anaerobic one – containing CO_2, CO, H_2, H_2O, and so on – by outgassing of its lithosphere (Rubey, 1955; Miller and Orgel, 1974); Kenyon and Steinman, 1969).] Recent lunar exploration has revealed that the Moon's crust may have been partially or completely molten during that body's initial 100 million years. Some meteorites also give evidence of comparable heating four and a half billion years ago. Consequently it is now felt that the earth's surface too was initially very warm if not actually molten.

A hot to molten lithosphere would lead to a different picture of the earth's initial atmosphere (and, certainly, hydrosphere) than the biologist now accepts. Under these conditions the readily volatilized compounds would all be released during the final stages of accretion of the planet, and would partition between the atmosphere and a molten lithosphere – there being no hydrosphere. Water in particular will dissolve in silicate melts: and it has been estimated that rather than possess an enormous atmosphere containing 400 atm or so of water vapor, a sufficiently warm planet could dissolve almost all of its water in a molten cortex (Hamilton et al., 1965; Holland, unpublished calculations).

As the earth cooled somewhat with the waning of its accretional phase, the question is, then, what would be the condition of the atmosphere and hydrosphere. It has been calculated that the planet Venus – so like the earth in size, density, and apparent composition – is sufficiently close to the sun to unavoidably develop a runaway greenhouse condition, but that whether the earth did so, depended at least upon its initial temperature (Rasool and DeBergh, 1970). Up to this point it has been assumed that the earth did not develop such a runaway greenhouse – largely because this condition is stable, is self-sustaining, and the earth is not now in such a state. However, I will make the opposite assumption, that the condition of the primitive earth did indeed lead to a runaway greenhouse state, and ask what this might mean in terms of the origin of life.

Thus Venus today serves as a partial model for the state of the earth during its first several hundred million years of existence. The former planet presently has a heavy atmosphere whose sole major constituent is carbon dioxide, in an amount approximately equivalent to the total surface carbon on earth, i.e., 7 x 10^4 gm/cm^2 (Rassol and DeBergh, 1970). Venus' surface temperature estimated to be in the range of 500°C, is well above the boiling point of water at 80 atm, its surface pressure. The planet appears to possess relatively little water however, less than 0.1% of that found on earth today. It is generally believed that over the planet's 4.6 billion year history, the bulk of its water, which initially should have been equivalent to that on the primitive earth, has been converted to H_2, which then escaped, leaving Venus in a highly oxidized state— as indicated by the high ratio of CO_2 to CO (Eberstein et al., 1969). The planet Venus is surrounded by extremely dense cloud banks, comprising not water droplets, but seemingly droplets of hydrated sulfuric acid.

The early earth is pictured in somewhat this type of state – with certain crucial differences. The earth then is seen initially to possess a dense, CO_2-rich atmosphere, but an atmosphere that also contained appreciable water. This, in addition to the presence of metalic iron or iron oxides on the hot planetary surface, would result in there being significant quantities of hydrogen, along with appreciable CO, perhaps some methane, H_2S, and some NH_3 and/or N_2. Exactly how much water was present in the atmosphere cannot be assessed for the reason just mentioned; however, I will assume that much of the water had initially been dissolved by a molten cortex and may have remained trapped there as the earth cooled somewhat.

Like Venus the early earth would be shrouded in a thick cloud layer, and also like Venus, the clouds would not comprise water droplets per se. Weather on the primitive earth should be severe beyond anything we now know. The earth at this early stage would still be bombarded by meteorites and planetessimals in significant numbers. (The moon appears to have suffered heavy bombardment up to about 3.9 billion years ago.) The temperature differentials so created would generate massive convection currents. Winds sweeping the hot, dry planetary surfaces would produce violent dust storms, carrying particulate matter high into the heavy atmosphere. The dust would tend to dissolve in, would serve as foci for condensation of, the water vapor in the atmosphere. Thus the clouds would comprise salt water droplets. How concentrated the various salts would be is a moot point, given the indeterminacy in the atmospheric water content and other factors.

Chemically this atmosphere could be viewed as a gigantic reflux column, or as a connected series of chemostats. In any case it seems a stratified, steady state, chemical and photochemical system, under severe, highly reactive conditions.

In such an atmosphere all stages in evolution are basically "cellular". The droplet phase serves as a natural definition of the proto-cell. Such droplets do not exist *within* an oceanic biochemistry; the droplet phase *is* that biochemistry.

In such an atmosphere the primary chemistry is "membrane" (interface-associated) chemistry. Solution chemistry would be the by-product of "membrane" chemistry, not the reverse. The relative surface area in a system of droplets is enormous. Macromolecules in particular tend to partition at interfaces, which would enhance reactivities. Membranes, moreover, can provide a relatively hydrophobic phase, in which biological polymerization might then more readily occur. Photoabsorbers, transducing electromagnetic energy into chemical energy, are the central molecules in the scheme. Once such molecules begin to be formed (by whatever means) their syntheses would tend to become autocatalytic. Concentration of photoabsorbers in a droplet phase, particularly at membrane interfaces would significantly increase the efficiency of the conversion of light into chemical and other organization.

There is little need for highly energetic events (absorption of ultraviolet light or electrical discharge) to effect chemical reactions in such an atmosphere. Mixtures of CO_2 or CO and H_2 are potentially reactive at normal temperatures, albeit at extremely slow rates (Miller and Orgel, 1974). Thus much of the primitive chemistry should be inherent in processes that catalyze the interaction of these and other gasses. Although CO_2 does not form many complexes, CO exhibits an intriguing range of complexes and reactions. It is conceivable that some of the early photoabsorbers were CO complexes.

A major problem that any origin of life scheme faces is how to pass from biochemistry to genetics. How does a primitive entity that possesses what can be called biochemical organization evolve to become something possessing genetic organization as well, and so become capable of evolving to states of far greater complexity and (biological) specificity than is otherwise the case? This problem is not solved by the present proposal. (However, the problem at issue here is not the simplistic one of which came first, the gene or the protein. It is the more demanding question of how a genotype-phenotype relationship develops.)

A second major problem is peculiar to the present scheme. How can a runaway greenhouse condition be broken, permitting the earth to assume its present, far cooler state? Physical factors may be involved. The planet during its first 100-500 x 10^6 years received significant heat from sources that later played relatively minor roles – meteorite impacts and radioactive decay. However, the key factor in the transition from an earth too warm to possess liquid water to one in which oceans are a dominant feature, may be biological. Mixtures of CO_2 (and CO) and H_2 are thermodynamically unstable at normal temperatures. Thus as the earth's surface cooled somewhat, a point may have been reached where production of CO_2, CO, and H_2 at or near the very hot surface could not keep pace with the conversion of these gasses to methane in the cooler atmosphere. Catalytic conversion of CO_2 (and to a lesser extent CO) and H_2 to methane and water is, of course, the principle metabolic reaction of organisms called methanogens, organisms inhabiting a wide variety of anaerobic niches on the planet today (Wolfe, 1972). Genealogical analysis of these organisms suggests methanogenesis to be one of the most ancient, if not *the* most ancient, of biochemistries. It is reasonable therefore, to consider methanogenesis to be (part of) the primeval metabolism of prebiotic forms (Fox et al., 1977; Woese, 1977). If so, then CO_2 (and CO) levels at some stage may have dropped below a critical value required to maintain the runaway greenhouse condition – which would result in a change in the earth's albedo, and the appearance of the first oceans in the planet's history. At this point too, the production of H_2 would drop dramatically, starting the earth on its course toward an eventual oxygen atmosphere.

At the present time the value of the scheme outlined here lies neither in truth nor completeness. Its main function is to force a relization that there may exist genuine alternatives to Oparinism, that prebiotic conditions for synthesis may have been more severe than presently allowed, that visible range photoreactions may have had a generally unrecognized importance in life's origins, and that the early evolutionary course of the planet Venus may not have been so different from that of the earth as now seems the case.

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