Origin of Life: Clues from Relations between Chemical Compositions of Living Organisms and Natural Environments

Abstract. *When elemental enrichment factors in living organisms are plotted against the ionic potential of the elements, a strikingly similar pattern is found for different groups of organisms; the pattern is also similar, in its general features, to that found in seawater. These relationships support the idea that life began in a water-rich environment interfacing with the primitive atmosphere of the earth.*

How life was created on the earth is a question that has long occupied theologians and philosophers. While Darwinian evolution has replaced spontaneous generation as the generally accepted explanation of the origin of species, science has not yet satisfactorily answered the question of how life arose on this planet. The realization of how old and large the universe is relative to our own solar system has led to speculation that there are other worlds that support life. Indeed, it has been suggested that life was seeded here from some other part of the galaxy. Earth supplied the nutrients, so to speak, like an agar dish. The seeding may have been inadvertent, as in the concept of panspermia (*1*), or deliberately done by intelligent beings, as in the concept of directed panspermia (*2*).

While it is not our purpose in this report to grapple with the problem of whether life exists elsewhere, we wish to discuss whether there are any anomalous elemental abundances in biochemical systems that warrant resort to an extraterrestrial origin for their explanation.

The chemical composition of a present-day organism must be a function or reflection of the chemical conditions confronted by its ancestors. Of the two points with which Crick and Orgel (*2*) support the directed panspermia concept, one is that there are apparent discrepancies between the concentrations of metals in certain biological systems and their abundance in the earth. (The other argument is the universality of the genetic code, which supports the idea that life developed from one source; the location of the genesis is, however, indeterminate.) Molybdenum is one such element; it is enriched in living material compared to its mean concentration in the earth. Nickel and chromium are not similarly enriched. The reasoning is that vital body chemistry should bear a similarity to the primordial chemical environment. An organism would not make itself dependent on a rare element for its existence. Therefore the utilization of a rare element possibly reflects a greater abundance of that element in the ancestral (and thus nonterrestrial) environment.

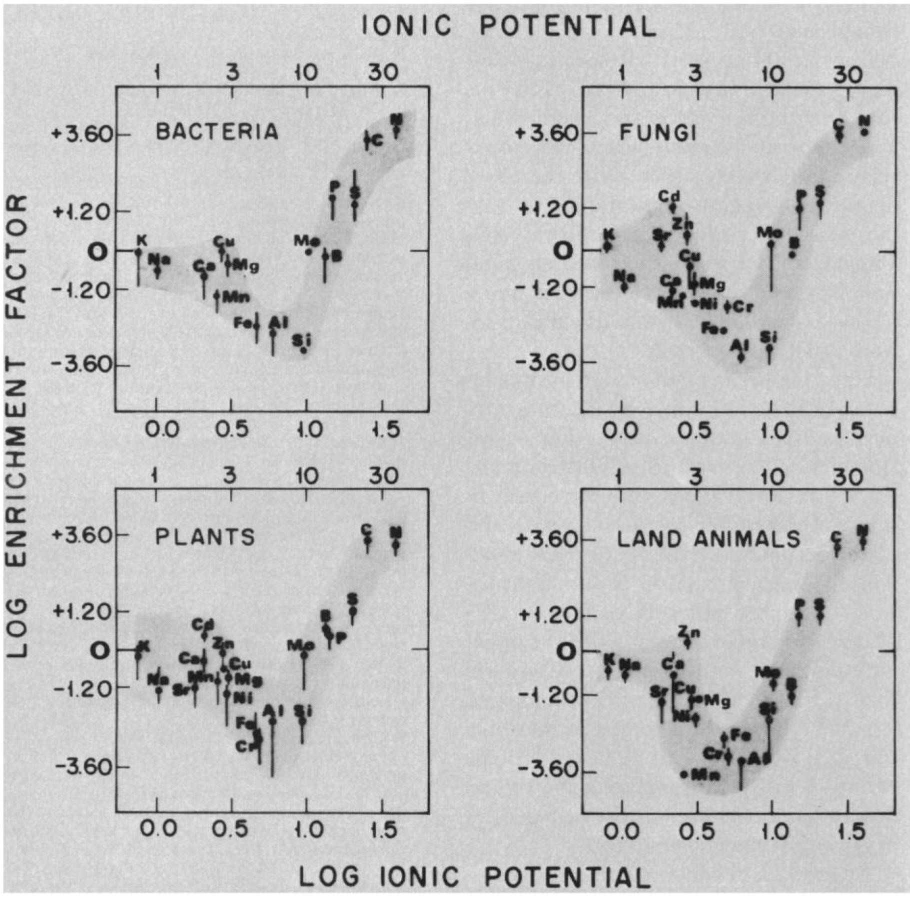

Fig. 1. Elemental enrichment factors in four major groups of organisms, plotted on a log-log scale against the ionic potential of the elements. For each element the full circle gives the most frequent value and the vertical bar (if any) gives the range of enrichment factors, depending on the range of concentrations in the group of organisms.

Responding to Crick and Orgel (*2*), Chappell *et al.* (*3*) questioned the stress placed on the biological importance of Mo compared to Cr and Ni. They also questioned the use of whole earth values for elemental abundances instead of average crustal values. Jukes (*4*) correctly pointed out that Mo is more abundant in seawater than Cr or Ni and that, generally speaking, abundances in seawater are consistent with an oceanic genesis. However, Orgel (*5*), in reply to these criticisms, questioned whether the Mo concentration in the oceans of the primitive earth was as high as it is in the oceans today, basing his argument on possible differences in the oxidation state of this element. Thus, the question of the relationship between elemental compositions in the natural environment and in living organisms is still open.

Abundances in the solid phase of the crustal rocks will not be directly reflected in aqueous media. This is clear if we consider the chemical concept of ionic potential (*IP*), which is defined as the positive charge of an ion divided by its radius. Ionic potential has been used as a quantitative criterion for explaining trends in the distribution of elements, especially minor elements in sedimentary rocks (*6*). It is related to the way various elements will interact with water molecules. Every positive ion in water is attracted to the negative ends of the polar water molecules in its vicinity and competes with hydrogen ions for the oxygen of water. The outcome of this competition depends on the relative strength of the attraction between hydrogen and oxygen and between the positive ion and oxygen, and can be estimated by the ionic potential. For low ionic potential values (< 3) the attraction between the positive ion and oxygen is small and the ion remains free in solution, somewhat solvated by a loose envelope of water molecules; this is typical for most of the alkali and alkaline earth elements. For intermediate ionic potential values (3 to 10) the two bond strengths are comparable and a hydroxide (usually insoluble) is formed, with the oxygen "shared" between the positive ion and hydrogen; this is characteristic for most of the elements in the center of the periodic table, such as the transition elements. Finally, when the ionic potential is high (> 10) the positive ion appropriates one or more oxygen ion, freeing the hydrogen and forming an oxyanion, which is generally soluble; this is characteristic of the nonmetals in the upper right corner of the periodic table.

If life began in the primitive terrestrial oceans, elements whose abundances in the aqueous phase are high should have a high representation in living material. In Fig. 1, the enrichment factor for a number of elements—that is, the ratio of the concentration of the element in an organism to its concentration in the earth's crust (*7*)—is plotted against ionic potential. A similar curve is seen for all major groups of organisms, as we proceed up the evolutionary scale from bacteria to fungi to plants to land animals, and for the ocean (Fig. 2).

A general pattern is observed for all living organisms: (i) For elements of low ionic potential values ($IP < 3$) the log of the enrichment factor (EF) is in the range of -1 to +1 indicating small enrichment or small depletion relative to the crust. (ii) For intermediate IP values ($3 < IP < 10$) log EF is -3 to -4 indicating large depletion in living organisms. (iii) For large IP values ($IP > 10$) log EF increases as the ionic potential increases and varies from -4 to +4. It should be noted that the elements mentioned by Crick and Orgel as showing anomalous distribution patterns—Mo, Ni, and Cr—also follow this general pattern. Specifically, Mo does not show any significant enrichment in living organisms as compared to the earth's crust. Obviously, taking each element and each group of organisms separately, we may expect many exceptions to the rules; still, the general pattern is strikingly similar for all the groups of organisms investigated.

According to Oparin (*8*), some combinations of biochemical reactions are characteristic of all contemporary organisms. These are combinations of patterns acquired by the emerging living matter in its very early stages of development, before further specialization and differentiation took place. Thus the basic similarity of the elemental composition pattern of all groups of living organisms (Fig. 1) indicates that the pattern was determined at the initial steps of the development of life.

It should be noted that in the range of ionic potentials higher than 10, where the major biochemical elements sulfur, carbon, and nitrogen are found, organisms have a very significant enrichment of 10 to almost 10,000 relative to the ocean. This may be taken as a clue to a more exact location for the origin of life. It can be speculated that life began at the interface of the primitive atmosphere and the ocean, in the thin microlayers at the surface of the ocean where large enrichments of the atmospheric constituents (mainly nitrogen and carbon at that stage) may occur. Various other elements may also be concentrated in these microlayers because of the effects of surface-active materials, surface tension, and the transfer processes between the liquid and the gaseous phase. In any event, it is evident that a chemical environment similar to the earth's ocean is sufficient to explain the elemental abundance relationships in living materials. A nonterrestrial explanation, especially one that has invoked special chemical conditions as being advantageous to the rapid development of life, is not justified.

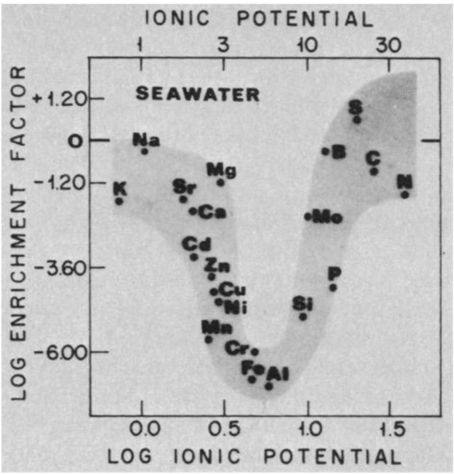

Fig. 2. Elemental enrichment factors in seawater, related to the ionic potential of the elements.

AMOS BANIN
JERZY NAVROT

Department of Soil and Water Sciences,
Hebrew University of Jerusalem,
Rehovot, Israel

References and Notes

1. S. Arrhenius, *Worlds in the Making* (Harper & Row, New York, 1908).
→ F. H. C. Crick and L. E. Orgel, *Icarus* **19**, 341 (1973).
→ W. R. Chappell, R. R. Meglen, D. D. Runnells, *ibid.* **21**, 513 (1974).
→ T. H. Jukes, *ibid.*, p. 516.
→ L. E. Orgel, *ibid.*, p. 518.
6. K. B. Krauskopf, *Introduction to Geochemistry* (McGraw-Hill, New York, 1965).
7. Data on concentration ranges and mean values of elemental abundances were compiled from the following sources: (Earth's crust) S. R. Taylor, *Geochim. Cosmochim. Acta* **23**, 1280 (1964). (Seawater) J. P. Riley and G. Skirrow, Eds., *Chemical Oceanography* (Academic Press, New York, 1965), vol. 1, pp. 164–165. (Bacteria and fungi) J. R. Porter, *Bacterial Chemistry and Physiology* (Wiley, New York, 1948), p. 365; W. S. Spector, Ed., *Handbook of Biological Data* (Saunders, Philadelphia, 1956), pp. 88–89; C. Long, Ed., *Biochemists' Handbook* (Spon, London, 1961), pp. 1050–1052. (Plants) H. D. Chapman, Ed., *Diagnostic Criteria for Plants and Soils* (Univ. of California Press, Berkeley, 1966), p. 793. (Land animals) H. J. M. Bowen, *Trace Elements in Biochemistry* (Academic Press, London, 1966), pp. 174–210; A. Banin and J. Navrot, *Commun. Soil Sci. Plant Anal.* **3**, 177 (1972). Where available, data for a range of concentrations were used to calculate a range of enrichment factors for a group of organisms. When only the mean concentration was available, only one enrichment factor value was given. The ionic potential was calculated using crystal radius values giver → L. H. Ahrens [*Geochim. Cosmochim. Acta* **2**, 155 (1952)]. For elements appearing in various oxidation states the most abundant form was chosen.
8. A. I. Oparin, in *Exobiology*, C. Ponnamperuma, Ed. (North-Holland, Amsterdam, 1972), p. 11.
9. For constructive criticism of this manuscript we extend our thanks to J. Kronfeld and I. Cohen.

11 March 1975

Exposure to Asbestos in the Use of Consumer Spackling, Patching, and Taping Compounds

Abstract. *Analysis of representative samples of spackling, patching, and jointing compounds, purchased at retail stores in the New York City area, has shown that some contain asbestos minerals as well as other biologically active substances. Measurements suggest that home repair work involving the use of such materials may result in exposure to dust at concentrations sufficient to produce disease.*

Spackling and drywall taping compounds consist of extremely fine-grained white powders or premixed pastes. Plaster of Paris is supposedly the major constituent, but other light-colored materials including clays, micas, quartz, talc, and ground limestone, supplement or replace the plaster in many formulations. Chrysotile is added to some products, apparently because these minute fibers act as reinforcing agents. The presence of amphibole asbestos in some products results from its natural occurrence in talc, carbonates, and other rocks used as raw materials (*1*).

Fifteen samples of consumer spackling and patching compounds were purchased at hardware stores in the New York City area, four in 1972 or earlier and the remainder in January 1974. We analyzed the samples for mineral phases by polarized light microscopy, x-ray powder diffraction, and transmission electron microscopy, with particular attention to quantitative determination of asbestos minerals. The spackling and taping compounds consist mainly of particles smaller than 3 μm in average diameter or length (Fig. 1). Particles of this size are generally too small to