Cosmochemistry and the origin of life

from Geoffrey Eglinton, Ann Henderson-Sellers and Stephen Moorbath

AT a recent NATO conference* on 'Cosmochemistry and the origin of life', Ponnamperuma (University of Maryland) summed up the overall picture by showing that there is a continuity stretching from space through to the present in terms of the formation of organic molecules and those that are found in present-day living organisms, and held that this is the natural course of events. Viola (Indiana University) started with the 'big bang' and then discussed nucleosynthesis and the abundance of the elements, particularly those essential to life. He also discussed the life cycle of stars and models of the Universe — salutary topics which should be compulsory course work for all scientists at some stage in their careers. Greenberg (University of Leiden) and Irvine (Chalmers University, Sweden) continued with details of the nature, composition and distribution of the interstellar dust and gas medium, and emphasized the enormous reservoir of organic molecules and most basic raw materials of life known to exist in interstellar space. Conference participants thought it unnecessary, at this state of our knowledge, to invoke *Panspermia* — the seeding of our planet, at any stage in its history, by life from extraterrestrial sources. In this much publicized context the conference generated neither science fiction nor science friction.

NASA's spaceship Enterprise, ably piloted by de Vincenzi (NASA Headquarters), took us on a tour of the Solar System, culminating in an account of the Mars Lander's biological experiments. Initial optimism and excitement soon gave way to the more sober realization that surface oxygen release could be better accounted for by presence of labile, active inorganic oxides in martian soil than by biological activity. Prospects for contemporary life on Mars are bleak, but perhaps in its originally airier and wetter manifestation it might have temporarily harboured the seeds of early life. The rest of the Solar System is decidedly no place for protoplasm!

The conference then rapidly came down to Earth. However improbable it seems, life and mind flourish, and some 4 billion years separate the earliest replicating organic molecules from the deliberations of the present conference. After presenting an inventory of terrestrial surface carbon, Henderson-Sellers (University of Liverpool) noted that, without its hydrosphere and biosphere, the Earth would be very similar to Venus, where carbon dioxide is not tied up in carbonate rocks. She, as well as Ponnamperuma, summarized much of the evidence that the atmosphere of the early Earth was dominated by carbon dioxide, water, nitrogen and possibly some carbon monoxide, and not by ammonia, methane and hydrogen as was once widely believed. The bulk of the hydrosphere was undoubtedly present from very early prebiotic times. Ample energy sources, including electrical discharges, ultraviolet radiation, radioactivity and volcanic/geothermal heat, were available on the early Earth to foster complex, prebiotic organic syntheses from relatively simple mixtures of volatiles and gases, with clay minerals as a likely base for the earliest biotic processes.

Moorbath (University of Oxford) showed that isotopic dates on early Precambrian sediments containing biological or molecular fossils could frequently be obtained from stratigraphically closely associated igneous rocks, and more rarely from the sediments themselves. Algal stromatolites and other simple cellular structures were known from sediments probably as old as 3.5 billion years, although in some cases there is a worrying stratigraphic gap between the sediment and the dated igneous rock. Whether the Isua metasediments of West Greenland, dated at about 3.8 billion years, contain biogenic markers is still a matter of controversy. Schidlowski (Max-Planck-Institut, Mainz) is convinced from detailed carbon isotope studies that Isua carbonaceous sediments represent a 3.8 billion year-old record of biological activity. There is a continuity of the $\delta^{13}C$ record from the present back to Isua times, and yet the Isua rocks also exhibit a marked shift in $\delta^{13}C$ which may result from their strong metamorphic overprint. Indeed, some workers claim that the $\delta^{13}C$ record of the Isua rocks has been achieved by metamorphism alone. Walters (University of Maryland), after painstakingly pyrolizing 27 Isua graphite samples, observed no trace of biogenicity, with one possible exception. The metamorphism was certainly intense enough to erase any biogenic evidence.

Ochiai (University of Maryland) pointed out that bioinorganic chemistry was essential for understanding chemical evolution. Many trace metals, such as Fe, Cu, Mo, Mn, Co, Zn, Ni, Cr and V, form complexes which catalyse organic reactions considered essential for life processes. He also discussed the problem of the major Precambrian Banded-iron Formations, ranging in age from about 3.8 to 2.2 billion years, and regarded by many as biogenic markers in the sense that their precipitation may have required oxygen released from marine organisms, in the virtual absence of atmospheric oxygen. This 'iron age' was followed at about 1.5 billion years onwards by copper sulphide deposits — the 'copper age'. Before this, prevailing redox conditions would not permit copper to appear in a dissolved, mobile state. A tentative correlation might be made between the sudden appearance of the copper deposits and the distribution of copper enzymes in present-day organisms. In this view, the copper superoxide dismutase is a later and more efficient development than the manganese and iron superoxide dismutases.

From the organic record in more recent sediments, Eglinton (University of Bristol) produced abundant evidence that molecules can retain a high degree of structural and stereochemical specificity over hundreds of millions of years if they are not exposed to raised temperatures or subject to oxidation or microbial attack. Specific biological marker compounds, or 'chemical fossils', can be interpreted in terms of the palaeoenvironment. The thermal history of a sediment can also be understood in terms of epimerization, aromatization and carbon–carbon bond cleavage reactions observed in samples with different burial histories. Of particular interest is the possibility of relating the molecular lipid record to microbial activity. Thus the archebacteria display unusual membrane lipids which may provide a clue to their activity during the Precambrian.

All participants agreed that there is an urgent need to continue the search for ancient, unmetamorphosed sediments from the earliest accessible Precambrian, so that micropalaeontologists, inorganic and organic geochemists, clay mineralogists, geologists and geochronologists can work closely together towards a progressive characterization, through geological time, of the biological record in the rocks. Recent geological work clearly shows that the earliest known (about 3.8–3.5 billion year) sedimentary and volcanic rocks characterize a depositional environment which is totally compatible with conditions now widely regarded as favourable for the earliest life on Earth. Of course, one big question was forcibly put to us by the students — "when did life begin?". The best bet was 4.0±0.1 billion years ago. The origin of life could be even older, but most people agreed that it was unlikely to be younger.

Altogether, it was a creative and original Study Institute, which looked as much into the future as into the past. Is it just conceivable that a conference on the same topic is at this moment being held somewhere else up there in the night sky?

*The NATO Advanced Study Institute was held in Maratea, Italy on 1–12 June 1980. The director of the institute was Professor Cyril Ponnamperuma.

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