NATURAL EVIDENCE FOR CHEMICAL AND EARLY BIOLOGICAL EVOLUTION

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Abstract. Meteorites, particularly type II carbonaceous chondrites, provide natural, tangible evidence for chemical evolution, but they do not appear to contain any evidence for biological evolution. On the other hand, some of the oldest sedimentary rocks of the earth have yielded good evidence for early biological evolution; whatever evidence there may be for chemical evolution in these old rocks is generally obscure.

Carbonaceous chondrites (types I, II, and III) have been examined for their content of various kinds of organic compounds. Amino acids have been reported to be present in the three types, but only in type II carbonaceous chondrites (Murray and Murchison) has an indigenous suite of amino acids been found which is apparently free of most terrestrial contaminations. These indigenous compounds are thought to have resulted from extraterrestrial, abiotic, chemical syntheses, and the presence of the amino acids in meteorites provides strong support for the theory of chemical evolution.

The geological record of the Swaziland Sequence and Bulawayan System of southern Africa contains morphological and chemical fossils which indicate that early biological evolution was taking place at least 3.0 to 3.3 aeons ago. Interpretation of the significance of the chemical fossil record has proven to be difficult. At present the occurrence of simple compounds in these very ancient rocks is believed to have little or nothing to do with biochemical processes three aeons ago. The bulk of the reduced carbonaceous material in these rocks, however, probably represents the residue of three billion years old and older organic matter. Isotopic studies of this carbonaceous material may provide chemical evidence for early biological evolution.

Modern concepts of chemical evolution were formulated in the 1920's when Oparin (1924) and Haldane (1929) independently hypothesized that life arose under reducing conditions through an evolutionary sequence of events involving increasingly complex organic substances which were synthesized and accumulated over long periods of time. Tests of these concepts generally have been confined to laboratory experiments wherein attempts have been made to simulate primitive, prebiotic environmental conditions. The first really successful test of the concept was reported by Miller (1953), who demonstrated the generation of amino acids resulting from the interaction of an electric discharge on a mixture of gases which was presumed to simulate the atmosphere of the primitive Earth. Numerous subsequent experiments over the last 20 yr have followed this same theme, and these have been succinctly reviewed by Lemmon (1970).

Besides the experimental results from laboratory simulation studies, naturally occurring evidence also has been observed which relates to concepts of chemical evolution. Except for that evidence found in meteorites, lunar samples and ancient rocks of the Earth, the majority of the evidence has come about through astronomical observations of the Sun, interstellar media, comets, and the planets (Oró, 1972). Although the astronomical information is important in any consideration of chemical evolution, this paper will focus on the natural evidence found in tangible samples which have been chemically analyzed in earth-bound laboratories. These samples include the extraterrestrial materials, meteorites, and the terrestrially occurring early Precambrian rocks.

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1. Carbonaceous Meteorites

Before 1969, the only tangible samples available of extraterrestrial origin which could potentially relate to chemical evolution were meteorites, particularly carbonaceous chondrites. These substances, at first thought to represent some of the well-mixed rubble from the inner solar system, are now generally believed to be relatively unaltered condensate from the solar nebula (Anders, 1971). After 1969, extraterrestrial samples from several localities on the earth's Moon became available through the space programs of the United States and the Soviet Union. Whether or not any of these samples contain evidence related directly to the theory of chemical evolution is not yet clear. Although the number of extraterrestrial samples available for study has increased markedly as a result of the Apollo Program, it is still the carbonaceous meteorites that provide the best evidence with regard to chemical evolution.

That carbonaceous meteorites contain organic substances has been known for more than a century. Berzelius (1834) extracted complex organic substances from the Alais meteorite and wondered about the significance of his findings and their relationships to the possibility of extraterrestrial life. Since that time a number of studies of the organic chemistry of meteorites have been undertaken sporadically. Starting with the work of Mueller (1953) and Nagy et al. (1961) the field has gained momentum, and during the last twelve years significant advances have been made. Review articles and summaries of the work have become common (Briggs and Mamikunian, 1963; Mason, 1962-1963; Urey, 1966; Nagy, 1966; Hayes, 1967; Nagy, 1968; Baker, 1971; Ponnamperuma, 1972; Lawless et al., 1972a; Oró, 1972). This paper will focus on the discoveries of amino acids in carbonaceous meteorites.

Amino acids, being components of proteins, seem to have received the most attention in considerations of chemical evolution. Ease of both synthesis and analysis probably has promoted this attention. Amino acids were first reported to be present in meteorites (Murray and Bruderheim) by Degens and Bajor (1962). The following amino acids were observed either free and/or combined: serine, glycine, alanine, leucine, aspartic acid glutamic acid, ornithine/arginine, threonine, lysine, histidine, valine, proline, tyrosine and phenylalanine. Most of these amino acids are known to be in proteins of living systems, but the authors cautiously avoided the interpretation that the source of these compounds was extraterrestrial life. Rather they suggested that the compounds were abiotic in origin or were terrestrial contamination or both.

1.1. Orgueil (a Type I Carbonaceous Chondrite)

In a more detailed paper, Kaplan et al. (1963) assessed the amino acid content of eight carbonaceous chondrites (including Orgueil) and five non-carbonaceous chondrites. They reported, in addition to the compounds just listed, methionine and \( \beta \)-alanine. Anders et al. (1964) found that their analysis of amino acids in water extracts of Orgueil were in good agreement with the results of Kaplan et al. (1963). These compounds were interpreted to have resulted from abiotic chemical synthesis with a possible small overprint of terrestrial contamination. Certainly if these com-