CONFERENCE ON BIOCHEMISTRY, PALEOECOLOGY, AND EVOLUTION

BY W. P. WOODRING

U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C.

Communicated January 11, 1954

Introduction.—Progress in biochemistry during the last few decades has opened new avenues for advances in geology, paleoecology, paleontology, and the study of evolution. To catalyze progress in exploiting these possibilities, an informal Conference on Biochemistry, Paleoeology, and Evolution was held at Shelter Island, Long Island, June 9–11, 1953, under the auspices of the Academy. Twenty-three biochemists, biophysicists, biologists, paleontologists, geologists, and geochemists participated (P. H. Abelson, E. S. Barghoorn, W. Bergmann, H. F. Blum, W. H. Bucher, P. E. Cloud, Jr., Carl Epling, Bently Glass, S. Granick, S. B. Hendricks, G. E. Hutchinson, G. L. Jepsen, J. L. Kulp, Bernhard Kummel, H. S. Ladd, H. A. Lowenstam, W. D. McElroy, D. A. MacInnes, B. H. Mason, A. S. Romer, W. W. Rubey, G. G. Simpson, W. P. Woodring). Eight sessions were held under the direction of Abelson, Cloud, Epling, Hutchinson, McElroy, Mason, Rubey, and Simpson as discussion leaders. The following brief report is based principally on summaries prepared by Glass, Granick, Kulp, and Ladd, who served as reporters, and on editorial advice from Abelson, Cloud, and Rubey. In this summary account it is impractical to mention numerous contributions, including contributions from participants whose names do not appear. Throughout the sessions, Hutchinson in particular guided the discussion into profitable channels. Although it is impossible to convey on paper the spirit of enthusiasm of the meeting, some examples of the topics discussed will serve to indicate the areas which were vigorously examined.

Biochemistry.—A modified Oparin-Horowitz-Bernal scheme of the origin of life was outlined by McElroy. He emphasized the possible role of group transfer in the early production of complex molecules. An absorptive surface such as clay could serve as an inorganic catalyst in the absence of enzymes. Thereby phosphate, methyl, acetyl, and peptide could be exchanged without loss of bond energy. Hendricks pointed out that clay would also combine with purines, pyrimidines, and phosphates. Thus several of the components of nucleic acid could get together on clay.

Granick discussed the hypothesis that the fundamental functions of protoplasm, such as oxidation and photosynthesis, may have been carried out by relatively simple compounds during early stages of protoplasm development. As protoplasm evolved, these functions came to be carried out with greater efficiency by more complex compounds. As an example involving oxidation metabolism, he pointed out that the present iron porphyrin proteins all cooperate to bring about oxidation. These iron porphyrin proteins may be classified into five groups according to their specific activities. Inorganic ferrous-ferric iron or its hydroxides, however, possess all these activities, but in low degree. Thus at an early stage the simpler inorganic iron compounds may have functioned in essentially the same manner as later more complex iron compounds, which came to have highly selective and enhanced activities.
As an illustration of the view that selection of a particular system as most useful may follow concomitant development of a number of systems, Granick cited hemoglobin. Though hemoglobin appears in many of the invertebrates, only the vertebrates have used it to great advantage. Its selective advantage, however, depended on the evolution of other systems to satisfy the high iron requirements: the HCl of the stomach to dissolve the iron of food and to make it more readily absorbable; a regulatory mechanism in the intestinal mucosa for absorbing more or less iron as the occasion requires; a transport protein, transferrin, to transport the iron in the blood stream; and an iron storage protein, ferritin, to store the iron in liver, spleen, and bone marrow.

Glass cited the evolution of the mitotic mechanism, so nearly universal and so basically similar, as the best argument for a single origin of life. Only the blue-green algae and possibly the bacteria still survive as representatives of a more primitive organization. The origin of sexual reproduction is equally basic to evolution and almost as primitive.

Hutchinson suggested consideration of the pattern of evolution in the range of biochemical composition. The testing ground for various kinds of metabolism may be found in the invertebrates. As an example of comparative biochemistry, Bergmann discussed his work on sterols. Sponges are exceptionally rich in sterols. They contain little or no cholesterol, but at least 15 other sterols have been found in an examination of 50 species, as many as four in one sponge. In the vertebrates the diversity of sterols is reduced and cholesterol is the typical sterol. Fell recently found that a consistent interpretation of embryological evidence led to the conclusion that echinoids and ophiuroids are closely related, and that asteroids and holothurians are closely related. Fell rejected the results on conventional grounds of adult morphology. His results are substantially supported by biochemical evidence. Cholesterol is the principal sterol of all echinoids so far examined and has been tentatively identified in the only ophiuroid so far studied. On the contrary, stellasterol and the similar hitodesterol are the principal sterols of asteroids, and stellasterol of holothurians.

The phosphagens lend further support to Fell's results. Baldwin has called attention to the distribution of arginine and creatine. Arginine is found in nearly all invertebrates, creatine in all vertebrates. Echinoids and ophiuroids are exceptional among the invertebrates, for both arginine and creatine occur in echinoids, only creatine in ophiuroids.

The distribution of sterols and phosphagens also supports the embryological evidence that the protochordate acorn worms represent a link between the echinoderms and the vertebrates.

Bergmann further pointed out that the fatty acids reveal an evolutionary pattern similar to that of the sterols. Invertebrates have a wide spectrum of fatty acids. Sponges, for example, contain fatty acids ranging from C-14 to C-28, C-24 and C-26 being most abundant. The fatty acids of vertebrates are mostly of C-16 and C-18 structure (stearic, oleic, palmitic).

In summary, Hutchinson developed the view that simpler organisms experimented, so to speak, with a wide range of chemical compounds and more complex forms specialized in a limited range.
Geochemistry.—The role of geochemistry in imposing limits on speculations concerning the origin of life and in evaluating paleoecology was emphasized and also the contributions that biochemistry may eventually make to geochemistry. Regardless of the manner in which life originated, its mere persistence since that time furnishes information, not now understood, about the subsequent history of the earth and the living matter thereon. Rubey reviewed some aspects of his studies on the geological history of sea water. The mineral constituents of ancient muds and other sediments suggest strongly that the temperature and chemical composition of the ocean and atmosphere have changed only slightly through much of the geologic past. But if the fossils preserved in these sediments could be interpreted in terms of their biochemistry, we would have far more precise knowledge than that now available about the environmental conditions of the past.

The fundamental life-processes of fertilization, reproduction, respiration, digestion, etc., depend upon the presence and specific catalytic action of particular enzymes; and the activity of these enzymes is closely dependent upon the temperature, chemical composition (including minor as well as major constituents), and concentration of various ions in the surrounding media. Many present-day organisms can tolerate only slight changes in the physical and chemical conditions of their environment (as, for example, the narrow range of pH of sea water within which Arbacia eggs are fertilized). Some groups have developed special organs, such as the kidney, which afford partial protection against certain aspects of the external environment; but other groups, such as the echinoids, cephalopods, and brachiopods, appear to have no comparable mechanisms for protection. To what extent may such unprotected organisms adapt themselves to significant changes in their external environment without substituting different enzymes to replace those on which their life-processes have previously depended? And to what extent would such biochemical adaptations be evident in the morphology of the organisms affected particularly in the hard parts available for paleontological study? It will require the collaboration of biochemists, paleontologists, and geochemists to develop this neglected field of investigation.

Mason pointed out that there are good grounds for attributing most of the chlorine in the ocean to volcanoes. What part of the chlorine in volcanic emanations, however, came from the interior of the earth? Kulp presented data on the absence of C\textsuperscript{14} in the CO\textsubscript{2} collected at Kilauea, indicating that at least 98 per cent of the CO\textsubscript{2} is primary, unless the time constant for the seepage of ocean water into the volcano is greater than 30,000 years.

The geological timetable was reviewed by Mason, who emphasized the increasing precision due to new measurements and new methods. A reliable time scale is a prerequisite for consideration of pre-Cambrian evolution.

Paleontology and Paleoecology.—Romer discussed the loss of ossification in several lines of Triassic amphibia—a loss of ossification accompanied in some groups by an increase in dermal armor. Though several suggestions were made concerning possible biochemical control, none seemed to be entirely satisfactory.

Romer cited geological evidence for the view that the earliest fishes lived in fresh water and that at a later time placoderms and shark-like fishes and still later bony fishes invaded the sea. The nitrogen-excreting mechanism of fishes supports this view.
Lowenstam reported on the discovery of a temperature effect on the carbonate deposition of certain marine animals. In serpulid worm tubes aragonite increases over calcite with increasing temperature. The same effect has also been detected in a number of gastropod and pelecypod species. Deviations from the gross trend suggest superposition of lesser effects by other environmental factors, possibly including salinity. Controlled tank experiments are planned to determine the role of the various factors. Data were presented to show that concentration of the trace constituent strontium in serpulid worm tubes rises with the increase in aragonite as the temperature rises and therefore is indirectly sensitive to temperature.

Lowenstam also mentioned the work in collaboration with Epstein on the climatic history of Cretaceous post-Aptian seas, principally of western Europe, as indicated by the $^{14}O/^{18}O$ ratio of the skeletal calcium carbonate of belemnites and some associated fossils. Cyclical temperature variations, based on analyses of cross-sections of single belemnites, are interpreted to indicate latitudinal migration rather than seasonal depth migration.

Woodring raised the question whether physiological differentiation, as shown by habitat and habits, is likely to be correlated with biochemical differentiation. Though the opinion was expressed that different physiological aspects may have the same biochemical background, paleontologists would be interested in the comparative biochemistry of species that are closely related morphologically—or even indistinguishable on the basis of characters available to paleontologists—but have different physiological characters.

Cloud exhibited an alga-like fossil from Upper Cambrian rocks of Texas that shows filamentous branching structure. Though fossils of the same gross form range well back into the pre-Cambrian, the specimen exhibited is, so far as known, the oldest to show such structure. He cited examples of fossil organic material possibly suitable for biochemical studies, including original organic matter from the Pleistocene; organic material in the lacustrine Green River formation of middle Eocene age, the Permian Phosphoria formation, the Devonian-Mississippian black shale suite, the Upper Cambrian Kulm of Sweden, and the Middle Cambrian Burgess shale member of the Stephen formation. A Middle Devonian terebratuloid brachiopod, which was exhibited, has maroon color bands that presumably contain original pigment and should be examined for carotenoids or protoporphyrins. Original shell material probably is preserved in calcareo-phosphatic brachiopods of Cambrian to Silurian age. Pseudokeratin or similar material is preserved in fossils representing several phyla and a wide age range. Even deposits as old as late Paleozoic contain aragonite shells, apparently original shell material protected by enclosing asphalt. Barghoorn pointed out that much material is available among fossil plants, including cellulose as old as Carboniferous, and that porphyrin has been isolated from anthracite coal of Carboniferous age. Bergmann cited Jurassic crinoids that have bright red disks, perhaps due to preservation of a quinoid pigment. The label of a Lower Jurassic squid in the British Museum is written in ink from its own ink sac.

The importance of black shales was emphasized. Lowenstam aptly designated them anerobic burial traps. They contain much unidentified organic matter and are rich in trace elements.

Suggestions.—Suggestions for biochemical studies bearing on evolution and
paleoecology were summarized and discussed by Abelson during the closing session.

Evolution in the ordinary sense is an elaboration of pre-Cambrian and possibly very Early Cambrian developments that laid the basic patterns. Anything that might give clues to pre-Cambrian evolution would be significant. Discovery and characterization of pre-Cambrian fossil biochemicals would be particularly valuable. Did the graphite in pre-Cambrian schists originate from the reduction of carbonate or was it of organic origin? Attempts have been made to differentiate organic from inorganic graphite by measurements of the ratio of $\text{C}^{12}$ to $\text{C}^{14}$. Results suggest that some of the graphite may be of organic origin, but the evidence is not conclusive. A variety of experimental tests could bring forth considerably more evidence on this question. The isotope studies could be expanded to include measurements of $\text{S}^{32}/\text{S}^{34}$ abundance ratios. The graphite could be examined for the presence of other elements usually associated with living processes, such as nitrogen, phosphorus, and sulphur. The presence of heterocyclic compounds containing nitrogen would be of particular interest. Fluorescence may reveal the presence of organic compounds in pre-Cambrian sedimentary rocks.

A systematic study of the organic and inorganic compounds found in marine black shales would be valuable. Such an investigation on shales of increasing age would provide data on the aging processes of organic compounds in geological settings. Black shales contain a relatively high concentration of certain trace elements. Some organic substances are good ionic-exchange materials and trace elements would tend to accumulate both during the life of the organism and after its death. Knowledge of the specific ensembles of elements concentrated as a result of these processes could aid in the establishment of conclusive evidence regarding past biological events.

The ratio of strontium to calcium, which is much higher in sea water than in fresh water, is a potential tool in paleoecological studies. Study of the biochemistry of calcite and apatite deposition and a study of bone formation in the bony as compared with the cartilaginous fishes would be of value, especially for paleoecology.

Biochemical studies of exceptionally preserved fossils would yield interesting results. The biochemistry of "living fossils"—such as the South African coelacanth fishes, the Port Jackson shark, and the sole surviving rhynechocephalian reptile (the New Zealand tuatara)—may give clues to patterns of biochemical evolution.

Expansion of studies on comparative biochemical processes and biosynthetic chains would provide valuable information on possible evolutionary trends. Additional studies of the biochemistry of embryological development, such as Needham's work on nitrogen excretion in the frog, might be useful in providing data on the origins of biochemical systems and the origins of differentiation.

The hope was expressed that some of the suggestions may be followed up as a part of current or new programs.

Selected Bibliography


Blum, H. E., Time's Arrow and Evolution, Princeton, 1951, 222 pp., 20 figs.


Florkin, Marcel, Biochemical Evolution (translation by Sergius Morgulis), New York, 1949, 157 pp., 25 figs.


