Meetings

Environment of the Primitive Earth

For the past few years interests of some biologists, geologists, geochemists, geophysicists, and space scientists have converged on the events early in the earth's history that were associated with the origin of oceanic and continental crust, the evolution of the primitive atmosphere into that of today, the growth of the oceans, and the origin of life. An informal research conference of 30 active workers in the fields concerned was held from 10 to 13 March 1968 at the Hoffman Laboratory of Experimental Geology at Harvard University. The conference was sponsored by the Geochemical Society, financially supported by the National Science Foundation, and directed by R. Siever of Harvard University.

F. Birch (Harvard) presented an analysis of possible changes of the gravitational constant and recent experimental data on compressibility and density of various silicate phases at very high pressures that led him to reject the hypothesis of an expanding earth. P. Morrison (M.I.T.) discussed possible terrestrial effects of the early universe and concluded that it was unlikely that there could have been significantly increased radiation from a brighter sky or supernovae explosions, thus no astronomical events that have been particularly effective on the earth as compared with the effect of the sun. F. Whipple (Harvard, Smithsonian Astrophysical Institution) inferred from the chronology of the early earth that within the first billion years solar winds may have been 10^4 to 10^7 times the present value. Solar wind plus proton flux in a primitive earth with no magnetic field may have caused the initial loss of the first primitive atmosphere. A. E. Ringwood (Australian National University) was concerned whether the primitive material of the earth had been reduced prior to accretion, or iron reduction took place afterwards. He concluded on the basis of comparison of terrestrial rocks and meteorites that heavy metal fractionation was more compatible with reduction before accretion. W. Salisbury (Harvard Observatory) described experiments on the production of lightning in dust clouds that might explain chondrule formation.

P. Hoffman (Johns Hopkins) described an unmetamorphosed sedimentary rock sequence 1.7 to over 2.5 billion years old near Great Slave Lake, Canada, that appears to be normal in every respect, including reef carbonates, red beds, and evaporites. Most striking were the photographs of what appeared to be *Scolithus* tubes (worm tubes) in rocks older than 2.17 billion years. H. Eugster (Johns Hopkins) described evaporite, sodium silicate, and silica deposits from Lake Magadi in Africa that suggested an origin for Precambrian banded iron-chert formations from evaporite lakes. J. W. Schopf (Harvard) reviewed occurrences of fossil algae up to 3.1 billion years old and indicated that the combination of fossil filamentous algae, light ratios of C^{13} to C^{12}, and presence of pristane and phytane in the earliest rocks pointed toward the early evolution of photosynthesis.

A. E. J. Engel (University of California, San Diego) developed a model for evolution of continental masses such that oceanic crust was dominant early and that the present thick continental crust accreted episodically. He further related the orogenic cycle, rates and types of sedimentation, and associated igneous rocks in unstable crustal belts to ratios of SiO_2 to MgO, K_2O to Na_2O and abundances of Rb, K, U, Th, and Pb. H. Craig (University of California, San Diego) reviewed stable carbon isotope data on crustal and mantle materials and presented recent data on diamonds that were most reasonably interpreted as evidence of heterogeneous clumps of mantle carbonaceous material whose carbon isotopes have not been homogenized. P. Hurley (M.I.T.) presented a method for estimating the abundance of trace elements for the entire earth so that he could calculate the initial concentration of radioactive nuclides and thus calculate heat production in the earth. From this came the surprising conclusion that the rate of crust formation and outgassing has been steadily increasing to the present.

R. M. Garrels (Northwestern University) estimated present rates of sediment deposition and the total sediment now present at the earth's surface. He showed how sediments have been continually cycled through the crust, calculating a "mass half-age" (one half older than, one half younger than) 6 to 8 $\times$ 10^8 years. Because of recycling, and the low probability of preserving much of the early rock record it is not possible to choose between degassing being linear with time or largely complete at an early stage. L. D. Kaplan (M.I.T.) discussed the absorption of radiation by atmospheric gases with reference to balance of solar and terrestrial radiation in early Precambrian times. His calculation of CO_2 absorption indicates that a tenfold increase in CO_2 pressure would result in a temperature increase of only one or two degrees. S. L. Miller (University of California, San Diego) discussed an atmosphere with a high content of carbon monoxide, which is both thermodynamically and kinetically unstable. In the presence of ultraviolet light or various types of ionizing radiation, CO reacts with H_2 to give formaldehyde. In addition, CO reacts with OH^- to give formate. Kinetic data for this reaction show that the CO would be depleted from the atmosphere at a geologically rapid rate for reasonable values of the temperature, *p*H, and size of the primitive ocean. Miller also discussed his recently published estimates of the limits of NH_4^+ concentration in the early ocean [Bada and Miller, *Science* **159**, 423 (1968)]. W. Broecker (Columbia) proposed a model for evolution of C^{13}/C^{12} ratios and reservoirs in sediments and the oceans. Secular trends of carbon isotope ratios in limestones, organic carbons, and shales through geologic time involve a feedback mechanism using fluctuations in oxygen in the oceans that affects the distribution of carbon between organic and carbonate phases.

H. D. Holland (Princeton) proposed that reactions of the type chlorite + calcite + CO_2 = dolomite + kaolinite + quartz + water have exerted a considerable buffering effect on atmospheric CO_2 during much of geologic time. But he suggested that before the evolution of land plants the CO_2 content of the atmosphere was approximately 10 times greater than at present, and that the *p*H of ocean water was approximately one half of a *p*H unit lower. W. T. Holser (Chevron Oil Field Research Co.), after noting the deficiency of salt and gypsum deposits in the Precambrian, pointed out the difference between the ratios of S^{32} to S^{34} of late Precambrian evaporites and organic shales as evidence of activity of sulfate-reducing bacteria at that time. He presented the secular variation of ratios of S^{32} to S^{34} in evaporites, showing pronounced variations that he attributed to non-steady withdrawal and supply of isotopically light sulfides with respect to the oceanic reservoir. L. G. Sillén (Swedish Royal Institute of Technology) proposed an equilibrium model for the oceans based on free exchange between atmosphere, ocean and crust, and dominance of silicate equilibria in controlling oceanic *p*H and atmospheric CO_2. He used the nine-component system CO_2-H_2-O-CaO-MgO-Al_2O_3-K_2O-Na_2O-HCl-SiO_2 to present probable phase relations and emphasized equilibrium models as the most important first approximation of this complex system. P. K. Weyl (State University of New York, Stony Brook) hypothesized an oceanic density gradient layer (thermocline) at a depth near 100 meters in which life may have originated and evolved. This layer would have been protected from ultraviolet radiation fed by convective cells from the sea surface and the low rate of diffusion in the layer would have led to an early accumulation of free oxygen. G. Nicholls (University of Manchester, United Kingdom) sought to infer evolutionary changes in the composition of seawater by following a chain of calculations from terrestrial abundances of trace elements to the abundance of sodium in Precambrian sediments, which seem to be richer in sodium than later rocks. He explained the richness of nitrogen as the result of lack of chemical "winnowing" during sedimentation in the early Precambrian.

The last morning was devoted to questions related to the origin of life. C. Ponnamperuma (NASA Research Center, Ames, California) described a scheme for synthesis of organic compounds from H, C, N, and O; reviewed energy sources, ultraviolet being by far the most important; and attempted to develop criteria for biogenic origin of organic compounds. J. Oró (University of Houston) discussed the evolution of self-replicating proto-DNA and similar molecules from primitive organic compounds in the early Precambrian. He argued for the need for estimates of maximum and minimum permissible concentrations of necessary building materials, such as sulfur and phosphorus. L. Margulis (Boston University) distinguished between evolution of procaryotic and eucaryotic cells and emphasized the importance of free oxygen in the atmosphere as a precondition for the evolution of eucaryotic organisms, which probably took place later in the Precambrian. A. R. Palmer (State University of New York, Stony Brook) summarized worldwide distribution of Early Cambrian faunas and concluded that shelled representatives of the major phyla and of many minor groups within the phyla all appeared within about 5 million years, but significantly later than the first records of metazoans without shells.

Discussion of papers was spirited and it appeared that there was no general agreement on the types of models to be used for the evolution of the earth's crust or for the evolution of the oceans or atmospheres. Equilibrium models vied with complex feedback mechanisms for support. The rock record was invoked to support many models but our current ways of looking at it seem not to provoke convergence to a unique solution. There was more general agreement that much of the Precambrian rock record showed no great differences from later rock sections in gross aspect. It seems that the general earth surface system, including the presence of primitive life, was established by 3.5 billion years ago, leaving only the first billion years of the earth's history for many significant events to have taken place. In the absence of any rock record of that first billion years, it may be that organic chemical investigations of the first steps in the formation of prebiogenic compounds and then the evolution of the first cell will prove to be the best guides to the nature of the physical and chemical environment of the earliest stage of earth history.

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