the two editions of the topographic sheets. The contour lines on the 1901 and 1955 topographic sheets agree closely, except for the effect of building construction since 1901. Because both Bruckner Boulevard and Country Club Road existed in 1901, their elevations tightly control any possible removals of earth between these dates that are not explicitly shown. There is no evidence of such removals. Thus the first two of the four possibilities probably can be safely dismissed.

Six holes were drilled at the road intersection in 1958 during preparation for construction of the overpass. These holes, numbered J-5 through J-10, went through sand, silt, and rarer "gravel" (4 to 6 m in thickness, depending on the hole) underlain by a zone of disintegrated gneiss; the holes bottomed in Precambrian and Lower Paleozoic crystalline rocks which are the prevailing country rocks in this area (*5, 6*). Nothing that may be interpreted as Triassic or Upper Paleozoic bedrock was recorded. It appears that the fossil-bearing rock was indeed a large glacial boulder.

A glacial-boulder interpretation, however, leads to problems. The boulder seems much too fresh to be derived from an earlier glacial advance. Derivation of the boulder from basal Cretaceous strata in the lower Hudson valley or southwestern Connecticut, now totally removed by erosion, cannot be ruled out, but large boulders have not been found in basal Cretaceous beds in the Long Island–Staten Island area and seem unlikely. Another hypothesis, that the boulder came by ice-rafting from the extensive Carboniferous basins of the Maritime Provinces in eastern Canada, cannot be ruled out, but it too seems a remote likelihood because of the great distance in an odd direction.

The dominant direction of movement of continental ice sheets of Wisconsin age during Pleistocene glaciation in the area of New York City is considered to be north–south (*5*), but the only reasonable source of undeformed, unmetamorphosed Pennsylvanian rocks is the anthracite region of eastern Pennsylvania, almost 130 km due west of the Bronx. If the boulder did come from eastern Pennsylvania, a rather thick sheet of ice (to overcome the major north–south ridges such as Kittatinny Mountain) would have been needed, and our ideas on the direction of movement of ice would have to be drastically revised. Rather, the boulder suggests to us the existence along the Hudson valley of hitherto overlooked outliers of Pennsylvanian rocks.

Carboniferous basins of deposition extend from western Newfoundland, central and southern New Brunswick, Nova Scotia, Rhode Island, and eastern Massachusetts, to Pennsylvania. Rocks in the Narragansett basin of Rhode Island are severely deformed and metamorphosed (*7*), and those in the Maritime Provinces are only locally deformed and metamorphosed (*8*), whereas those of Pennsylvania are mildly deformed but unmetamorphosed. A possible location of a basin of deposition in the Hudson valley would be on trend with the major basins; the fact that these specimens are free of deformation and metamorphism would then place significant restrictions on the extent of late Paleozoic diastrophism in the northern Appalachian region.

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References and Notes

1. Identified by D. B. Seaman, Museum of Natural History, New York.
2. By Gary Zippelius.
3. E. N. Goddard *et al.*, *Rock-Color Chart* (National Research Council, Washington, D.C., 1948) (republished by Geol. Soc. Amer., 1951).
4. C. B. Read and S. H. Mamay *U.S. Geol. Surv. Profess. Paper 454-K* (1964), p. K1.
5. F. J. H. Merrill, N. H. Darton, A. Hollick, R. D. Salisbury, R. E. Dodge, B. Willis, H. A. Pressey, *U.S. Geol. Surv. Geol. Atlas* (1902), folio 83.
6. C. K. Seyfert and D. J. Leveson, in *Program Geol. Soc. Amer. Northeastern Sect. Ann. Meeting 3rd Washington, D.C.* (1968), p. 54.
7. A. W. Quinn, in *Guidebook New Engl. Intercoll. Geol. Conf. Ann. Meeting 55th Providence, R.I.* (1963).
8. J. C. Smith, in *Guidebook Geol. Assoc. Can.–Mineral Assoc. Can. Ann. Meeting Halifax, N.S.* (1966); D. G. Kelley, *Geol. Assoc. Can. Spec. Paper 4* (1967), p. 213.
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Precambrian Marine Environment and the Development of Life

Abstract. *The tropical thermocline must have existed since the ocean's depth exceeded 300 meters. The density gradient in this layer concentrated organic aggregates formed abiologically near the surface of the sea, and the low rates of diffusion across this layer permitted the accumulation of oxygen once the layer was populated by blue-green algae; thus the evolution of eukaryotes became possible within the layer. Because of rapid mixing over the shelves, the eukaryotes were restricted initially to the thermocline over deep water. The shelves could not be permanently inhabited by organisms requiring respiration until the oxygen level of the atmosphere was adequate. At this stage, the swimming Metazoa of the thermocline could adapt to a benthic environment on the shelves by developing exoskeletons.*

In order to investigate the origin and early evolution of life on Earth one must consider the Precambrian environment. Our knowledge of Precambrian paleooceanography is extremely limited, and so the Precambrian ocean has usually been characterized by a single value for its parameters as if it had been a well-mixed system. A more realistic reconstruction of the Precambrian ocean may lead to new insights into the early development of life on Earth.

The distribution of noble gases on Earth and in stars indicates that Earth initially lost its fluid envelope, and that the present ocean and atmosphere must have accumulated from outgassing of Earth's interior (*1*). Thus the volume of the oceans has increased with time during the last 4×10^9 years. If the ratio of outgassing of chlorine and water remained relatively constant, the salinity of sea water did not vary greatly; thus its density has probably always been a function of salinity as well as temperature.

The volume of the oceans increased significantly during Precambrian times and approached its present value at the beginning of the Cambrian. This increase in volume does not necessarily imply an increase in the fractional area of Earth covered by the oceans. If, as is probable, the evolution of continental crust paralleled the outgassing of the mantle, the ocean became deeper with time, while covering approximately the same area.

As a first approximation we can consider the ocean to consist of three superimposed layers: a seasonally variable mixed surface layer, a layer in which the density increases rapidly with depth, and a more uniform deep layer. In low latitudes the density gradient in the intermediate layer results primarily from a decrease in temperature (thermocline), while in high latitudes the density gradient results from increase in salinity with depth (halocline). The two upper layers extend to a depth of only about 200 m, while the third layer comprises most of the ocean.

The density-gradient layer results from the latitudinal variation of the insolation at the top of the atmosphere, which in turn results from the spherical shape of Earth and the inclination of its axis to the plane of its orbit. The latitudinal variation of the heat received results in a poleward transport of heat by winds, as latent heat of vaporization, and by ocean surface; thus the temperature difference across the thermocline has varied significantly over geologic time. When the temperature gradient was great, the salinity gradient also was great; during times of low temperature gradient the more rapid circulation resulted in a lesser salinity gradient. Since heat and salt affect the density oppositely, the density gradient across the thermocline has varied relatively little.

During the Precambrian the gross density structure of the two upper layers probably differed little from the present configuration. As soon as the ocean became deeper than 300 m, the vertical layering must have been similar to that of today's ocean. The Precambrian density-gradient layer, particularly the thermocline between 30°N and 30°S, may have played an important role in the origin and Precambrian evolution of life.

The initial surface environment being devoid of oxygen (*2*), ultraviolet light from Sun penetrated the upper 10 m of the ocean (*3*). The ultraviolet irradiation of the reducing atmosphere and ocean led to abiotic photosynthesis of organic molecules (*4*). Bernal (*5*) has suggested that this organic matter became concentrated by absorption on mineral grains on the seashore where it was polymerized into coacervate drops. An alternative mechanism for concentration is provided within the ocean. In today's ocean, surface-active dissolved organic matter is swept to the surface by rising bubbles and compressed into lines of convergence by the Langmuir circulation, where it is polymerized into particulate organic matter (*6*).

In the present ocean, the dissolved organic matter is derived from organisms, and the particulate organic matter produced sinks in the zones of convergence, where it is consumed by zooplankton. In the early ocean, the organic molecules would have been produced by abiotic processes, and the aggregates would not have been consumed. Depending on their bulk densities, the aggregates would have been concentrated in the density-gradient layer and on the ocean bottom. The steepest density gradients, and hence the largest concentrations, would have accumulated in low latitudes on both sides of the equator, where the present density increases from 1.023 to 1.026 between 50 and 100 m. Once removed from the sea surface, the organic aggregates would have been shielded from ultraviolet radiation. Prokaryotic heterotrophs could have evolved either at the ocean bottom or within the density-gradient layer where there was a concentration of organic aggregates and where they were shielded from ultraviolet radiation.

Conditions for the evolution of photosynthetic prokaryotic autotrophs would have been optimum in the tropical thermocline which was shielded from ultraviolet radiation while visible sunlight penetrated this layer. Evolution would have proceeded at constant density, since cells that became too heavy would have sunk below the illuminated region, while a reduction in density would have carried the cells into the mixed surface layer where they would have become exposed to ultraviolet radiation. The thermocline is a more extensive and more stable environment than the bottom of the shallow seas.

Vertical convection across the density-gradient layer is very slow, so that significant oxygen concentrations would have accumulated in the thermocline once oxygen was evolved by the blue-green algae. By use of data from the low-productivity regions of the present tropical oceans, an oxygen production rate of 1 mole m^{-2} $year^{-1}$ would have led to an oxygen partial pressure in the themocline equivalent to about 3 percent of the present atmospheric level.

Oxygen that diffused from the thermocline would have been mixed rapidly into the atmosphere and the underlying sediment—where it would have been used for oxidation of reduced minerals. If the algae were primarily restricted to the density-gradient layer, that layer would have had a significant concentration of oxygen while the concentration in the rest of the ocean and the atmosphere would have been very low until the products of weathering were oxidized. Thus the thermocline probably was an extensive, stable, oxygenated environment for the evolution of eukaryotic cells. This environment was more extensive in time and space than the microenvironment postulated by Fischer (*8*).

Where the thermocline intersected the sea floor, mixing would have been enhanced by the breaking of internal waves and by upwelling. As a result of rapid diffusion, the oxygen content of the water over the continental shelf would not have been significantly greater than that of the atmosphere. Therefore the early animals probably were planktonic and restricted to the density-gradient layer over the deeper parts of the oceans. The evolution of a skeleton would have been strongly inhibited since such organisms would have sunk out of the oxygen-containing layer unless their bulk densities were maintained constant by the simultaneous evolution of flotation mechanisms.

Blue-green algae were able to carpet the bottoms of the continental shelves, where development of a shallow seasonal thermocline would have provided temporary concentrations of oxygen. Thus organisms that evolved active swimming mechanisms could have seasonally exploited the food resources on the continental shelves. As winter mixing reduced the oxygen concentration on the shelves, these organisms had to return to the deep-water thermocline region to survive. Only after the atmospheric concentration of oxygen became sufficiently high could the continental shelves have been permanently inhabited by animals. At that time the organisms could have adapted to a benthic habit and increased their bulk density by skeletogenesis. This transition supposedly occurred at the beginning of the Cambrian.

If the blue-green algae in the open ocean were concentrated in the tropical thermocline as I have suggested, an environment containing sufficient oxygen for the evolution of Metazoa existed earlier than 10^9 years before the Cambrian. The early animals could not permanently populate the continental shelves and could not readily evolve a skeleton; thus the probability of their preservation in the fossil record would have been small. Without a Precambrian thermocline, one is forced to assume a very rapid rate of evolution for the Metazoa once the concentration of oxygen in the atmosphere was adequate for respiration (*9*). The thermocline, however, provided an extensive offshore environment between about 50 and 150 m that probably was oxygenated and within which floating and (later) swimming animals were able to evolve. The existence of a seasonally oxygenated continental-shelf environment, carpeted by algae, would have offered an adaptive advantage to organisms that evolved swimming mechanisms. Once the atmospheric concentration of oxygen became sufficient, these swimming organisms could have adapted to a benthic habit on the shelves. At this stage, density would no longer have been a problem, and the organisms could have evolved skeletons. In the early stages these exoskeletons would have provided an adaptive advantage as ultraviolet shields and would have permitted the organisms to seal themselves from the environment to survive temporary anoxia. According to my hypothesis the beginning of the Cambrian marks the first time Metazoa could permanently occupy the floors of the continental shelves.

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References

1. W. W. Rubey, *Bull. Geol. Soc. Amer.* **62**, 1111 (1951).
2. H. D. Holland, *Proc. Nat. Acad. Sci. U.S.* **53**(6), 1173 (1965).
3. L. V. Berkner and L. C. Marshall, *J. Atmos. Sci.* **22**, 225 (1965); **23**(2), 133 (1966).
4. S. L. Miller, "Formation of organic compounds on the primitive earth," in *The Origin of Life on the Earth*, F. Clark and R. L. M. Synge, Eds. (Pergamon, New York, 1959), vol. 1.
5. J. D. Bernal, in *Oceanography*, M. Sears, Ed. (AAAS, Washington, D.C., 1961), pp. 95–118.
6. W. H. Sutcliffe, Jr., E. R. Baylor, D. W. Menzel, *Deep-Sea Res.* **10**, 233 (1963).
7. W. J. Schopf, "Antiquity and evolution of Precambrian life," in *McGraw-Hill Yearbook of Science and Technology* (McGraw-Hill, New York, 1967).
8. A. G. Fischer, "Fossils, early life, and atmospheric history," in *Proc. Nat. Acad. Sci. U.S.* **53** (15 June 1965).
9. P. E. Cloud, "Premetazoan evolution and the origins of the Metazoa," in *Evolution and Ecology*, E. Drake, Ed. (Yale Univ. Press, New Haven, Conn., 1968).

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Gels Composed of Sodium-Aluminum Silicate, Lake Magadi, Kenya

Abstract. *Sodium-aluminum silicate gels are found in surficial deposits as thick as 5 centimeters in the Magadi area of Kenya. Chemical data indicate they are formed by the interaction of hot alkaline springwaters (67° to 82°C; pH, about 9) with alkali trachyte flows and their detritus, rather than by direct precipitation. In the process, Na_2O is added from and silica is released to the saline waters of the springs. Algal mats protect the gels from erosion and act as thermal insulators. The gels are probably yearly accumulates that are washed into the lakes during floods. Crystallization of these gels in the laboratory yields analcite; this fact suggests that some analcite beds in lacustrine deposits may have formed from gels. Textural evidence indicates that cherts of rocks of the Pleistocene chert series in the Magadi area may have formed from soft sodium silicate gels. Similar gels may have acted as substrates for the accumulation and preservation of prebiological organic matter during the Precambrian.*

Natural silicate gels have been reported in several localities and geologic environments (*1*). During field studies of the area of Lake Magadi, Kenya, we have encountered silicate gels containing substantial amounts of sodium and aluminum; we believe that they bear directly on the formation of authigenic zeolites in many lake beds; perhaps also on certain chert deposits.

Lake Magadi lies in the Eastern Rift Valley, Kenya, at 2°S (Fig. 1); it is a highly alkaline lake containing a large deposit of trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). Little Magadi, or Lake Nasikie Engeda, lies 1.6 km north of Lake Magadi from which it is separated by a narrow horst. Both lakes occupy closed basins. Lake Magadi is intermittently dry, while Little Magadi is perennially saline. Inflow is predominantly from a series of hot springs around the edges of the basins. The geology and geochemistry of the area (*2*) and the silica content of the waters (*3*) have been reported.

Silicate gels were found in two locations: near the hot springs that feed Northeastern Lagoon, north of Lake Magadi (48 in Fig. 1); and north of Little Magadi, near spring 14 (Fig. 1) and where the river of hot water formed by 62 (Fig. 1) enters the lake. The gels form surficial deposits as thick as 5 cm, some of which are covered by a thin, leathery skin of algal material (Fig. 2). This algal mat does not seem to be involved directly in precipitation of the gels; rather it protects them from erosion. The gels occur in almost stagnant pools of hot water on the banks of inflow channels; at Little Magadi they cover the entire lakeshore to a width as great as 30 m; they have not been found in moving water. Near some springs, deposition is restricted to the spring orifice and the immediately adjacent area. Some of the gel above water level is covered by an efflorescent crust of sodium carbonate–bicarbonate minerals.

In consistency the gels vary from soft, water-logged gelatin [resembling in texture certain material from Hawaii (*4*)] to rubber cement; they usually contain considerable amounts of organic material as well as detrital sand and silt of the unconsolidated alluvial sediment on which they are deposited. This silt and sand are rich in alkali feldspar and seem to derive predominantly from the Pleistocene alkali trachyte flows (*2*) that form the hills and scarps surrounding the basins. The springs issue directly from or from close to the bases of these flows. Total discharge

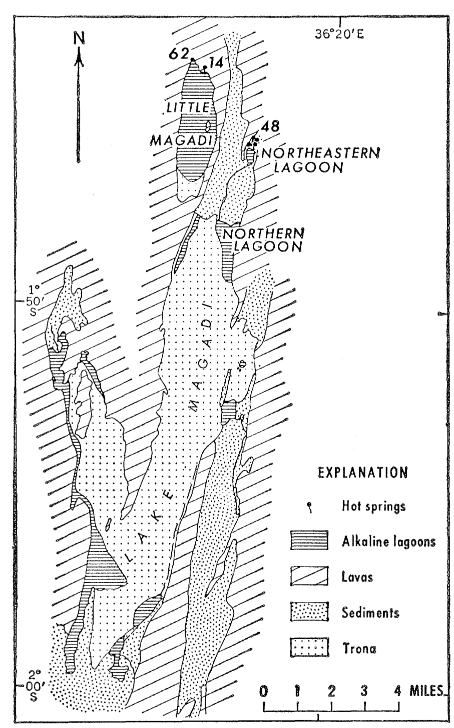

Fig. 1. Lake Magadi, Kenya; modified from Baker (*2*). Numbers (1966 numbers in Table 1) identify the hot springs with which the gels are associated.