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netic and geographic axes is not fortuitous. Magnetization studies in rocks up to 50 million years old locate the magnetic poles in clusters about the geographic poles. Theoretical studies of the probable pattern of fluid motions in the core (where the magnetic field is believed to have its origin) indicate that the earth's magnetic field, when observed over a long period of time, should be symmetrical about the geographic axis. Thus it seems reasonable to believe that when these rocks were magnetized, the geographic axis was about 45° away from its present position. On the basis of this picture, it can be said that about 200 million years ago the equator crossed lower California, west Texas, Massachusetts, Gibraltar, Kenya, and Tasmania.

An interesting possibility that is suggested by the magnetizations of these rocks is that the sense of the earth's magnetic field has reversed; i.e., the north and south magnetic poles have exchanged positions. But this possibility cannot be confirmed solely on the basis of observations of the sense of magnetization of rock samples, because it is known that in nature the direction of magnetization of some specimens under appropriate circumstances can undergo a spontaneous self-reversal of direction. Criteria for determining whether or not a given specimen has undergone the self-reversal process have not yet been established; and thus, even though the sense of magnetization of many samples of Permian and Triassic rocks implies reversals of the earth's field, the possibility remains that actually the field has maintained a constant sense. The whole problem remains as one of the most interesting and baffling in the subject of rock magnetism.

At the beginning of the report year, we made some observations bearing on the problem of the overprinting of original magnetizations. In some New York state Devonian limestone beds, which by very localized slumping had been greatly deformed very soon after their deposition

while they were still essentially unconsolidated and plastic, we observed that the magnetization directions throughout the deformed structures were practically uniformly oriented, and not in the direction of the earth's present magnetic field. Using the techniques developed by Dr. P. H. Abelson, of the Geophysical Laboratory, the amino acids present in the fossils of the limestone were isolated and identified. Although the concentration of amino acids amounted to only a few parts per million, the nature of the assortment of identified species strengthened the belief, earlier advanced on the basis of geological evidence, that these particular beds had never been subjected to extensive heating. Thus, from this and from other experiences we must conclude that lack of elevated temperatures during the history of a sediment may be a necessary but is not a sufficient condition for the preservation of primary magnetizations acquired at the time of deposition.

ISOTOPE DATING OF ANCIENT MINERALS

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In the report of this group one year ago it was mentioned that our initial aims of measuring, comparing, and evaluating mineral ages by the different naturally occurring radioactive elements uranium, thorium, rubidium, and potassium, all extracted from the same rock sample, had been partially achieved with the measurements on the minerals in the Quartz Creek region, Gunnison County, Colorado. The process of measuring comparative ages and evaluating the results has been extended this year to several other localities, has been applied to several new minerals for the different elements, and has seen the measurement of potassium-argon ages for most of the minerals to which our methods for rubidium-strontium had previously been applied. As a result of this extension, we believe that we are now ready to begin

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tions can be made, in most laboratories a thickness of 30 microns is standard. Thus the bias given above may be written as $[(3)(30)]/4r = 22.5/r$, where r is now in microns. The bias obviously is relatively small if r is of the order of the diameter of opaque granules encountered in most plutonic rocks. In most of these rocks, furthermore, the total amount of opaque material is small, so that, even if the grains were sufficiently spherical to permit application of the appropriate correction, the procedure would hardly be worth while. In the analysis of fine-grained sediments, however, and particularly of those rich in finely divided organic matter, the situation is quite different. If $r = k$, for instance, the observed result is high by 75 per cent; and for r considerably less than k , something not at all uncommon in rocks of this type, the "correction" factor can easily become so large that one would hesitate to use it under any circumstance.

The difficulty arises because the theory of modal analysis requires that areas be measured on a surface, and if one of the

constituents is opaque this surface cannot be located with sufficient accuracy. But similar difficulty may also be encountered in the absence of opaque material. Most of the members of a swarm of albite stringers in a grain of perthite, for instance, may be below the surface of the thin section, yet all may show the appropriate refringence and birefringence. They are all albite, but only those which actually intersect the surface should be recorded in the analysis. A finite thickness is indispensable in making the identifications, but the measurement is only of the surface. When the intersections of grain sections with the surface cannot be suitably located, the lower limit of modal analysis has been reached. This limit will vary with the optical properties, form, and habit of the minerals involved. There is room for a careful experimental study of the problem; such a study would appear to be almost a prerequisite in the establishment of reliable analytical techniques for the fine-grained sediments and partially glassy volcanic rocks.

PALEOBIOCHEMISTRY

Organic constituents of fossils (Abelson). The organic constituents of the earth's crust provide the key to the answer to many important questions and raise others. Some of these are of great philosophic interest, such as: What was the origin of life? What can be said about the nature of biochemical processes of extinct animals? Other questions have important practical facets: What is the origin or origins of petroleum? What are the chemical processes involved in the formation of coal?

The research program of the past year in paleobiochemistry has been aimed at providing information which may help in answering some of these great questions. Central to all these problems is the behavior of organic substances in geological environments.

For this purpose it was illuminating to

study the fate of organic matter incorporated in shells and bones. The clam shell from *Mya myarenaria* was employed to check the effect of relatively short exposures to geological environments. Through the courtesy of Wilmot Bradley, recent specimens of this shell and items dated by Lawrence Kulp at 1000 years could be compared. Solution of the recent shell in dilute hydrochloric acid left a residue of filamentous light-colored protein. The 1000-year-old specimen yielded protein which was amber-colored and had only a relatively limited mechanical strength. Tests were made to determine total protein content and comparative amino acid analysis. Results were identical on the two types of specimen.

In another experiment, shells were dissolved in a mixture of dilute hydrochloric acid and trichloroacetic acid. Insoluble pro-

tein was removed from the mixture by centrifugation. The clear supernatant solution was examined as to its content of free amino acids, peptides, or soluble protein. A negligible amount was found in each case, a fact which shows that the proteins of the 1000-year-old shell had not been broken into fragments of low molecular weight.

For studying older materials the clam *Mercenaria mercenaria* was a convenient object. This edible hard-shell clam, which lives today, is represented by fossil specimens dating back 30,000,000 years. Specimens of Pleistocene age were made available by Wendell Woodring. These were originally collected at Wales Bluff, Virginia, and on geologic evidence are thought to be in the range 100,000 to 1,000,000 years old. Comparison of recent and older specimens showed that marked changes had occurred in the fossil proteins. The material isolated by the usual protein precipitants was a black, tarry substance which could scarcely be called a protein, although it yielded amino acids on hydrolysis. Examination of the clear supernatant solution revealed that it contained peptides and free amino acids. The total amino acid content of the Pleistocene shell was only 18 per cent of that found in recent shells.

When Miocene (30,000,000-year-old) shells were examined, amino acids were found, but no traces of proteins or peptides could be detected. These results are summarized in table 1.

A picture emerges. Initially most of the protein of the shell is present in water-insoluble layers. For thousands of years only moderate changes occur, which do not affect the solubility of the protein. By the time 1 to 5 per cent of the peptide bonds are broken (10,000 to 100,000 years), the protein fragments are much more soluble and some can be leached out of the shell. Some of the amino acids or peptides are probably entrapped in the aragonite structure. Ultimately in the presence of water these peptide bonds are broken, leaving

only free amino acids in the shell. It is of interest to note in table 1 that the free amino acid content of the shell changed only moderately in the period from 1,000,000 to 30,000,000 years.

Examination of bones from the La Brea tar pit in Los Angeles yielded an interesting result. These fossils were preserved in an asphalt matrix for perhaps 100,000 years. Total amino acid content of several specimens of bone was 10 to 12 per cent. Studies of the peptide linkage showed that there were virtually no free amino acids and that the amino acids remained linked together. Undoubtedly the asphalt had several protective functions. It provided an essentially sterile, anaerobic environment

TABLE 1
AMINO ACID CONTENT OF *Mercenaria mercenaria*

AGE	AMINO ACID CONTENT (μ MOL/G)		
	Protein bound	Soluble protein or peptide	Free
Recent	33.0	1.5	<0.35
Pleistocene	2.1	2.25	1.0
Miocene	0	0	0.75

in which the concentration of water was very low.

The results from these studies have significance in two areas: (a) Pleistocene dating and (b) theories of the origin of life.

Dating by C^{14} methods is limited by the 5300-year half life of this isotope. Under favorable conditions specimens as old as 40,000 years may be measured. On the other hand, uranium-lead and rubidium-strontium time clocks are not suitable for times as short as 1,000,000 years. There is thus a very important period which cannot be accurately dated. In this period the culminating evolution of man occurred, and the great ice ages, whose dates should be better known to establish a possible pattern of recurrence. The time rate of degradation of proteins in fossils could, in prin-

ciple, provide a dating method. This method could not have the accuracy of the schemes based on radioactivity, but might nevertheless be useful. It would be particularly interesting to correlate isotopic measurements on shells with such dating. From this could come a measure of the temperature of the marine environment at the time of formation of the shells.

Studies of the stability of organic substances are of particular interest to those concerned with possible mechanisms of the origin of life. Recent studies by Miller and Fox have demonstrated two methods by which some of the key amino acid building blocks could be synthesized under terrestrial conditions by nonvital processes.

Synthesis of peptides by nonbiological means has also been demonstrated. One can therefore visualize a primitive environment in which amino acids and peptides were present. Rate of degradation is the factor limiting the ultimate concentration of these key substances. Work at the Geophysical Laboratory has demonstrated that most of the amino acids are sufficiently stable to endure for millions of years at moderate temperatures. The new results on proteins show that peptide bonds may endure for as much as a million years even in a moist environment. Under special conditions where water is not present, peptides would probably be stable for even longer periods.

RADIOACTIVITY

Low-background counting (Libby, Abelson). Naturally occurring radioactive substances provide the key to many geochemical and geophysical problems. C^{14} dating of carbon-containing materials is a typical example of the kind of problem that may be approached. Tritium has many applications in meteorological and ground-water investigations. Recent work elsewhere has demonstrated that other light-radioactive substances are produced through action of cosmic rays.

Measurement of these substances is not easy, since intensities are low and radiations emitted are usually easily absorbed. Special equipment permitting high counting efficiency and low background, originally developed at the University of Chicago, has now been installed at the Geophysical Laboratory. One use for this equipment is in the study of reaction rates. Reactions involving C^{14} -tagged compounds can be studied even if the time required for the process to proceed halfway is as long as 10,000 years. Conway at the University of Chicago has been studying the thermal degradation of alanine. The stability of some of the organic constituents of fossils, petroleum, shale, and coal can now be determined at the Geophysical Laboratory.

"Hot atom" chemistry (Libby, Abelson). Nuclear reactions often lead to the formation of radioactive isotopes, and usually the newly formed nucleon has a considerable amount of kinetic energy. In some cases this may amount to 20,000 electron volts, a value far in excess of chemical binding energies. These newly formed isotopes are accordingly called "hot atoms."

If a substance such as alanine ($C_3H_7NO_2$) is exposed to neutrons in a nuclear reactor, some of the nitrogen is converted to C^{14} . The newly formed atom travels for a short period at high velocity in the neighboring alanine molecules. Its ultimate fate is not at present predictable. Some experiments have been carried out at the Geophysical Laboratory to study this problem. Alanine was irradiated with neutrons at the Argonne National Laboratory. The alanine was dissolved in water and repeatedly recrystallized from an alcohol-water mixture. After six crystallizations, specific activity of the product reached a constant value. It was determined that 8 per cent of the hot C^{14} atoms came to rest as part of alanine molecules, apparently as a result of a billiard-ball-type collision in which C^{14} replaced one of the carbon atoms.