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Isotopes in Earth Science

Improvements in instrumentation have increasingly affected the ways in which research in the earth sciences is conducted. An example is a proliferation of equipment capable of providing accurate data concerning isotopes of beryllium, carbon, nitrogen, sulfur, rubidium, strontium, neodymium, samarium, rhenium, osmium, lead, and uranium. Measurements of isotopes of these elements provide crucial data concerning earth history, heterogeneities in the earth's mantle, subduction of tectonic plates, paleotemperatures and atmospheres, and biogeochemistry.

Stable and radioactive isotopes have been used for many years to provide information relevant to earth science. But during the past 5 years, precision and sensitivity of measurements have greatly improved. The desirability and practicality of employing ^{10}Be (with a half-life of 1.5 million years) and ^{187}Re (half-life 43 billion years) have been demonstrated.

More than one radioactive clock is used in dating old rocks. A favorite and perhaps most trustworthy one is uranium-lead preserved in zircons. The rubidium-strontium and samarium-neodymium clocks are also commonly employed. The rhenium-osmium chronometer is being developed. Its attractive features guarantee that it will become important, particularly in dating ultramafic rocks.

Some of the earth history of the last 570 million years was deciphered employing paleontological evidence. However, events occurring between 4500 and 570 million years before the present were only partially known. Earth tectonic processes occurring then may have differed from those now prevalent. In those earlier times the heat emanating from the interior of the earth was substantially greater than that flowing at present.

In Canada there are large areas where Precambrian rocks are exposed, and the Canadians are world leaders in studying ancient events. They have perfected radioactive dating techniques and are able to detect differences of age of 2 million years in rocks that are 2700 million years old. Their work has practical applications in the discovery of ore deposits.

Scientists at the Australian National University have developed and have at present the sole copy of a Super-High Resolution Ion Microprobe (SHRIMP), which has enabled them to date a series of spots on a polished section of zircon at 4100 years before the present.

Samples of the mantle are obtained when xenoliths are violently propelled from depths. Slabs of the mantle have been brought to the surface. Magma (partially contaminated with crust) can also be studied. Isotopic measurements conducted on such samples testify to the heterogeneity of the mantle. In these studies the strontium isotopes are particularly useful.

Small amounts of ^{10}Be are formed by the action of cosmic rays on atmospheric oxygen. The radioactive isotope falls to the surface and is incorporated in sediments (about 10^{-17} g/g) at the top of tectonic plates. When the plates are subducted, the ^{10}Be is carried along down and, ultimately, when magma is formed at about 150-km depth, the ^{10}Be accompanies it upward. Half-gram samples of the rock are processed, together with a known amount of ^{9}Be. The abundance of the ^{10}Be is determined by accelerator mass spectrometry; high-energy ions of ^{10}Be are individually counted.

This type of equipment has also been applied to determinations of ^{14}C ages. The measurements can be conducted comparatively rapidly and require smaller samples than the older beta-counting procedure. An important application for the method relevant to possible greenhouse phenomena will be a determination of the rate at which $^{14}CO_2$ from earlier atmospheric bomb tests moves downward in the ocean.

Chemical compositions of phytoplankton membranes change in response to sea-surface temperatures. Organic compounds associated with these changes can be recovered from sedimentary rocks as old as 200 million years. The variations in abundance correlate with the oxygen isotopic temperature scale.

Evidence concerning food sources for humans and ecological webs can be obtained by measuring carbon and nitrogen isotope ratios of organic matter recovered from fossil bones.—PHILIP H. ABELSON

Under the chairmanship of Peter Wyllie of Caltech, a National Research Council report delineating opportunities in the earth sciences is being prepared. It will cover in detail phenomena studied by applications of isotopes as well as many other phenomena, some of which are highly relevant to present-day societal concerns.