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Stable isotope geochemistry

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DESCRIPTION

Isotopic geochemistry has several principal roles in geology. One is concerned with the enrichment or impoverishment of certain isotopic species that results from the influence of differences in mass of molecules containing different isotopes. Measurements of the proportions of various isotopic species can be used as a form of geologic thermometer. The ratio of oxygen-16 to oxygen-18 in calcium carbonate secreted by various marine organisms from calcium carbonate in solution in seawater is influenced by the temperature of the seawater. Precise measurement of the proportions of oxygen-16 with respect to oxygen-18 in calcareous shells of some fossil marine organisms provides a means of estimating the temperatures of the seas in which they lived. The varying ocean temperatures during and between the major advances of glaciers during the ice ages have been inferred by analyzing the isotopic composition of the skeletons of floating organisms recovered as fossils in sediment on the seafloor. Other uses of isotopic analyses that involve temperature-dependent rate processes include the progressive removal of crystals from cooling igneous magmas.

Stable Isotope Geochemistry is an introduction to the use of stable isotopes in the geosciences. It is subdivided into three parts: theoretical and experimental principles; fractionation processes of light and heavy elements; the natural variations of geologically important reservoirs. Since the application of stable isotopes to earth sciences has grown in the last few years, a new edition appears necessary. Recent progress in analysing the rare isotopes of certain elements for instance allow the distinction between mass-dependent and mass-independent fractionations. Special emphasis has been given to the growing field of "heavy" elements. Many new references have been added, which will enable quick access to recent literature. For students and scientists alike the book will be a primary source of information with regard to how and where stable isotopes can be used to solve geological problems.

The origin and fate of elements and their compounds (such as in fluids, metals, nutrients, organics, gases, and pollutants) in planetary, Earth, and environmental sciences is most effectively traced using stable-isotope geochemistry. Isotopes of an element are atoms having the same number of protons but different numbers of neutrons. All but 35 elements have more than one stable isotope that can be used to trace the element through various natural systems. In contrast to unstable (radioactive) isotopes or isotopes produced from the decay of another element (radiogenic), stable-isotope geochemistry uses isotopes whose abundances do not change with time. For example, oxygen has three stable isotopes, each having eight protons, but 99.763% of oxygen atoms have eight neutrons (16O, where 16 is the atomic number and refers to the sum of protons plus neutrons), while 0.0375% have 9 (17O) and 0.1995% have 10 (18O). The three isotopes of oxygen share the same general chemical properties, but differ in mass and therefore form bonds with slightly different energies, which results in differential partitioning of the light and heavy isotopes of oxygen among various compounds.

Although chemical processes involve only the electrons of atoms, atomic mass does play a role in the chemical and physical behavior of atoms. This leads to slightly different behavior of the various isotopes of an element, which in turn leads to variations in the ratios of isotopes within the Earth and the Solar System. Stable isotope geochemistry began with the study of a few of the lightest and most abundant elements, H, C, N, O, and S, that exhibited large variations in isotopic composition.

Stable isotope geochemistry is the study of natural variations in the isotopic composition of elements that occur as a consequence of chemical and physical processes other than radioactive decay in the Earth and Solar System.

Another role of isotopic geochemistry that is of great importance in geology is radiometric age dating. The ability to quantify the geologic time scale—i.e., to date the events of the geologic past in terms of numbers of years—is largely a result of coupling radiometric dating techniques with older, classical methods of establishing relative geologic ages. As explained earlier, radiometric dating methods are based on the general principle that a particular radioactive isotope (radioactive parent or source material) incorporated in geologic material decays at a uniform rate, producing a decay product, or daughter isotope. Some radiometric “clocks” are based on the ratio of the proportion of parent to daughter isotopes, others on the proportion of parent remaining, and still others on the proportion of daughter isotopes with respect to each other. For example, uranium-238 decays ultimately to lead-206, which is one of the four naturally occurring isotopic species of lead. Minerals that contain uranium-238 when initially formed may be dated by measuring the proportions of lead-206 and uranium-238; the older the specimen, the greater the proportion of lead-206 with respect to uranium-238. The decay of potassium-40 to form argon-40 (calcium-40 is produced in this decay process as well) is also a widely used radiometric dating tool, though there are several other parent-daughter pairs that are used in radiometric dating, including another isotope of uranium (uranium-235), which decays ultimately to form lead-207, and thorium-232, which decays to lead-208.