HELIUM ISOTOPES

The two naturally occurring isotopes of helium are ^{3}He and ^{4}He. ^{3}He is much less abundant than ^{4}He; the atmospheric ^{3}He/^{4}He ratio (R_a) is 1.39×10^{-6}. Nearly all the terrestrial ^{4}He has been produced as alpha-particles from the radioactive decay of ^{238}U, ^{235}U and ^{232}Th over geological time. By far the most important terrestrial source of ^{3}He is degassing of primordial volatiles from the Earth's interior. Other sources include auroral precipitation of solar wind, accretion from cosmic rays, and flux of cosmic dust and meteorites. Small amounts of ^{3}He are also produced during radioactive decay of U and Th as a result of neutron interactions with Li according to the reaction $^6\mathrm{Li}(n,\alpha)^3\mathrm{H} \rightarrow {}^3\mathrm{He}$. The neutrons are produced by alpha-particle interactions on target elements such as Mg, Si and O in the host rock. This results in a low ^{3}He/^{4}He production ratio (typically $< 0.02R_a$), even in crustal rocks that are relatively enriched in Li. Consequently, the terrestrial ^{3}He/^{4}He ratio varies by several orders of magnitude, from high values ($> 10^{-5}$) in mantle-derived lavas and fluids, to low values ($\sim 10^{-8}$) in continental regions due to increased amounts of radiogenic ^{4}He. Helium undergoes gravitational escape from the thermosphere and has an atmospheric residence time of 1–10 million years. Therefore, it is not recycled by plate tectonics to the Earth's interior, making the ^{3}He/^{4}He ratio unique among isotopic tracers of mantle sources involved in volcanism.

Helium isotopes have several important applications in geochemistry. ^{3}He is a useful tracer of abyssal ocean circulation, because hydrothermal alteration of the newly formed crust at mid-ocean ridges releases fluids enriched in ^{3}He into the overlying water column. This present day ^{3}He flux is ~ 4 atoms/cm^2/s. Its effects may be traced at 2500–3000 m water depth for several thousand kilometers across the Pacific Ocean.

The ventilation of the oceanic thermocline, the apparent rate of oxygen utilization by planktonic organisms, and the aging of continental ground waters may be studied using the tritium–helium (^{3}H–^{3}He) dating method. The tritium produced by nuclear tests in the mid-1960s is a useful oceanic tracer due to its incorporation into rainwater molecules. The half-life of ^{3}H is 12.3 years, making it a transient tracer of climatic changes over decadal time scales.

Small, measurable amounts of ^{3}He are produced in rocks exposed at the Earth's surface by high energy cosmic rays, predominantly from the spallation of O, Si, Mg and Fe atoms. The production rate varies with latitude and with altitude, being significantly less at lower elevations due to attenuation of cosmic rays in the Earth's atmosphere. The production rate is also likely to have varied in the past due to variations in the Earth's geomagnetic field. The modern cosmogenic ^{3}He production rate is ~ 110 atoms/g/year at sea level and 35°N. Surface exposure dating with this technique may be used to infer the rates of glacial retreat during the last ice age.

The ^{3}He/^{4}He ratio of groundwaters, thermal springs and oil and natural gas fields is often higher than the radiogenic production ratio for the local crust, and may be taken as evidence for some contribution from mantle-derived fluids even in continental tectonic settings. Mid-ocean ridge basalts (MORB) display a narrow range of ^{3}He/^{4}He from 7 to $9R_a$, while ocean island basalts are more variable and often extend to higher values. The highest values are found at the Hawaiian hotspot and are in excess of $30R_a$. Other high ^{3}He/^{4}He localities include Iceland, Samoa, Galapagos, Réunion, Yellowstone and the Ethiopian Rift. The presence of high ^{3}He/^{4}He at these hotspots supports the existence of mantle plumes, thermal upwellings from regions deep in the Earth. These regions must have remained more effectively isolated over geological time, and are thereby less degassed and have lower (U + Th)/^{3}He, compared with the shallower mantle source regions for MORB.

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Cross-references

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Cosmogenic nuclides
Earth's atmosphere
Earth's mantle geochemistry
Earth's ocean geochemistry
Elements: noble gases
Geochemical tectonics
Geothermal systems
Helium
Hydrogen isotopes
Isotope fractionation
Mid ocean ridge basalts (MORB)
Natural gas
Stable isotopes
Uranium–lead thorium–lead decay system
Volcanic gases
Volcanism

The Encyclopedia of Geochemistry
C. P. Marshall and R. W. Fairbridge (ed.)
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