Residence time of helium isotopes in sediments and related groundwaters, Molasse Basin, Northern Switzerland

I. TOLSTIKHIN[1], I. KAMENSKY[1], M. GANNIBAL[1], S. TARAKANOV[2], B.E.LEHMANN[3] AND H.N. WABER[4]

[1]Geological Institute, Kola Scientific Centre, RAS, Apatity, Russia (tolstikin@yahoo.com)
[2]Institute of Silicate Chemistry, RAS, St. Petersburg, Russia (svtar@peterlink.ru)
[3]Physics Institute, University of Bern, Sidlerstr.5, CH-3012 Bern, Switzerland (Lehmann@climate.unibe.ch)
[4]Institute of Geological Sciences, Rock-Water Interaction, University of Bern, Switzerland (nick@geo.unibe.ch)

Generally radiogenic He isotopes are readily released from magmatic, metamorphic and sedimentary, rocks, so that usually less than 10% of He, produced since the rock formation is retained. The released atoms accumulate in related groundwaters. The measured He concentrations in ground-waters might be transferred into helium residence times providing (1) the rock-water system is at steady state and (2) a helium flux from external sources is negligible. Helium is an extremely conservative tracer and the major removal mechanism (from a given rock-groundwater system) is its migration as a constituent of water flow followed by helium discharge into the atmosphere. Therefore the helium residence time in groundwaters might be translated into the rate of water flow, which is a parameter of primarily importance.

In this contribution we use new measurements of He and Ar isotope abundances and of the parent elements concentrations in rocks and mineral separates from the Permo-Carboniferous sediments (Molasse basin, Northern Switzerland) in order to (1) discuss parameters, which are important to understand helium behaviour in water – rock system, (2) confirm internal production of He isotopes in rocks, minerals, and related groundwaters and investigate rocks/minerals which are major generators of helium isotopes, (3) present first estimates of He concentrations in pore fluids inferred from helium isotope abundances in quartz separates, and (4) estimate the helium and groundwater residence times.

The study shows that intra-basin production and loss of radiogenic helium (and argon) isotopes are responsible for their presently observed concentrations. Permo-Carboniferous shales generate most of ^{3}He and ^{4}He in the Permo-Carboniferous cross-section. This allows modeling of the inventory of helium isotopes in the Permo-Carboniferous rocks/groundwaters in order to derive helium residence times.

The modeling shows that the diffusion/removal rate of helium from the Permo-Carboniferous rock-groundwater system must be very slow, the residence time of helium in this system is not less than 1 Ma, with the best estimate ≥10 Ma.

Generation of a long-lived primitive mantle reservoir during late stages of Earth accretion

IGOR N. TOLSTIKHIN AND ALBRECHT W. HOFMANN

Max-Planck-Institut für Chemie, Postfach 3060, 55020 Mainz, Germany (tolstikin@yahoo.com)

Global geochemistry and seismology have produced conflicting views of the Earth's deep interior. Geochemical budgets favor models of a layered mantle, in which primordial noble gases, heat production, and regions rich in incompatible trace elements are located in the deep mantle. These models have generally assumed that the upper, "depleted" and a lower, more "primitive" reservoir are separated by the 660-km discontinuity. However, seismic tomography shows strong evidence for very deep subduction. This process would destroy the long-term chemical "identity" of the upper and lower-mantle layers. Kellogg et al. (1999) proposed a smaller, irregular, compositionally dense, primitive reservoir in the deep mantle. Here we propose that a dense D'' boundary layer was formed during late stages of accretion, and we show that it can satisfy the geochemical constraints given by noble gas data, incompatible trace element budget, and heat production.

Current accretion models typically require 50 to 100 Ma and they link the impact of a giant planetesimal with the formation of the moon, a post-impact terrestrial magma ocean, and core formation (e.g. Cameron, 2001). Later impacts of smaller bodies continued, and the smallest, chondritic bodies, implanted with solar wind, were added to an early-formed basaltic crust without extensive melting, degassing, and segregation of metallic iron. Portions of the early basaltic crust were therefore significantly enriched in iron, noble gases and noble metals. When these were subducted, the bulk density of some of the subducted lithosphere in the deeper mantle was significantly greater than that of ordinary "primitive" mantle, which had lost its metallic iron to the core. This subducted material (called DD) may contain up to 5 times BSE concentrations of highly incompatible elements including U, Th, about 0.1 of the chondritic abundance of involatile siderophile elements, including noble metals, and it will be enriched in solar rare gases with abundances approaching 10–2 cc g-1 He per g. We estimate that an initial mass of DD amounting to merely 5% of the Earth's mass is sufficient to sustain 3He and 129Xe fluxes and budgets through Earth history (Tolstikhin and Marty, 1998). At present, residues of this reservoir are seen as D'' boundary layer. Mantle plumes are likely to be generated just above this layer. Noble gases migrate into this boundary layer and thus into the plume sources, and small amounts of DD material may be entrained by the plumes without otherwise dominating their compositions.

References

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