TECTONIC IMPLICATIONS OF RADIOGENIC NOBLE GASES IN PLANETARY ATMOSPHERES.

D.L. TURCOTTE
Department of Geological Sciences, Cornell University, Ithaca, NY 14853

G. SCHUBERT
Dept of Earth and Space Sciences, Univ. of California, Los Angeles, CA 90024

Measurements of the quantity of noble gases in the atmospheres of the terrestrial planets and the moon provide important constraints on the dynamics of atmosphere formation and loss. In addition, concentrations of the radiogenic isotopes provide constraints on the tectonic activity within these bodies.

Uranium, thorium, and potassium are the principal heat producing elements within planetary interiors. The decay of the radioactive isotopes of uranium and thorium generate helium 4 and the decay of the radiogenic isotope ^{40}K generates argon 40. The efficiency of escape of these noble gas isotopes from planetary interiors can provide insights into both transport mechanisms and internal processes. Diffusion processes are unlikely to be important on the planetary scale; however, diffusion can transfer the noble gas to grain boundaries or regions where other processes are active. Partial melting is likely to play an important part in the transport. On the earth erosion and the circulation of water are likely to be important near surface processes for transport. Comparisons between the earth and the other bodies may provide information on the relative role of these processes.

Studies using the noble gas daughters can be carried out in one of two ways. The first is to use present flux rates. The principal difficulty with this type of measurement is the relatively large errors associated with the observations. The second method is to associate the total mass of the noble gas isotope in a planetary atmosphere with the integrated flux from the planetary interior. Because of loss mechanisms from the atmosphere this approach is only applicable to heavy gases such as argon. However, the hypothesis that the heavy gases are not lost may be open to question.

The systematics for ^{4}He and ^{40}Ar loss from the earth's interior have been reviewed by Turcotte and Kellog[1]. In addition to the primordial ^{3}He, ^{3}He is generated within the earth's interior by nuclear reactions involving ^{6}Li and in the upper atmosphere by cosmic ray bombardment. Uncertainties in these rates and the rate of escape from the atmosphere make a global balance of little value. However, Craig et al.[2] have specified the ^{4}He flux from the oceans to the atmosphere to be $F(^{4}He) = 3.2 \pm 1 \times 10^{5}$ kg yr^{-1}. If it is hypothesized that the flux is in a steady state balance with ^{4}He being produced in the upper mantle, the mean concentration of uranium is 8 ppb. This is identical to the value given for a depleted upper mantle reservoir by Jochum et al.[3]. Thus the helium flux observations support layered mantle convection.

It is appropriate to hypothesize that the ^{40}Ar in the atmosphere was generated by the decay of ^{40}K within the earth's crust and mantle. Taking $M(^{40}Ar) = 6.60 \times 10^{16}$ kg (with $C_K/C_U = 12{,}700$), we find that this amount of argon can be produced from the crust and upper mantle if the mean U concentration is 30 ppb. For the crust plus the whole mantle the required value is 8 ppb. The latter value is low by at least a factor of two. Most authors favor a mean concentration of uranium in the enriched continental

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crust and depleted upper mantle to be in the range 20-25 ppb although some favor a value as high as 30 ppb. It is reasonable to conclude that the ^{40}Ar in the atmosphere represents a complete outgassing of ^{40}Ar from the crust and upper mantle and a partial outgassing from the lower mantle.

We next turn our attention to Venus. The available data on argon has been reviewed by McElroy and Prather[4]. One of the important discoveries of Pioneer Venus was that the mass of primordial ^{36}Ar on Venus (1.2×10^{16} kg) is much greater than the mass on the earth (2.1×10^{14} kg). However, this is probably related to processes of atmosphere generation and loss.

The mass of ^{40}Ar on Venus ($\sim 1.3 \times 10^{16}$ kg) is considerably less than the value for the earth (6.6×10^{16} kg). Assuming approximately equal concentrations of potassium on the two bodies, the difference must be attributed to less efficient transport mechanisms on Venus. One hypothesis is that the absence of plate tectonics on Venus has reduced the transport of ^{40}Ar to the atmosphere; an alternative hypothesis is that the absence of circulating water restricts the transport of ^{40}Ar to the surface.

Prather and McElroy[5] have estimated that the flux of ^{4}He from the interior of Venus is $F(^{4}He) = 7.2 \times 10^{5}$ kg/yr. The flux from the earth including both mantle and crust is[6] approximately $F(^{4}He) = 10^{6}$ kg/yr. Thus the flux from Venus is slightly less than the flux from the earth although there are many uncertainties.

The flux of ^{40}Ar from the lunar interior has been estimated by Hodges[7] to be 4.2×10^{3} kg/yr. Assuming a lunar crustal abundance $C_K = 600$ ppm[8] this flux implies an escape of argon from the upper 9 km of the lunar crust. With the low value of gravity on the lunar surface it is not unreasonable to postulate significant porosity to this depth. The above result constrains the resulting permeability.

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