NOBLE GASES FROM A CONTINENTAL HOT SPOT: THE YELLOWSTONE CALDERA.

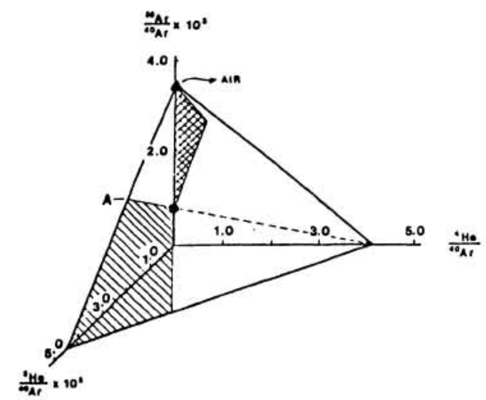
B. M. Kennedy, J. H. Reynolds, and S. P. Smith, Dept. of Physics, University of California, Berkeley, CA 94720.

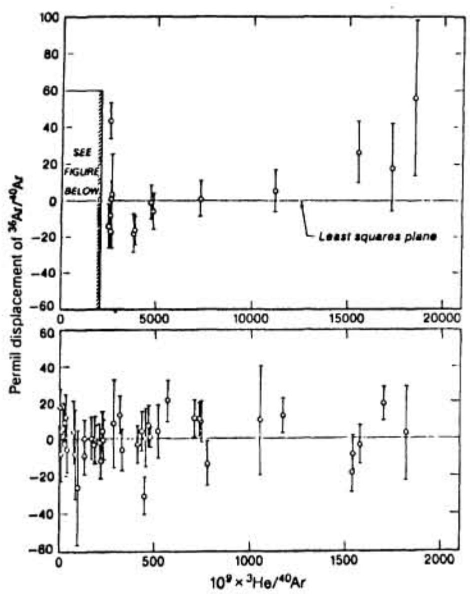
The Roving Automated Rare Gas Analysis lab (RARGA) of U.C. Berkeley's Physics Department has the capability to make on-site (as well as at home) measurements of the elemental and isotopic compositions of the noble gases contained in fluids (gas or liquid). The first field deployment of the RARGA lab was in Yellowstone National Park. Deployment was for a 19-week period beginning in late June 1983. During this time 85 samples of gas and water were collected from the numerous surface features - hot springs, fumaroles, etc. - and 66 of these samples representing 19 different regions of hydrothermal activity within and around the Yellowstone caldera were analyzed on-site.

Despite the limitation that only surface samples were collected and therefore only an integrated surface fluid composition was measured, we found that correlated variations in the isotopic compositions of He and Ar could be explained by mixing three independent components. This is shown graphically in the figures below. The first component is magmatic in origin and is identified by an enrichment in the primordial isotope ^{3}He. The minimum $^{3}He/^{4}He$ ratio of this component is 16 times the atmospheric value (in agreement with 1) and thus comparable to other mantle hot spots such as Hawaii or Iceland. This component also contains argon with $^{40}Ar/^{36}Ar \geq 500$. The lower limit corresponds to there being no ^{4}He in the mantle component (i.e. the $^{3}He/^{4}He$ ratio being infinite, point labeled A in figure), which is far from a likely assumption. The radiogenic nature of Yellowstone's magmatic argon conflicts slightly with recent suggestions (2) that rare gases from hot spots originate in a relatively undegassed portion of the mantle where the argon isotopic ratio is expected to be more air-like. However, attenuation from "prime" hot spot gas is a likely possibility in view of the argument (3) that the apparent source of the rhyolitic magmas at Yellowstone is partially melted material from the lower crust, which would have contributed crustal argon to some degree to the magmatic gas. The composition of the second component is consistent with a purely radiogenic origin containing only $^{4}*He$ and $^{40}*Ar$ (with $^{4}*He/^{40}*Ar = 4.08 \pm 0.33$). This component is the probable carrier of observed excesses of $^{21}*Ne$, attributed to the α,n reaction on ^{18}O. Its radiogenic character implies a crustal origin presumably scavenged by deep circulating hydrothermal fluids from U, Th, and K-rich aquifer rocks. The third component is isotopically indistinguishable from atmospheric noble gases. This component originates largely from infiltrating air-saturated water recharging the hydrothermal system.

From the standpoint of these three components, we see a magmatic (mantle) component enriched in primordial helium escaping from a magma body or cooling batholith, becoming entrained in deeply circulating hydrothermal fluids, and subsequently transported to the surface. While in transit, it is diluted to varying degrees by the admixture of the two additional components: radiogenic or crustal gas and atmospheric or air-saturated water. What we have measured then is the surface distribution of the escape of a magmatic noble gas component (and presumably other volatiles) and the extent of dilution while in transit. From this point of view, we feel that the various thermal regions within Yellowstone are best characterized by the maximum value (least diluted) of $^{3}He/^{4}He$ seen for the regions. Variations in this parameter from one thermal region to another reflect the efficiency with which mantle volatiles are extracted and transported to the surface. The extraction efficiency will be related to variations in the structure of the cooling batholith such as deep fracture zones or near surface areas of partial melt where migration and subsequent extraction are expected to be more efficient. If the extraction efficiency is everywhere the same, then variations in the maximum $^3He/^4He$ ratio can be used to map the surface topography of the cooling batholith in units of transport distance. Somewhat surprisingly, within the caldera the $(^3He/^4He)_{max}$ parameter is relatively constant at 7 ± 1 times the air value. There are exceptions, most notably at Mud Volcano (∿16 times air) and Gibbon Basin (∿13 times air). The Gibbon area is the site of the Park's most recent volcanic activity and Mud Volcano sits along a crest of present day rapid uplift. Immediately outside the caldera the proportion of magmatic helium decreases rapidly and virtually disappears.

References. 1. Craig H. et al. (1978). Geophys. Res. Lett. 5, 897-900. 2. Allegre C. J. et al. (1983). Nature 303, 762-766. 3. Doe B. R. (1982). J. Geophys. Res. 87, 4785-4806.





The bold lines in the 3-dimensional plot on the left depict the surface of plane determined by an unconstrained 3-dimensional least squares fit to the entire data array. The array occupies the cross-hatched region. The composition of Yellowstone's magmatic component is constrained to the hatched area.

The figure on the right shows the vertical deviations (1σ) of the data from the surface of the least squares plane as a function of the $^3He/^{40}Ar$ ratio. A similar distribution exists when the deviations are graphed as a function of $^4He/^{40}Ar$.