Volatile budgets, sources and losses

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The origins of Earth's highly volatile elements (H, C, N and the noble gases) have long been debated. Early models could be divided between those that envisaged incorporation during main stage accretion versus those that advocated the addition of volatiles in a late veneer. Increasing evidence points to the former but neither properly replicate the complexity that is apparent in the relative inventories and isotopic compositions of Earth's highly volatile elements.

The most powerful constraint that exists on Earth's volatile budgets comes from the mantle K/U and U concentration. The former can be assessed more confidently now because of improved K/U data for the MORB source. The latter has been clarified because Nd nucleosynethetic anomaly data for meteorites provide evidence that the silicate Earth's Sm/Nd is chondritic - there has not been collisional erosion of (incompatible) K and U. On this basis mantle $^{40}Ar^{*}$ and thereby ^{36}Ar budgets can be calculated and confirm that >97% of primordial ^{36}Ar, regardless of its origin, is in the atmosphere. The ratios of Ar to other volatiles then provide evidence of higher concentrations in the lower mantle, and total mantle inventories of >90% of Earth's C and H. The budgets for the core are very unclear.

Noble gas isotopes and elemental abundance patterns provide evidence of a high degree of recycling of volatile elements such as Xe and N into the mantle. Nevertheless, fundamental differences between mantle and atmosphere have been preserved for non-recycled volatiles like Ne providing evidence that atmospheric noble gases are not simply derived from the current mantle. Rather, the mantle retains a much higher proportion of Solar like componenents. Plume-derived basalts also provide evidence of extremely early and deep heterogenities that have survived mantle convection, including the possibility of nebular H.

The biggest puzzle of relative terrestrial volatile budgets as currently estimated is that they do not resemble any cometary, Solar or meteorite pattern or mixture. There is evidence of a component of clathrates in the heavy noble gases but this does not explain the major volatile patterns, which display extreme depletion in N relative to C and H. The recent focus on enstatite chondrite like components makes this still more challenging because they have relatively low C/N. The most likely explanation is loss of N from the atmosphere or to the core. Arguments have been presented recently for both and this major issue needs further study.