NEON ISOTOPE HETEROGENEITY IN THE TERRESTRIAL MANTLE : IMPLICATION FOR ACQUISITION OF VOLATILE ELEMENTS IN TERRESTRIAL PLANETS.

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Introduction: Neon in samples from the terrestrial mantle show isotopic variations representing mixing between air and a deep mantle component rich in ^{20}Ne and ^{21}Ne relative to ^{22}Ne (Fig.1) [1-4]. ^{21}Ne enrichments are due to nuclear production within the mantle, but no known nuclear process can account for excess ^{20}Ne. Thus ^{20}Ne/^{22}Ne ratios higher than air are interpreted as representing the occurrence of a solar-like neon component][2-4]. There are two potential sources for this neon; i) Solar Nebula gas; or ii) a mixture of solar wind and and solar energetic particle (SEP) neon, called Ne-B found in gas-rich meteorites [5]. Identifying which of these sources provides the neon in the Earth has profound implications for the formation of the Earth. A solar nebula origin requires nebula gas to be present. Recently, Trieloff et al. [6] argued that published data rather select Ne-B,. Although these authors proposed a "planetary" origin for neon and presumably other terrestrial volatiles, others noted [7] that the data sets investigated could not rule out a Solar nebula origin.

Primordial Ne isotope heterogeneity in the mantle: Two new sets of high precision data shed light on the Ne isotopic composition in the mantle. First, samples from the Kola (Russia) ultramafic intrusions show noble gas isotopic ratios indicative of material deriving from the deep mantle source of plumes. These characteristics are best explained by the occurrence of a mantle domain rich in volatile elements and preserved from whole mantle convection [8]. For Kola samples, magnetite separates from Levskaia plutonic body have ^{20}Ne/^{22}Ne ratios clearly higher than the Ne-B value of 12.5±0.2 and require a deep mantle end-member with ^{20}Ne/^{22}Ne >13 [9] (Fig.1), in the same range of solar wind (13.7±0.3) [10], leading credence to a solar origin for gases trapped in the source(s) of mantle plumes [9]. Second and in contrast, precise analyses of natural gases from New Mexico (USA) show noble gas isotopic ratios and abundance pattern diagnostic of a convective mantle origin. In a three Ne isotope plot (Fig 1) these display a strong correlation between (i) a pole resulting from mixing between air and crustal Ne rich in nucleogenic ^{21}Ne, and (ii) a high ^{20}Ne/^{22}Ne component. The intersection of this correlation and the correlation of the convective mantle defined by MORB (but never precisely constrained for its highest ^{20}Ne/^{22}Ne end-member) defines the convective mantle end-member of 12.2-12.5 [11]. This is compatible with a Ne-B origin (when addition of nucleogenic ^{21}Ne is discarded) and clearly distinct from solar nebula neon (SWC, Fig. 1).

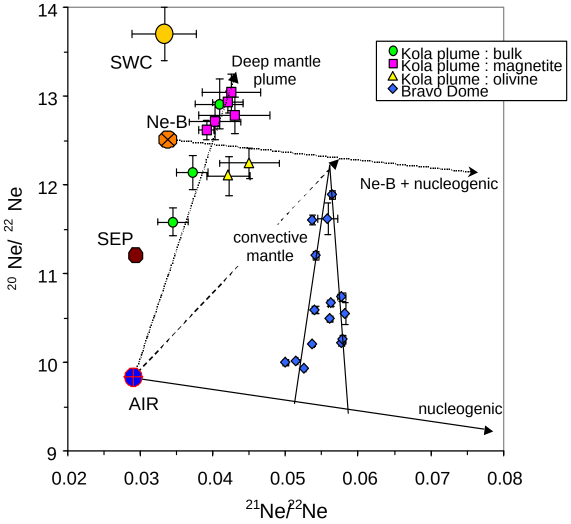

Fig.1: Ne three-isotope diagram. Deep mantle plume (Kola) data from [9], CO_2 well gas (Bravo Dome) data from [11].

The difference between the mantle plume end-member and the convective mantle end-member can not be due to recycling of air Ne because such process would have completely overprinted the mantle characteristics of the heavy noble gases. We argue that such difference reflects a large-scale heterogeneity for trapped volatile elements and have implications for models of Earth's formation.

Timing of reservoir heterogeneity: The Martian mantle sampled by the Chassigny meteorite also contains solar-like xenon [12], extending presumably the case of Earth to other terrestrial planets. Irradiation of dust and compaction of the latter might have led to trapping of a Ne component having ^{20}Ne/^{22}Ne ratios <13, such as those observed in lunar soils or in gas-rich meteorites. Trapping of solar nebula gas would have been most efficient through dissolution of a solar-like atmosphere into molten silicates during magma ocean episodes [13]. The development of a solar-like atmosphere requires the solar nebula to be present and sets an upper time limit of 10 Myr at most after start of solar system condensation (ASSC) [14]. During this time interval, the proto-Earth would have grown up to a size significant enough to retain a solar-like atmosphere [13]. Both extinct radioactivities in Martian meteorites [15] and modelling of solar system accretion (e.g., [16]) predict Martian-like bodies to have grown up and differentiated in few Ma ASSC. An independent time constraint is given by the Lunar impact record, now settled at 11-50 Myr ASSC from Hf-W chronology [17, 18], as it seems unlikely that a massive atmosphere, or even mantle noble gases, could have survived this event.

Solar noble gas storage in the core: Deep mantle neon needs to have been isolated from convective mantle neon throughout most of Earth's history in order to preserve the observed heterogeneity. However, seismic tomography and geochemical evidence for the occurrence of recycled crust in the source of plumes both argue for indicative of whole mantle convection. A further difficulty is to preserve a mantle reservoir for solar Ne during the lunar impact event.

A way to preserve noble gases during the Lunar cataclysm, and to account for the apparent isolation of the plume-like noble gas reservoir during mantle convection, is to store them in the core, as already proposed on other grounds (e.g., [19]). One of the major uncertainties in evaluating this possibility is the lack of metal/silicate partitioning data in conditions relevant to ocean magmas. Data from Matsuda et al. [20] predict metal/silicate K values between $\sim 10^{-2}$ and $\sim 10^{-4}$ at low to moderate pressure (20-100 kbar), which could be relevant if metal-silicate separation occurred in this pressure range without further re-equilibration during metal sinking. By computing pressures of the solar atmosphere (following Sasaki and Nakasawa's approach [21]) for Earth's formation time intervals of 10-50 Ma, with a nebula dissipation at 10 Ma, we find ^{22}Ne contents in the core of $\sim 10^{-16}$-10^{-13} mol/g depending on pressure during partition. Crystallisation of the inner core could increase this concentration towards the outer core prone to interaction with the deep mantle. For comparison, a closed system ^{22}Ne content in the source of mantle plumes is estimated at 2×10^{-14} mol/g from the nucleogenic ^{21}Ne inventory [9]. Thus the core could supply enough Ne to the source of mantle plume during outer core-lower mantle interaction and noble gas partitioning.

Acquisition of "planetary" neon: ^{20}Ne/^{22}Ne ratios <13 now seen in the convective mantle suggest trapping of noble gases from material irradiated by the Sun, presumably after the Lunar impact. the similarity of D/H and ^{15}N/^{14}N ratios between asteroidal material (chondrites, micrometeorites) and terrestrial reservoirs together with the PGE inventory of the terrestrial mantle [22] suggest contribution of asteroidal material to Earth (0.1-0.8 % terrestrial mass) after core formation to provide volatile as well as siderophile elements [23]. Volatile elements trapped in such matter needed to survive atmospheric entry, impact degassing and possibly atmospheric erosion. Cosmic dust (IDPs micrometeorites) is a good candidate for such delivery as it is able to deliver gently volatile elements to the Earth's surface. The presence of significant quantities of dust relatively late in the accretionary process is supported by recent observation [24] of cosmic dust in β Pictoris planetary system (~20 Myr old) 6-7 orders of magnitude more abundant than in the present-day solar system. Incorporation into the mantle without extensive degassing requires a specific process, like the one recently proposed as cold subduction in early Earth [25].

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