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Noble Gases in the Loihi and Iceland Mantle Plume Sources and Constraints on Earth's Early History

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Noble gas isotopes are important tracers for various stages of terrestrial evolution, e.g. accretionary processes in the solar nebula, the origin of the atmosphere, and degassing, structure and evolution of the mantle (Allègre et al., 1986). Mantle-derived rocks contain juvenile, solar-type He and Ne that cannot be recycled from the atmosphere or crust. They also contain excess of radiogenic isotopes (^{4}He, ^{21}Ne, ^{40}Ar, ^{129}Xe, $^{131-136}$Xe), indicating massive early mantle degassing. Excesses of radiogenic isotopes are higher for MORB than OIB glasses, pointing to a less degassed reservoir associated with mantle plumes. However, the exact magnitude of the ^{40}Ar excess of "primitive" mantle plumes (i.e. with the highest ^{3}He/^{4}He anomalies, as found on Hawaii and Iceland) is not yet clarified, for Xe, isotopic anomalies are not yet conclusively proven at all. Moreover, it is highly debated, if nonradiogenic heavy noble gases display solar characteristics similar to Ne or not. To clarify these problems, we analysed dunite xenoliths from Loihi seamount, Hawaii and subglacial basalt glasses from the Reykjanes peninsula, Iceland. Noble gases were extracted by in vacuo stepwise crushing and analysed on the mass spectrometer ARESIBO I at the IPG.

^{3}He/^{4}He-ratios are 24.5±0.5 R_A for Loihi dunites, and vary between 16.8 and 18.8 R_A for Icelandic glasses. Neon isotopic composition follows the Loihi trend defined by submarine basalt glasses. Dunite KK27-9, subglacial glasses Dice 10 and 11 and mid-atlantic popping rock 2IID43 (Kunz, 1999) have indistinguishable maximum ^{20}Ne/^{22}Ne ratios in several advanced crushing steps with a mean of 12.49±0.06, indicating that this composition corresponds to the pristine mantle neon preserved in the most retentive vesicles of these rocks. This ratio is clearly different from the solar value of 13.80±0.10, but indistinguishable from Ne-B, the meteoritic occurrence of solar neon with ^{20}Ne/^{22}Ne =12.52±0.18 (Black, 1972), which therefore can be suggested as the actual solar neon component in Earth's interior. Excess of ^{20}Ne and ^{40}Ar are well correlated for Loihi dunites implying ^{40}Ar/^{36}Ar ratios of 8000 for the Hawaiian mantle plume source. We also detected small but significant excesses of ^{129}Xe and ^{136}Xe that are similarly correlated as in MORB glasses. If ^{129}Xe excess is inherent to the plume sources, it would indicate early degassing, similar to the MORB reservoir.

The presence of solar type He and Ne in Earth's mantle led to a number of discussions about the characteristics of primordial nonradiogenic isotopes of heavy noble gases (e.g. Kunz, 1999). The ^{38}Ar/^{36}Ar ratio at high ^{40}Ar/^{36}Ar values (i.e. after discriminating against recent local atmospheric contamination) is still atmosphere-like or planetary, similar to meteoritic Ar associated with Ne-B, but different from solar-like Ar. Nonradiogenic Kr and Xe isotopes are better reconciled with atmosphere-like than planetary or solar composition.

Some models consider that the atmosphere-like signature of Ar, Kr and Xe was established in the atmosphere itself, during a period of hydrodynamic escape (Pepin, 1991) that dissipated (and fractionated) a massive solar-type proto-atmosphere acquired by gravitational capture within the dense solar nebula. Within the framework of these models, our results would imply subduction of these nuclides. According to other models (Ozima und Zahnle, 1993), the atmosphere-like signature was acquired during earlier stages of accretion by planetesimals through gravitational capture and accompanying fractionation. If Ne-B is indeed the initial terrestrial solar neon component, its origin cannot be explained by the above mentioned models, but must be related to implantation of solar corpuscular irradiation into the accreting planetesimals, while they were small and while the nebula was already relatively transparent, i.e. had lost most of its volatile or gaseous component. Such an early irradiation period was advocated previously in order to explain the high fraction of gas-rich meteorites among carbonaceous chondrites and irradiation features of single meteoritic grains (Goswami and Lal, 1979).

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