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Noble gas isotope signals of mid-ocean ridge basalts and their implication for upper mantle structure

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The geochemical structure of the upper mantle in general and its noble gas isotopic structure in particular have been the subject of countless studies, as both provide important insights into mantle dynamic processes and are essential for the formulation of mantle geodynamic models. This contribution presents a noble gas study of basaltic glasses derived from the Mid-Atlantic-Ridge (MAR) between 4 and 12°S, an area well known for its high degree of lithophile isotope heterogeneity and exhibiting anomalous crustal thickness. The Sr, Nd, Pb and Hf isotopies along this segment of the MAR range from ultra-depleted (more than NMORB) to highly enriched, and different concepts have been proposed to explain the observed isotopic signatures. Here we show that the high degree of heterogeneity is not confined to the isotopes of the lithophile elements, but is also shown by the noble gas isotopes and noble gas interelement ratios, such as e.g. ^{3}He/^{22}Ne$_{M}$ or ^{4}He/^{40}Ar*. ^{3}He/^{4}He, ^{21}Ne/^{22}Ne$_{extra}$ and ^{40}Ar/^{36}Ar range from 7.3 to 9.3 R$_{A}$, from 0.05 to 0.08, and from 346 to 37,400, respectively. Nevertheless, the majority of the Ne isotope data are clearly aligned along a single mixing line in the Ne-three-isotope diagram, represented by the equation ^{20}Ne/^{22}Ne=70.5 x ^{21}Ne/^{22}Ne + 7.782, with a slope distinctly different from that of the MORB line, indicating that the ultra-depleted material is characterised by a significantly more nucleogenic ^{21}Ne/^{22}Ne isotopy than the normal depleted mantle. We show, based on covariations between ^{3}He/^{4}He and ^{21}Ne/^{22}Ne$_{extra}$ with ^{206}Pb/^{204}Pb and ^{178}Hf/^{177}Hf, that the ultra-depleted material erupted at this MAR segment was most likely produced by an ancient, deep melting event. This implies that isotopic heterogeneities in the upper mantle are not solely caused by the injection of enriched materials from deep-seated mantle plumes or by crustal recycling but may also be due to differences in the depth and degree of melting of upper mantle material within the lifetime of our planet. In addition, the observed along-ridge and off-axis isotope patterns in conjunction with spatial distribution patterns of off-axis seamounts in the area show that the upper mantle can be extremely heterogeneous in space and time even at small scale and that the mixing efficiency of either large or small scale convection processes in the upper mantle is thus lower than commonly assumed.