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Noble Gas Evidence for Undegassed Terrestrial Mantle

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Measurements of noble gas isotopes in oceanic basalts provide important evidence for undegassed reservoirs within the deep earth. The most robust evidence comes from helium and neon isotopes in oceanic island basalt glasses having lower $^{4}He/^{3}He$ and $^{21}Ne/^{22}Ne$ than mid-ocean ridge basalts (MORB). These isotope systems are consistent in requiring lower long-term (Th+U)/He and (Th+U)/Ne ratios, and are most easily explained by undegassed mantle reservoirs. Although this generalization is based primarily on Hawaiian submarine glasses, these systematics have also been found in Icelandic subglacial basalts. The interpretation that low $^{4}He/^{3}He$ and $^{21}Ne/^{22}Ne$ ratios reflect undegassed reservoirs has been challenged for a number of reasons. Some researchers have suggested that helium and neon behave as compatible elements on melting (i.e., more compatible than Th and U), which would yield 'undegassed material' as the residuum from melting. Other alternative explanations for low $^{4}He/^{3}He$ and $^{21}Ne/^{22}Ne$ ratios include subduction of interplanetary dust (IDP) into the mantle, or storage of noble gas rich material in the lithosphere. Consideration of the noble gas abundances in mantle derived samples, existing experimental data for noble gas partitioning, and terrestrial IDP fluxes, make all of these explanations unlikely. In addition, the correlations between helium, neon, and the isotopes of Sr, Nd, and Pb are most easily explained by relatively undegassed mantle reservoirs. This hypothesis can be reconciled with ubiquitous geochemical evidence for recycled material in the mantle by the fact that the lowest $^{4}He/^{3}He$ and $^{21}Ne/^{22}Ne$ ratios are found in moderately depleted sources, having intermediate Sr, Nd, and Pb isotopes, which are not influenced by recycled crust and sediments. These considerations make the lower mantle the most likely source for volcanism with low $^{4}He/^{3}He$ and $^{21}Ne/$-Ne ratios. Simple models show that the early earth could be extensively degassed and still retain sufficient helium and neon to accommodate present-day isotopic values. The isotopic characteristics of argon and xenon are presently undetermined due to the low solubility of argon and xenon in basaltic melts and ubiquitous evidence for post or syn-eruptive atmospheric contamination of these gases. However, the helium and neon isotopic systematics are sufficient to establish the existence of undegassed materials in the deep earth, and highlight the importance of noble gases as tracers of lower mantle sources.