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# Mantle deformation and noble gases: Helium and neon in oceanic mylonites

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ABSTRACT

In an effort to constrain the behavior of noble gases during mantle deformation, we present new helium and neon data in mylonites from subaerial St. Peter and St. Paul Archipelago (Mid-Atlantic Ridge) and the submarine Southwest Indian Ridge. Coupled vacuum crushing and melting experiments show that most of the helium and neon within the mylonites is contained in the mineral matrices rather than fluid or melt inclusions: only 5 to 18% of the total helium is released by crushing. The mylonites and ultramylonites have much higher total helium concentrations than expected, based on their small grain size. The St. Paul's Rocks mylonites have helium contents equivalent to gas-rich MORB glasses, ranging from $6\times10^{-6}$ to $3.8\times10^{-5}$ cc STP He/g. The submarine mylonites and ultramylonites have helium contents between $5\times10^{-8}$ and $4.4\times10^{-7}$ cc STP He/g, compared to $6.2\times10^{-9}$ to $3.6\times10^{-8}$ for the protogranular/porphyroclastic peridotites. Although the dataset is small, it suggests a relationship between metamorphic texture and noble gas abundance, and that mylonitization introduces mantle helium into mineral matrices. The mylonites are extremely fine grained, with an average grain size of ~10 µm, so helium residence in grain boundaries is also plausible. St. Paul's Rocks have modal hornblende, extreme geochemical enrichments in incompatible elements, and high temperature alteration phases (e.g., talc) that are rare or absent in the other samples; mineralogy must also play an important role. The $^3He/^4He$ ratios in the peridotites are primarily mantle derived, based on comparison with MORB data, suggesting that peridotites reflect the source mantle isotopic compositions. Neon isotopes in St. Paul's Rocks are a mixture of air and normal mantle, and fall along the line defined by MORB glasses. The atmospheric neon signal is preferentially released by crushing in vacuum, suggesting it resides within weakly bound sites in cracks and grain boundaries. He/Ne ratios in St. Paul's Rocks vary widely (~20×) with deformation and mineralogy, with the highest He/Ne ratios (and helium concentration) found in the finest grained ultramylonite peridotite. The neon and helium isotopic data show that mantle gases are preserved in fine-grained mylonites at very high concentrations. The most likely mechanism is diffusive trapping within defects at pressure in the mantle. The relationship between texture and helium abundance in peridotites suggests that metamorphism is a potentially important control on noble gas distribution in the mantle and crust.



## 1. Introduction

Models for the evolution of noble gases in the earth's mantle and atmosphere are dependant on understanding the residence sites of gases in mantle minerals and in the crust, which control their behavior during melting, outgassing, and metamorphism. Noble gases in ground water and fumaroles are widely used as tracers of crustal versus mantle influence, and may be used as earthquake precursors due to gas release during deformation (e.g., Italiano et al., 2004; Fu et al., 2005). In the laboratory, atmospheric contamination is a ubiquitous problem, but the mechanisms and residence sites of atmospheric contamination in mantle-derived samples are poorly understood. There is also considerable debate regarding the residence of noble gases in the mantle, particularly the explanation for unradiogenic helium and neon isotopic signatures found in some ocean island basalts such as Hawaii, Iceland and Galapagos. The "standard model" holds that unradiogenic helium and neon derive from relatively undegassed reservoirs deep in the earth (e.g., Kurz et al., 1982; Allègre et al., 1983). Recent models suggest an alternative explanation, either by the preservation of ancient isotopic signatures in the residue of melting or by enrichment of gases in ancient lithosphere (e.g., Anderson, 1998a,b; Parman et al., 2005). However, the partitioning behavior of noble gases is not well enough known to constrain these models. Parman et al. (2005) showed that significant amounts of helium were released from experimental olivine charges (in solubility experiments) by crushing in vacuo, suggesting that their

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experiments may have been influenced by crystal defects. This study focuses on oceanic mylonites to constrain the relationship between deformation, crystal defects and the noble gas budgets of peridotites.

Many noble gas studies have used basalts as the best representatives of bulk mantle isotopic composition, but it is difficult to infer mantle concentrations from basalt data due to the complex effects of melting, shallow fractionation, and degassing. Peridotites provide important insights into mantle geochemistry, but have not been as extensively studied for noble gases, have large concentration variations due to the presence of fluid inclusions, and oceanic samples often have extensive alteration to serpentine or talc. There have been several noble gas studies of continental peridotite xenoliths, which typically have $^{3}He/^{4}He$ lower than MORB and are assumed to represent the subcontinental lithosphere (e.g., Gautheron and Moreira, 2002; Gautheron et al., 2005). There are few noble gas studies of oceanic peridotites (e.g., Kumagai et al., 2003) and we are unaware of any previous noble gas study of mylonites. Mylonites are the fine-grained products of ductile deformation associated with the down-dip extension of faults (Warren and Hirth, 2006). In the oceanic lithosphere, they are found at both fracture zones and ridge axes. Their temperature of deformation is in the range of 600–800 °C (Jaroslow et al., 1996), suggesting formation depths of ~10–25 km, at

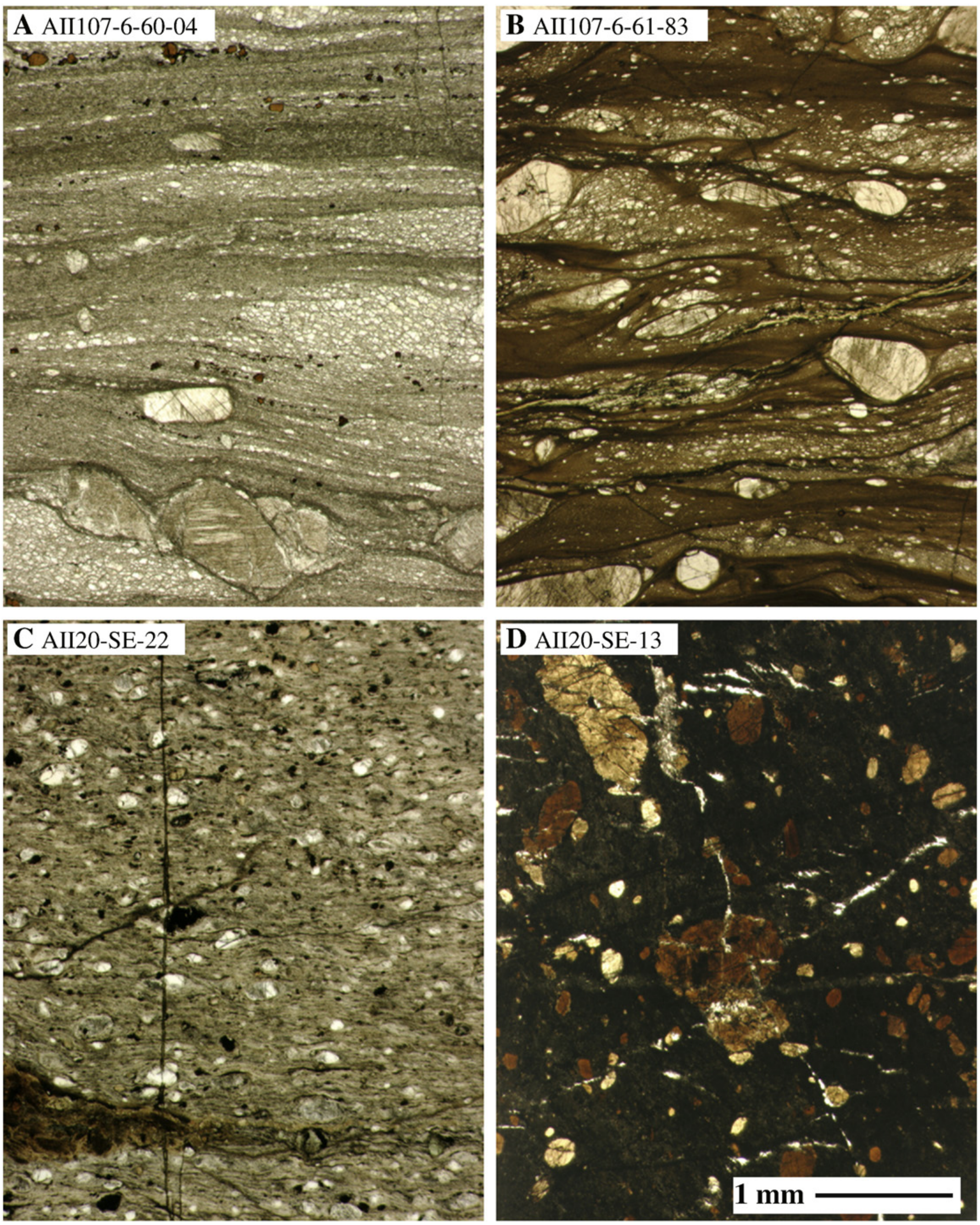


**Fig. 1.** Photomicrographs of deformed peridotites, all at the same scale; scale bar is shown at the bottom right. (A.) Mylonite AII107-6-60-04 from the Shaka Fracture Zone, illustrating the fine-grained nature of mylonites due to deformation. (B.) Ultramylonite AII107-6-61-83 from the Shaka Fracture Zone. The dark layers contain grains of <10 μm diameter, resulting in multiple grains within the standard 30 μm thin section thickness. (C.) Ultramylonite SE-22 from St. Paul's Rocks. The stretched brown patch at the lower left is hornblende. (D.) Protomylonite SE-13 with a cataclastic overprint from St. Paul's Rocks; brown grains are hornblende. Note that both the St. Paul's samples have a high degree of alteration to talc and magnetite, whereas the Shaka Fracture Zone samples are unaltered.