Nitrogen solubility in the upper terrestrial magma ocean: an experimental approach

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During its accretion and earliest evolution, Earth experienced partial or perhaps complete melting as a result of the heat provided by radioactive decay, energetic impacts, and core formation. Magma ocean (MO) in- or outgassing thus controlled the abundance and distribution of nitrogen (N) within the young Earth. In this study, we investigate the influence of the oxygen fugacity (fO_2) and melt composition on the N solubility in silicate melts through N equilibration experiments at atmospheric pressure and high temperature (1425°C). The oxygen fugacity (expressed with respect to the Fe-FeO (IW) buffer) was varied from IW-9.2 to IW, and the melt composition covered a wide range of polymerization degrees, defined by the NBO/T ratio (i.e., the number of non-bridging oxygen atoms per tetrahedrally-coordinated cations). The N content of the quenched run products (i.e., silicate glasses) was analyzed by both in-situ SIMS and bulk CO_2-laser extraction-static mass spectrometry. The results from the two methods are in good agreement. Furthermore, SIMS analyses demonstrate that the N concentration is homogenous across the glass spherules, confirming that equilibrium is reached between the gas and the melt during the 24-hour experiments.

The data obtained here highlight a fundamental control of both the fO_2 and the polymerization degree of the silicate melt on the N solubility. The N content at IW increases from 0.3±0.1 (NBO/T = 0.2) to 1.51±0.27 ppm (NBO/T = 0.4) and at IW-8 from 15.6±0.4 for highly polymerized melts (NBO/T = 0.05) to 5847±454 ppm for moderately polymerized melts (NBO/T = 1.2).

The new N solubility results provide constraints on the behavior of N in the shallow part of a MO. Mafic to ultramafic melts can incorporate up to 180 ppm to 2.1 wt.% N under reduced conditions (i.e., at IW-5 to IW-8). The N storage capacity of a reduced MO, in equilibrium with a N-rich atmosphere, is thus significantly higher than the N content of the present-day terrestrial mantle, suggesting that Earth has lost N to the atmosphere and/or space, or, alternatively, that N is stored in its deep interior (i.e., transition zone, core).