The role of stishovite as a deep nitrogen carrier indicated from high-pressure and high-temperature experiments

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Nitrogen occupies about 80% in the Earth's atmosphere and is one of essential elements of life. For these reasons, nitrogen is an important volatile element in various aspects of geoscience, including climates (e.g. Goldblatt et al., 2009; Wordsworth and Pierrehumbert, 2013) and the origin of life. However, we couldn't have still understood details of behavior or cycle of nitrogen in the Earth's interior. For example, it is known that the amount of nitrogen in deep Earth is more depleted than that of other volatile elements (Marty, 2012). This is called "missing" nitrogen and suggested to be caused by nitrogen stored in the upper mantle, the mantle transition zone, and the lower mantle through magma ocean from experimental researches (e.g., Li et al., 2013; Yoshioka et al., 2018). However, only two experiments corresponding to the lower mantle were conducted in the previous study (Yoshioka et al., 2018). In addition, subducting slab have played important role for volatile cycle into the deep Earth.

In this research, in order to investigate how much nitrogen is incorporated into stishovite which can carry nitrogen to the lower mantle, we conducted high-pressure and high-temperature experiments using multi-anvil apparatus installed at Geodynamics Research Center, Ehime University. All experimental pressure conditions were 27 GPa and temperature conditions ranged from 1400 ℃ to 1700 ℃. Fe-FeO buffer was used to control the redox state equal to the lower mantle. Nitrogen in recovered samples were analyzed using NanoSIMS installed at Atmosphere and Ocean Research Institute, The University of Tokyo. Nitrogen implanted standard samples were prepared in order to estimate nitrogen solubility in silicate minerals at National Institute for Materials Science.

A series of experimental results revealed that stishovite can incorporate 39-418 ppm nitrogen which is higher than nitrogen solubility in bridgmanite (5-50 ppm nitrogen solubility reported by Yoshioka et al. (2018)). Stishovite is mainly formed by the transition of nitrogen-rich sedimentary rocks transported to the lower mantle via subducting slabs. Our study suggests that nitrogen would continue to be supplied to the lower mantle via subducting slabs since when the plate tectonics had begun. This implies that "hidden" nitrogen reservoir was formed in the lower mantle approximately 4 billion years ago. Furthermore, this " hidden" nitrogen reservoir may play a role in decreasing high-concentration nitrogen which had enhanced greenhouse effect in the early atmosphere (Goldblatt et al., 2009) to the present nitrogen concentration level. Thus, our experimental results support the young faint Sun paradox explained by high-concentration nitrogen in the early Earth (e.g. Goldblatt et al., 2009; Wordsworth and Pierrehumbert, 2013) and suggest that "missing" nitrogen has been caused by forming a "hidden" nitrogen reservoir in the lower mantle.

Keywords: "Missing" nitrogen, Deep nitrogen cycle, Plate techtonics, Stishovite, The faint young Sun paradox

