Evidence for chondritic lunar water and nitrogen trapped in Apollo 17 volcanic glasses

E. FÜRI[1*], B. MARTY[1], E.DELOULE[1] AND A. GURENKO[1]

[1]CRPG-CNRS, BP20, 54501 Vandoeuvre-les-Nancy, France (*correspondence: efueri@crpg.cnrs-nancy.fr)

The notion of a largely devolatilized lunar interior has been challenged by the discovery of trace amounts of water in lunar volcanic glasses (LVGs) [1], melt inclusions [2] and apatites [3-5]. However, the caveat in the search for indigenous lunar volatiles (e.g., H_2O and N) is that any sample collected at the Moon's surface likely also contains volatiles implanted by solar wind (SW) irradiation and certain volatile element isotopes produced by spallation reactions.

Here, we first assess the proportion of solar, cosmogenic, and indigenous water (hydrogen) trapped in single Ti-rich 74002 LVGs by coupling SIMS measurements of water abundances and D/H ratios with CO_2 laser extraction-static mass spectrometry analysis of noble gases (He, Ne, Ar). Our noble gas results show that the large single Ap17 LVGs have been exposed at the lunar surface for ≤36 Myrs, and that they contain a negligible amount of SW-derived volatiles. Therefore, the detection of water in these primitive melts confirms the presence of a non-anhydrous mantle source within the Moon, with a chondritic isotopic signature.

Secondly, nitrogen was extracted from different 74002 grain size fractions by CO_2 laser heating. The surface-correlated N component shows a $\delta^{15}N$ value of +4.4 ± 7.8 ‰ relative to air. This value likely reflects the isotope composition of N-bearing volcanic vapor that condensed onto the surface of the LVGs, and it represents a minimum estimate of the $\delta^{15}N$ signature of the melt source. Preferential loss of light isotopes from the melt, followed by condensation of isotopically light vapor [6], as well as addition of SW-derived N, may have lowered the initial $\delta^{15}N$ value. Nonetheless, the isotopic composition of indigenous nitrogen in the lunar mantle appears to be comparable to the values observed in carbonaceous chondrites (e.g., [7]).

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Effects of oxide ions on the stabilization of pentoses

YOSHIHIRO FURUKAWA[1]*, MANA HORIUCHI[1], SAKIKO NITTA[1] AND TAKESHI KAKEGAWA[1]

[1]Department of Earth Science, Tohoku University, 6-3 Aza-aoba, Aramaki, Sendai, Japan (*correspondance: furukawa@m.tohoku.ac.jp)

Ribose, an aldopentose, is an essential component of RNA that has been regarded an important organic compound for the origin of life [1,2]. Thus, the formation and accumulation of ribose on the prebiotic Earth may be a requisite for the emergence of primordial RNA. However, pentoses including ribose are unstable under alkaline conditions where they typical form [3]. Formation of complexes between pentoses and several oxide ions such as borate, silicate, and molybdate, have been investigated. In particular, stabilization of pentoses by borate and silicate were demonstrated in previous studies [4,5]. However, it is still unclear which oxide ion more effectively stabilize pentoses and which pentose, among the four aldopentoses, is stabilized.

We conducted incubation experiments of each aldopentoses under several oxide ion concentrations at a fixed temperature. The experiments were conducted under an alkaline condition (pH~12) with continuous stirring. The incubation solution was sampled at a pre-determined time interval and quantitatively analyzed for residual and produced pentoses with liquid chromatography-mass spectrometry.

We confirmed the formation of pentose-borate complexes, but the pentose-silicate complexes were below the detection limit. The concentration of all residual pentoses gradually decreased with the incubation time. Both borate and silicate reduced the decrease of pentose concentration, but the stabilization effect was greater with borate. This result suggests that borate played an important role in the accumulation of pentoses on the prebiotic Earth and formation of primordial RNA.

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