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Importance of Serpentine and Smectite for Reconstructing the Aqueous Environment of C-type Asteroids Related to the Origin of Life

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Aqueous alteration of C-type asteroids within five million years after the formation of the Solar System produced phyllosilicates (serpentine and smectite) from primary anhydrous silicates. These phyllosilicates constitute the dominant matrix minerals of the Ryugu samples returned by the Hayabusa2 mission and therefore preserve records of the physicochemical conditions within the parent asteroid.

We conducted detailed geochemical analyses of phyllosilicates —mainly lizardite (serpentine group) and saponite (smectite group)— found as major minerals in the Ryugu samples. Speciation and elemental compositions were investigated using X-ray absorption fine structure (XAFS) spectroscopy and electron probe microanalysis (EPMA), minimizing exposure to the terrestrial atmosphere. The redox state of iron (Fe) and the abundances of exchangeable major cations (Na^+, K^+, and Ca^{2+}) in saponite were used to reconstruct the redox potential (Eh) and pH of the alteration fluids, assuming chemical equilibrium during aqueous alteration.

The results show that (i) almost all Na and K occur as exchangeable interlayer cations in saponite; (ii) saponite exhibits a high Fe^{2+}/Fe_total ratio (>0.68); and (iii) the Ca/Na molar ratio is low (<0.20). The total salinity of the water was evaluated from chlorine (Cl) abundance and speciation. Chlorine occurs predominantly not as soluble salts (e.g., NaCl) but as structurally bound Cl in lizardite, indicating limited solubility and consequently low effective salinity of the aqueous system.

Thermodynamic equilibrium calculations incorporating the low Ca/Na ratio, high Fe^{2+}/Fe_total ratio, and low NaCl/Cl_total ratio indicate that the alteration fluids were highly reducing and alkaline. Such Eh–pH conditions are favorable for amino acid formation, peptide synthesis, and abiotic production of phospholipid precursors. These reducing and alkaline conditions can be explained by the presence of metallic iron in the primordial materials of the asteroid. Therefore, the Fe/(S+Si) ratio in planetesimals may be a critical parameter controlling the generation of aqueous environments conducive to the emergence of Earth-type life composed of RNA, proteins, and sugars.