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Water Content of the 4.56Ga D'Orbigny Parent Body Estimated from Phosphate

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Behavior of water in the formation of planets is essential to understand the origin of the terrestrial water (Albarede, 2009) and evolution of planets. We estimated the water content of the parent body of D'Orbigny meteorite, a ˜4.56Ga angrite, as 0.001˜0.006wt% combining the water content of phosphate and petrological and mineralogical information on melting and crystallization history of D'Orbigny. This study shows that a planetesimal contains a minor but an appreciable amount of water in the very early stage of the solar system evolution.

At first, we have estimated the timing of phosphate crystallization to estimate the water content of D'Orbigny parent body from phosphate, an accessory mineral. D'Orbigny consists chiefly of plagioclase, clinopyroxene and olivine with ophitic texture accompanying many spherical voids and druses (Kurat et al., 2001; Mittlefehldt et al., 2002). Phosphate is always found in interstices of the major constituent minerals, and Fe and Ca in olivine and Fe, Al and Ti in clinopyroxene are extremely enriched to almost Mg-free composition toward the interstices, and intergrowth of olivine and kirschsteinite is developed. The interior of the intergrowth is systematically occupied by skeletal phosphate, ulvospinel, troilite, and rounded voids. This microstructure indicates that the phosphate crystallized from a residual melt before formation of troilite and voids (vesicles) in the waning stage of crystallization.

We analyzed 3 coarse grains of phosphate with a NanoSIMS to determine the hydrogen concentration and hydrogen isotopic composition. The average water content and isotopic composition is obtained to be 0.03wt% and D/H=2.9×10^{-4}, respectively. This D/H ratio is near the lower limit of D/H of comets and Martian meteorites (Canup and Righter et al., 2000). This implies that the water in the D'Orbigny parent body had a similar origin as that of comets and that the D'Orbigny parent body could be a planetsimal that accreted to form Mars.

The water content of the D'Orbigny parent body is estimated from that of phosphate on the basis of the following petrologic evaluation. At first, D'Orbigny is inferred to have been liquid magma solidified in a closed system but not a cumulate, which is supported by ophitic texture and continuous Fe-increase and Mg-decrease in olivine and clinopyroxene towards the interstices. Then, the crystallinity at the phosphate crystallization is calculated to be 98 vol.% from the volume of troilite and voids, which further implies that the water content of the D'Orbigny melt is 0.003˜0.012wt% on the basis of the water partition coefficient between apatite and melt (McCubbin et al., 2011). On the other hand, the meteorite contains much larger spherical voids and druses, which suggest that the melt was vesiculated at the early stage of crystallization. Assuming that water is the most dominant gaseous component and that the vesicles maintained equilibrium with the melt, the water held in the vesicles is calculated to correspond to 0.0005˜0.0038 wt% in the melt by using the ideal gas equation and the volume fraction of spherical voids and druses. The sum of the two estimates is the initial water content of the melt. The water content of the parent body (mantle) is further estimated to be 0.001˜0.006 wt% on the assumption that the melting degree was high enough (30˜40 %) to consume pyroxenes, because the REE pattern of D'Orbigny is unfractionated. The estimate is comparable to 2˜13 % of the water content of the Earth (0.046 wt%), if the Earth's interior has an equivalent amount of water to the amount of the seawater (Hirschmann, 2006). This study shows a planetesimal, which accreted to form solid planets, contained a little amount of water in the very early stage of planet formation. Application of this approach to various types of meteorites may pave the way for better understanding of the water origin and transporation in the planetary formation process.