

Comparison of Oxygen Isotopic Compositions and Mineralogical Characteristics of Carbonates in Ryugu Samples

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Introduction: Ryugu sample analysis indicated that Ryugu's parent body formed in the outer protoplanetary disk [1, 2]. The returned samples are the key material to clarify the characteristics of the nebular dust at the outer disk and the chemical evolution of the whole disk, which could not be unraveled from studies of meteorites. Petrological and mineralogical analysis revealed that Ryugu samples consist mainly of phyllosilicate, magnetite, carbonate, sulfide, and phosphate and have experienced pervasive aqueous alteration [2]. In addition, Ryugu samples are breccia of mm-size clasts with various lithologies [2]. Based on the differences in the lithologies, the clasts can be classified into lithologies I–VI with increasing the degrees of aqueous alteration [3].

Previous oxygen and carbon isotope analysis of dolomite and calcite in Ryugu samples revealed that $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ values reflect the conditions of the aqueous fluid (temperature and isotopic composition) from which the carbonates were crystallized [4, 5]. However, the previous studies focused on carbonates themselves and did not take any consideration of lithologies where the carbonates exist. In the present study, we characterized lithologies first and then analyzed mineral chemistry and oxygen isotopes of carbonates in order to understand the relationship between carbonate elements and isotopic composition and the lithological variation.

Samples and methods: This study used four polished sections made from chamber C Ryugu samples (C0002 plate5, C0002 plate6, C0025-03, C0107-01) [2]. We performed electron microscopy and elemental analysis of Ryugu samples at Tohoku University using FE-SEM/EDS and EPMA and clarified the distribution and chemical composition of clasts and the mineral chemistry of carbonates. We analyzed the oxygen isotopic composition of the carbonates using SIMS CAMECA IMS 1280-HR at the Kochi Institute, JAMSTEC. We used carbonate standards which have similar chemical composition with those in the Ryugu samples [6].

Results and Discussion: We identified many clasts with carbonates whose sizes ($> 5\ \mu\text{m}$) are enough for SIMS analysis (Fig. 1). Based on the classification scheme proposed in [3], we classified the clasts in Ryugu samples. We identified all lithological types and the major lithology among them was lithology-III. The lithology-I clasts contain only small ($< 5\ \mu\text{m}$) carbonates, while lithology-II, -III, and -IV clasts contain carbonates with sizes ($> 5\ \mu\text{m}$) enough for SIMS analysis. Among lithology-II, -III, and -IV clasts, carbonates in the lithology-II are rare and small.

Three clasts in C0002plate5, four in C0002plate6, and one in C0025-03 were identified as lithology-II, which includes calcite as major carbonate phase and shows a low degree of aqueous alteration. Three clasts in C0002plate5, four in C0002plate6, and one in C0025-03 are lithology-III, which include dolomite as major carbonate phase and shows high degree of aqueous alteration. Three clasts in C0107-01 are lithology-IV, which include dolomite and magnesite as major carbonate phases and show the degree of aqueous alteration higher than lithology-III.

Figure 2 shows the result of oxygen isotope analysis of dolomite and calcite in all the clasts. $\Delta^{17}\text{O}$ and $\delta^{18}\text{O}$ values of calcites show a variation. On the other hand, $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ values of dolomite show lesser variation than those of calcite. This result is consistent with previous works [4, 5]. It indicates that the temperature and composition of the fluid from which calcite crystallized are diverse, while those of the fluid from which dolomite crystallized are relatively homogeneous.

$\delta^{18}\text{O}$ values of carbonates in the clasts of the less altered lithology II are higher than those in the clasts of highly altered lithology-III and -IV (Fig. 2C, D). This suggests that the crystallization temperature of carbonates in the less altered clasts is lower than that in the highly altered clasts. The difference in the degrees of aqueous alteration was suggested between

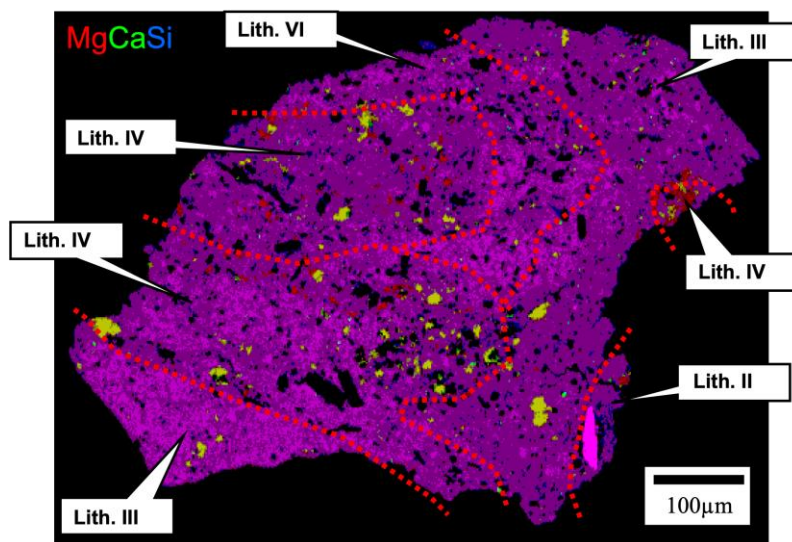


Figure 1. Mg, Ca, and Si map of C0107-01. Most of the matrix, as the purple part, is phyllosilicates, and the yellow-green part is dolomite. Clasts are classified into lithologies -II, -III, and -IV [3].

lithologies-III and -IV, but there is no difference in the oxygen isotopic compositions of dolomite in the two types of clasts. It suggests that the temperature and composition of the aqueous fluid become constant on the way to the progress of aqueous alteration.

Moreover, the oxygen isotopic compositions of calcite in the same clast are similar. However, those in the different clasts are different (Fig. 2A, B). This indicates that the temperature and composition of the fluid are homogeneous only in the local areas. The variation of oxygen isotopic compositions among calcites in different clasts show a diversity among the clasts. The result indicates that the condition of the crystallization carbonate of each class (temperature and isotopic composition of water) is different.

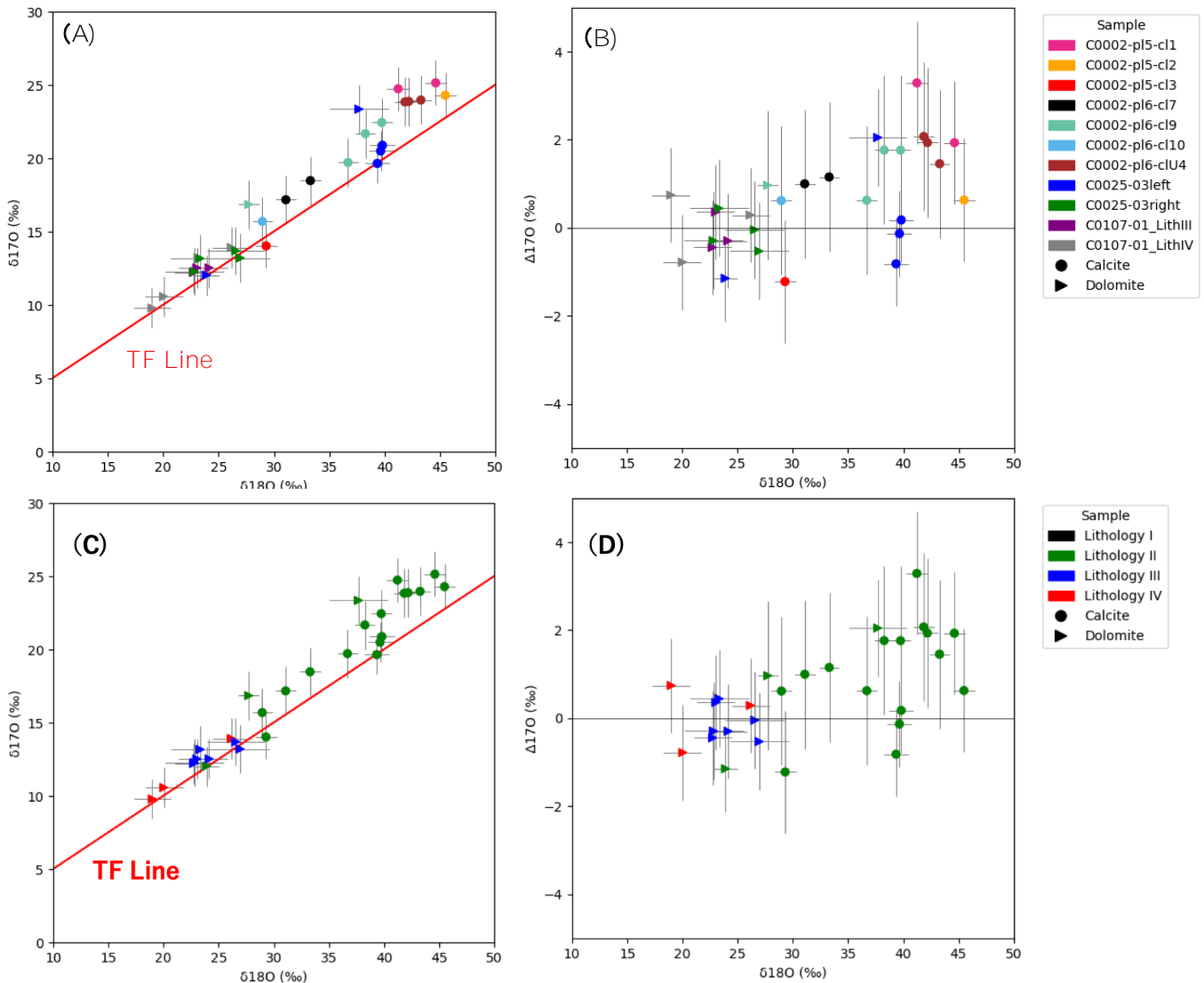


Figure 2. Oxygen three-isotope plot of carbonates in Ryugu samples. Error bars are set at 2σ : (A) A relationship between $\delta^{17}\text{O}$ vs $\delta^{18}\text{O}$ between clasts; (B) $\Delta^{17}\text{O}$ vs $\delta^{18}\text{O}$ between clasts; (C) $\delta^{17}\text{O}$ vs $\delta^{18}\text{O}$ between lithology types; (D) $\Delta^{17}\text{O}$ vs $\delta^{18}\text{O}$ between lithology types.

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