THREE-DIMENSIONAL LITHOLOGIES WITHIN A MILLIMETER-SIZED RYUGU GRAIN

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Introduction: Ryugu is a primitive rubble-pile asteroid thought to have been formed by re-accretion after a disruptive impact on a bigger first-generation parent-body [1]. Similarly to CI chondrites, Ryugu samples returned by Hayabusa2 show the presence of fragments with various mineralogical and chemical assemblies. These fragments, also called lithologies range in size from several tens to several hundreds of µm and were, so far, described in 2D polished sections [2, 3, 4]. Looking at the lithologies in 3D would help us to better understand complex alteration, brecciation and re-accumulation processes that occurred on the parent body of Ryugu and CI-chondrites. In this work, we combined a typical voxel by voxel segmentation with a new method we developed to detect and analyze lithologies in 3D using micro-computed tomography (µXCT) data.

Material: The sample used for this study is a millimeter-sized Ryugu grain (A0159) from the first sampling site (Chamber A). We measured µXCT data at the PSICHÉ beamline of Synchrotron SOLEIL (France) using a monochromatic X-ray beam at 25 keV. CT-images have a voxel resolution of 1.295x1.295x1.295 μm^3 and each voxel has a Linear Attenuation Coefficient (LAC) value which depends on the local density and composition of the material.

Data processing & results: The first method (voxel by voxel segmentation) consists in classifying each voxel as a single component: either it corresponds to a "low LAC" value component (pores or organic matter), a matrix component, a carbonate component, or an opaque component (sulfides or oxides). Other minor phases (phosphates, olivine…) were either too small or too rare to be attributed to a single component. Segmentation results show that A0159 is extremely rich in carbonate with a carbonate/matrix ratio of about 1:2. This is significantly higher than the carbonate abundance measured in previous studies on mm-sized Ryugu samples [4,5]. In particular we detected a millimeter-sized vein (1100x900x100 μm^3) going through the sample; the largest carbonate vein found so far in Ryugu or CIs. The second data processing method uses a user-independent clustering technique on histograms obtained by analyzing the local distributions of the LAC values on resampled volumes of 25x25x25 voxels. The final result gives 8 clustered histograms which can be interpreted as the 8 mineralogical assemblies (lithologies) that best describe A0159 sample.

Discussion: The presence of these aggregated lithologies confirms that Ryugu is a breccia with fragments having different histories of formation and evolution. The combination of these two methods provides information on the 3D mineralogical assemblies, and their individual mechanical and physical properties with no damage on the sample. A0159 can be characterized by four main domains grouping one or two lithologies: First, the carbonate-rich vein (1) crossing a matrix-rich domain (2), indicating an important fluid circulation that took place during or after the alteration processes that formed (2). Then, another matrix-rich domain (3) enriched in dense materials (carbonates and/or opaque components) is present as a shell around (2), and could therefore have experienced the same alteration event. However, the mineralogical differences between the domains (2) and (3) might be related to the heterogeneity of the starting material or a progressive (radial) aqueous alteration. Finally, the last domain (4) is enriched in low-LAC value materials. If low-LAC values are due to a high porosity, domain (4) might have been either, i) less compacted; porosity decreasing when the number of impact increases [6] or, ii) less aqueously altered than the matrix-rich domain (2) and the dense materials-rich domain (3). If low-LAC values are mainly organic matter, this indicates a strong heterogenous distribution in the sample. This distribution could also be due to the heterogeneity of the starting material and/or a possible redistribution by aqueous alteration [7]. Finally, fractures are heterogeneously distributed through the sample, with some fractures surrounding domains, while other fractures have progressed within domains which indicates a low strength property. The former might testify of accretion and/or impact processes, whereas the latter might testify of thermal fatigue [8] processes.

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References: [1] Michel P et al. (2001) *Science*, vol. 294, no. 5547, p. 1696– 1700. [2] Nakamura T. et al. (2023) *Science*, vol. 379, no. 6634 p.eabn8671. [3] Morlok, A. et al. (2006), *Geochimica et Cosmochimica Acta*, vol. 70, no. 21, p.5371–5394. [4] Yamaguchi, A. et al. (2023), *Nature Astronomy*, vol. 7, no. 4, p.398–405. [5] Nakamura, E. et al. (2022), *Proceedings of the Japan Academy*, Series B, vol. 98, no. 6, p. 227–282. [6] Friedrich, J. M. et al. (2017) *Geochimica et Cosmochimica Acta*, vol. 203, no.4, p.157–174. [7] Dionnet, Z. et al (2023), *Meteoritics & Planetary Science*. [8] Delbo, M. et al. (2014), *Nature*, vol. 508, no. 7495, p. 233–23.