Iron valence state and mineralogy in particles from asteroid Ryugu

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Introduction: Iron is a major element in rocky material from the solar system that can occur under multiple valence state. As such it can be used to trace geological processes that occurred on asteroid Ryugu, including thermal metamorphism and aqueous alteration. Observations of the mineralogy of carbonaceous chondrites have revealed the presence of minerals assemblages that are barely in thermodynamic equilibrium. Even at the micron-scale, iron is often present under multiple valence state (most frequently 0, +2, or +3) in a wide range of minerals (primary or secondary in nature), including silicates, oxy-hydroxide, sulfides, sulfates, clay minerals and carbonates. Such heterogeneous assemblages are the results of post-accretion processes that often triggered a partial textural and chemical equilibration, associated to a modification of primary Fe-bearing minerals and their valence state. It is therefore tricky to disentangle the different processes recorded by the iron mineralogy of chondritic materials. Furthermore, since most Fe-bearing phases are redox-sensitive, exposure to terrestrial atmosphere may also induce iron oxidation and additional, late modifications of the iron mineralogy. In this context, Hayabusa2 sampled Ryugu, an asteroid that did not suffer extensive thermal metamorphism, and returned rocks to Earth with minimal air exposure. It offers a unique opportunity to study the redox state of carbonaceous asteroids and evaluate the overall redox state of the most oxidized primitive rocks of the solar system.

Samples and methods: Here, we determine the mineralogy and the redox state of Fe-bearing minerals from ten Ryugu samples (five from the chamber A used for the first sampling and five from the chamber C for the second sampling) prior to and after exposure to air. We use Synchrotron Mössbauer Spectroscopy (SMS) technique that enables to probe the bonding environment of iron at the microscopic scale. These measurements are combined with co-aligned X-ray diffraction, permitting to assess locally the mineralogy and valence state of iron in Ryugu particles. We also apply conventional Mössbauer spectroscopy on a couple of large (mm-size) Hayabusa returned samples from the chambers A and C.

Results and discussion: We will present the bulk proportions of iron-bearing minerals and the Fe redox state (Fe^{3+}/Fe_{tot}) at the 'Stone' scale. We will then provide the first estimate of the redox state of Ryugu as compared to the large array of bulk redox data collected over several decades on meteorites. We will also describe the redox states of iron-bearing clay minerals before any air contamination. The first clues on the ageing of these minerals after exposure to air will be discussed based on data collected on the same sample before and after exposure to air. We will compare in greater details Ryugu samples to a series of well-known chondritic meteorites including Orgueil and Murchison. We will show, more specifically, that most of the iron is accommodated in magnetite and sulfides (pyrrhotite and pentlandite). Clay minerals also contain a fraction of the total iron. Overall, the investigated Ryugu samples appears to be (or are) more reduced than the Orgueil, both considering the bulk composition and the clay minerals fraction. The redox state recorded in a pristine sample and in the same sample exposed to air for more than two months do not show clear evidence of oxidation suggesting that, as far as iron is concerned, samples can be prepared and analyzed at ambient conditions at least for several weeks if stored in vacuum or in inert gas after preparation.