Editorial

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Ryugu in the spotlight

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Four years ago the Japan Aerospace Exploration Agency's Hayabusa2 mission returned samples of an asteroid to Earth. The latest results in the analysis of the sample material are presented in this issue of *Nature Astronomy*.

This month four years ago, on 5 December 2020, the return capsule from the Hayabusa2 spacecraft re-entered Earth's atmosphere with 5.4 grams of material extracted from near-Earth carbonaceous asteroid Ryugu on board. In coincidence with this anniversary, this issue of *Nature Astronomy* includes a number of articles presenting the latest results from the ongoing sample return analysis.

Even after four years, the sample is still able to unveil surprises, such as unexpected minerals. In a paper by Cédric Pilorget et al., the authors identified a new type of grain rich in phosphorus (which they call HAMP — hydrated ammonium–magnesium–phosphorus grains). Phosphorus is an essential element for biochemistry, but it is rarely found in the Solar System beyond the atmospheres of gas giants. As Matthew Pasek explains in his News & Views, this mineral is all the more interesting as it is much more soluble in water than other phosphorus-rich compounds. As carbonaceous asteroids have likely delivered material to the early Earth via impacts, a source of highly soluble phosphorus could have played an important role in the formation of biochemically relevant molecules. The data from the imaging spectrometer MicrOmega analysed by Pilorget et al. show several micron-sized HAMP inclusions in the Ryugu sample, and first results from the sample brought back by the OSIRIS-REx spacecraft from another carbonaceous asteroid, Bennu, also hint at the presence of HAMP-like grains. These discoveries suggest that HAMP material might be common in carbonaceous asteroids, but one needs to look closely to find it, which is possible only by sample return.

One of the main components that was likely delivered by small bodies to early Earth is water. Considering the prevalent role of water in shaping the evolution of early Earth and the development of life, determining the actual contribution of extraterrestrial water delivery to early oceans is a key question, but meteorites are usually altered by aqueous processes after they arrive on Earth, making robust inferences challenging to draw. Ryugu is not a particularly hydrated asteroid, at least at the surface, but multiple lines of evidence suggest that water activity happened in its past or in that of its parent body. The study of the pristine sample in the laboratory provides details on the processes and the chronology of aqueous activity in carbonaceous asteroids.

Two papers in this issue look at the matter from two different points of view. A paper by Matsumoto et al., accompanied by a News & Views written by Prajkta Mane and Michael Zolenski, looks at the composition of the sample and, like Pilorget et al., finds yet another kind of mineral not found previously on Ryugu: sodium carbonates. Other forms of sodium salts have been identified in Ryugu samples before, but the presence of halite (Na_2CO_3) and thermonatrite ($Na_2CO_3 \cdot H_2O$) provides a more precise determination of the timing of aqueous alteration within Ryugu's parent body. The authors infer that the precipitation of sodium carbonates happened quite late and thus that water activity on Ryugu's parent body was rather extended in time, probably across multiple alteration episodes, and involved a substantially larger primordial water content available on Ryugu's parent body than the current one. This detection also links this small asteroid to much larger bodies in the outer Solar System with extant or past internal oceans. Sodium carbonates were in fact detected on Ceres, whose bright spots contain high abundances of sodium carbonates, Europa, Enceladus and Ganymede, where they can indicate hydrothermal activity.

The other paper on Ryugu's hydration, by Matthew Genge et al., looks at structural rather than mineralogical features. Our own experience tells us that water can easily create cracks and affect the integrity of rocks especially when undergoing freezing–melting changes, and these are the kind of signatures that Genge et al. looked for. This freeze–thaw cycle is not easily detected in the micro-scale structure of Ryugu's samples, and water works differently in microgravity. Despite these difficulties, Genge et al. were able to detect a micro-network of faults and veins in Ryugu's grains and infer that these micro-networks can be a significant factor in disrupting asteroids and in spreading hydration and brines in the interior of the asteroids, mixing the various fluids and volatiles contained therein.

If all these studies demonstrate the power of sample return analysis by discoveries that could have only been made in the laboratory, the Analysis by Christian Potiszil et al. focuses instead on a cautionary tale: why do the results from the samples sometimes differ to what has been observed from orbit by remote sensing, and what does that entail for our knowledge of the asteroid? Potiszil et al. focus in particular on the difference in estimated carbon content, which has an impact on the albedo, between data taken by Hayabusa2 while orbiting Ryugu (between 14.6 and 53.5 vol% of organic matter) and the samples (a mere 2.92 vol%). The results indicate that microscopic effects like the surface roughness at small scales and the fine distribution of organic matter can impact remote sensing data substantially.

Nature Astronomy has been involved in the publication of the Ryugu sample discoveries since the very first results three years ago. As all these results belong to a unity that includes studies from the Hayabusa2 spacecraft itself, we set up a living Collection so that they can be found all together in one place.

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