PARENT BODY OF THE HAYABUSA2 TARGET (162173) RYUGU: HIGH POROSITY, EARLY ACCRETION, SMALL SIZE. W. Neumann[1,2], M. Grott[2], M. Trieloff[1], R. Jaumann[3], J. Biele[4], M. Hamm[5], E. Kührt[2,6], [1]Heidelberg University, Institute of Earth Sciences (Wladimir.Neumann@dlr.de), [2]German Aerospace Center (DLR) Berlin, [3]Free University of Berlin, [4]German Aerospace Center (DLR) Cologne, [5]University of Potsdam, [6]China Academy of Space Technology, Beijing.

Introduction: Both observations of C-type near-Earth asteroids and laboratory investigations of carbonaceous chondritic meteorites provide strong evidence for a high porosity of C-type asteroids. Observations of (162173) Ryugu by Hayabusa2 demonstrated that this asteroid is a low-density rubble pile[1] whose surface is dominated by large boulders[2]. Boulder thermal properties imply low thermal conductivity values of k=0.06-0.16 $Wm^{-1}K^{-1}$ and high boulder microporosity of $\phi_{boulder}$≈28-55%[3,4], which is substantially higher than for water-rich carbonaceous chondrite samples and could indicate distinct evolution paths for the parent body of Ryugu and parent bodies of carbonaceous chondrites, despite spectral similarities. High boulder microporosity values are consistent with the overall low bulk density of 1190±20 kg m^{-3} [5], a high bulk porosity of ≈50%[1], and a macroporosity of ≈16%[6].

In the present study, we calculate the evolution of the temperature and porosity for early solar system's planetesimals in order to constrain the range of parameters that result in microporosities compatible with Ryugu's high-porosity material and likely burial depths for the boulders observed at the surface. By varying key properties of the parent body, such as accretion time t_0 and radius R that have strong influence on temperature and porosity and by comparing the interior porosity distribution with the measured boulder microporosity, hydration, and partial dehydration of the material, we constrain a field within the (R,t_0)-diagram appropriate for bodies that are likely to have produced such material.

Methods: Within the sequence of events that preceded the formation of Ryugu (original parent body evolution, potentially a series of disruption events and accretion of intermediate parent bodies, and the final accretion to Ryugu[5]), the local microporosity of a single boulder results mainly from processes that took place during the thermal evolution of the original parent body, e.g., ^{26}Al-induced early internal heating, hydration, compaction, and partial dehydration prior to the first disruption.

We investigate the microporosity using global thermal evolution and compaction models for the porosity of two-component mixtures of spherically symmetric bodies described in detail in [7]. Such models predict the microporosity of planetesimal material established due to internal heating within creep processes that are driven by the joint action of temperature and pressure under conditions that favor creep of constituent materials. No notable creep processes can be expected in a late formed and small object such as Ryugu or in an intermediate object between the first and last disruption events. Therefore, assuming that the microporosity changes little after the disruption of the original parent body, we calculate the microporosity throughout the interior of planetesimals with different sizes and accretion times in order to reproduce $\phi_{boulder}$.

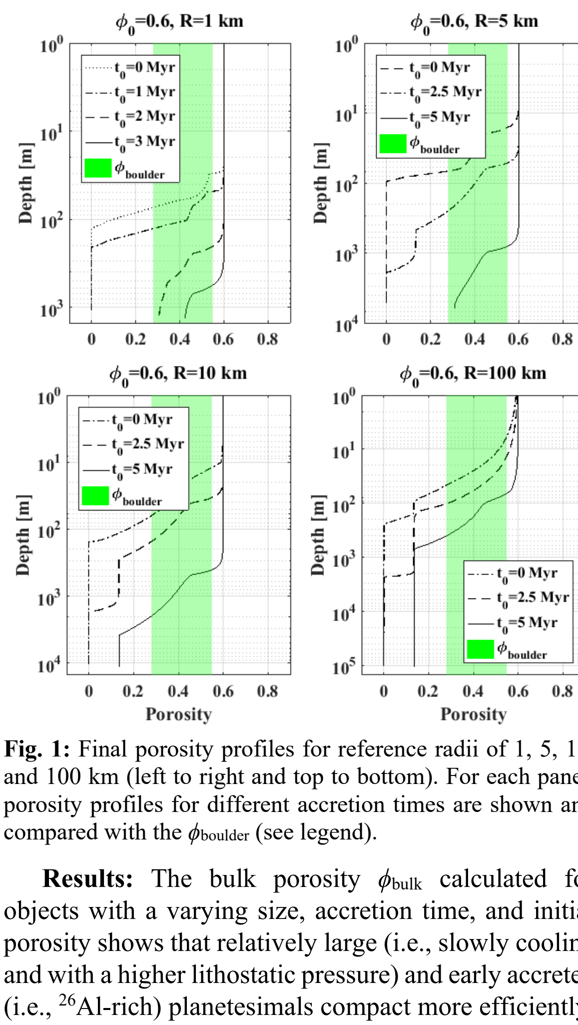

Fig. 1: Final porosity profiles for reference radii of 1, 5, 10, and 100 km (left to right and top to bottom). For each panel, porosity profiles for different accretion times are shown and compared with the $\phi_{boulder}$ (see legend).

Results: The bulk porosity ϕ_{bulk} calculated for objects with a varying size, accretion time, and initial porosity shows that relatively large (i.e., slowly cooling and with a higher lithostatic pressure) and early accreted (i.e., ^{26}Al-rich) planetesimals compact more efficiently, retaining only a thin porous blanket. By contrast, small

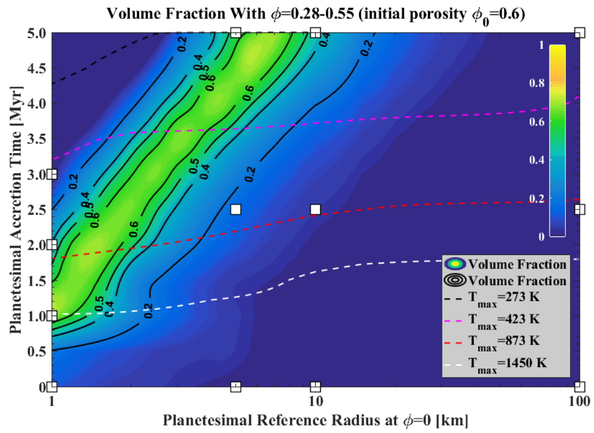

Fig. 2: The volume fraction of the material with $\phi=\phi_{boulder}$ as a function of the reference radius and accretion time. Isolines for the maximum temperature T_{max} are added for comparison: 273 K (onset of aqueous alteration), 873 K (serpentine dehydration), and 1450 K (onset of silicate melting). White squares correspond to bodies from Fig. 1.

and late accreted bodies with relatively small pressures remain highly porous, deviating negligibly from initially constant porosity profiles. While the value of ϕ_{bulk} does not provide information about the porosity distribution, it shows that intermediate conditions with a trade-off between size and accretion time should produce bodies with a high relative volume of material matching $\phi_{boulder}$. Of importance for the accretion of Ryugu from the remnants of a larger object is the location of such material within the parent body. The porosity distribution is shown in Fig. 1 by means of profiles established after the cessation of compaction and compared with $\phi_{boulder}$. Profiles for reference radii of 1, 5, 10, and 100 km and several accretion times shown represent different types of structures, which can have up to three layers and are defined by a straightforward comparison with $\phi>\phi_{boulder}$, $\phi\approx\phi_{boulder}$, and $\phi<\phi_{boulder}$.

The likelihood that a pair (R,t_0) identifies a parent body scales with the relative volume of the material with $\phi \approx \phi_{boulder}$, in particular, if materials from all depths contribute to each small object produced after the disruption of the original parent body[5]. Fig. 2 shows the volume fraction $f_{boulder}$ defined as the ratio of the bulk volume with $\phi \approx \phi_{boulder}$ and the planetesimal volume within the (R,t_0) parameter space. For an initial porosity of $\phi_0 \geq 0.6$, diagonal maximum $f_{boulder}$ fields emerge. As such, the consideration of $f_{boulder}$ confines a set of objects limited by a maximum radius of ≈10 km and an accretion at 5 Myr after CAIs.

Further observations to be reproduced is aqueous alteration, that can be assumed as quasi-instantaneous on a geological time scale[8,9] and a partial dehydration. A first-order indicator and a prerequisite for hydration is the melting temperature of water ice. It can be surpassed for a variety of accretion times and planetesimal sizes (Fig. 2, black dashed line showing T_{max}=273 K), e.g., $t_0 \lesssim 4.5$ Myr for km-sized objects (an effect of the rapid decay of ^{26}Al), and also for a late accretion of larger bodies (an effect of their weaker cooling). A rough upper limit on the thermal conditions is the production of silicate partial melt, occurring for $1 \lesssim t_0 \lesssim 1.8$ Myr after CAIs (Fig. 2, white dashed line showing with T_{max}=1450 K the silicate solidus). Under such conditions, dehydration is highly likely, such that traces of aqueous alteration would be erased contradicting Ryugu's observed composition. Thus, only the objects in the field between the dashed black and red lines should have experienced thermal conditions that allowed for hydration, and remained cool enough not to dry out. In particular, T_{max} obtained for a number of models satisfy the CI/CM alteration temperature range of 273-423 K, while those obtained in the patch between red and white dashed lines indicate dehydration at ≈873 K, consistent with the dehydration temperatures of the CI chondrite Y-86029 and CM chondrites Y-793321 and Jbilet Winselwan[10] shown to resemble closely Ryugu in their spectral appearance[5].

Summary and Conclusions: Our calculations indicate a parent body size of only a few km and its early accretion within ≲2-3Myr after the formation of CAIs. A gradual final porosity profile of best-fit bodies indicates production of both low-and high-density boulders from the parent body material. By contrast, parent body properties for CI and CM chondrites obtained additionally by fitting carbonate formation data[7] indicate a radius of ≈20-25 km and an accretion time of ≈3.75 Myr after CAIs[7]. These results imply a population of km-sized early accreting highly porous planetesimals as parent bodies of the rubble-pile NEA Ryugu (and, potentially, other NEAs) and a population of larger and late accreting less porous planetesimals as parent bodies of water-rich carbonaceous chondrites. The model assumptions and results can be verified by upcoming sample analyses. Particle texture and mineral analyses (lack of magmatic textures, presence of matrix minerals, phyllosilicates, or chondrule fragments) could yield alteration temperatures, while analyses of coarse grains could provide porosity estimates.

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