DO WATER-RICH CARBONACEOUS CHONDRITES AND THE NEA RYUGU SHARE A COMMON PARENT BODY? W. Neumann[1,2], M. Grott[2], M. Trieloff[1], [1]Heidelberg University, Institute of Earth Sciences (Wladimir.Neumann@dlr.de), [2]German Aerospace Center (DLR) Berlin, Institute for Planetary Research.

Introduction: Hayabusa2 pre-flight and in-orbit spectroscopic observations of Ryugu showed presence of phyllosilicates and general consistency with carbonaceous chondrites (CCs), in particular, with moderately dehydrated CI and CM groups[1-3], implying that Ryugu's parent body was a water-rich planetesimal that accreted from dust and ice. MASCOT in-situ measurements provided a boulder microporosity of $\phi_{boulder}$≈28-55%[4,5] that 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 CCs.

By fitting the temperature and age data for the formation of secondary minerals in CI and CM chondrites with thermal evolution models for early solar system's planetesimals, we obtained properties of their parent bodies and compared them with our best-fit results for the parent body of Ryugu[6], examining in this manner a potential common source suggested by Ryugu's spectral properties.

Overview and Methods: The sequence of events that preceded the formation of Ryugu comprises original parent body evolution, potentially a series of disruption events and accretion of intermediate parent bodies, and the final accretion of Ryugu[3]. Some of the processes at work during the thermal evolution of the original parent body are ^{26}Al-induced early internal heating, hydration, compaction, and partial dehydration prior to the first disruption. Our modeling indicates a parent body size of only a few km and its early accretion within ≲2-3Myr after the formation of CAIs[6].

Notably aqueously altered CCs are CI, CM, and CR groups. Their overall alteration temperatures range from 273 K to 423 K[9,10]. The petrographic types range up to 2 (CI, CM) and up to 3 (typical CRs), lacking significant thermal metamorphism. Of note is the related Yamato-type (CY) that indicates metamorphism at 773-1073 K and is potentially derived from a near-Earth source.

Characteristic properties of the CI and CM parent bodies can be derived from the analysis of formation of mineralogical components, for example, carbonates (calcite, dolomite, breunnerite) that are secondary minerals formed in the presence of aqueous solutions. Overall CI and CM carbonate formation times of 4.8-6.1 Myr after CAIs[8] provide, along with the precipitation temperature range of ≈293-423 K, data points that need to be approximated by temperature evolution in different regions of the parent body in the respective time interval.

We fitted key properties of the CI parent body using global thermal evolution and compaction models for ^{26}Al heated planetesimals described in detail in [7]. Carbonate formation occurred close to the peak of hydrothermal activity in CI and CM chondrites triggered by ^{26}Al heating. Oxygen isotopic compositions of calcite and dolomite[11,12] and thermodynamic modeling[13] yields T≈293-343 K and T≈373-423 K for CM and CI carbonates, respectively. As carbonates incorporate Mn (including the short-lived isotope ^{53}Mn) the decay system ^{53}Mn-^{53}Cr can be used to constrain their formation age.

Concerning Mn-Cr ages, we followed the calibration by [8], who used a (U isotope corrected) U-Pb-Pb age of 4567.94±0.31 Myr for CAIs by [14], a (U isotope corrected) U-Pb-Pb age of 4563.37±0.25 Myr for the Mn-Cr anchor D'Orbigny by [15], and a ^{53}Mn/^{55}Mn ratio of (3.54±0.18)x10^{-6} by [16]. This calibration of the ^{53}Mn-^{53}Cr time scale results in Mn-Cr formation times of 4.8-6.1 Myr after CAIs for CI and CM carbonates. In particular, the CM carbonate and the CI dolomite formation times are almost identical within error bars. In addition, the CI breunnerite formation occurred during an extended time interval of 6.1-13.3 Myr after CAIs[10]. For a comparison of Mn-Cr ages and thermal models of the parent body at various depths, (t,T) curves should intersect the above time-temperature regimes.

Results: Testing a potential Ryugu connection, the evolution of the temperature at different depths was compared with CI and CM carbonate formation ages and temperatures. The models show that such fits are possible only for formation times of t_0≲4 Myr after CAIs. On the one hand, representative bodies from the favored parameter space for Ryugu's parent body from [6] that satisfy this condition are considered. On the other hand, also a second group of several larger objects that accreted before 4 Myr after CAIs are included.

The (t,T) regimes represented by boxes and optimal (t,T) curves as well as associated depths are shown for selected models in Figure 1. For nearly all bodies shown, the CM carbonate and CI dolomite data can be fitted. However, for the first group, and even for radii of R<15 km with any t_0, rapid cooling does not allow to fit the breunnerite data. In addition, in most cases the porosity at the fit depth surpasses the CI and CM class average values and only for R=1 km temperature evolution indicates serpentine dehydration. Thus, a potential precursor of Ryugu with R=1.5-3 km and t_0=2-3.5 Myr could only be a CM or CI source, if constrains on partial dehydration, CI and CM porosity, and breunnerite formation data are neglected. Furthermore, contrary to the general concept of a low maximum temperature of T_{max}≲423 K throughout a CI or CM parent body, it would have heated up to ≥600-800 K. Only the late-forming case of R=3 km, t_0=3.5 Myr after CAIs agrees with this concept, without being compatible with the breunnerite formation time.

Larger and relatively late accreting bodies of the second group allow for fitting the CI breunnerite data in addition to dolomite in some cases. Here, it is required that after crossing the dolomite data point, a (t,T) curve proceeds through the breunnerite rectangle without surpassing its T_{max}, and then leaves it near the lower right corner. This cannot be fulfilled for an early accretion, since temperature curves would either surpass T_{max}=423 K, or fall below T_{min}=373 K too early. For an accretion after 3.8 Myr, it is not possible to fit the dolomite formation data. Larger objects, in addition, fail to fit the CI data, as shown for R=50 km. The CM data are fitted best at smaller depths of less than 1 km, while the CI data are fitted typically between a half-depth and the center of a planetesimal, where heat can be retained longer. In such cases, the (t,T) fit curve crosses the CI dolomite data range, indicating consecutive mineral formation, with dolomite precipitating during the prograde T evolution and breunnerite forming on both the prograde and the retrograde branch of the (t,T) curve at the same depth. None of the low-T bodies of the second group produce dehydrated material or CI and CM porosities at fit depths. Bodies from the second group are bad candidates for Ryugu's precursors[6], but some of them provide far better fits to the carbonate formation data and are relatively homogeneous with T_{max}≲423 K throughout most of the interior. Bodies with radii of 15≲R≲25 km are more suitable as CI and CM parent bodies. While debris from these layers could contribute to Ryugu in a re-accretion event, its alteration temperature would be too low for dehydration, attributing partial dehydration to an impact.

Summary and Conclusions: The heating of potential precursors of Ryugu is consistent with CI/CM alteration temperatures[9,10]. However, rapid cooling of those models that fit the CM carbonate and CI dolomite data is inconsistent with CI breunnerite data, and their porosities surpass those typical for CI/CM chondrites. While a common source is unlikely, mineralogies that would appear CI- or CM-like in their spectral image are produced. More consistent with the meteorite data that suggest a relatively homogeneous parent asteroid with T_{max}≲423 K, are bodies with R=15-25 km and t_0≈3.75-3.8 Myr after CAIs, that allow for fitting both CI and CM data (including breunnerite) in one asteroid. Here, objects with R=20-25 km are preferred, since they satisfy carbonate formation conditions in their central areas. Although relatively large CI/CM parent bodies derived are less favored as Ryugu's precursor[6], re-accretion of a small part from specific depth region of such bodies provides another formation scenario for Ryugu, which would then be a rubble fragment. However, this rubble would originate from shallower regions than the CI/CM fit depths and a partial dehydration would be attributed to impact heating.

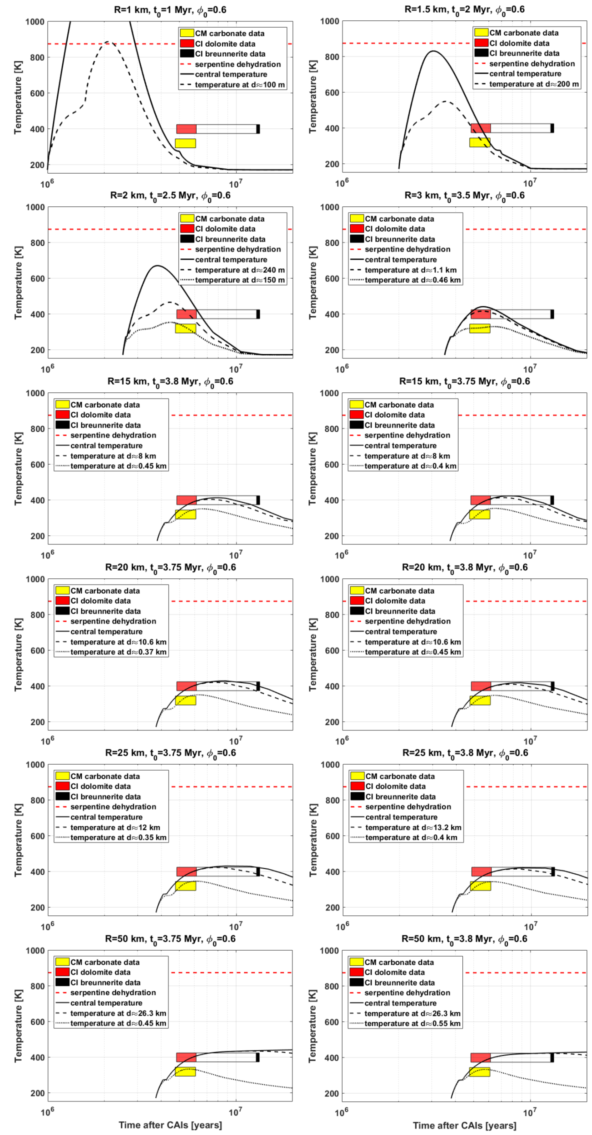

Fig. 1: The (t,T) curves at the center and at fit depths of the CI and CM carbonate data. First and second rows: first group. All other rows: second group.

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