GENETIC RELATIONSHIPS AMONG SMALL BODY RESERVOIRS FROM GEOPHYSICAL CONSTRAINTS. J. C. Castillo-Rogez[1], K. J. Walsh[2], P. Vernazza[3], D. Takir[4], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States, (Julie.C.Castillo@jpl.nasa.gov), [2]Southwest Research Institute, Boulder, CO, United States, [3]Aix Marseilles Universite, CNRS, LAM, UMR 7326, Marseille, France, [4]SETI Institute, Mountain View, CA, United States.

Introduction: Per their large number, midsize asteroids in the 100-300 km diameter range represent the bulk of the mass of the asteroid belt after Ceres, Vesta, and Pallas are removed. This has been interpreted as a primordial feature [1], i.e., this generation of planetesimals accreted fast and then contributed to the growth of larger bodies. Smaller asteroids are fragments/debris from collisions between these midsize planetesimals, many of which are progenitors of asteroid families. Midsize planetesimals are also found in all small body reservoirs, such as the Kuiper Belt, the Trojan asteroids, and the irregular satellites. Phoebe stands out in the outer solar system as a high density planetesimal when most other 100-300 km objects in that region have cometary-like densities. Conversely, many asteroids found in the asteroid belt also have densities ≤ 1 g/cm^3. These discrepancies show that midsize planetesimals across the solar system had very different heat budgets and those currently found in the same reservoirs may have formed in different accretional environments.

Comparison between populations of objects in the same size range can help constrain these environments via a quantification of the heat budget of these bodies, by taking current porosity estimates as a gauge of internal evolution. Gravitational energy and accretional heating are minor contributors to that class of bodies, per their small sizes [2]. Heat from long-lived radioisotope decay cannot keep up with heat lost by diffusion from these small bodies. They might promote some creep-driven compaction depending on the volume fraction of volatiles, but otherwise these bodies are expected to remain globally porous. Only short-lived radioisotopes, and especially ^{26}Al, can incur dramatic internal changes, e.g., extensive compaction, ice melting, and then aqueous alteration. We know this to be the case for C*h* and C*gh* asteroids, the classes of C-type asteroids that display a water of hydration signature over their surfaces [3] and are believed to be parent bodies of the CI/CM chondrites [e.g., 4]. Hence the density and spectral properties of <300 km planetesimals provide first order constraint on the time of formation of these bodies.

Approach and Results: We track the evolution of porosity in these bodies in order to explain the disparities in porosity between main belt asteroids and irregular satellites, on the one hand, and Kuiper Belt objects and Trojan asteroids, on the other hand. We model the thermal and porosity evolution of midsize planetesimals following previous work for Phoebe and Trojans [5, 6]. Representative results are presented in Figure 1.

Genetic Relationships Between Reservoirs of Small Bodies: Similar evolution between Trojan asteroids, P- and D-type asteroids found in the main belt, Centaurs, and KBOs support a genetic relationship between these classes of bodies, as simulated by many studies [7, 8]. Limited internal evolution is consistent with accretion models; for example, Kenyon et al. [9] estimated that objects forming in the 20–25 AU region would take at least 5 My to start accreting and reach a 100 km radius in ~1 My.

Many irregular satellites display spectral properties akin to C-asteroids, such as Phoebe and Himalia. Saturn's satellite Phoebe was suggested to come from the Kuiper Belt based on the observation that its density matches the grain density inferred from cosmochemical models of bodies formed in the Solar nebula [10]. Thermal modeling showed that most of Phoebe's original porosity could be removed provided that it accreted in less than 4 My after calcium-aluminum inclusions taken as a time reference [5]. The density discrepancy between Phoebe and KBO questions that relationship and cannot be uniquely explained by a difference in volatile content. Many previous studies noted the similarities between the spectra of Phoebe, Himalia, and hydrated asteroids and suggested that the two irregular satellites actually migrated from the inner Solar system [e.g., 11, 12]. The Grand Tack and alternate models [13, 14] could provide an alternate scenario for a common origin for hydrated C-type asteroids and irregular satellites. In that context, the primary reservoir for C-types is between and beyond the orbits of the giant planets. So that material could have been available for capture by the giant planets early on. This model implies accretion was fast and early in that region, consistent with recent accretion scenarios [15]. Density and spectral variations found among the various subclasses of C-type asteroids [16] might further support a scenario where these bodies formed at different distances from the Sun, i.e., between Jupiter-Saturn, Saturn-Uranus, and beyond, resulting in different volatile composition and heat budget.

Implications for Ceres: Following the logic introduced above, it might be possible to constrain the accretional environment of Ceres and Ceres-like asteroids (e.g., 10 Hygiea). Ammoniated material on Ceres' surface [17] and its large fraction of volatiles (almost 50vol.%) suggest that the dwarf planet formed from material originating beyond Jupiter. However, it is not confirmed yet whether Ceres as a whole originated far in the outer Solar system or if it grew from outer solar system planetesimals migrated to the main belt. It might be possible to constrain Ceres' time of formation assuming it formed in the same region of the solar system as 10 Hygiea, an asteroid that shares a similar surface composition involving carbonates and ammoniated clays [18]. Hygiea is half the size of Ceres and thus is more sensitive to the heat budget available post-accretion. Our modeling of Hygiea's thermal evolution requires ^{26}Al decay heat for its interior to reach conditions amenable for hydrothermal processing on a global scale. Furthermore, the depth of altered material should be relatively shallow in order to be exposed either by subcatastrophic disruption (which produced Hygiea's family) or by overturn of an unaltered crust. We infer a time of formation of less than 3.5 My after CAIs for Hygiea. This early formation is similar to that inferred for CM chondrite parent bodies [e.g., 19] and Phoebe [5].

Summary: The heat budget of midsize planetesimals varied across the Solar system. Jupiter Trojan asteroids, D/P asteroids in the main belt, and midsize KBOs appear to have preserved up to 40% bulk porosity, which we explain as accretion with few or no short-lived radioisotopes. This reinforces the genetic relationship between these classes of bodies proposed by dynamical models. On the other hand, C-type bodies distributed in the main belt and among the irregular satellite population show evidence for low-porosity and, in many cases, aqueously altered material on their surface. This suggests C-type bodies shared a common reservoir that possibly existed early on between the orbits of the giant planets [14].

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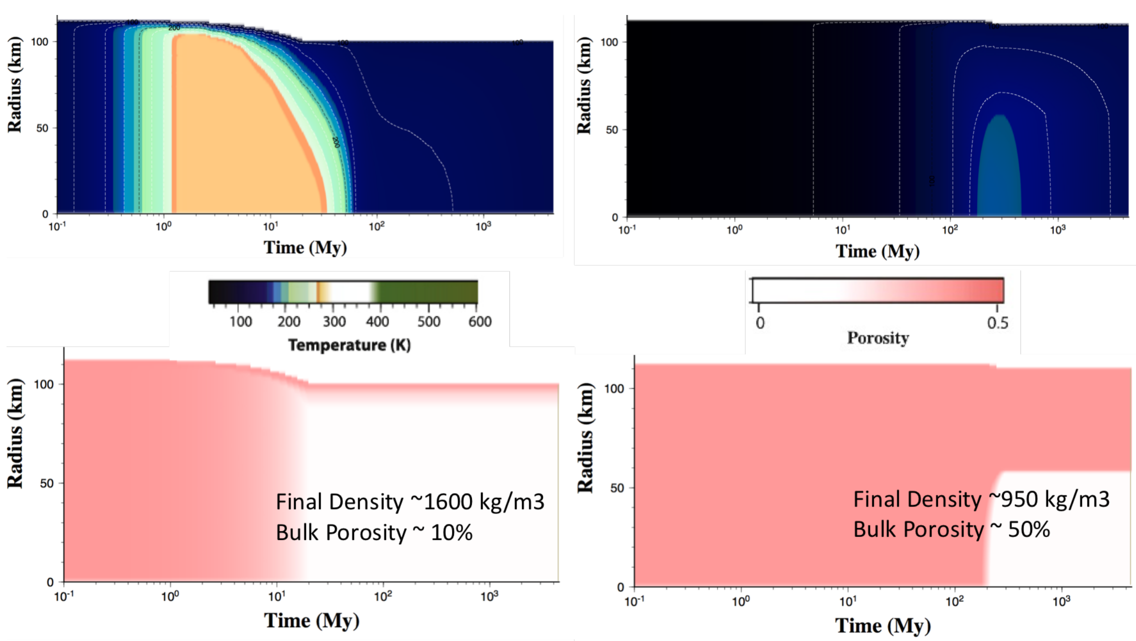

Figure 1. Thermal (top) and porosity (bottom) evolution models for a ~200 km planetesimal accreted in conditions representative of the Jupiter-Sasturn region (left, with an assumed time of formation t_f=3 My after CAIs) and of the transneptunian region (right, with assumed t_f>4 My after CAIs). The limited ^{26}Al budget combined with the low initial temperature leads to limited heating and high remnant porosity consistent with density data available for mid-sized transneptunian objects. ,