EVOLUTION OF PLANETESIMALS ACCRETED IN THE EARLY SOLAR SYSTEM. D. L. Matson[1], T. V. Johnson[1], J. C. Castillo-Rogez[1], P. C. Thomas[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena CA 91101, United States, dmatson@jpl.nasa.gov, [2]Center for Radiophysics and Space Research, Space Sciences Building, Cornell University, Ithaca, NY 14853, United States .

The purpose of this presentation is to point out that the origins and abundances of short-lived nuclides in the early solar system had important consequences for "icy planetesimals". It is believed that these planetesimals, composed of ice and rock, were once very abundant in the early, outer solar system. Today, spacecraft can visit remnants of that population and measure their properties. *Cassini's* flyby of Saturn's satellite Phoebe may have been the first visit to an object related to this population.

Particular physical properties of interest are size, shape, and density. These can be determined by remote sensing. Size is available as soon as images resolve the object. Enough images from different perspectives allows the determination of shape. With close flybys the mass can be determined from perturbations of the spacecraft's trajectory. All of these quantities together enable the calculation of the mean density.

The shape of a body contains information about its evolution. Small bodies tend to retain their shapes. It has long been recognized that asteroidal sized bodies can retain topography on a scale of their radii (i. e.: irregular shapes) unless they have been heated (i.e., to near their melting temperature) or are made of material that is mechanically weak. In these situations they can relax toward a hydrostatic shape [1].

The time of formation and size set the stage for the evolutionary paths of planetesimals. Accretion at a time when significant amounts of ^{26}Al were available could have yielded bodies that became warm enough to relax toward a hydrostatic shape. The smaller objects (e.g., tens of km or less) cannot warm sufficiently to relax because the ease with which heat is lost (along with other factors) scales as the ratio of surface area to volume. It should be noted that an object that accretes late relative to short-lived nuclides may be able to warm and relax if it is sufficiently large and other sources of heat, such as long–lived radionuclides, are available.

Density can be a discriminator among evolutionary paths for small bodies that have near-hydrostatic figures. In the case of so-called rubble piles, the near-hydrostatic figure can be achieved by the transport of fragmental debris, as governed by the gravitational potential. The objects tend to be porous and have relatively low densities. However, when a small body, such as one with sufficient ^{26}Al, warms enough to relax its figure, its density can increase due to the collapse of much of its internal void space or porosity. Its density is typically near the range of the material densities of ice and silicate mixtures in solar abundances. Also, as previously implied, its shape is realized by the (viscous) flow of material until a near-hydrostatic shape is obtained. For small bodies the important difference is the presence or absence of short-lived nuclides. When short-lived nuclides are required in order to produce the shape, a constraint can be derived on the formation time/age.

We have recently completed a study of the geophysical evolution of Saturn's small satellite Phoebe which we suggest is an example of a large planetesimal in the outer solar system [2]. We will use it here to illustrate the information that can be garnered from such bodies.

Phoebe is the only roughly equidimensional, low-porosity object in the ~100-km size range visited by a spacecraft to date. It is the best-characterized representative of the C-type objects, thanks to the close flyby by the *Cassini* spacecraft in June 2004.

Phoebe's figure approximates a spheroid in hydrostatic-equilibrium, rotating with Phoebe's spin period of ~9^h 17^m. Phoebe, at 1630 kg/m^3, is significantly denser than the mean density of 1240 kg/m^3 for the regular Saturnian satellites. Johnson and Lunine suggested that Phoebe's density is closer to that for Kuiper-Belt Objects, but lighter by 15 to 20% due to porosity [3]. One scenario is that Phoebe formed in the outer planetesimal disk contemporaneously with carbonaceous chondrite parent bodies, with a density of ~2000 kg/m^3.

Our modeling suggests that Phoebe formed ≤3 My after CAIs were created, early enough to have had significant heating by ^{26}Al. Today it should have a layered internal structure with rock concentrated at depth, possibly in hydrated form, and a porous, outer, ice-rich shell. Thus, only part of the interiors of such objects would actually be expected to be "primordial", unprocessed material. If so, Phoebe may be typical of many objects in the outer solar system including present Kuiper Belt Objects (KBO) and Trans-Neptunian Objects (TNO). We suggest that Phoebe is "...an exemplar of planetesimals that formed in the transneptunian region and later accreted onto outer planet satellites, either during the satellite's formation stage, or still later, during the late heavy bombardment." [2].

The results of our study of Phoebe allow us to address a key question that was raised in the Decadal Survey Report that was recently released: "W*ere KBOs* *and comets formed too late to have included significant amounts of live ^{26}Al as a heat source*?" [4]. The Phoebe results suggest that a primordial population of large planetesimals formed early, and rapidly enough that short-lived nuclides supplied heat for partial to full melting and differentiation of their interiors [2].

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