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Phoebe's shape: implications for internal structure and origin

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The Cassini-Huygens spacecraft flew by Phoebe in June 2004 [1-3]. Phoebe's mean density, 1629 kg/m3, is greater than the average density of the Saturnian satellites, which led [4] to suggest that Phoebe's solid density could be close to the density of KBOs and Centaurs, i.e., around 1,900 kg/m3, if a 15% allowance is made for porosity. Thomas et al. [3] have determined fits for Phoebe's principal axes. The mean radius is equal to 106.5±0.7 km, with radii of: a = 108.6±0.7 km, b = 107.7±1.4 km, c = 101.5±0.3 km. Phoebe's shape is close to an oblate spheroid, with a$\sim$b. The corresponding equilibrium difference between the equatorial and polar radii (i.e., a-c) if Phoebe were homogenous and hydrostatically relaxed would be about 10.7 km. The data give (a-c) = 6.7 ± 1.1 km. This suggests concentration of mass toward the center and is due either to compaction, or to stratification due to a rock-rich core below an icy shell as a result of melting and differentiation. We follow the modeling approach of [5]. We assume that Phoebe formed within a few My after calcium-aluminum inclusions (CAIs) formed, i.e., contemporaneously with the parent bodies of carbonaceous chondrites. For models forming 5 My after CAIs, the internal temperature barely exceeds 100 K. Only the deep-seated internal porosity is some-what decreased. There is an outer layer about 15 km thick that is undifferentiated and highly porous. In these models, we infer a density for the compacted material of $\sim$2000 kg/m3, consistent with the suggestion by [4]. However, the hydrostatic (a – c) is greater than 9 km, which is in-consistent with the observed oblateness. For earlier forming models the 26Al heating rapidly leads to internal melting and differentiation. The final internal structure is similar for all times less than 4 My after CAIs. Melting driven by 26Al decay heat could have been accompanied by hydrothermal and geochemical activity, as has been suggested for meteorite parent bodies (e.g.[6]). This category of model also has a thin (5-10 km thick), porous, icy layer whose thickness is a function of the initial surface temperature. The hydrostatic shapes for these models have (a – c) between 6.8 and 8 km, consistent with the observed oblateness. Since there is a range of possible solid densities and porosity structures, we cannot determine a unique internal structure for Phoebe. However, we can draw some general conclusions: First, cold, relatively homogeneous, internal models, even with porosity, do not match the observed oblateness for a hydrostatic figure. In addition, such cold models are less likely to have relaxed to a hydrostatic figure because their internal temperature could not reach the necessary creep temperature. For such models, Phoebe's oblate shape must be assumed to be a coincidence of impact 'sculpting'. Second, if Phoebe formed early enough to have significant heating from 26Al (before $\sim$4 My after CAIs), a plausible and consistent (but not unique) picture is that it is a body that formed in the outer planetesimal disk contemporaneously with carbonaceous chondrites, with a density $\sim$2000 kg/m3 and has a layered internal structure due to at least partial differentiation, consistent with a hydrostatic shape matching the observed oblateness. If so it may be typical of many objects in the outer solar system including the present KBOs, TNOs. Part of this work has been carried out at the Jet Propulsion Laboratory, California Institute of Technology. Copyright Caltech. Government sponsorship acknowledged. [1] Porco, C. C., et al. (2005) Science 307, 1237-1242. [2] Jacobson, R. A., et al. (2006) Astronomical Journal 132, 2520-2526. [3] Thomas, P. C., et al. (2006) Eos Tans. AGU 87(52), Fall Meet. Suppl., Abstract P32-01. [4] Johnson, T. V. and J. I. Lunine (2005) Nature 435, 69-71. [5] Castillo-Rogez, J. C., et al. (2007) Icarus 190, 179-202. [6] Grimm, R. E. and H. Y. McSween (1989) Icarus 82, 244-280.