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Compaction and possible differentiation of asteroid 21 Lutetia

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The Rosetta flyby at the asteroid 21 Lutetia revealed an unexpected high bulk density of 3400±300 kg m^{-3} from the mass measurements and a global shape model (the dimensions are 121±1 by 101±1 by 75±13 km). This high density indicates a bulk composition which is enriched in heavy elements like iron. Furthermore, spectroscopic data suggests that Lutetia formed from enstatitic material[1] and the complex geology and an ancient surface infer that Lutetia may be a primordial planetesimal[2]. It has been even suggested that Lutetia is partially differentiated[3]. In the present study, we investigate the thermal evolution of Lutetia by the means of a comprehensive numerical model[4], which includes accretion[5], compaction due to sintering[6], associated changes of material properties, melting, advective heat transport and differentiation.

For the observed bulk density of 3400±300 kg m^{-3}, we vary the present-day intrinsic density (and hence the macroporosity ϕ_m) and the onset time and duration of accretion. The initial material properties (intrinsic density, mass fractions of the components, abundances of the radiogenic heat sources ^{26}Al and ^{60}Fe) are calculated assuming an enstatite chondritic nature of the primordial material. Evolution scenarios arising from assumptions on ϕ_m are examined to derive implications on the compaction of an initially highly porous material, (partial) differentiation and the internal structure. The final bulk density is compared with the observations in order to derive bounds on the present-day macroporosity and internal structure.

We obtain a number of compaction and differentiation scenarios consistent with the observations. Our results imply that the most probable macroporosities of the present-day Lutetia are $\phi_m \geq$0.04. Small changes arise if the possible error of ±300 kg m^{-3} in the bulk density is considered. Depending on the adopted value of ϕ_m, the formation times range from the formation contemporaneously with the CAIs for ϕ_m=0.04 to 8 Ma after the formation of the CAIs for ϕ_m=0.25. If Lutetia is differentiated and has an iron rich core, the present-day macroporosity ranges between 0.04 and 0.06 and the formation time is between 0 Ma and 1.8 Ma after the CAIs. In that case, the size of the core is at most 25 km and the thickness of the mantle amounts to approximately the same value. On top of the mantle is a partially differentiated layer whose composition deviates only slightly from the primordial composition. The outer layer is undifferentiated but compacted except the upper few radius percent. Regardless on the degree of differentiation, the extent of the partially molten zone and the degree of melting does not suffice for the melt to extrude through the porous layer. This is consistent with the lack of basalt at the surface of Lutetia. For $\phi_m \geq$0.6, differentiation is not possible but the interior is substantially compacted below a porous outer layer.

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