Internal state of Lutetia as a function of the macroporosity

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The asteroid (21) Lutetia appears to be an intermediate object between the small near-primordial asteroids and a fully differentiated dwarf planet (4) Vesta. Understanding its evolution is crucial for the understanding of the accretion chain from km-sized planetesimals to full-sized planets and of the possible origin of both differentiated and undifferentiated meteorites. Remarkable is the bulk density value of 3400 kg m^{-3} obtained by the Rosetta flyby in July 2010 [1]. It indicates a relatively high intrinsic density, because the heavily cratered surface suggests a certain macroporosity of this body. Thereby, the macroporosity φ_m remains an uncertainty. We adopted the numerical model from [2] to consider an enstatite chondritic composition suggested by the spectrum [3], and supplemented it with a radiation boundary condition. Thereby, the nebula temperature is variable in order to simulate the cooling of the protoplanetary nebula with time and the migration of Lutetia from the inner Solar System (where it could have formed) to its present orbit. Assuming a value of φ_m in the range of 0–25 %, we calculate the intrinsic material properties, such as the density, composition, and radiogenic heat-source abundance. Subsequently, we simulate the accretion of Lutetia from the protoplanetary dust as a porous aggregate. Upon radiogenic heating by the short-lived radionuclides ^{26}Al and ^{60}Fe, compaction of the interior to the consolidated state by hot pressing is modeled using a creep-law-related approach. In the frame of a complex numerical model, a variety of physical processes is taken into account, like the calculation of melting, latent heat consumption and release, magmatic heat transport, melt segregation by porous flow, and the associated approach on differentiation modelling. The equations describing the physical processes like simultaneous growth due to the accretion, shrinkage due to the compaction, and differentiation, are solved simultaneously. The goal is to constrain the present-day macroporosity of the asteroid and its possible internal structure (porous/compacted/differentiated), starting with accretion from a highly porous building material.

The evolution scenarios arising from assumptions on the macroporosity φ_m are examined to derive implications on the compaction of an initially highly porous material and (partial) differentiation. The calculated final structures are compared with the observations of Rosetta in order to derive bounds on the present-day macroporosity and internal structure of Lutetia. We obtain a number of possible compaction and differentiation scenarios consistent with the properties of the present-day Lutetia. The most probable macroporosity for a Lutetia-like body with the observed bulk density of 3400 kg m^{-3} is $\varphi_m \geq 0.04$. Small changes can be expected if an error of ± 300 kg m^{-3} in the bulk density is considered. Depending on the adopted value of φ_m, Lutetia may have formed contemporaneously with the calcium-aluminium-rich inclusions ($\varphi_m = 0.04$) or up to 8 Ma later ($\varphi_m = 0.25$). The degree of differentiation varies significantly and the most evolved structure consists of an iron core and a silicate mantle that are covered by an undifferentiated but sintered layer and an undifferentiated and unsintered regolith. We find a differentiated interior, i.e., an iron-rich core and a silicate mantle, only for a rather narrow interval between $0.04 \leq \varphi_m < 0.06$ with the formation times between 0 Ma and 1.8 Ma after the CAIs. Regardless of melting and partial differentiation, no melt extrusion through the porous layer is likely — a finding that is consistent with the lack of basalt at the surface of Lutetia. Thus, although the outside is primordial, it could still have experienced substantial melting, have an iron core and a hidden igneous activity in the past. For $\varphi_m \geq 0.6$, an iron-silicate differentiation is not possible, but the interior is compacted due to sintering below a porous outer layer.

Our results [4] confirm the idea raised theoretically in [2,5] that a small asteroid like Lutetia can be a parent body of undifferentiated (chondritic), partially differentiated (primitive achondritic), and differentiated (achondritic) meteorites. Thus, enstatite chondritic, iron, and primitive achondritic meteorites can, in principle, originate from Lutetia, because it may be partially differentiated and was clearly disturbed by several major impacts. Furthermore, the timing of the occurrence of thermal convection in the metallic core suggests the possibility of an internal dynamo on Lutetia. This could explain the remanent magnetization found in undifferentiated chondritic meteorites.

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