Modeling of planetesimal compaction by hot pressing

W. Neumann[1], D. Breuer[1], and T. Spohn[1]

[1]Deutsches Zentrum für Luft- und Raumfahrt, Institut für Planetenforschung, Rutherfordstraße 2, 12489 Berlin, Germany

Compaction of initially porous material prior to melting is an important process that has influenced the interior structure and the thermal evolution of planetesimals in their early history. On one hand, compaction decreases the porosity resulting in a reduction of the radius. On the other hand, the loss of porosity results in an increase of the thermal conductivity of the material and, thus, in a more efficient cooling. Porosity loss by hot pressing is the most efficient process of compaction in planetesimals and can be described by creep flow, which depends on temperature and stress. Hot pressing has been repeatedly modeled using a simplified approach, for which the porosity is gradually reduced in some fixed temperature interval between 650 K and 700 K [see e.g. 1–3]. This approach neglects the dependence of compaction on stress. In the present study [see 4], we compare this ”parametrized” method with a self-consistent calculation of porosity loss via a ”creep-related” approach. We use our thermal evolution model from previous studies [5] to model compaction of an initially porous ordinary chondritic body and consider four basic packings of spherical dust grains (simple cubic, orthorhombic, rhombohedral, and body-centered cubic). Depending on the grain packing, we calculate the effective stress and the associated porosity change via the thermally activated creep flow. For comparison, compaction is also modeled by simply reducing the initial porosity linearly to zero between 650 and 700 K. Since we are interested in thermal metamorphism and not melting, we only consider bodies that experience a maximum temperature below the solidus temperature of the metal phase. For the creep related approach, the temperature interval in which compaction takes place depends strongly on the size of the planetesimal and is not fixed as assumed in the parametrized approach. Depending on the radius, the initial grain size, the activation energy, the initial porosity, and the specific packing of the dust grains, the temperature interval lies within 600–1200 K. This finding implies that the parametrized approach strongly overestimates compaction and underestimates the maximal temperature. For the cases considered, the post-compaction porous layer retained at the surface, is a factor of 2.5 to 4.5 thicker for the creep-related approach. The difference in the temperature evolution between the two approaches increases with decreasing radius, and the maximal temperature can deviate by about 40 % for small bodies.

References: [1] Sahijpal, S., et al., 2007. Numerical simulations of the differentiation of accreting planetesimals with $_{26}$Al and $_{60}$Fe as the heat sources. MPS 42, 1529–1548. [2] Gupta, G., Sahijpal, S., 2010. Differentiation of Vesta and the parent bodies of other achondrites. JGR 115, E08001. [3] Solano, J. M., et al., 2012. Modelling the thermal history of asteroid 4 Vesta. LPSC XLIII, 2063. [4] Neumann, W., et al., 2014. On the modelling of compaction in planetesimals. A&A, in review. [5] Neumann, W., et al., 2012. Differentiation and core formation in accreting planetesimals. A&A 543, A141.