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Modelling the thermal evolution and differentiation of the parent body of acapulcoites and lodranites

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The acapulcoites and lodranites are rare groups of achondritic meteorites. Several characteristics such as unique oxygen isotope composition and similar cosmic ray exposure ages indicate that these meteorites originate from a common parent body (Weigel et al. 1999). By contrast to both undifferentiated and differentiated meteorites, acapulcoites and lodranites are especially interesting because they experienced melting that was, however, not complete (McCoy et al. 2006). Thus, unravelling their origin contributes directly to the understanding of the initial differentiation stage of planetary objects in the Solar system. The information preserved in the structure and composition of meteorites can be recovered by modelling the evolution of their parent bodies and comparing the results with the laboratory investigations.

Model calculations for the thermal evolution of the parent body of the Acapulco and Lodran-like meteorite clan were performed using two numerical models. Both models (from [3] and [4], termed (a) and (b), respectively) solve a 1D heat conduction equation in spherical symmetry considering heating by short- and long-lived radioactive isotopes, temperature- and porosity-dependent parameters, compaction of initially porous material, and melting.

The calculations with (a) were compared to the maximum metamorphic temperatures and thermo-chronological data available for acapulcoites and lodranites. Applying a genetic algorithm, an optimised set of parameters of a common parent body was determined, which fits to the data for the cooling histories of these meteorites. The optimum fit corresponds to a body with the radius of 270 km and a formation time of 1.66 Ma after the CAIs. Using the model by (b) that considers differentiation by porous flow and magmatic heat transport, the differentiation of the optimum fit body was calculated. The resulting structure consists of a metallic core, a silicate mantle, a partially differentiated layer, an undifferentiated layer where still some partial melt was produced, and an outer unmelted shell. Subsequently, the temperature evolution obtained with the differentiation model was successfully fitted to the cooling ages of the meteorites. The burial depths of acapulcoites and lodranites derived by (a) range between 4 and 8 km. The layers these depths are located in experienced only minor melting and small-scale melt migration, fitting the observations of partially melting of the meteorites under consideration.

Our results indicate a larger size and an earlier formation time, than typical estimates for ordinary chondrites' parent bodies. This is, however, in a good agreement with a higher degree of thermal metamorphism observed. The optimum fit initial temperature of nearly 300 K suggests a formation closer to the proto-Sun in a hotter part of the accretion disk than the parent bodies of ordinary chondrites. The burial depths support the assumptions that acapulcoites and lodratnites were excavated by a single impact event. Presence of a differentiated core and mantle indicates further that these meteorites could share a common parent body with some differentiated stony and magmatic iron meteorites.

[1] Weigel, A. et al., GCA, 63, 175–192, 1999.

[2] McCoy, T. J., et al., Meteorites and the Early Solar System II, 733–745, 2006.

[3] Henke, S. et al., A&A, 545, A135, 2012.

[4] Neumann, W. et al., A&A, 543, A141, 2012.