MODELING THE EVOLUTION OF THE PARENT BODY OF ACAPULCOITES AND LODRANITES: A CASE STUDY FOR PARTIALLY DIFFERENTIATED ASTEROIDS.
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Introduction: The acapulcoites and lodranites (AL) are rare groups of primitive achondritic meteorites. Although they have the texture of achondrites, they are compositionally closely related to ordinary chondrites. Several characteristics such as unique oxygen isotope composition and similar cosmic ray exposure ages indicate that these meteorites originate from a common parent body[1-3]. By contrast with both undifferentiated and differentiated meteorites, ALs are especially interesting because they experienced partial melting and only minor melt segregation[4-7]. Thus, unravelling their origin contributes directly to the understanding of the initial differentiation stage of planets objects in the Solar system. The information preserved in meteorites' structure and composition can be recovered by modeling the thermo-chemical evolution of their parent bodies and comparing it with the laboratory measurements, e.g., closure ages and temperatures.

In this study we investigate the thermal and structural evolution of the parent body of the AL meteorites using two models that consider compaction, partial melting as well as metal-rock differentiation, and provide best-fit estimates for the parameters that define the key properties of the parent body. We compare the model calculations with the maximum metamorphic temperatures, the differentiation degree and the thermo-chronological data (Table 1). We obtain a consistent set of parameters that fits the available thermo-chronological data for the members of the AL-clan (Table 2). Our models provide estimates of the size, formation time, orbit of formation, nature of the precursor material and internal structure of the AL parent body. Based on the differentiation degree of the source region we draw conclusions regarding the compositional and metamorphic variations of the AL meteorites. We establish connections with other achondritic, primitive achondritic, as well as chondritic meteorites, and place AL meteorites into a general context. We discuss the possibility of an internally generated magnetic field and indicate moreover concrete observed asteroids as possible parent bodies.

Model: On the one hand, a thermal evolution model should fit the thermo-chronological data available. On the other, acapulcoites and lodranites experienced partial but not complete melting and even some small scale melt migration. Therefore, also melting of the metal and silicate rock and differentiation due to the migration of the melts should be considered. We calculated the thermal evolution of the parent body considering heating by short- and long-lived nuclides, temperature- and porosity-dependent parameters, and compaction of porous material. Numerical calculations have been performed using two numerical models. The first model *A* is described in detail in [8]. The second model *B* is based on [9,10]. Both models 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. In addition, the model *B* considers differentiation of a metallic core and silicate mantle by porous flow as well as magmatic heat transport and convection at melt fractions $\geq$ 50 %, while *A* includes a genetic algorithm for parameter optimization. Our study proceeded in two steps. First, thermal evolution models that considered conductive heat transport, compaction and melting were calculated with *A* and compared to the thermo-chronological data in order to obtain an optimized parameter set. Using this parameter set, we then performed more detailed calculations with *B* that included melt migration.

Results: The models were compared to the observed maximum metamorphic temperatures and thermo-chronological data available (Table 1). An optimized parameter set which fits to the data for the cooling histories of the meteorites was determined (Table 2). Because the obtained maximum temperatures were higher than the metal solidus, we calculated the differentiation of the optimum fit body. These calculations confirm the fits obtained in the first step and provide additional information about the interior structure of the parent body. These re-

Method	Closure T		Closure time	
	$T^{(c)}$	σ_T	$t^{(c)}$	σ_t
	K	K	Ma	Ma
Acapulcoites				
Hf-W	1248	50	4.8	0.7
U-Pb-Pb	720	50	12.6	0.7
I-Xe (fsp)	750	100	9.8	1.6
I-Xe (pho)	700	50	14.8	0.4
Ar-Ar	550	20	21.3	6.0
Pu fission	390	25	131.0	14.0
U-Th-He	393	50	56.3	45.0
Lodranites				
Hf-W	1298	50	5.7	0.6
I-Xe (fsp)	750	100	16.6	2.3
Ar-Ar	550	20	41.3	10.0
Chondrule bearing acapulcoites				
Hf-W	1248	50	3.1	0.7
Ar-Ar	550	20	14.3	11.0

Table 1: Closure time and temperature data used for fitting the meteorites (averaged over single groups).

sults indicate differentiation in the interior and small-scale melt migration at shallow depths. The resulting structure shows a fully differentiated metallic core and silicate mantle, a partially differentiated layer, and an undifferentiated shell that was once partially molten in its deeper part. The degree of differentiation of the burial layers derived is, furthermore, consistent with the meteoritic evidence.

Variable	Symbol	Unit	Value
fixed parameters			
Grain size	b	μm	0.2
Max. temp. Acapulco	$T_{A,max}$	K	1323
Initial porosity	ϕ_0		0.3
Initial $^{60}Fe/^{56}Fe$		10^{-8}	1.15
optimized parameters			
Formation time	t_0	Ma	1.68
Radius	R	km	263
Surface temperature	T_s	K	250
results			
Max. central temperature	$T_{c,max}$	K	1704
average burial depth			
Chondrule bearing acapulcoites		km	4.67
	T_{max}	K	1248
Acapulcoites		km	5.89
	T_{max}	K	1327
Lodranites		km	8.83
	T_{max}	K	1451

Table 2: Optimum fit parameters obtained with the model *A* and used to compute differentiation with the model *B*.

Conclusions: Our results indicate a larger radius (≈270 km) and an earlier formation time (≈1.6 Ma) of the acapulcoite-lodranite parent body than typical estimates for ordinary chondrites' parent bodies (<130 km and >1.8 Ma, see [11]), consistent with a stronger thermal metamorphism. The optimum fit of the initial temperature of ≈250 K suggests, furthermore, a formation closer to the Sun as compared with the the ordinary chondrites (≈180 K, see [11]). The burial depths of ≈7-11 km support excavation by a single impact event. The differentiated interior indicates that these meteorites could share a common parent body with some differentiated stony and iron meteorites.

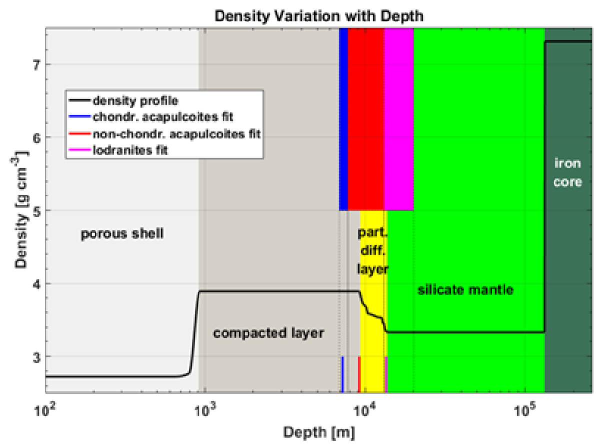

Figure 1: Density variation with depth after compaction and differentiation of the parent body (solid black line). The unsintered shell (light grey) has a density of ≈2.7 g cm^{-3}, the layer at the depth of ≈1-9 km is compacted but not differentiated (dark grey) with a density of ≈3.9 g cm^{-3}. It is followed by an ≈4 km thick partially differentiated layer (yellow) where the density decreases to the mantle density of ≈3.3 g cm^{-3} due to iron depletion. The silicate mantle (light green) stretches to a depth of ≈132 km where the density jumps to ≈7.3 g cm^{-3} in the core (dark green). The layers that contain chondrule-bearing acapulcoites (blue), chondrule-free acapulcoites (red) and lodranites (pink) are indicated with the colors and dotted lines. The depths at which the data were fitted are indicated by the short lines with

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