EPSC Abstracts
Vol. 12, EPSC2018-881, 2018
European Planetary Science Congress 2018

Modeling the Evolution of the Acapulcoite-Lodranite parent body: An Insight into a Partially Differentiated Asteroid

Wladimir Neumann[1,2], Stephan Henke[3], Doris Breuer[2], Hans-Peter Gail[3], Mario Trieloff[3], Winfried Schwarz[3], Jens Hopp[3]; and Tilman Spohn[2], [1]Institute of Planetology, University of Münster (wladimir.neumann@dlr.de), [2]German Aerospace Center, Institute of Planetary Research, Berlin, [3]University of Heidelberg

Abstract

We investigate the thermal and structural evolution of the parent body of the acapulcoites and lodranites. We compare the calculations with the differentiation degree and the thermo-chronological data. We obtain a consistent set of parameters that fits the available thermo-chronological data and provide estimates of parent body's size, formation time, orbit of formation, nature of the precursor material and internal structure.

1. Introduction

The acapulcoites and lodranites (AL) are rare groups of primitive achondritic meteorites. Although they have the texture of achondrites, they are compositionally related to ordinary chondrites. Several characteristics, such as oxygen isotope composition and cosmic ray exposure ages indicate origin on a common parent body[1-3]. By contrast with undifferentiated and differentiated meteorites, ALs are especially interesting because they experienced partial melting and only minor melt segregation[4-7]. Thus, unravelling their origin provides important insights into the initial differentiation stage of planetary objects. The information preserved in their 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 calculations with the metamorphic temperatures, the differentiation degree and the thermo-chronological data (Table 1). We obtain a set of parameters that fits the thermo-chronological data for 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 we draw conclusions about the compositional and metamorphic variations of the AL meteorites. We establish connections with other achondritic, primitive achondritic, and chondritic meteorites, and place ALs into a general context. We discuss the possibility of a magnetic field and indicate concrete asteroids as potential parent bodies.

Method	Closure T $T^{(c)}$ K	σ_T K	Closure time $t^{(c)}$ Ma	σ_t 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).

2. 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. Calculations have been performed using two models. The first model *A* is described in detail in [8], the second model *B* is based on [9,10]. Both solve a 1D heat conduction equation in spherical symmetry considering heating by short- and long-lived radionuclides, temperature- and porosity-dependent parameters, compaction of porous material, and melting. In addition, *B* considers differentiation of a Fe core and silicate mantle by porous flow as well as magmatic heat transport and convection at melt fractions ≥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.

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*.

3. 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). Since 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 and provide additional information about the interior structure of the parent body. These results 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 consistent with the meteoritic evidence.

4. 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[11]), consistent with a stronger thermal metamorphism. The optimum fit of the initial temperature of ≈250 K suggests a formation closer to the Sun as compared with the ordinary chondrites (≈180 K[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.

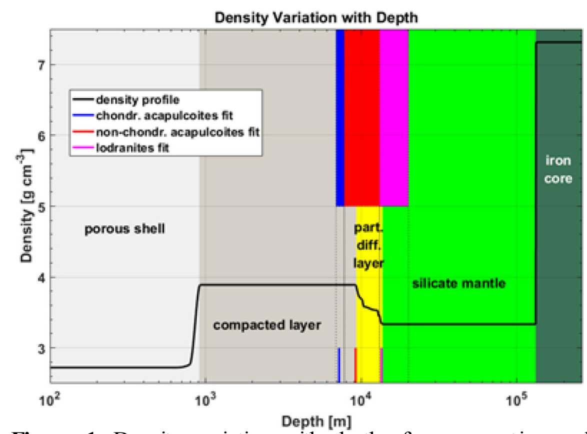

Figure 1: Density variation with depth after compaction and differentiation of the parent body. The unsintered shell (light grey) has a density of ≈2.7 g cm^{-3}, the layer at the depth of ≈1-9 km is compacted but not differentiated (dark grey) with a density of ≈3.9 g cm^{-3}. It is followed by an ≈4 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 respective colors.

References:

[1] Weigel A. et al. (1999) GCA, 63, 175-192. [2] Mittlefehldt D. W. et al. (1996) GCA, 60, 867-882. [3] Eugster O. and Lorenzetti S. (2005) GCA, 69, 2675-2685. [4] McCoy T. J. et al. (1996) GCA, 60, 2681-2708. [5] McCoy T. J. et al. (1997) GCA, 61, 623-637. [6] McCoy T. J. et al. (1997) GCA, 61, 639-650. [7] McCoy T. J. et al. (2006) Meteorites and the Early Solar System II, UAP, 733-745. [8] Henke S. et al. (2012) A&A, 537, A45. [9] Neumann W. et al. (2012) A&A, 543, A141. [10] Neumann W. et al. (2014) EPSL, 395, 267-280. [11] Henke S. et al. (2012) A&A, 545, A135.