RARE EARTH ELEMENT INSIGHTS INTO THE PETROLOGIC EVOLUTION OF THE ACAPULCOITE - LODRANITE PARENT BODY.

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Introduction: Primitive achondrites are among the first objects in the solar system to have experienced variable degrees of heating and/or melting and melt migration processes. In this study we present petrological and geochemical constraints on the evolution of the acapulcoite-lodranite (A-L) parent body with emphasis on new rare earth element (REE) data.

Members of the A-L group are known to resemble iron-rich H-chondrites in terms of their chemical and mineralogical compositions [1], although they are of distinct O-isotopic composition relative to ordinary chondrite groups. Some of the acapulcoites have preserved primitive textures such as chondrules [2], but in general the A-L meteorites display achondritic textures. In detail, several lines of evidence suggest that the lodranites have experienced a higher degree of melting than acapulcoites. For example, the former have depleted proportions of troilite and plagioclase, and larger average grain size relative to the former [2]. Given the similar O-isotopic composition of the A-L [3], this has led to the idea that lodranites are the residues of partial melting of acapulcoite-like material, which had been heated enough to experience melting and migration of Fe,Ni-FeS and silicate melts.

In this study, we attempt to constrain the metamorphic and partial melting processes on the A-L parent body, and answer questions about the composition, (including rare earth element content) and migration process of the melts. Petrologic and microstructural studies of the transition between metamorphism and partial melting have been initiated, using H6 ordinary chondrites as a proxy for the unmelted A-L parent body.

Samples and Analytical Techniques: We analyzed Estacado (H6 ordinary chondrite), Acapulco (acapulcoite) and Lodran (lodranite). All three samples were provided as thin sections by the MNHN (Paris, France). Rare earth elements (REE) in some silicate minerals and especially in phosphates, which are their principal host phase, were measured by femtosecond Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS) using an Agilent 7500 CX in Toulouse. In addition, the thermodynamic phase equilibrium calculator, pMELTS [4], has been employed to simulate the degree of partial melting of lodranites using H6 material as a proxy for the initial bulk composition. Conditions used for the pMELTS simulations are : pressure 1 kbar, starting temperature 1273 K and oxygen fugacity IW-3.

Results and discussion: The pMELTS simulations were used to shed light on the differences in mineralogy and mineral proportions between acapulcoites (ol>opx) and lodranites (ol<opx). Modal proportions have been estimated from BSE images (quantifying the number of pixels of each mineral over a representative area). Partial melting of two bulk compositions was simulated: **(1)** Average H6 bulk composition [5]; In this case, during partial melting the proportion of ol is always greater than that of opx (Fig. 1, blue curve); plagioclase is completely eliminated from the residue at 1403 K when the degree of partial melting reaches 26%. **(2)** A H6-like composition, but enriched in SiO_2, FeO, MgO, P_2O_5 and depleted in Al_2O_3, Cr_2O_3, Na_2O [6]. In this case, the proportion of ol becomes less than that of opx, approximately at the point at which plagioclase is completely eliminated (1373 K and 15% melting: Fig. 1, red curve).

The results of the first model would suggest that Lodran suffered at least 26% of partial melting since plagioclase is absent in this meteorite. This is in agreement with the model of Taylor et al. [7], who proposed that melting a chondritic H-type parent body will enrich the end-product in olivine with regard to others minerals. The second model is consistent with the experimental observations of Stolper et al. [8] showing that interaction between olivine and melt may eventually lead to an end-product enriched in orthopyroxene.
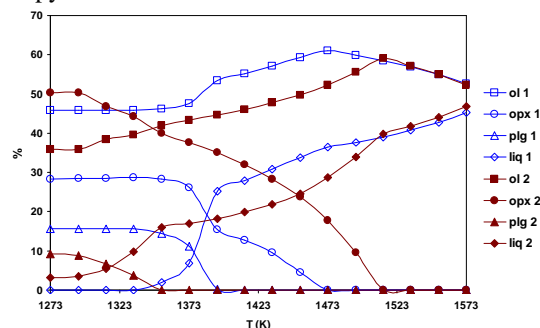

Figure 1. Proportion of phases as a function of temperature calculated with pMELTS (blue–first model, red–second model (see text)). Abbr.: ol-olivine, opx-orthopyroxene, plg-plagioclase, liq-melt).

In addition to these mineralogical differences between acapulcoites and lodranites, we have also considered differences in mineral chemistry, in particular their REE contents. We have determined by LA-ICP-MS the REE contents of individual mineral phases (olivine, orthopyroxene, clinopyroxene, spinel, plagioclase, whitlockite and Cl-apatite) in Acapulco and Lodran have been measured.

Using these data and measured modal abundances, the whole rock REE concentrations of Acapulco and Lodran have been reconstructed, as shown in Fig. 2 (open diamond and filled circles, respectively). There is a good agreement between our estimations and previous studies [9,10], with variable contents in light rare earth elements (LREE), and similar contents in heavy rare earth elements (HREE) : Lodran is clearly depleted in LREE compared to Acapulco. The Acapulco REE pattern presents a small positive anomaly in Eu, which is not typical of a chondritic-like material and suggests the occurrence of igneous feldspars in the meteorite.
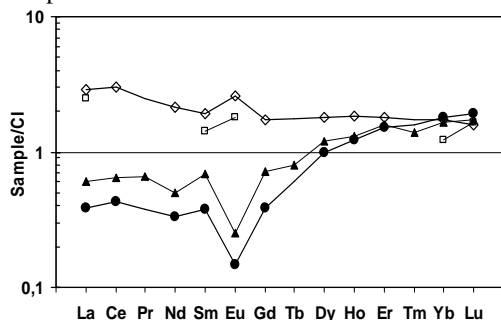

Figure 2. Calculated whole rock CI-chondrite normalized REE patterns for Acapulco (open diamonds) and Lodran (filled circles), compared to that measured for Acapulco (open squares) [9] and for Lodran (filled triangles) [10].

With the exception of Eu, whole rock REE concentrations of Acapulco and Lodran are similar to that of their phosphates (whitlockite) (Fig. 3), demonstrating that phosphates are indeed the principal hosts of REEs in these types of meteorites. The concentration of REEs in whitlockites are high and variable (100-500 x CI) with an obvious negative Eu anomaly (Fig. 3).

Using the data of Fig. 2 and the degrees of partial melting inferred from the thermodynamic modeling presented above, the REE composition of the liquid lost from Acapulco to produce Lodran may be calcuated, using simple mass balance (Fig. 4).

In this case, this melt is calcalculated to be enriched in incompatible elements: $[La/Yb]_N = 9.6$ for 26% of partial melting and 19.2 for 15% of partial melting. The relatively high Eu concentration results

from the high melting proportion of plagioclase. Other REE contents are controlled by phosphates, with the exception of Lu, which is compatible in orthopyroxene, the dominant mineral in the residue. This REE spectrum bears some similarities to the aubrites [11], although the oxygen fugacity conditions of the latter are clearly very different to the A-L parent body. On the other hand, we note that the positive Eu-anomaly and Light REE enriched nature of bulk Acapulco may indicate addition of a feldspathic melt component (produced then extracted from a deeper, hotter, Lodran-like region of the parent body, for example). In this case, the REE spectra of the 'missing' liquid component (Fig. 4) should be treated with caution.
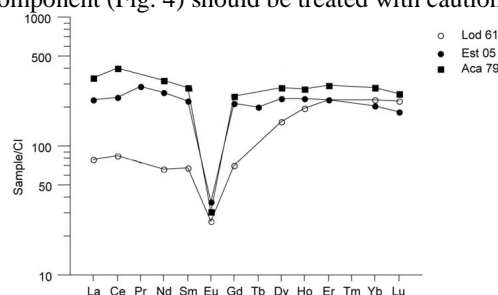

Figure 3. CI-chondrite normalized REE patterns in phosphates (whitlockite) from Acapulcoites and Lodranites, measured by LA-ICP-MS. (Lod61 = Lodran, Est05 = Estacado, ACA 79 = Acapulco).
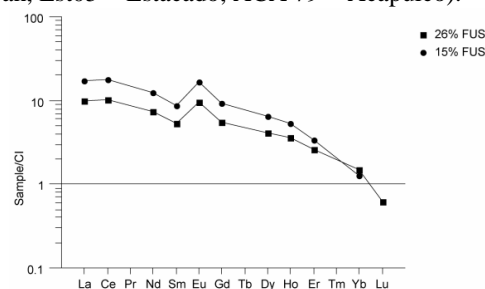

Figure 4. CI chondrite-normalized REE patterns of the calculated composition of the melt at 26% of partial melting (filled squares) and 15% of partial melting (filled circles) in the lodranite-acapulcoite parent body.

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