AN EQUILIBRIUM PHASE DIAGRAM MODEL TO STUDY THE METAMORPHISM EXPERIENCED BY THE VILLALBETO DE LA PEÑA ORDINARY CHONDRITE PARENT BODY. **Maria J. Herrero Pérez [1], Joan Reche Estrada [2], Josep M. Trigo-Rodríguez [1], Martin Lee[3], Jordi Ibáñez-Insa[4]** (1) Institute of Space Sciences (CSIC-IEEC), Barcelona, Catalonia, Spain. Meri.h.p.9@gmail.com (2) Dept. de Geologia, Universitat Autònoma de Barcelona, Cerdanyola del Vallés, Catalonia, Spain (3) School of Geographical and Earth Sciences, University of Glasgow, United Kingdom (4) Institut de Ciències de la Terra Jaume Almera, Barcelona, Catalonia, Spain.

Introduction: Chondritic meteorites help us to constrain the evolutionary history of asteroids. The Villalbeto de la Peña (VP) chondrite fell in 2004 in Palencia, NW of Spain. This meteorite shows considerable thermal metamorphism and was initially classified as L6 [1], but later defined as a polymict chondritic breccia [2]. It has also experienced a significant degree of shock as evidenced by the presence of dark impact veins, cracks filled with merillite and other high-pressure minerals [2,3]. Moreover, VP shows signs of short-lived water rock reactions consistent with hydrothermal activity on its parent body [2,4].

We constructed an equilibrium phase diagram model that has proved to be useful to approximate the temperature (*T*), pressure (*P*), redox (X_{Fe2+}) and X_{H2O} conditions during metamorphism of VP in its parent body. We present NCFMASHOCr *P*-*T*, *T*-X_{Fe2+} and *T*-X_{H2O} phase diagrams for the Villalbeto's bulk composition contoured for modes and compositions of minerals: olivine, pyroxene, plagioclase and chromite. Constraining the metamorphic *T* and *P* recorded by meteorites is key to understanding the size and thermal history of their asteroid parent bodies. Chondritic meteorites have not been altered by melting or differentiation of their parent body and, as such, can be well modeled using new thermodynamic data originally calibrated for solid and melt phases in terrestrial mantle peridotites, largely based on the chondrite's similar bulk composition to that of terrestrial mantle rocks [5].

The redox state of Fe is a fundamental variable in the classification of chondrite groups, as is the degree of volatile-element depletion as well as the extent of aqueous alteration. Modeling of these variables also helps to constrain the possible parent asteroid redox and hydration conditions in which they formed.

Methods: Bulk rock composition data measured for the VP chondrite are shown in Table 1. Also, its bulk density has been estimated to be 3.42 g cm^{-3}, with a ~3 vol% metallic Fe-Ni content. From the reported bulk content of Si, Mg, Fe, Al, Ca, Na, S, Ni and Cr, mass balance calculations allow us to derive a modal mineralogy of 52.2% in volume olivine, 26.9% pyroxene, 12.1% plagioclase, 6.1% troilite, 2.0% kamacite, 1.1% taenite and 1.0% chromite.

Table 1. *Bulk compositions (mol.%) used in the construction of phase equilibria.*

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5
0.88	37.69	1.23	35.95	0.09

NiO	CaO	TiO_2	Cr_2O_3	FeO
1.15	1.40	0.074	0.25	21.36

In modeling, sulfides can be assumed to be present in excess or not. The results shown in this paper consider Ni-S alloys to be present in all the possible mineral assemblages. A small amount of CaO was excluded to account for the phosphates present in the form of apatite, which are not considered in the model.

Phase diagrams were computed in the system NCFMASHOCr using the software *Theriak-Domino* and the internally consistent thermodynamic dataset given in [5,6]. Calculations consider the following phases: garnet (g), olivine (ol), orthopyroxene (opx), clinopyroxene (cpx), plagioclase (pl), spinel (spin) and silicate melt (liq). Water is included by normalizing the data from Table 1. The observed phase relations allow some theoretical considerations of metamorphism in the core of asteroids.

Results and Discussion: The isochemical *P*-*T* phase diagram for the bulk composition of VP chondrite from 700-1200 ^{o}C and 1-15 kbar are shown in Fig. 1. The prograde onset of partial melting occurs at *T*~1000 ^{o}C at low pressures to *T*~1100 ^{o}C at ~12.5 kbar, where plagioclase disappears to higher pressures at the solidus intersection, as the abundance of olivine increases and that of the remaining silicate minerals decreases as *T* increases.

The abundances (in mol.% as well as vol.%) of the main silicate minerals olivine, orthopyroxene, clinopyroxene and plagioclase have also been calculated in order to estimate their respective stability regions under different *P*-*T* regimes. For the bulk composition of VP we used the results obtained by Llorca et al. [7]. Comparing these values with the calculated abundances of the minerals, we can estimate the *P*-*T* range under which such minerals can coexist.

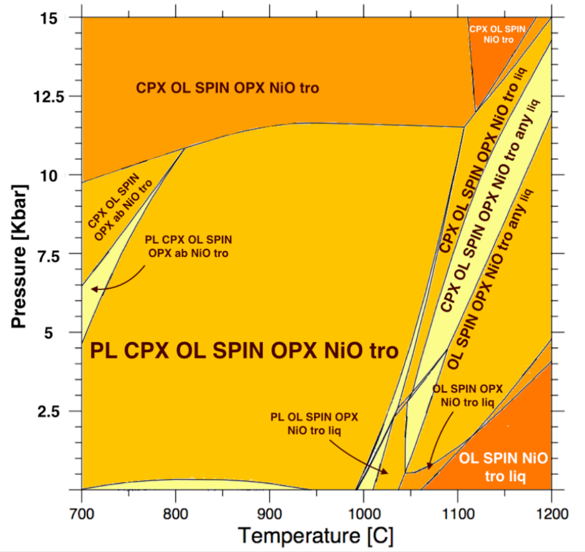

Fig. 1. Calculated isochemical P-T phase diagrams in the NCFMASHOCr model system showing equilibrium assemblages in the bulk composition of VP chondrite.

First, from the phase diagram in Fig. 1 it can be observed that plagioclase is unstable under high-*T* conditions (above ~1100 K) at any given pressure. Thus, the absence of plagioclase is a strong indicator of high-grade thermal metamorphism. High-pressure phases present in the shock melt veins in VP as well as their formation conditions have been studied and support the results of this work [8].

By looking at molar abundances of minerals in the VP chondrite as shown in Fig. 2, it has been estimated that the VP corresponds to formation conditions of ~1050 K and < 4 kbar.

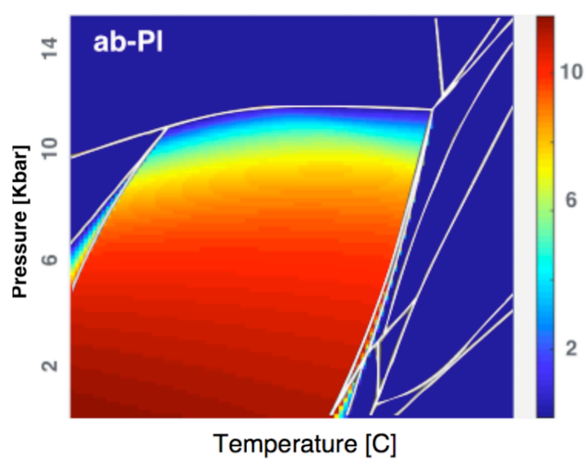

Fig. 2. Calculated phase diagram contoured for mineral abundance in vol.% of plagioclase (albite).

Conclusions: Our study suggests pressure conditions of maximum 4 kbar for a high-temperature (c. 1050 ^{o}C) near solidus episode. Finally, we also assess the value of phase equilibria modelling to set key constraints on the evolution in chondritic asteroids. Although our chemical analysis disregards elements like K and Mn, the phase equilibria model is a valuable quantitative tool to investigate metamorphic processes in chondrites. It enables visualization of possible mineral assemblages for different *P*, *T* and bulk compositions, further providing constraints on physical dimensions of the parent asteroid from which this meteorite was derived.

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