METAMORPHIC CONTROL OF NOBLE GAS ABUNDANCES IN PRISTINE CHONDRITES.
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Introduction: One of the most enduring enigmas of meteoritics is the nature of the Q (or P1) phase carrier with its associated trapped "planetary Q-gases" (He, Ne, Ar, Kr and Xe), defined by [1]. Many evidences suggest the Q-phase carrier is carbonaceous [e.g. 2], but the location of noble gas atoms in the carbon network has not been yet identified. Among the suggested structural forms of Q-phase carrier are carbynes, various macromolecular carbonaceous substances, turbostratic carbon, graphene sheets, adsorption sites in a labyrinth of pores of amorphous carbon, closed carbon structures such as fullerenes, carbon nanotubes, or carbon onions (ref. in [3], [4]).

Many studies suggested that the abundance of the Q phase in pristine chondrites is controlled by thermal metamorphism [5,6], and that this parameter should be used as a petrologic indicator. But, this general trend was established using petrologic types derived by Induced Thermo-Luminescence, which may be erronated [7], and in any case which do not provide a direct information on the structure of OM where the Q-phase is sited.

In this study, the structure and the texture of chondritic OM was studied by High Resolution Transmission Electron Microscopy (HRTEM) in Kaba, Leoville, Mokoia, Allende and Tieschitz. HRTEM allows direct imaging of the polyaromatic layers and reveals their multiscale organization. It provides a de-averaged structural information at the nanometric scale, and clues on the microtexture. Structural improvement in polyaromatic matter is mostly controlled by metamorphic conditions (temperature, time), whereas microtexture may witness the chemical nature of the precursor. These parameters have been considered along with previous results obtained by Raman spectrosocopy, which does provide a structural information averaged at the micrometric scale [7,8]. Using noble gas abundances available in literature, we have revisited the question of the metamorphic control of the Q (P1), P3 and P6 components, the carrier of the Q phase and the chemical homogeneity/heterogeneity of the organic precursors accreted by chondrites.

Experimental: A Jeol 2010 microscope operating at 200 kV (resolution in fringe mode : 0.14 nm) was used. Image analysis techniques developed by [9] allows to obtain semi-quantitative structural data: the fringe length (i.e. the polyaromatic layer extent) L; the interlayer spacing d, the height and the diameter of the coherent domains, Lc and La, respectively.

Results: Fig. 1a, b, c, d are representative images from IOM of Kaba (a), Leoville (b), Mokoia (c) and of the best organized parts of Allende (d). Unfortunatley, the structural parameters vary noticeably from a carbon nanoparticle to an other. Differences between the studied CV3 are evidenced. The least metamorphosed Kaba exhibit a microporous texture. Leoville still exhibit a poorly organized texture, but the length of the aromatic layers is larger. Mokoia (PT~3.6) is definitely more organized, the layer exhibiting different shapes, and is no longer microporous. Allende, the more metamorphosed object (PT > 3.6), exhibit circular shapes, and very organized nanometric area. These results demonstrate that the texture is controlled by thermal metamorphism. The least metamorphosed objects have a microporous texture, in which the Q(P1) phase is originally located.

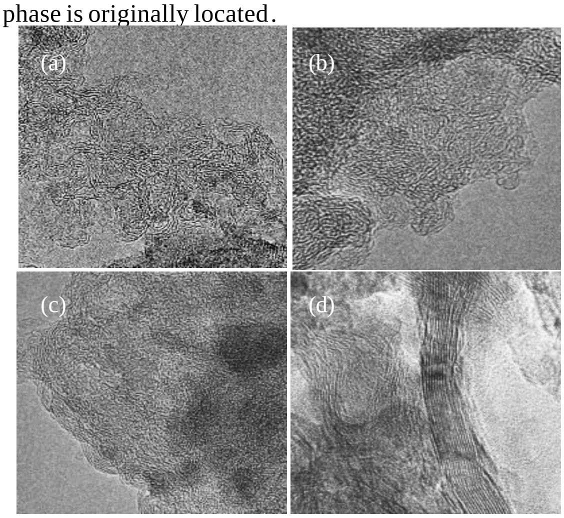

Figure 1: HRTEM images of the insoluble carbon from the CV3 chondrites : (a) Kaba, (b) Leoville, (c) Mokoia, (d) Allende; images size: 40nm x 40nm

From a quantitative point of view, de-averaged structural information is consistent with Raman spectroscopy indications [7]. For Allende, the aromatic layers are the longest (until a few nm, with a mean value of 0.9 nm), and the best stacked (55% of unstacked layers, stacks formed by 3 to 6 layers, with a mean value of 2.4 and the mean interlayer spacing is here 0.40 nm). According to the analysed nanoparticle, the layer length varies between 0.8 and 0.9 for Leoville and between 0.7 and 1nm for Mokoia.

Discussion: HRTEM results point out that within the series of chondrites studied here, the microtexture is controlled by thermal metamorphism. In particular, the microtexture in Mokoia and Tieschitz (both have a PT ~ 3.6) are very close, suggesting metamorphic conditions. This statement is strictly qualitative, but consistent with Raman measurements [7].

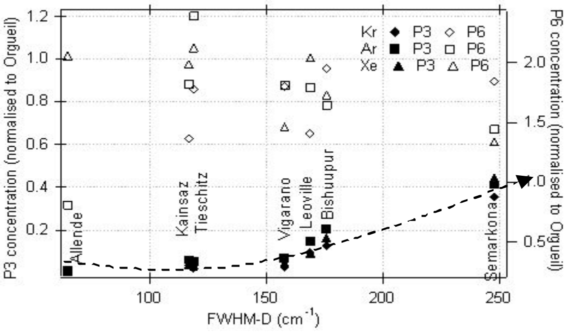

Figure 2: P3 and P6 abundances normalised to Orgueil P3 content vs. Raman spectral tracer of metamorphism grade.

Trapped noble gases may be separated into different components according mainly to their carrier and to the release temperature [10]. These components may have distinct behaviors to processes on asteroidal parent body. Our data allow to revisit the question of the metamorphic control of the P1, P3 and P6 abundance [10 and ref. within]. Using the Raman tracer FWHM-D, P3 appears as well correlated to the metamorphism grade (Fig. 2). This confirms the result of [10]. On the other hand, P6 is not correlated, consistently with the fact the P6-carrier sited in nano-diamonds is released at very high temperatures.

Our results demonstrate that the Q (=P1) abundance is not well correlated to the metamorphism grade (Fig. 3). This parameter should not be used as a petrologic indicator for deriving low petrologic types.

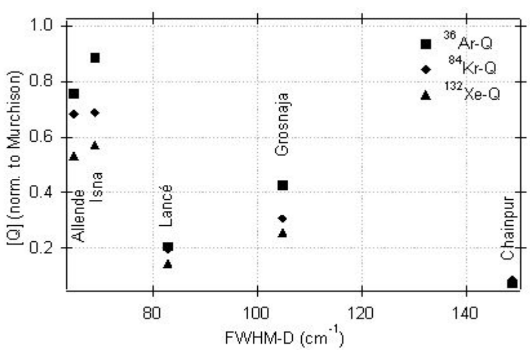

Figure 3: Q concentration normalised to Murchison Q content. Q is not correlated to the metamorphic grade.

This last result questions the nature of the carrier of the Q (P1) phase. As mesoporous carbons and onion-like structures are the result of thermal metamorphism, they cannot be this carrier as suggested by [3]. Our results are however consistent with a very complex siting, in contrast with a single carrier for the P3 component (surface of nanodiamonds), for which the release pattern is simple. This multiple carrier might include the interlayer space sitings [4], but the complex metamorphic control suggest other carriers. Moreover, the lack of clear correlation between the P1-abundance and the metamorphism grade demonstrate that chondrites inherited the same P1 carrier, in the sense of variable contributions of multiple carriers within OM.

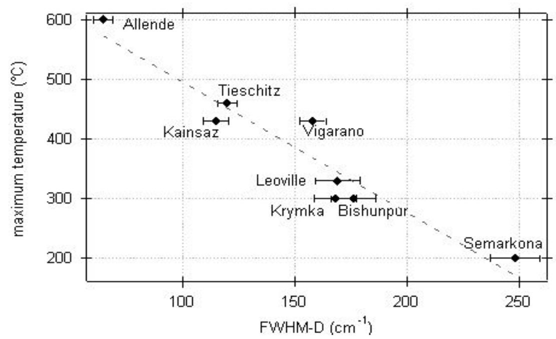

Figure 4: correlation between the upper limit of the metamorphism peak temperature and metamorphic grade.

Nanodiamonds being a single and simple carrier of noble gases abundance, they provide reliable metamorphic information. The P3 planetary noble gases component, give some constraints on the maximum temperature of metamorphism peak experienced by the diamonds of several classes of chondrites. Plotting these values along with the metamorphic tracer FWHM-D (Fig. 4) reveals a very good correlation (R=0.954). A similar result was obtained in terrestrial rocks [11]. This suggest that in the future, Raman spectroscopy might provide the temperature of metamorphism peak. Nevertheless, deriving temperatures requires the knowledge of the kinetic law of nanodiamonds transformation (into nanographite or graphitic nanoparticles). Further experimental studies are thus required.

References: [1] Lewis et al. (1975) *Science 190*, 1251-1262. [2] Ott U. et al. (1981) *GCA 45*, 1751-1788. [3] Vis R.D. et al. (2002) *MPS 37*, 1391 – 1399. [4] Marrochi Y. et al. (2005) *EPSL 236*, 569-578. [5] Busemann H. et al. (2000) MPS 35, 949-973. [6] Huss G. et al. (1996) GCA 60(17), 3311-3340. [7] Bonal, L. et al. (2006) GCA, in press. [8] Quirico, E. et al. (2003) *MPS 38(5)*, 795-811 [9] Rouzaud and Clinard (2002) Fuel Proc Tech, 77-78, 229-235. [10] Huss et al. (1994) *MPS 29*, 811-829. [11] Beyssac O. et al (2002) CoMP 143 (1) 19-31.