MATURATION GRADE OF ORGANIC MATTER IN METAMORPHOSED CARBONACEOUS CHONDRITES

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INTRODUCTION:

The determination by Raman spectroscopy of the maturation grade of meteoritical organic matter (OM) is used as a metamorphic tracer [1, 2]. Indeed, maturation grade of OM is sensitive to the peak metamorphic temperature and independent of the mineralogy and aqeous alteration. In addition, the transformation of the structural grade of OM by thermal metamorphism is irreversible [e.g., 1–3]. This method was used by [2, 3] in order to determine the metamorphic grade of several CV3 and CO3 chondrites, but, up to now, was never extended to higher petrologic types. During this study, we tried to determine the maturation grade of OM in metamorphosed CVs and CKs that are the only metamorphic group of carbonaceous chondrites (from types 3 to 6) [4].

SAMPLES AND METHODS:

We studied Allende (CV3), NWA 779 (CV3), NWA 2900 (CV3), NWA 1559 (CK3), and Tnz 057 (CK4). We used a microspectrometer Renishaw InVia equipped with a Spectra Physics argon ion laser using 514.5 mm excitation. The laser beam was focussed by a microscope equipped with a x50 objective. Spectra were acquired under atmospheric conditions. Acquisition parameters were: - Power at the sample surface: 2 mW - Spectral region: 800–2200 cm^{-1} - Acquisition time: 60–120 s - Grating: 1800 l/mm
We used the method defined by [2] to obtained the D- (~1350 cm^{-1}) and G-band (~1600 cm^{-1}) spectral parameters (peak position: $\omega_{D,G}$, full width at half maximum: FWHM-D,G, and peak intensity: $I_{D,G}$).

RESULTS:

PETROGRAPHY:

Allende is the least metamorphosed sample analyzed (mean matrix olivine grain size: 6.1±0.2 µm; mean olivine composition: $Fa_{50.0±5.0}$) (Fig. 1). NWA 779 display a higher metamorphic grade: matrix ($Fa_{45.4±4.1}$) contain tabular olivine grains (10–20 in size) embedded in a fine-grained matrix (2–5 µm). Matrix in the CK3 NWA 1559 is mainly composed of olivine grains ($Fa_{36.1±0.1}$) with a mean size of 16.7±0.6 µm. Matrices in Tnz 057 and NWA 2900, although classified as CV3, are chemically equilibrated ($Fa_{32.0±0.5}$ and $Fa_{35.0±0.8}$, respectively) and olivine grains have a mean size of 65.0±25.0 µm and 52.4±3.5 µm, respectively.

MATURATION GRADE OF ORGANIC MATTER:

All spectra obtained exhibit first order D- and G-band (Fig. 2), but the intensity of the fluorescence background is weak for Allende and NWA 779, rises for NWA 1559 and NWA 2900, and is high for Tnz 057. The spectral parameters of the D- and G-bands are given in Table 1.

For the CV3 Allende and NWA 779, $I_D/I_G > 1$, whereas spectra obtained in NWA 2900, NWA 1559, and Tnz 057 display an $I_D/I_G < 1$ (Fig. 2, 3). In addition, carbon content decreases from Allende, NWA 779, to NWA 1559.

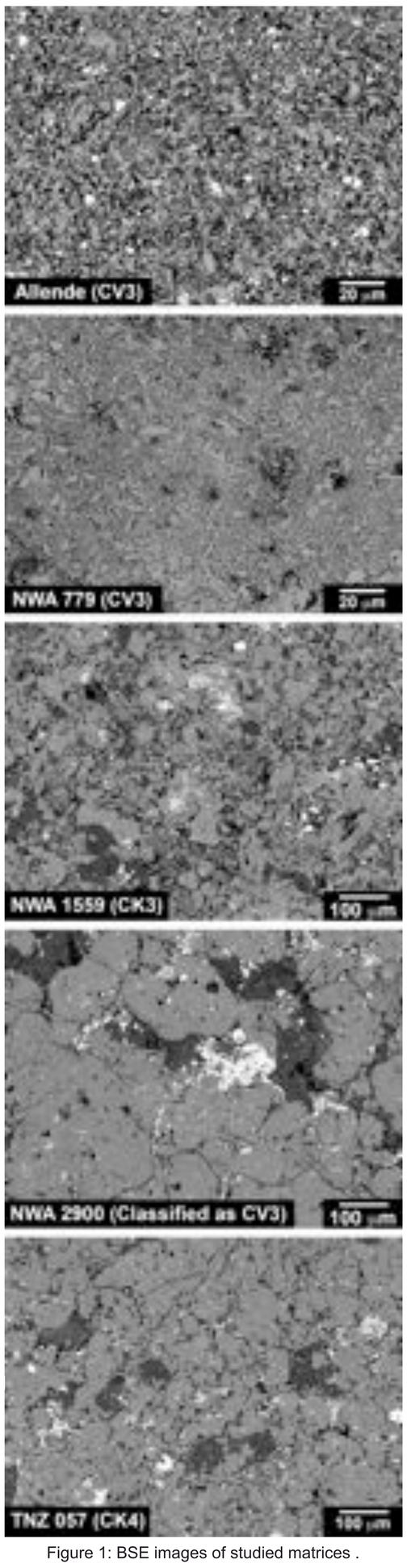

Figure 1: BSE images of studied matrices .

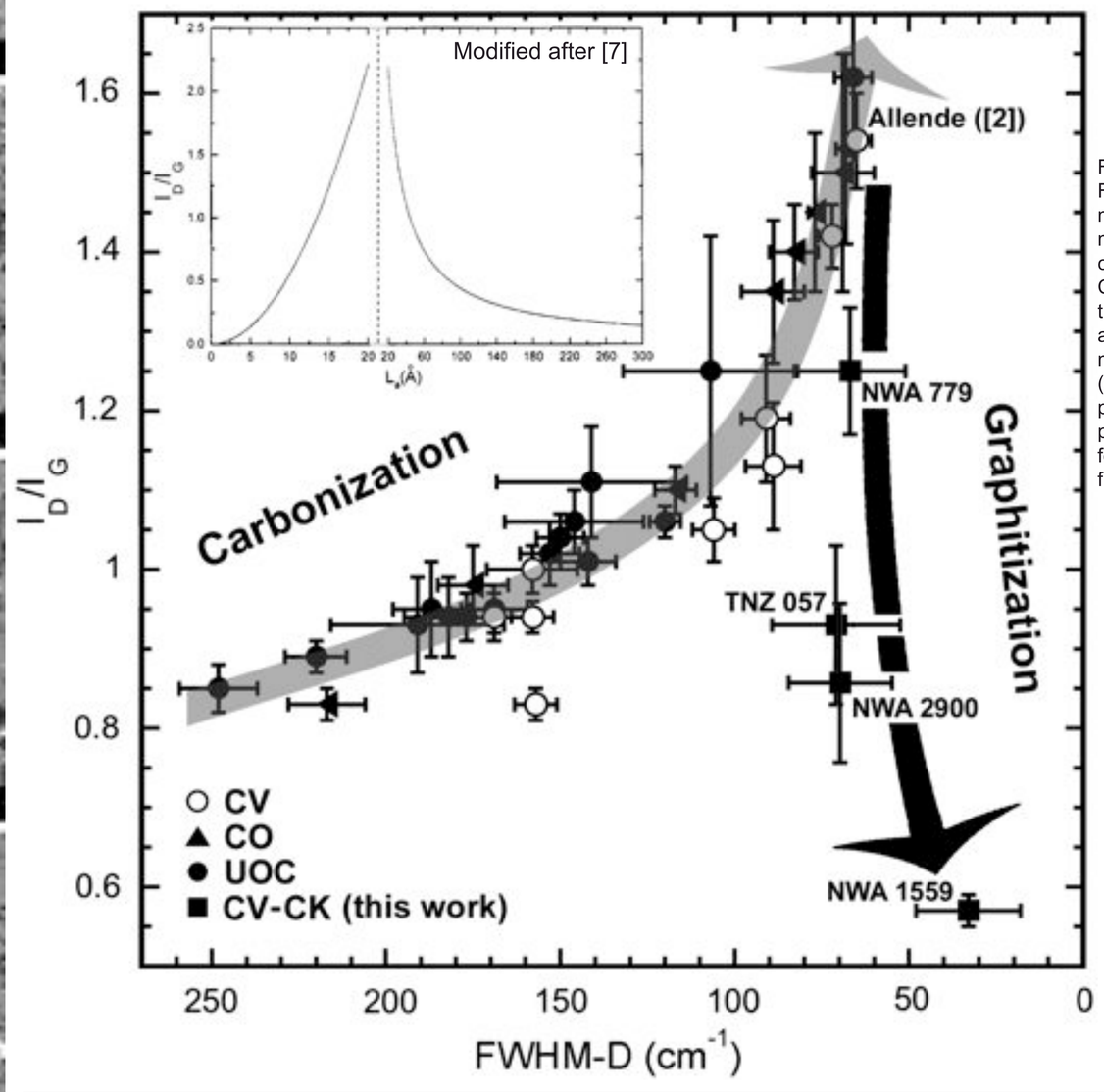

Figure 3: Diagram I_D/I_G vs. FWHM-D showing the metamorphic evolution of three metamorphic series of primitive chondrites [2, 3] and containing CVs and CKs analyzed during this work. The grey and black arrow indicate an increase of the metamorphic grade (carbonization and graphitization process, respectively). For comparison, the diagram I_D/I_G vs. L_a for carbonaceous matter, modified after [7] is presented.

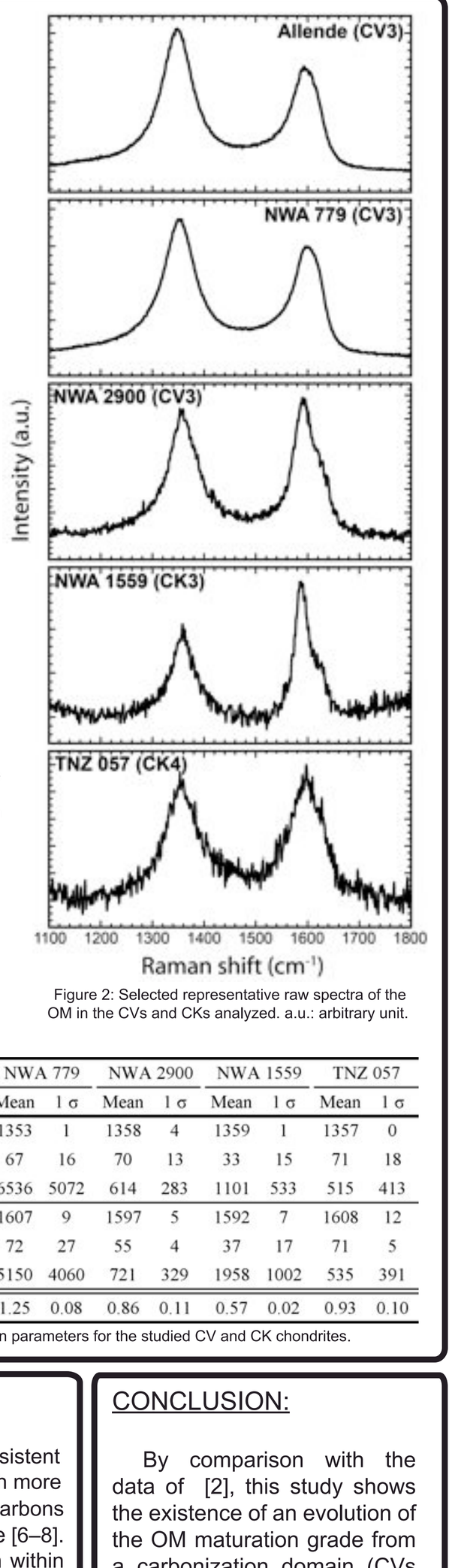

Figure 2: Selected representative raw spectra of the OM in the CVs and CKs analyzed. a.u.: arbitrary unit.

	Allende		NWA 779		NWA 2900		NWA 1559		TNZ 057	
	Mean	1 σ	Mean	1 σ	Mean	1 σ	Mean	1 σ	Mean	1 σ
ω_D	1350	2	1353	1	1358	4	1359	1	1357	0
$FWHM_D$	70	3	67	16	70	13	33	15	71	18
I_D	10686	4053	6536	5072	614	283	1101	533	515	413
ω_G	1605	2	1607	9	1597	5	1592	7	1608	12
$FWHM_G$	64	3	72	27	55	4	37	17	71	5
I_G	7804	2957	5150	4060	721	329	1958	1002	535	391
I_D/I_G	1.37	0.05	1.25	0.08	0.86	0.11	0.57	0.02	0.93	0.10

Table 1: Raman parameters for the studied CV and CK chondrites.

DISCUSSION:

Studies of [1–3] on primitive chondrites (Allende was the most metamorphosed sample analyzed) are consistent with a carbonization process (Fig. 3). OM in metamorphosed CVs and CKs analyzed during this work is much more mature than in primitive chondrites [1–3] and appears to enter the graphitization domain (Fig. 3). Indeed, the study of [7] shows two evolution trends for carbons submitted to the temperature effect. The first, where I_D/I_G increases, correspond to the carbonization domain, and the second to the graphitization one [6–8]. This study distinguish a carbonization domain (obtention of a pure sp^2 carbon, without crystalline growth) and a graphitization domain (crystal growth within already pure sp^2 carbons).

The pioneer results of [8] showed that the I_D/I_G decrease is a signature of a graphitization process. The evolution of the structural maturity of OM in non or weakly metamorphosed CVs characterized by HRTEM by [2] falls within the left part of the figure 3 and corresponds to coherent domain sizes (L_a) < 2 nm; no crystalline growth occured and all these OM suffered a carbonization process only. In contrast, our results obtained on metamorphosed CVs and CKs show a diminution of the I_D/I_G ratio as the FWHM-D decreases, fall within the right part of the figure 4 (L_a > 2 nm), i.e. in the true graphitization range [6]. The maximal I_D/I_G ratio seems reached for Allende, in agreement with the L_a measured by HRTEM, c.a. 2 nm [9].

CONCLUSION:

By comparison with the data of [2], this study shows the existence of an evolution of the OM maturation grade from a carbonization domain (CVs less metamorphosed than Allende) to the beginning of the graphitization domain (CKs). Thus, this study supplies a new argument in favour of a continuous CV-CK metamorphic series, where the OM is first carbonized, then graphitized for the highest petrologic types (> 3).

References: [1] Quirico E. et al. (2003) *MAPS* 38:795–811. [2] Bonal L. et al. (2006) *GCA* 70:1849:1863. [3] Bonal L. et al. (2007) *GCA* 71:1605:1623. [4] Kallemeyn G. W. et al. (1991) *GCA* 55:881:892. [5] Ammar M. R. et al. (2011) *Spectr. Lett.* 44:535–538. [6] Charon E. et al. (submitted) *Carbon.* [7] Ferrari A. C. and Robertson J. (2000) *Phys. Rev.* B61:14095–14107. [8] Tuinstra F. and Koening J. L. (1970) *J. Chem. Phy.* 53:1126–1130. [9] Le Guillou C. et al. (2012) *MAPS* 47:345–362.