STUDY OF SHOCKED MINERALS IN CR2 CHONDRITE GRA 95229 BY RAMAN SPECTROSCOPY

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Introduction: CR chondrites are breccias, they have large chondrules, which occupy from 40 to 60 % vol. Chondrules are carbonaceous and silicate rich, with metal sulphide blebs and enveloped by conspicuous rims. The fine-grained matrix is dark and opaque and occupies from 30 to 51 % vol. It is mainly formed by carbonaceous materials, chondrule fragments and metal inclusions, Calcium-Aluminium rich Inclusions (CAIs) are not very abundant. It is typically composed by olivines and carbonates, magnetite, smectites and chlorides [1-2].

Our target of study is GRA 95229, a carbonaceous chondrite from the Antarctic Collection, classified as a CR2. Chondrules occupy from 50 to 60 % vol, and are mainly composed by Fe-poor olivines/pyroxenes. The rims around chondrules are rare, poorly defined and often discontinuous. The matrix is dark, containing silicates, rare Fe-Ni sulphides and chondrules fragments [2]. Carbonaceous materials are more abundant than expected in this type of meteorites.

Chondrites were formed in the protoplanetary disk and have not undergo differentiation, thereby they are significant specimens of the creation and evolution of the solar system, and especially of the rocky planets. Some chondrites exhibit mild aqueous and mild thermal alteration, which appear as altered and secondary minerals, like serpentine or magnetite. Some others also host significant amounts of shocked minerals that provide valuable information about post-accretionary processes [3].

The main goal of this work is to identify shocked minerals, compare their Raman spectra with spectra simulated by quantum mechanical methods, and determine qualitatively the degree of shock and thermal annealing experienced by GRA 95229.

Experimental Procedure: First, a SEM/EDX analysis was done on selected regions of interest (ROIs) in the sample, to undergo a compositional analysis. Then Raman spectra were obtained of those ROIs that later were compared with theoretical simulated spectra to infer clues on the mineralogical composition of the sample and about thermal alteration suffered by the meteorite due to shock.

SEM/EDX Analysis: An uncoated thin sheet of the sample, GRA 95229, was brought to the Catalan Institute of Nanoscience and Nanotechnology (ICN2) to get SEM images of the ROIs. The analysis was performed on a FEI Quanta 650 FEG spectrometer with a Back Scattered Electron Detector at low vaccum. The voltage of the electron beam is set to 20 keV, the diameter of the dot was 4 nm and reach magnification within 2,000X and 50,000X. The EDX analysis was performed altogether with the SEM analysis, at the same time and in the same conditions, incorporating an X-Ray detector Inca 250 SSD XMax20 with Peltier cooling and with a detection area of 20 mm^2. X-Ray chemical mapping were performed on sample's ROIs and punctual analysis were also carried out in specific points.

Raman Analysis: Raman analysis were performed on specific ROIs, usually defined to be the same than those studied by EDX. Raman spectra were recorded on a Jobin-Yvon T-64000 spectrometer attached to an Olympus microscope equipped with a liquid Nitrogen cooled CCD detector, using the 514.5 nm emission line of argon. The laser power is kept under 1 mW, to avoid destroying the sample. The experimental Raman spectra have a 2.2 cm^{-1} resolution on the working range, from 100 to 2,000 cm^{-1}.

Computational Simulations: Computational simulations of the Raman spectra were performed for the main minerals present in these kind of meteorites. Simulations were carried out using the CRYSTAL software, which performs quantum chemical simulations of periodic systems. Calculations were based on the B3LYP Density-Functional Theory (DFT) method employing in general high quality triple-ζ basis sets. The bulk structure of the minerals (both the atomic positions and unit cell parameters) were first optimized and then the vibrational frequencies were calculated to simulate the Raman spectra [4].

Results: *Presence of secondary minerals:* Secondary minerals have been identified all through the sample. Magnetite, antigorite and dolomite are present and are products of mild aqueous alteration. Vermicullite and glassy inclusions might be products of thermal alteration caused by shock, as analyzed below.

Description of shock evidence: Disctintive shock features [5] are found on the SEM images; *e.g.*, the fractures that are present all through the sample. Specially interesting is the presence of shock induced ingrown minerals found in the fractures, produced by the shock waves crossing the sample in the aftermath of impacts. The EDX analysis shows the presence of vermicullite, incrusted on a glassy inclusion, envisioned as the byproduct of the high temperatures reached during the shock *(See Fig. 1)*.

Displacement of the Raman spectra: A way to assess the degree of shock that a mineral have suffered is to analyse the displacement of the bands present in the Raman spectra [6-7].

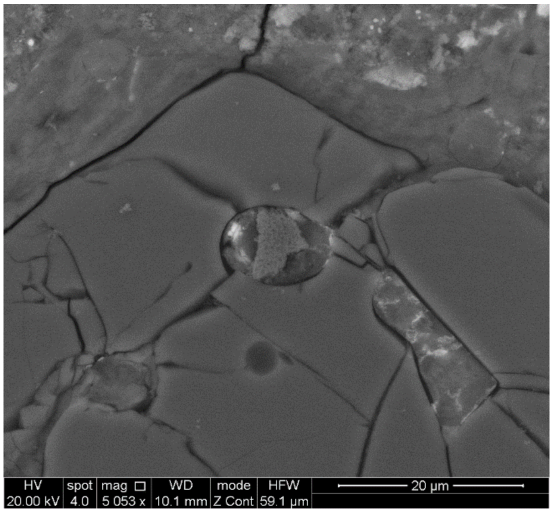

Fig 1: General view of a fractured chondrule with glassy inclusion thorugh the fractures.

Our Raman analysis revealed some other aqueous alteration minerals; *e.g.*, magnetite or dolomite. The dolomite experimental spectrum has been compared with two simulated spectra, one for aragonite and other for dolomite *(see Fig. 2)*. This was done to discriminate the shift produced by shock and the shift produced by dolomization, which is the progress that tranforms aragonite or calcite to dolomite.

The found mineral is probably dolomite at almost 100% in composition, as it is appreciated in the distinctive and well-defined band at 741 cm^{-1}. Further microprobe studies will determine the exact composition. Dolomite probably formed before the shock event because the features are shifted to lower frequencies. The shock produced a compression in the unit cell and shifted the Raman lines to lower frequencies.

Conclusions: We have found clear evidence for shock and aqueous alteration on the CR2 chondrite GRA 95229. Mild thermal alteration due to shock is reflected on the glassy inclusions present in the fractures and it is noticed on a shifting in the Raman lines comparison. It is clear that GRA 95229 have suffered a significant episode of shock that caused the mild alteration. Our data points that aqueous alteration was not necessarily promoted by shock, as previously reported in other CRs [2], so primary radiogenic heating seems more probable for GRA 95229.

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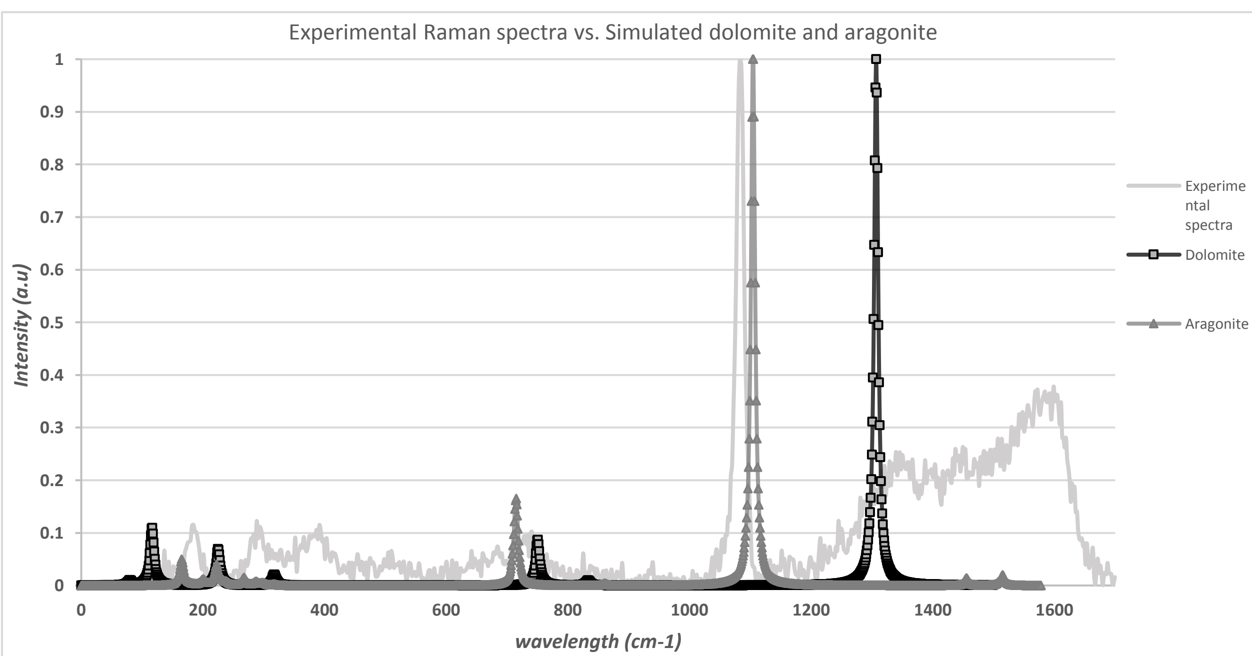

Fig 2: Comparison between experimental dolomite spectra and simulated aragonite and dolomite spectra