**IN-DEPTH STUDY OF THE CALCITE PRESENT IN THE MARTIAN NAKHLITE NORTHWEST AFRICA 6148 METEORITE.**
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**Introduction:** The in-depth studies of Martian meteorites have been an essential part of the progress of the knowledge and understanding of Mars, specially of the magmatic evolution of the planet. In this sense, the NorthWest Africa (NWA) 6148 is a fairly new Martian meteorite, from which there is not much information in the literature. It was originally documented as a nakhlite due to the augite and olivine relative proportions and their respective geochemistry [1]. A recent work about this meteorite stablished the geochemical properties of the main and secondary mineral phases using a fast and inexpensive methodology, based on Raman spectroscopy, which can compete with the usual technicques that are employed nowadays [2, 3]. In this work, the use of the same methodology in order to analyze the minoritary compounds present in the NWA 6148 meteorite is proposed.

The olivine present in this nakhlite has the highest forsterite proportions of any other nakhlite studied so far, having a geochemical composition of $Fo_{55}Fa_{45}$ in some olivine grain cores [2]. In nakhlites, the composition of olivine has usually high amount of fayalite (iron) and low amount of forsterite (magnesium) [4], which turns the case of the NWA 6148 into an even more exceptional one. This kind of differences indicates that even though all the nakhlites were formed at the same time and area and with similar magmatic conditions [5], there are substantial differences among them. The cause of this diversity between nakhlites might be due to a compositional difference of the minor compounds present in the magma during their formation. Due to this fact, in this work we have studied the minoritary compounds present in the NWA 6148, particularly the calcite inclusions, in order to understand those geochemical differences among nakhlites.

**Sample NWA 6148:** NWA 6148 was found in 2009 in the desert near the city of Erfoud, Morocco [1]. It contains millimeter-sized euhedral augite and olivine, with a relative proportion of 85:15, set in a glassy mesostasis of dendritic pyroxenes, acicular Ti-magnetite and other minor phases [1]. The analyzed sample weighs 0.246 g and does not present any visible impact crust because it was sampled from the inner part of the NWA 6148 body. This fact is ideal for investigating the minor compounds from the meteorite as well as the inner inclusions. A previous work with this sample [2] shown the presence of augite and olivine as major mineral phases.

**Spectral Measurements:** Molecular analyses were performed using a Renishaw inVia Raman micro-spectrometer (Renishaw, UK) equipped with a 532 nm excitation laser and a Renishaw RA-100 Raman spectrometer (Renishaw, UK), with a 785 nm excitation laser. The mean spectral resolution of both instruments is around 1 $cm^{-1}$. They were coupled to a microscope, where objectives of 20x and 50x were used for the spectral acquisition. In order to guarantee the accuracy of the spectra, a daily calibration of the instruments was performed using a silicon chip and its 520.5 $cm^{-1}$ band. The spectral acquisition conditions were optimized depending on the analyzed area, although the usual parameters were 5 acumulations and 5 seconds of exposure time. The laser power was modulated so that the sample received always less than 20 mW, in order to avoid thermodecomposition and chemical or mineralogical transformations. Finally, the inVia Raman micro-spectrometer was used to analyze the surface using its image mode.

**Results And Discussion:** As it was stated in literature [2], calcite ($CaCO_3$) has been found as the main minor mineral phase of NWA 6148. As can be observed in Fig. 1, the $\upsilon_1$ symmetric $CO_3$ stretching band at 1087 $cm^{-1}$ and the external vibration of the $CO_3$ due to translatory oscillations between the anionic group and the Ca band at 282 $cm^{-1}$ are present in the spectra. However, with an in-depth Raman study of different calcite grains present in the sample of the NWA 6148 it was observed that some of them had additional bands.

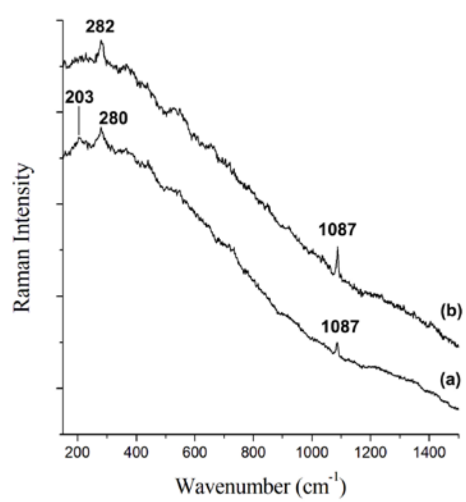


Figure 1. Raman spectra of different calcites obtained from the NWA 6148 sample with the 785 nm excitation laser.

More concretely, it was observed that the Raman band at 203 cm$^{-1}$ was present in all the calcite spectra (Fig. 1b) that had bands in addition to the standard ones (Fig. 1a). The presence of this band means that the calcite present in the NWA 6148 suffered at a certain point high pressure. When calcite suffers a pressure of at least 1.7 GPa, the crystal system transforms into a monoclinic one called calcite II, leading to the appearance of the 203 cm$^{-1}$ new Raman band [6]. This Raman band is also present in calcite III, the ortorombic phase stable at 2<Pressure<10 GPa.

In order to check this fact, two different standard calcites were measured. On the one hand, a normal calcite, sampled at the Greek isle of Thassos, which had not suffered high pressure was analyzed. On the other hand, the metaphorphic marble Markina Black was sampled in Biscay, Spain, from which several calcite grains were measured by means of Raman spectroscopy. The calcite present in this marble suffered high pressures in the past during its formation, because it is a metamorphic rock. As can be observed in Figure 2, only the calcite present in the Markina Black marble has the 204 cm$^{-1}$ band. This fact means that the calcite present in the meteorite NWA 6148 suffered high pressure at a certain point.

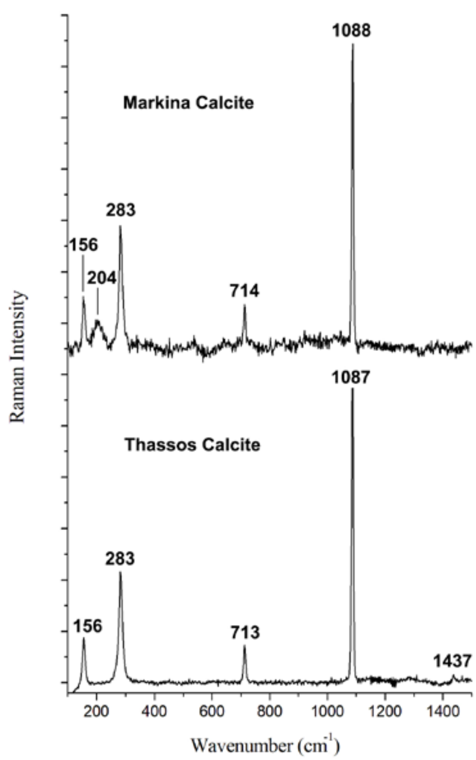


Figure 2. Calcite spectra of the samples from Thassos Calcite and Markina Black Marble.

At the moment they are ejected from a planet, meteorites go through two critical moments where they suffer high pressure. Either they get ejected due to an impact from another celestial body or due to a volcanic explosion. In either case, the ejected materials are subjected to high pressure. After traveling through space for years, they also suffer high pressure during the entrance into the atmosphere and impact as a meteorite in the destination celestial body. The fact that the calcite II (or calcite III) mineral phase is present in the NWA 6148 means that it was present in the meteorite when it suffered high pressure, either during the entrance and impact on Earth or during its ejection from Mars. In other words, the calcite present in the analyzed sample is originary from Mars.

Although carbonate mineral phases originary from Mars have been already found both in meteorites and in Mars [7], it is an odd and important finding. Concretely, calcite was found for the first time in-situ in Mars by the Mars Exploration Rover Spirit in 2008 [8]. As is known, calcite is one of the most important minerals regarding the study of a possible past life development on Mars [9] and the evolution of its atmosphere [7]. In this sense, the confirmation of the finding of calcite original from Mars in a meteorite allows further studies about those subjects.

**Conclusions:** Calcite originary from Mars is present in the nakhlite NorthWest Africa 6148 meteorite, because its Raman spectra shows the 204 cm$^{-1}$ band, characteristic of shocked (>1,7 GPa) calcite. Raman spectroscopy allows a fast way of recording molecular properties of meteorites, with even better accurary than other techniques commonly used. The confirmation of Martian calcite gives more clues about the possible past life development on Mars.

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