RAMAN SPECTROSCOPY ON THE NEW NORTHWEST AFRICA 11273 LUNAR METEORITE TO UNDERSTAND THE INITIAL IMPACT AND THE FINAL TERRESTRIAL WEATHERING. J. Huidobro, J. Aramendia*, P. Ruiz-Galende, I. Torre-Fdez and J. M. Madariaga, Department of Analytical Chemistry, University of the Basque Country (UPV/EHU), Barrio Sarriena s/n, 48940 Leioa, Spain (julene.aramendia@ehu.eus)

Introduction: Apollo and Luna missions brought to Earth Moon surface samples which are still under analysis to gain knowledge [1]. The collected samples and the Lunar Meteorites are the extraterrestrial materials used to answer the questions arisen along the time about the composition, origin and evolution of the Earth natural satellite. Nowadays, despite of the fact that the composition of the mantle is still debated, the feldspar is fairly sure to be the main compound in the surface. These feldspars appear in certain areas together with the so-called mare basalts.

To provide more data about the composition of the Moon, the Northwest Africa (NWA) 11273, a recently (2017) included Lunar Meteorite in the Meteoritical Bulletin Database, has been studied in this work. The NWA 11273 meteorite is a Lunar feldspathic breccia [2], found buried in Algeria in 2017, is said to be composed by clasts of anorthite, olivine, pigeonite, augite, chromite, Ti-Cr-Fe spinel, kamacite, taenite and troilite. Rare basalt clasts and glass fragments are said to be also present. However, no official peer reviewed works extend this information.

Sample NWA 11273: The 625 analyzed specimen is a polished slice without crust belonging to the University of the Basque Country (collection of the IBeA research group), with a weight of 0.61 g. We performed an initial characterization using non-destructive analytical techniques (Raman spectroscopy and XRF spectrometry) to ascertain the elements contained in the surface and the different mineral phases, as a first step to further accomplish the analysis inside the body of the different specimens in our hands [3]. We identified anorthite, olivine, pyroxene and calcite as the main mineral phases, together with minor amounts of the minerals described in the Meteoritical Bulletin Database for NWA 11273 [2]. Now, we have studied more in depth the inside phases and inclusions in order to find information related to the initial impact and the formation of new minerals due to terrestrial weathering.

Spectral Measurements: Molecular analyses were performed using a Renishaw inVia Confocal Raman micro-spectrometer (Renishaw, UK), equipped with the 785 and 532 nm excitation lasers and a high sensitive CCD with a mean spectral resolution of 1 cm^{-1}. Long range objectives of 20x and 50x were used for the spectral acquisition at microscopic level. 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 accumulations 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 imaging capabilities.

The Raman measurements were complemented with X-ray Fluorescence ones. The XRF analyses were conducted with a M4 TORNADO micro-spectrometer, in point-by-point and image modes, with spatial resolution down to 25 µm, for Mo Kα radiation, that can be increased up to 200 µm.

The methodology used to perform the spectral analysis combining the information from elemental and molecular analytical techniques is described elsewhere [4].

Results and Discussion: The XRF analysis gave Si, Ca, Al, Fe and Mg as the major elements (beyond a 0.1% w/w), together with other minor elements were also detected like Mn, Ti, K, Ni, S, Na, Cr, Sr and Zr. The most interesting elemental results were the identification of some metallic areas composed by Fe and Ni [3], in accordance with the observation of kamacite reported in the Meteoritical Bulletin Database [2].

Raman spectroscopy gave us the molecular (mineralogical) composition in the different areas of the surface of NWA 11273. The imaging capability of the instrument gave the distribution of the main mineral phases identified in this study, as Figure 1 shows. As seen, anorthite is widely distributed round all the surface analyzed. Pyroxenes and olivines are distributed in the same area of the sample. Although calcite was not included in the mineral phases reported by the Meteoritical Bulletin Database, its presence is important in the 625 specimen of the NWA 11273 meteorite analyzed, being distributed in the cracks and fissures.

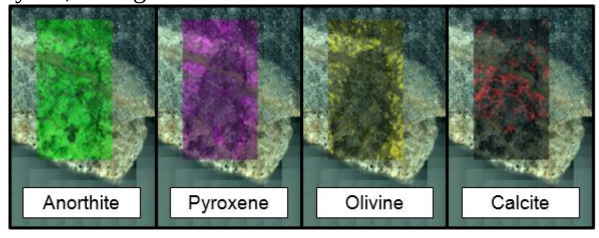

Figure 1. Raman imaging showing the distribution of the main mineral phases in the NWA 11273 sample with the 785 nm excitation laser.

Even though carbonate mineral phases originally from Moon have been already described in lunar soils and meteorites, we consider that its presence in this particular case is due to the precipitation of the calcium carbonate after the meteorite NWA 11273 arrived to Earth and buried in the "sand" of the Algerian dessert. Its formation could be explained like this: after the rain-wash events, the water containing dissolved ions moved from the sand to the fissures and cracks of the meteorite; when the rain stopped and the hot of the dessert evaporated the water, some salts start to precipitate, forming the small veins observed in the spectroscopic image shown in Figure 1 for calcite.

In addition, two important mineral phases were detected, although their presence must be considered as minor.

One of them is hematite. Its presence could be due to the terrestrial oxidation of the mentioned metallic grains of kamacite. The oxidized Fe(III) is precipitated as $Fe(OH)_3$ and then transformed to Fe_2O_3 with the hot events for years.

The second mineral phase is zircon, a type of zirconium silicate considered one of the oldest minerals from the Earth (it is formed when the magmatic rocks crystallize), and other terrestrial like bodies in the Solar System. Zircon has been detected always inside the NWA 11273 specimen. According to Zhang et al [5], the main Raman band of the zircon appears at 1008 cm^{-1}, whereas the second bands at 335, 439 and 975 cm^{-1}. However, in the experimental Raman spectrum shown in the Figure 2, the main band of the zircon has suffered a shift, appearing at 1004 cm^{-1}, while the bands at lower wavenumbers appear in the expected position. This is because the zircon is a mineral phase that changes its crystal structure when it is subjected to high pressures, as it occurred when the celestial body generating the meteorite impacted the Moon, creating the different NWA 11273 specimens.

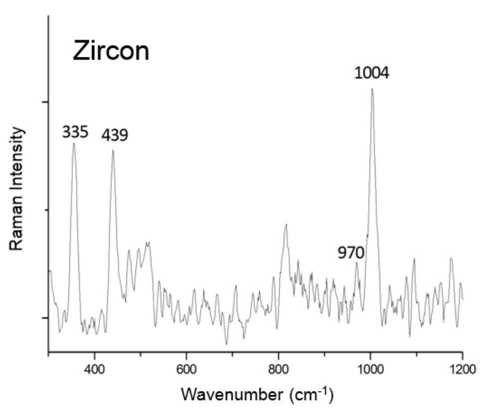

Figure 2. Shocked zircon Raman spectrum.

For this reason, the zircon found is a shocked zircon, that give us information about the applied shocked pressure when the body impacted the Moon. According to the observations of Gucsik et al [6], the main band of the zircon shits down into two wavenumber units when the zircon is subjected to 10 GPa of pressure. This fact occurs until 40 GPa, because the zircon changes to reidite. Therefore, as the of the shocked zircon in NWA 11273 appears at 1004 cm^{-1}, the pressure of the impact could be estimated around 20 GPa.

Conclusions: Apart from the mineral phases described in the Meteoritical Bulletin Database, we have found three important new ones, calcite, hematite and shocked zircon. Calcite and hematite are formed after terrestrial weathering processes. The shocked zircon provides us information about the pressure of the impact event shown in Figure 3. There is no doubt that the zircon is a mineral phase from the Moon, rather than the Earth weathering.

An impact of 20 GPa does not produce a crater with the enough depth to arrive the mantle of the Moon, where the kamacite mineral could exist. For this reason, it could come from the parent body. Thus, it would be interesting to continue with the investigations of the kamacite origin.

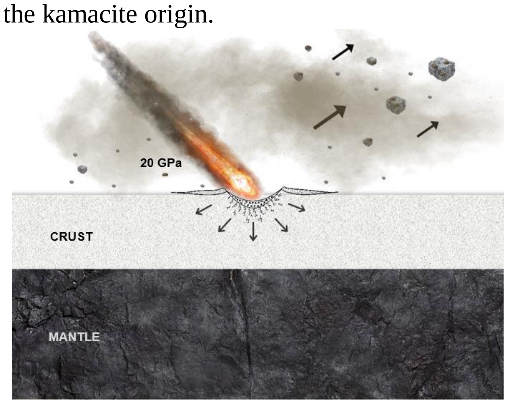

Figure 3. The hypothetical impact of the celestial body to the Moon with a pressure of 20 GPa, creating the NWA 11273 meteorites.

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