MARTIAN METEORITES: REFLECTANCE PROPERTIES, ATMOSPHERE-IMPLANTATION AGES, AND THE CLIMATIC EVOLUTION OF MARS.
C.E. Moyano-Cambero[1], J.M. Trigo-Rodríguez[1], F. J. Martín-Torres[2], and J. Llorca[3]. [1]Institute of Space Sciences (CSIC-IEEC). Campus UAB, Fac. Sciences, C5-p2, 08193 Bellaterra (Barcelona), Spain. trigo@ieec.uab.es [2]Centro de Astrobiología (CSIC-INTA). Torrejón de Ardos, Madrid, Spain. javiermt@cab.inta-csic.es [3]Institut de Tècniques Energètiques i Centre de Recerca en Nanoenginyeria. Universitat Politècnica de Catalunya, Diagonal 647, ETSEIB. Barcelona, Spain.

Introduction: Martian meteorites are so far the only samples of the red planet that are currently available to be studied in terrestrial laboratories. Three main classes have been identified and named as shergottites, nakhlites, and chassignites after the first identified meteorites of each class: Shergotty, Nakhla and Chassigny. Consequently, these achondrites are known by their acronym as SNC meteorites [1]. Despite their unique and distinctive chemical and oxygen isotopic values, the SNC suite was not completely accepted as martian in origin until that D.D. Bogard and P. Johnson noticed that some of them contain mineral phases with trapped gases that are consistent with Viking measurements [2]. New measurement capabilities in the eighties allowed to analyze tiny amounts of such gases that confirmed their martian origin. The extraordinary compositional match was well exemplified with the study of the shergottite Elephant Moraine 79001 (EET79001). This meteorite experienced a significant shock during the impact that released the original rock from Mars and during the flight through the martian atmosphere some of its components were retained in the melted shock-altered glasses and the maskelynite that were formed in the shock veins [2]. Later a similar pattern was found in Zagami shergottite [3]. Interestingly, such shock processes can be precisely dated by using different radiogenic systems and meteorites can be considered as time capsules. Different meteorites have been released by impacts at different times so in the practise we can obtain clues on the composition of Mars' atmosphere at different stages. For example, it is well known from isotopic studies that most shergottites reveal that were released from Mars at the time of the late Amazonian volcanism [4]. The preferred radiometric formation ages of basaltic and lherzolitic shergottites lie in the range ~165-475 Myr, while nakhlites and chassignites are compatible with an average age of ~1,300 Myr [4]. The oldest recognized martian meteorite is ALH84001 whose igneous crystallization date has been recently revised to be about 4,100 Myrs [5]. Then, the method to analyze trapped gases in SNC meteorites is a way to corroborate accurate physical models dealing with the evolution of Mars' atmosphere over time. In this work we start a common project in order to analyze and characterize SNC meteorites that will be used to validate a model of Mars' atmospheric evolution [6]. At this point we have started our analyses selecting two famous and well preserved SNC meteorites (Nakhla and Zagami) in order to explore our research capabilities.

Technical procedure: Two sections of Nakhla (2-mm thick) and Zagami (3-mm thick) meteorites were mounted on a slide to perform this study. A general high-resolution mosaic was generated from separate images taken with a Zeiss Scope petrographic microscope. The mosaic allow us to study the different lithologies and establish working areas for future detailed Raman studies. To generate the reflectance spectrum we used a Shimadzu UV3600 UV-Vis-NIR spectrometer. This instrument allows the measurement of the transmission, absorbance and reflectance for powder, solid, or liquid samples. The standard stage for the spectrometer is an Intregrating Sphere Radiometer (ISR) with a working range extending from 220- to 2,600-nm. The spectrometer uses multiple lamps, detectors and diffraction grates to work over a wide range of wavelengths. The light originates at one of two lamps, passes through a variable slit, is filtered to select the desired wavelength with a diffraction grating, and is then split into two alternating but identical beams with a chopper. The sample beam interacts with the sample and is routed to one of two or three detectors (depending on the sample stage). The reference beam interacts with the reference material and then goes to the same detector. The inside of the ISR is coated with a reflecting polymer called duraflect. For calibration of the detector a standard baseline was created using a conventional $BaSO_4$ substrate. This standard was taken before the measurements following a similar procedure that assures that the measured reflectances are absolute. The area sampled during the measurements corresponds to an identical slot for all samples of 1.5×0.5 cm^2. Two additional samples of Howardite–Eucrite–Diogenite (HED) meteorites (the eucrite Puerto Lápice and the diogenite NWA 1943) were also measured following the same standards.

Results and discussion: The reflectance spectra of Nakhla and Zagami are shown in Fig. 1 compared with the two above mentioned HEDs. Note that both SNC spectra exhibit clear similitudes with the HED suite meteorites. Both achondrite classes are formed by a similar assemblage of minerals. For example, the UV to NIR spectra for the four specimens shows the presence of the absorption bands that are characteristic of rocks being mostly formed by olivine and pyroxene.

Conclusions: In this preliminary work we have reached the following conclusions: a) SNC meteorites are martian rocks that provide valuable information about the atmospheric composition of Mars over time; b) The three SNC classes are scattered in time and consequently are not homogeneously sampling Mars' atmospheric evolution, it is obvious that they provide a complementary tool for atmospheric modeling. c) Detailed spectra of the SNC meteorites could be compared with certain regions of Mars that have been excavated by impacts. Due to the common minerals forming SNCs to identify such regions on Mars' surface using UV to NIR spectra seems impossible, but we are planning to complete from NIR to far-IR spectra (2.5- to 45-μm) of powders for a wide set of SNC meteorites in order to explore the possibility of finding the main source regions. We also plan to continue the characterization of the different minerals forming these rocks by using FIB/SEM, Raman, etc. This characterization will be used to validate our Mars' atmospheric evolution model [6].

As a general conclusion, we think that in situ sampling during future robotic and human exploration of Mars will provide very interesting clues on the atmospheric evolution, and probably will answer parallel questions concerning the global processes that originated aqueous altered minerals in SNC rocks (like e.g. in ALH84001), their timescales, and providing clues on the existence of life forms at some age in the fascinating evolution of Mars [7].

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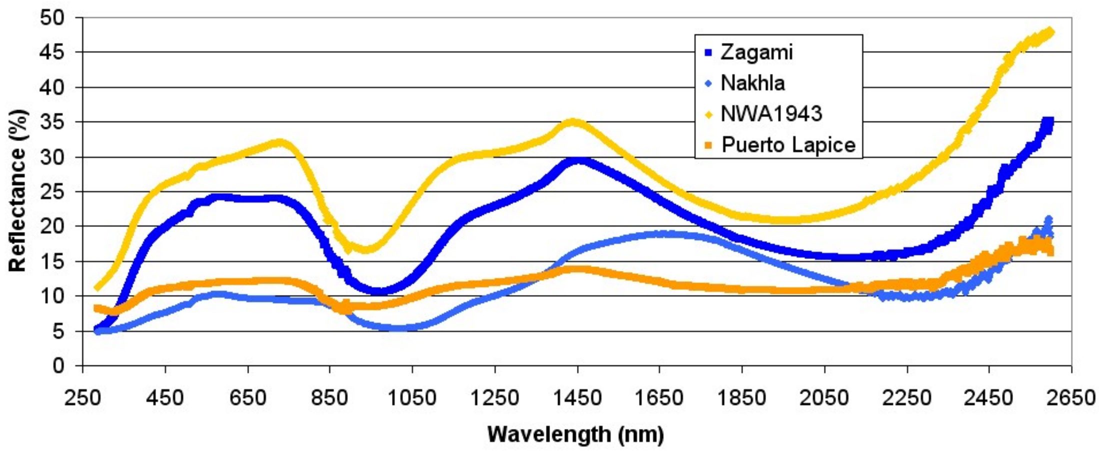

Figure 1. UV-visible-near IR spectra of the two Martian meteorites discussed in the text Nakhla and Zagami compared with selected HED meteorites associated with 4 Vesta. Absolute reflectance is plotted versus wavelength.

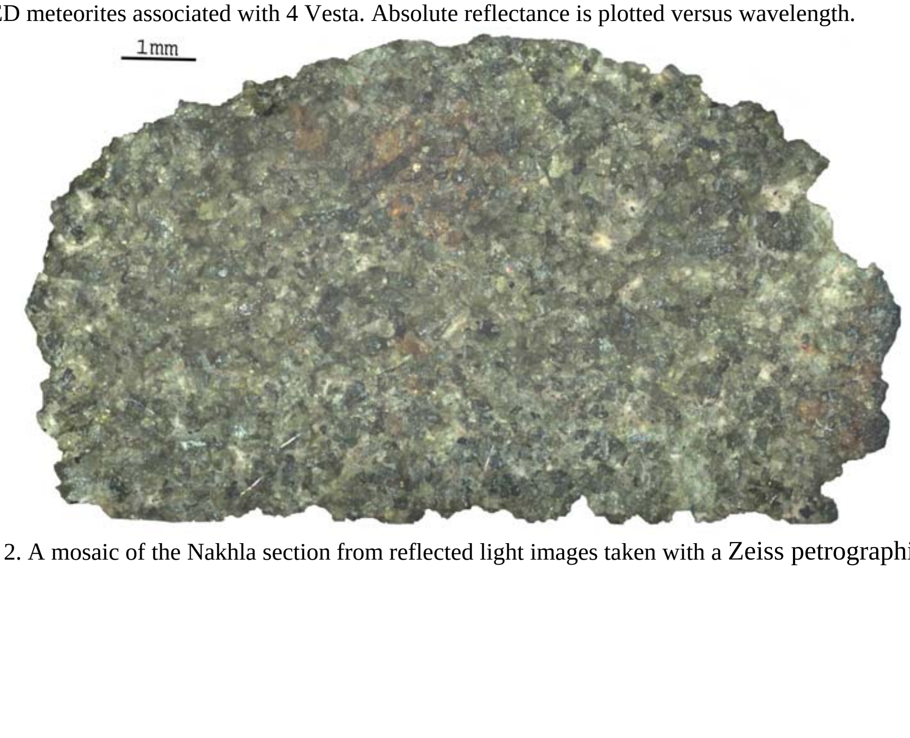

Figure 2. A mosaic of the Nakhla section from reflected light images taken with a Zeiss petrographic microscope.