DISCRIMINATION BETWEEN OLIVINE AND PYROXENE FROM CLEMENTINE NIR DATA: APPLICATION TO ARISTARCHUS CRATER. S. Le Mouélic, Y. Langevin, and S. Erard, Institut d'Astrophysique Spatiale, CNRS- Université Paris XI, Bât 121, 91405 Orsay cedex, France. Email: lemoueli@ias.fr

Introduction: From Clementine UVVIS data, it is possible to evaluate the degree of maturity of the surface [1] and to discriminate between mare and highland type material [2]. We show that Clementine NIR data makes possible the discrimination on the lunar surface between the two major classes of mare mafic minerals, olivine and pyroxene. In the Aristarchus region, we derived a high resolution map of maturity and FeO content. We then show strong evidence for olivine dominated areas on the south eastern rim of the crater.

Data Processing: We processed a north south strip of Clementine UVVIS and NIR data covering the eastern part of Aristarchus crater. UVVIS data were calibrated using the algorithm of Pieters and coworkers described at Brown's University web site (http://www.planetary.brown.edu/clementine). We selected NIR images at 1100, 1250, 1500 and 2000 nm according to image quality and mineralogical interest. NIR Images were calibrated following the technique described in [3]. Each flat field has been derived from a median filter on a set of ~40 homogeneous images of Oceanus Procellarum. A photometric correction has been applied within each frame and from one frame to the other. We used the phase function described in [4], which was derived from a set of 10000 pairs of overlapping UVVIS images at 950 nm. Both the dependence of the three parameters of the photometric model with the soil nature and with wavelength are not corrected. The reduction process leaves an unknown multiplying factor for each NIR images, which is determined by scaling the data cube to the telescopic spectrum 2a from [5].

Results: Previous studies have revealed the major heterogeneity of the Aristarchus plateau [5,6]. Clinopyroxene, plagioclase, olivine and ilmenite minerals have been detected in telescopic spectra [5]. Both highland and mare type materials have been found in Aristarchus crater [6].

Figure 1a displays a mosaic of three successive images of Aristarchus crater at 1500 nm (orbit 53). Mature soils, which have been exposed to the space weathering processes, have a reduced reflectance, and their spectra exhibit a redder continuum with reduced absorption band depths [7]. Spectral differences can therefore be attributed either to differences in maturity, or to differences in mineralogical composition. This ambiguity makes difficult the interpretation of the spectral data. In order to discriminate between these two effects, Lucey et al. proposed recently a method based on the roughly orthogonal effects of maturity and FeO content on a plot of the 950/750 nm ratio versus the 750 nm reflectance [1]. Some care has to be taken with the method, because the reflectance on local high slopes is modified by uncorrected photometric effects, which induce systematic errors. The maturity image derived from this method is displayed in Figure 1b. The maturity pattern is approximately symmetric with respect to the crater. The crater interior appears less mature than the surrounding ejecta. The elapsed time for a regolith formation is longer for impact melt surfaces in the crater interior, which delays the initiation of maturation processes compared to the surrounding materials [1,8]. The most immature areas appear in white and could correspond to surface areas which are freshened by downslope movements of debris (upper rim of the inner crater and sinuous rille on the top left corner). Small fresh craters also appear in white in this image.

The knowledge of the maturity permits a second level of interpretation in terms of mineralogy. Figure 1c displays the FeO content of the surface derived from the algorithm described in [2]. Error are estimated at ~2 wt %. The FeO image discriminates mainly between highland type materials (low to intermediate FeO content,) and mafic mare materials (high FeO, ~18-19 wt. %). The lowest FeO content is found on the central peak (~3 wt.%), where anorthosite has been previously identified as the major constituant [see 5, 6 and 9 for a discussion]. The highest FeO content (~22 wt. %) is found on the dark mantle deposits covering the north eastern part of the ejectas. The crater floor and the eastern part of the rim are dominated by highland type material. The impact event creating Aristarchus occurred on the boundary between the Aristarchus Plateau and Mare Imbrium. The asymmetry of the crater ejectas has been explained as the result of the pre-impact target site heterogeneity [10].

The UVVIS part of the spectrum discriminates between gabbroic highland materials, dark mantle deposits and mafic mare materials. The 2000/1500 nm ratio, compared to the albedo and maturity images, provides the discrimination within mare basalts, and more precisely between olivine and pyroxene. Olivine is present in mare materials. It is considered to be associated either with the lunar mantle or with Mg-rich plutons. The distribution of olivine on the lunar surface provide clues on the processes involving the lunar mantle and crust.

Pyroxene spectra exhibit two absorption at 1 µm and 2 µm, whereas olivine has a single broad composite absorption near 1 µm, and has no absorption at 2 µm. Figure 1d displays the 2000/1500 nm ratio. Olivine dominated areas appear brighter than pyroxene dominated areas. Arrow A shows an olivine dominated zone previously mentioned in [6]. The most striking feature is a ~4x10 km^2 area which appears in white in the 2000/1500 nm ratio (arrow B). The corresponding zone does not appear in the albedo image, nor in the maturity image, which confirms the interpretation in terms of mineralogy. It is interpreted as mare basalt according to UVVIS color ratio composite [6]. The shape of the extracted spectra suggests an olivine/pyroxene ratio >6 in this area, with a low degree of maturity within the upper rim, and a more mature material on the outer rim [9]. The TiO_2 content of this unit is evaluated using the method described in [2] at 1 wt. %. This implies a very low content in ilmenite.

Very few areas on the lunar surface have already been identified as completely dominated by olivine [11, 12]. Our findings of olivine-rich ejecta at Aristarchus suggests that a vertical mixing of plutons or other types of magmatic intrusions occurs on the underlying site.

Conclusion: Telescopic studies with a high spectral resolution provide essential information to identify minerals in lunar surface material. Clementine provides a complementary approach using spectro-imaging techniques, giving the possibility to detect and to map the spatial extent of major heterogeneities on almost 100% of the surface of the Moon. The calibration for the full NIR data set has been hampered by hard instrumental problems. Our study of a restricted area has led to the identification of a new olivine dominated zone. This shows the great potential of NIR data to complement the information provided by Clementine UVVIS data and telescopic spectral studies.

References: [1] Lucey P. G. et al. (1998) *LPSC XXIX*, *n°1356*. [2] Lucey P. G. et al. (1998) *JGR*, *103*, 3679-3699. [3] Le Mouélic S. et al. (1998) *JGR*, in Press. [4] Shkuratov Y. G. and Kreslavsky M. A. (1998) *LPSC XXIX*, *n°1117*. [5] Lucey P. G. et al. (1986) *JGR*, *82*, 344-354. [6] McEwen A. S. et al. (1994) *Science 266*, 1858-1862. [7] Fischers E. M. and Pieters C. M. (1996) *JGR*, *101*, 2225- 2234. [8] Malaret E. and Lucey P. G. (1996) *LPSC XXVII*, 797-798. [9] Le Mouélic S. et al. (1998), submitted to *Geophys. Res. Lett.*. [10] Guest J. E. (1973) *Geo. Soc. Am. Bull.*, *34*, 2873-2894. [11] Pieters C. M. (1982) *Science*, *215*, 59-61. [12] Lucey P. G. et al (1991) *Geophys. Res. Lett.*, *18*, 2133-2136.

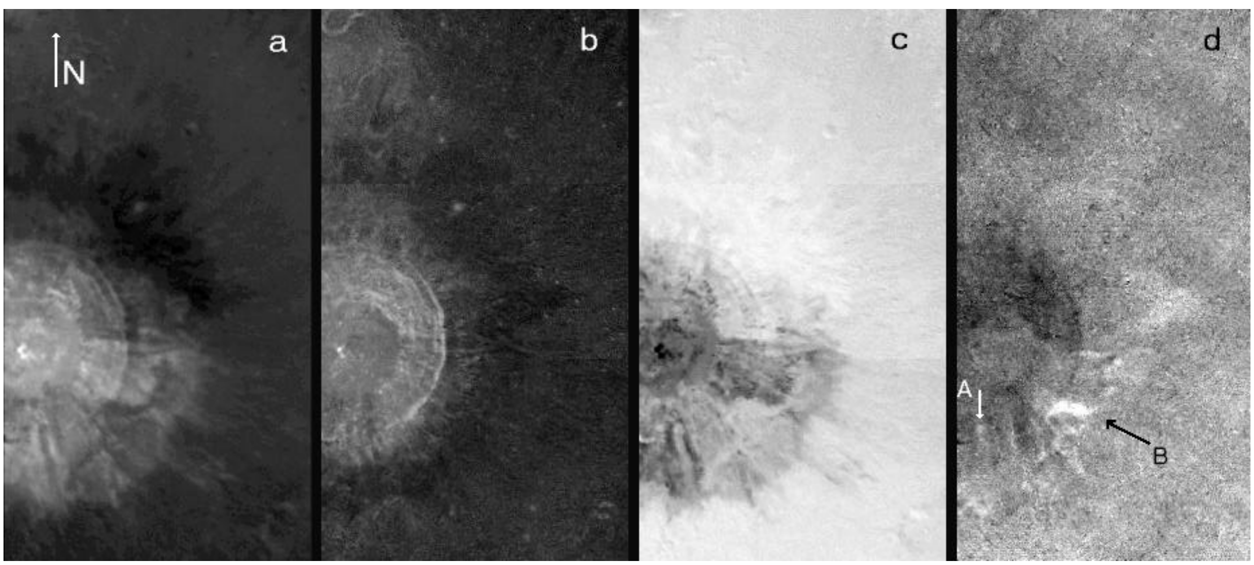

Figure 1. a: mosaic of 3 frames on Aristarchus at 1500 nm (orbit 53). b: maturity image derived from the algorithm of [1], where less mature areas appear in white (upper inner rim, small fresh craters and sinuous rille walls on the top left corner). c: FeO content, from 2 wt % (black) to 23 wt % (White). Highland type material appear in dark, with the darkest corresponding to the anorthositic central peak (~2 wt. % FeO). Mare type material appear in bright (~18-19 wt. % FeO). d: the 2000/1500 nm ratio discriminates within mare materials between pyroxene dominated areas (black) and olivine dominated areas (white). Arrow A: olivine-rich zone mentioned in [4]. Arrow B indicates the olivine-rich area newly discovered, extending over ~4x10 km^2 .