

IDENTIFICATION OF A NEW ROCK TYPE ON MARS: ANORTHOSITE. F. Poulet¹, J. Carter², ¹Institut d'Astrophysique Spatiale, CNRS/Univ. Paris Sud, 91405 Orsay Cedex (francois.poulet@ias.u-psud.fr), ²European Southern Observatory, Santiago.

Introduction. Although small pockets of sedimentary deposits have also been detected, the planet Mars remains in essence covered by mafic-bearing assemblages of volcanic origin. CRISM spectroscopic data from the Mars Reconnaissance Orbiter probe reveals the presence of a new and un-expected rock type on Mars, anorthosite. This igneous rock was previously known to exist in terrestrial plutons and in the lunar highlands only. The presence of anorthosites on Mars provides insights into the planet's primordial crust composition and later magmatic (plutonic) evolution.

Methods. Plagioclase minerals do not exhibit diagnostic bands in the near-infrared wavelength range but ferroan anorthosites that contain a small fraction (<10%) of mafic minerals, can be detected due to Fe²⁺ cations substituting Al and Si in the crystal structure. Although extremely minor, Fe²⁺ induces a single broad symmetrical electronic transition band centered at ~1.25 μm diagnostic of anorthosite rocks [1]. Anorthosite is detected using surface reflectance data from the CRISM imaging spectrometer. We utilize the 1.0-2.65 μm range spectrally sampled at 6.55 nm and spatially sampled < 36 m/pixel to perform a systematic search for this band.

Anorthosite signature is difficult to identify because it can be contaminated by other minerals. The identification of mineral with CRISM is based on special ratios or neutral mineralogy subtraction: the spectra of a given region of interest are either divided by or subtracted from spectra extracted from a region of spectrally bland (neutral) mineralogy. This technique can however induce a false anorthosite band in the presence of low-calcium pyroxene (LCP) in the ratio or denominator. Indeed LCP has a spectral shape in the 1.0-1.5 μm region almost identical to the opposite or inverse of the anorthosite band. If LCP is present in the ratio or denominator, it can yield a false anorthosite band. Hence, no identification of anorthosite can be made if LCP is present in noticeable amounts in the ratio or subtracted spectra. Figure 1 summarizes this effect: are shown spectra of lunar anorthosite (blue), forsterite olivine mixed linearly with dust (green), forsterite to which we subtracted LCP (red), and the opposite spectrum of LCP (orange). All of these are good matches to the anorthosite band. To further discriminate anorthosite from these artifacts, an additional step is required: we reject spectra, which the spectral slope between 1.7 and 2.65 μm is not flat or slightly positive, as all the other contaminants exhibit a negative slope in this range (Figure 1). This rejection criterion is applied

only if hydrous signatures are not present in the spectra. Hydrous minerals have a negative spectral slope in the [1.7-2.65] μm region, which should not be taken for an artifact (Figure 2) when mixed with pure anorthosite. After this filtering process, anorthosite is detected in the CRISM cubes by deriving a simple spectral index based on band maths comparing the reflectance value of the band center at 1.25-1.35 μm and its sides (1.05-1.10 μm and 1.40-1.45 μm). Anorthosite spectra and mineral maps are then derived for each relevant CRISM observation based on the endmember extraction method described in [2] and visually compared to spectra of laboratory analogues. The same approach is used to identify ancillary minerals (hydrous or mafic).

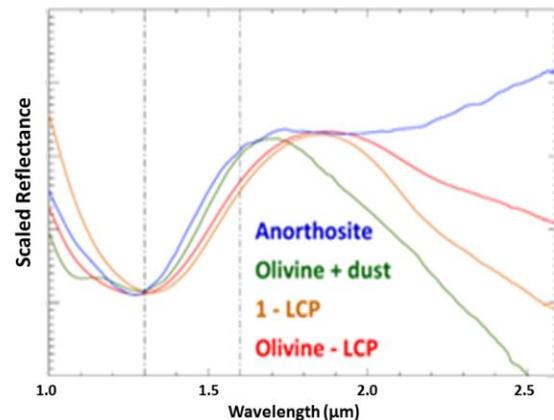


Figure 1. Comparison of a pure anorthosite spectrum (blue) with a linear mixture of olivine mixed with dust (green), olivine with LCP (low calcium pyroxene) in the denominator (red) or a spectrally bland spectrum with LCP in the denominator (orange).

Results. 8 sites were detected with unambiguous signatures of anorthosite rocks. All 8 sites show spectra of unaltered anorthosite but 6 of them also exhibit additional bands diagnostic of alteration minerals (phyllosilicates) at ~1.4, ~1.9 and 2.17-2.4 μm (Figure 2). The 8 exposures are scattered over the southern highlands with a cluster in the northern Hellas region, which may reflect the large number of observations analyzed there [3]. Anorthosite is associated with early Noachian hills (Figure 3) and rims of craters with diameters 50-70 km, as well as on the southern and northern rim of 140 km large Holden crater. The presence of anorthosite in large crater rims suggests that the material was excavated by the impact from a depth ranging down to several kilometers. The two types of

settings (crater rims and early Noachian buttes) are found in close association in northern Hellas, with some detections as close as 50 km, likely indicating a common origin from a formation process at the same period of Mars's history, i.e. during early Mars.

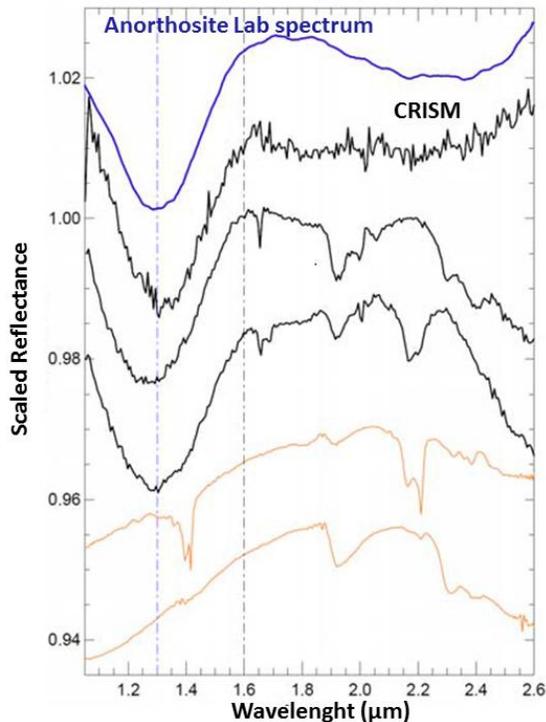


Figure 2. Three CRISM spectra (in black) of unaltered anorthosite (top) and anorthosite altered (or mixed) into (with) Al (bottom) and Fe/Mg phyllosilicates (middle). Laboratory spectra are shown in color. Blue: lunar bytownite-anorthite anorthosite ($An > 70$). Orange: terrestrial Al-rich kaolin (top) and Vermiculite (bottom.) The laboratory spectra originate from the NASA/Keck RELAB and JPL/ASTER spectral libraries.

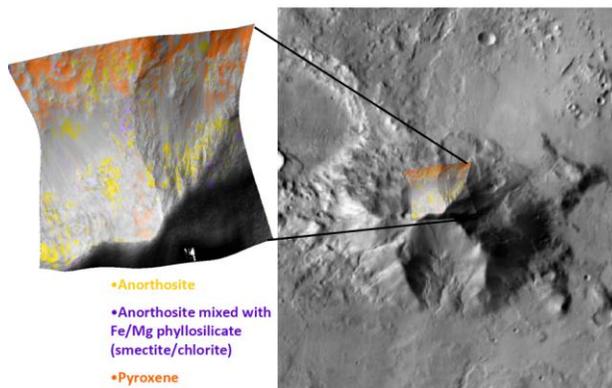


Figure 3. FRT18294 CRISM mineral map located on an early Noachian butte in the northeastern part of Hellas basin ($86.78^{\circ}E$, $-29.7^{\circ}N$).

Formation process. Significant quantities of anorthositic rocks can be produced either globally during differentiation through magma ocean or serial magmatism as proposed for the Moon [4,5], or locally requiring mechanisms such as fractional crystallization, assimilation, or partial melting of an already evolved source [6]. Although we cannot totally exclude an early lunar like crustal origin due to limitation in the detection capabilities, the small number of detections is overall in better agreement with a localized origin from a non-ultramafic magmatic source, leading to the formation of so-called plutonic anorthosites. The presence of alteration products provides an important constraint on the timing of the formation of these plutonic anorthositic rocks. Most of the hydrated silicates were formed before the late Noachian [3]. This implies that the anorthosite-bearing rocks were formed before the major period of alteration, which is consistent with the very ancient age of some of the deposits in the northern Hellas region.

References. [1] Anbazhagan, S. et al. (2010), *Planet. Space Sci.*, 58(5), 752-760. [2] Carter J. et al. (2013), *Planet. Space Sci.*, in press. [3] Carter J. et al. (2013), *JGR*, in press. [4] Wood et al (1970) *GCA Suppl.*, 1, 965-988. [5] Borg, L. et al. (2011) *Nature*, 447(7362), 70-72. [6] Ashwal L.H. (2010) *Canadian Mineralogist*, 4828(5), 711-728.