THE SECOND CONFERENCE ON THE LUNAR HIGHLANDS CRUST AND NEW DIRECTIONS

VNIR spectral variability of the igneous stratified Stillwater Complex: A tool to map lunar highlands†

CRISTIAN CARLI1,∗, GIOVANNI SERVENTI2 AND MARIA SGAVETTI2

1Istituto di Astrofisica e Planetologia Spaziali-INAF Roma, Via faro del cavalieri 100, 00133, Rome, Italy
2Dipartimento di Fisica e Scienze della Terra, Macedonio Meloni, Università degli studi di Parma, via Uesberti 157/A, 43100, Parma, Italy

ABSTRACT

Lunar highlands are plagioclase-rich terrains produced by crystal floating in a Magma Ocean system. Lunar samples revealed the presence of anorthositic (plagioclase > 90%) samples from the Highlands, associated to more mafic rocks. Recently, remote sensing data permit mapping those terrains with high spatial and spectral resolution allowing detection of plagioclase and mafic crystal field (C.F.) absorptions. 

In this paper we have studied bidirectional spectral characteristics in the visible near-infrared (VNIR) of rocks from the Stillwater Complex, a cumulitic igneous stratified complex, with composition varying from mafic to sialic (e.g., pyroxenite, anorthosite). We investigated both slabs and powders of these rocks to give indication of the spectral variability of rock analogs of lunar crust, from a mineralogical point of view. Samples have been spectrally separated in four main groups considering the different C.F. absorption association, reflectance and spectral shape for both slab and powder spectra. More spectral details can be obtained from the analysis of powder spectra than from the slab spectra.

The composition of rocks can be addressed by studying spectral parameters, such as the position and the intensity of the absorption (e.g., band center and band depth). The analysis of our plagioclase-pyroxene-bearing samples indicates that mafic composition can be clearly obtained for samples characterized by one pyroxene phase, even for few amounts of pyroxene, from powder spectra. On the other hand, slab spectra show clear pyroxene absorptions only for rocks with mafic abundance at least >20%. The intensity of the mafic absorptions of these samples shows a linear trend with respect to the abundance of pyroxenes (orthopyroxene + clinopyroxene, for samples with ferrosilite amount less than ca. 25%). Considering all pyroxene-bearing samples, the band depth of slab spectra are linearly related to the volumetric distribution of ferrous iron in pyroxenes.

Keywords: Lunar and planetary studies, terrestrial analogs, optical spectroscopy, VNIR reflectance spectroscopy, surface studies, highlands particulate, rock analogs

INTRODUCTION

Lunar highlands have been long considered the product of global Magma Ocean (MO), which produced a wide variety of mafic lithologies in a heterogeneous mantle and a ferroan anorthosite primary crust via the crystallization and flotation of plagioclase (e.g., Smith et al. 1970; Wood et al. 1970; Warren 1985). It is generally accepted that this body was largely molten during its early evolution (e.g., Warren 1985), and that the lunar magma ocean (LMO) crystallized from the cooling of the outer portion to form the early crust and the upper mantle (e.g., Warren 1985).

In particular, lunar surface lithology analyses have been often successful in placing the different rocks in the context of the LMO paradigm (Elardo et al. 2011) even if inconsistencies have been advanced by several authors (e.g., Walker 1983; Longhi and Ashwal 1985), pointing out, e.g., that several models for the evolution of LMO did not take into account the fact that lunar monomineralic rocks are rare (Snyder et al. 1992). Snyder

E-mail: cristian.carli@iaps.inaf.it
† Special collection papers can be found on GSW at http://ammin.
geoscienceworld.org/site/misc/specialissuelist.xhtml.

et al. (1992) modeled the crystallization for the LMO suggesting an early transition from olivine, orthopyroxene, to calcic pyroxene (ceasing olivine crystallization). After 65–70% of the LMO crystallized, plagioclase came on the liquidus and began to crystallize. This sequence is supposed to be formed from bottom up to the layering of the upper mantle and the crust of the Moon. Similar mineral assemblages’ sequences are recognized in the layered igneous intrusions on the Earth (e.g., Stillwater complex, Duluth Gabbro Complex, Skærgaard intrusion, Snyder et al. (1992)). Warren (1985) also evidenced as crystallization of the LMO can produce a wide variety of mafic lithologies in a heterogeneous mantle with the formation of a ferroan anorthosite crust via flotation of plagioclase-rich cumulates.

Recently, data from the multiband imager (M.I.) and the spectral profiler (S.P.) onboard the Japanese SELENE missions and from the Moon Mineralogy Mapper (M3) NASA-reflectance spectrometer onboard the Indian Chandrayaan spacecraft, have clearly indicated that a C.F. absorption band close to 1.2 μm is unambiguously recognizable in different regions on the lunar crust and is assignable to ferrous iron in plagioclase (Ohtake et al. 2009; Yamamoto et al. 2012; Donaldson Hanna et al. 2014). Moreover, it has been evidenced that regions close to