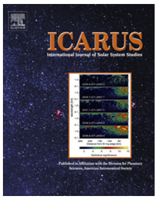
Icarus 226 (2013) 282–298

Contents lists available at SciVerse ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus



Spectral variability of plagioclase–mafic mixtures (1): Effects of chemistry and modal abundance in reflectance spectra of rocks and mineral mixtures

Giovanna Serventi[a,*], Cristian Carli[b], Maria Sgavetti[a], Mauro Ciarniello[b], Fabrizio Capaccioni[b], Giuseppe Pedrazzi[c]

[a] Department of Physics and Earth Sciences "Macedonio Melloni", University of Parma, Italy
[b] Inaf-IAPS Tor Vergata, Roma, Italy
[c] Department of Neurosciences, University of Parma, Italy

ARTICLE INFO

Article history:
Received 20 December 2012
Revised 31 May 2013
Accepted 31 May 2013
Available online 13 June 2013

Keywords:
Mineralogy
Mercury, Surface
Moon, Surface
Spectroscopy

ABSTRACT

Remote sensing from lunar highland and from Hermean surface showed reflectance spectra with no detectable absorption bands in the visible and near infrared, and recently M3 data from the lunar surface (e.g., Orientale Basin) have shown spectra with a weak absorption band centered at 1250 nm. Those terrains were generally interpreted as plagioclase rich regions. Plagioclase, however, has often been considered a spectrally transparent and almost featureless mineral. So it is difficult to recognize its presence and to quantify the abundance of this mineral even if it is one of the most important mineralogical component of the planetary surfaces.

In this work we investigate the influence of plagioclase absorption band on the absorption of Fe, Mg minerals. We consider three plagioclases with different FeO wt.% contents which have been mixed with three mafic end-members (1) pyroxene-bearing and olivine-free, (2) olivine-poor and (3) olivine-rich, at two different grain size. Plagioclase's influence has been expressed considering variation of different spectral parameters: band position, band intensity and band width.

We show that plagioclase has spectroscopically different behavior when mixed with olivine-bearing or olivine-free end-members, but, in general, adding modal abundance of plagioclase produces higher albedo and reduced spectral contrast. Increasing FeO content in plagioclase and coarsening the grain size have similar effects on the mixture spectra. We also observed the spectral convergence of mixtures with different composition and grain size.

With these results, we point out the importance of considering the plagioclase absorption on mixture's mineralogical composition, when spectra from different terrain are considered. Moreover, accurate evaluation of the abundance of plagioclase in those mixture should be discussed in subsequent works.

1. Introduction

Plagioclase (PL) is an important rock forming mineral that has been often considered a featureless, transparent phase in studies of VNIR (visible–near infrared) reflectance. Moreover, although it was considered one of the principal mineralogical component of the featureless reflectance spectra of different Mercury and Moon terrains, few studies are reported exploring the influence of Fe^{2+} absorption band in PL on the more evident mafic absorption bands (Nash and Conel, 1974; Crown and Pieters, 1987; Cheek and Pieters, 2012).

Mercury is a terrestrial, airless planet, whose surface is composed of fine regolith constantly melted, comminuted, sputtered, vaporized and overturned (Domingue et al., 2009). Mercury is called the iron planet (Solomon, 2003), due to its large and heavy iron-rich core representing 60% of the total planet's mass or more (Solomon et al., 2001). In contrast with this, spectral evidences suggested the lack of FeO in silicates on Hermean surface (Vilas et al., 1984; Vilas, 1985, 1988; Sprague et al., 1994; Blewett et al., 1997, 2002).

Recently, the Mercury Atmospheric Surface Composition Spectrometer MASCS (McClintock and Lankton, 2007), on the Mercury Surface, Space, ENvironment, Geochemistry, and Ranging MESSENGER (Solomon et al., 2001) mission, analyzed the 200–1400 nm spectral range with high spectral resolution (an average of 5 nm); the spectra show very low spectral contrast, a red slope

---

* Corresponding author. Address: Department of Physics and Earth Sciences "Macedonio Melloni", University of Parma, via Usberti 157/A, Parma, Italy.

E-mail address: giovanna.serventi@unipr.it (G. Serventi).

0019-1035/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.icarus.2013.05.041

and confirm the absence of clearly resolvable absorption bands in the 1000 nm region (Cloutis et al., 2008; McClintock et al., 2008; Solomon et al., 2008). Absorption processes in this spectral region are due to Fe^{2+} in octahedral M1 or M2 sites in silicates (Burns, 1993), like orthopyroxene (OPX), clinopyroxene (CPX) and olivine (OL); therefore, the absence of this absorption structure in the Mercury's surface spectra is generally explained by low-iron content in silicates (Robinson et al., 2008; Blewett et al., 2009). Other authors suggest different causes as possible explanations for featureless spectra. These causes include: (1) Mn-bearing CPX (Warell et al., 2010); (2) phenomena of shock metamorphism responsible for the "collapse" of the plagioclase crystal structure (Hawke et al., 2003) and (3) the mixtures of several, spectrally interacting iron-bearing mineral phases, which reduce the band contrast, particularly in aggregates that could be present in the Mercury's regolith (Carli and Sgavetti, 2011).

Nevertheless, spectra from the second MESSENGER's flyby show a possible crystal field absorption band at 1100–1200 nm (Izenberg et al., 2008); in previous Earth-based data of Mercury, this feature was interpreted to be due to Fe^{2+} in calcic pyroxene, PX (Warell et al., 2006).

In the future, the BepiColombo mission will provide data about the Hermean surface composition in a larger VNIR spectral range (400–2000 nm) and with higher spectral (256 channels with 6.25 nm spectral sampling) and spatial resolutions (100 m at Periherm) than MESSENGER.

Among the other Solar System bodies, the lunar highlands are anorthositic in composition, a PL-rich type of rocks. Early investigations based on Earth-based telescopic data and Clementine multispectral data (Spudis et al., 1984; Bussey and Spudis, 2000; Hawke et al., 2003) revealed featureless high albedo material inferred to be associated with shocked anorthosites. Recent investigations by the Moon Mineralogy Mapper (onboard the Chandrayaan-1 mission) with high spectral and spatial resolution, detected the PL diagnostic features at ca. 1250 nm widely distributed in the Orientale Basin (Pieters et al., 2009; Cheek et al., 2012; Donaldson Hanna et al., 2012). Also the SELENE Multiband Imager and Spectral Profiler highlighted that the diagnostic PL feature can be recognized in other locations on the lunar surface (Ohtake et al., 2009; Yamamoto, 2012), both in highlands and maria terrains.

In this paper, we present the preliminary results of reflectance spectroscopy analysis of a set of mineral mixtures, aimed at identifying the effects of PL when mixed with assemblies of ferromagnesian minerals. Our approach differs from previous studies on this topic in that PL with variable amount of Fe^{2+} are mixed with ferromagnesian end-members (e.g., OPX + CPX and OPX + OL). We want to analyze to what extent the interaction of adjacent absorptions bands due to different minerals can be a possible cause of low contrast spectra, showing both the effects of PL modal abundance and chemistry on the absorption bands of Fe, Mg minerals in the NIR spectral region, when these minerals are components of a complex mixture. We also investigated the possible, but unpredictable effects of different particle sizes.

2. Criteria for the mineral choice for this work

Taylor et al. (2009) suggested that lunar magma ocean cumulates, including PL cumulates, are composed of at least 90% An_{90-95} PL. These anorthosites were called ferroan anorthosites, FAN (Warren, 1985). They contain about 3.5 wt.% total FeO content, less than highland FeO content (3–8 wt.% FeO), and the iron content in PL is supposed to be less than 0.1 wt.%. The authors also modeled PL crystallization starting from a melt, for which a FeO Kd PL/melt of 0.03 was considered. They obtained the crystallization of a PL with 0.42 wt.% FeO, in disagreement with the typical value of 0.1 wt.% observed in highland PL. Observing the FeO behavior in terrestrial anorthosites affected by sub-solidus re-equilibration during metamorphism, the authors suggested a similar type of reaction in lunar rocks, made possible by greater heat and slower cooling conditions on the Moon with respect to the Earth; as a consequence, FeO wt.% in anorthitic PL may differ from the original composition.

According to these observations, further supported by iron rich PLs found in other lunar areas, PL compositions with more than 0.1 wt.% FeO were considered in the present work.

To reproduce a plausible PL-mafic mineral assemblage, we consider that on the Moon, areas rich in PL are associated to the presence of mafic minerals, e.g. OPX, CPX and OL. Moreover lunar samples have a mineralogical variability which includes also the norite and gabbronorite with amount of OL (see Lucey et al., 2006, and references therein).

On the other hand, the analysis of MESSENGER spectra (Izenberg et al., 2008; McClintock et al., 2008) indicated the possible presence of PL, high-calcium iron-poor pyroxenes, low-iron OPXs, like enstatite, and low-iron OLs such as forsterite, a mineral assemblage that was assumed as a possible explanation for the featureless spectra on Mercury.

Based on these considerations, for our mixtures we selected mafic minerals with low iron content which can be genetically related with the iron amount content of the plagioclase here considered.

3. Sample preparation and analytical methods

3.1. End-member preparation and characteristics

Separate end-member minerals were obtained from samples of two layered intrusions (Bjerkreim Sokndal and Stillwater Complex). The chemistry of the rock forming minerals was determined by electron microprobe analyses with a CAMECA SX50 (EMP) at the microprobe laboratory of C.N.R.-IGG (Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse), Padova, to define the most useful compositions.

The selected rock samples (see Table 1) were first crushed to a coarse particle-size class <2.00 mm, in order to preserve the original rock composition in powdered samples. The powders were then quartered and each fraction was ground to smaller particle-size classes. In particular, we have considered two particle-sizes, <250 μm and <125 μm. Each powder particle-size class was then quartered again and half material was then sieved into two size ranges: 125–250 μm and 63–125 μm. These particle sizes have been chosen in order to avoid problems arising when dealing with both very fine particles (e.g. coating processes) and coarse ones (e.g. band saturation effects).

From these particulate samples, three PLs with different iron content and three different mafic compositions with increasing OL amounts were separated, using a Frantz Isodynamic Magnetic Separator at the Department of Physics and Earth Sciences, University of Parma. In Table 2, the applied amperage, removed minerals and new samples obtained during magnetic separation are shown.

The selected PL phases include: an iron-poor PL (PL1: An_{45}, with 0.1 wt.% FeO), a medium-iron (PL2) and an iron-rich (PL3) PL (both An_{80}, with 0.36 and 0.5 wt.% FeO, respectively). The choice to include the PL1, with a different An content with respect to the other two PL compositions, arises from the absolute scarcity of An_{80} PLs with 0.1 wt.% FeO content in our rock samples. Also, the crystal field absorption band is controlled by Fe^{2+} transitions in the mineral crystal structure replacing other cations (Burns, 1993), and