THE LUNAR ROCK AND MINERAL CHARACTERIZATION CONSORTIUM (LRMCC): INTEGRATED ANALYSES AND MINERAL ENDMEMBERS FROM MARE BASALTS.
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Introduction: The current era of lunar exploration is rich, with a number of spacecraft in operation or soon to be launched. These international missions carry a range of sophisticated instruments that will map the lunar surface and environment in unprecedented detail. From this suite of instruments, the highest-resolution compositional data will be provided by optical instruments sensitive to surface mineralogy. These high spectral and spatial resolution optical instruments will provide the data needed for detailed characterization of the Moon's global mineralogy, which is a key to understanding the Moon's geologic evolution. These instruments rely on the unique absorption properties of lunar materials, which reflect solar radiation in characteristic ways depending on their mineralogy [1-5]. Optical instruments are not sensitive to elemental abundances, though these spacecraft carry other instruments that will acquire these critical data.

Interpretation of remotely acquired reflectance spectra relies in large part on high quality laboratory measurements of samples, either analogues or real ground truth (lunar samples) [6-10]. Synthetic mixtures of endmember minerals do not capture important subtleties found in real lunar samples, which can have profound implications for interpretation of the spectra. Additionally, terrestrial minerals differ in important ways from their lunar analogues. For these principal reasons, measurement of lunar samples is essential for remote exploration of lunar mineralogy. The Lunar Soil Characterization Consortium (LSCC) conducted coordinated analyses of a suite of lunar soils and addressed the space weathering process in bulk lunar soils, but did not analyze unweathered lunar materials [11]. The Lunar Rock and Mineral Characterization Consortium (LRMCC) has conducted similar coordinated mineralogy, petrology, and spectroscopy analyses of this unweathered component in the form of four lunar rock samples [12, 13]. The resulting dataset provides ideal ground truth and constraints for models of spectral mixing and space weathering.

Sample Preparation and Analysis: The LRMCC was allocated four lunar basalt slabs and paired thin sections. Two low-Ti (15058, 15555) and two high-Ti (70017, 70035) samples were allocated to the LRMCC. Mineral composition and modes were determined from the thin sections by electron microprobe (EMP) analysis using *Oxford FeatureScan* software using the procedure of [14]. Portions of the slabs were crushed and used to prepare separates of major mineral phases and the bulk samples. The compositional ranges of the mineral separates were determined by EMP analysis of grain mounts prepared from subsets of the separates [13]. Two pyroxene separates were prepared visually from each slab based primarily on color. Pyroxenes separated from a basalt are often similar in color, so compositionally distinct separates are very challenging to obtain. Thus, the pyroxene separates prepared by the LRMCC overlap somewhat compositionally. Prior to spectroscopy measurements in the RELAB at Brown University, the mineral separates and bulk samples were crushed and sieved to <125 μm and <45 μm grain sizes. The <125 μm splits are generally dominated by the clean large particles, though they have a non-negligible component of fine particles. Reflectance spectroscopy measurements were made in bidirectional reflectance (BDR) from 280 – 2600 nm, and in biconical reflectance by FT-IR to 50 μm. Measurements of the <125 μm splits are complete; measurements of the <45 μm splits are ongoing.

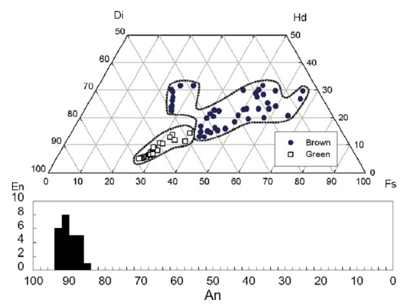

Fig. 1: Compositional data for mineral separates from 15058. Olivine is a trace phase in 15058, so a separate was not obtained for this sample.

Table 1: Modal Abundance Data for LRMCC Samples

	15058	15555	70017	70035
OLIV	0.1	11.8	1.5	1.2
OPX	3.7	0.3	--	--
PIG	25.6	32.4	17.7	20.2
AUG	16.7	18.6	34.2	27.7
Fe-PX	17.1	5.4	0.6	1.1
PLAG	30.1	27.3	25.7	30.1
TRID	3.5	0.8	1.6	0.9
ILM	1.4	1.3	17.3	17.4
CHRM	<0.1	0.4	--	--
USP	0.9	1.0	0.3	0.3
Tr-Met	0.2	0.2	0.3	0.4
K-GLS	0.5	0.4	0.6	0.6

Abbreviations for minor phases are chromite (CHRM), Ulvöspinel (USP), Troilite/Metal (Tr-Met), and K-rich glass (K-GLS).

Results: A subset of the results obtained by the LRMCC is presented here; full results will be presented at the conference.

Mineralogy/Petrology. We present compositional data for the major mineral separates prepared from one of the basalt samples (15058) in Fig. 1. Major minerals separated include two types of pyroxene and plagioclase. We present modal mineralogy for all four samples in Table 1. Additional petrology results have been presented previously [13].

Reflectance Spectroscopy. Bidirectional reflectance measurements for the four samples (bulk samples & mineral separates) at <125 μm grain size are presented in Fig. 2. Bulk sample spectra show spectral diversity consistent with their varying mineralogy. Pyroxene is the dominant phase, and all bulk sample spectra are largely dominated by pyroxene absorptions [2-4]. They show evidence for multiple pyroxene absorptions at 1 and 2 μm. The 15555 bulk sample, which contains the highest modal olivine, shows evidence for olivine near 1200 nm in its spectrum [1]. The high-Ti bulk samples show a significant contribution from ilmenite. This effect is explored in more detail in a companion abstract by Hiroi et al. [15]. Individual mineral spectra also show important absorption behavior. Ilmenites are opaque across most wavelengths, but show a number of interesting features, which are broadly consistent with analyses of synthetic ilmenite samples [16]. Plagioclase samples are Fe-rich (~0.3-0.5 wt.%), and their spectra have relatively strong absorption features and sharp downturns into the UV. Pyroxene spectra show the classic 1 and 2 μm absorption features, and in some cases show evidence for multiple absorption features caused by multiple pyroxene compositions [2-4, 17]. Many of the pyroxene separates are strongly zoned, so the presence of multiple absorption features is not surprising. The 15058 pigeonite spectrum is brighter and has stronger bands than other pyroxenes, likely due to minor differences in grain size. The most Ti-rich pyroxenes show broad features across visible wavelengths, which we attribute to inclusions of microcrystalline ilmenite.

Applications: As mentioned in the introduction, the coordinated analyses of mineralogy/petrology and spectroscopy of bulk samples and prepared mineral separates are ideal tests for spectral mixing models, which typically rely on a set of synthetic mineral spectra endmembers not representative of the actual phases in the sample of interest [e.g. 18-21]. The LRMCC results provide detailed mineral composition and modal abundance data, eliminating many of the degrees of freedom which complicate nonlinear spectral unmixing. Mixture modeling of the LRMCC spectroscopy results is ongoing [15]. In addition to mixture modeling, quantitative analysis of the absorption features observed in

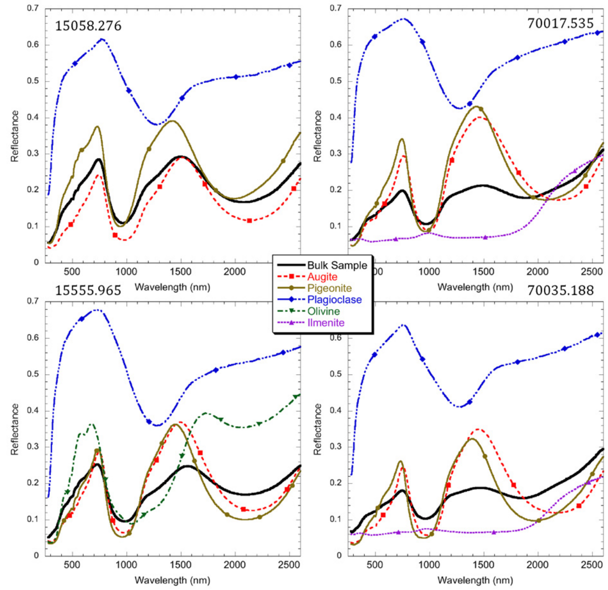

Fig. 2: BDR spectra of LRMCC bulk samples and mineral separates, <125 μm grain size. Bulk samples are dominated by pyroxene absorptions; major absorption features in mineral separates are discussed in the text.

the reflectance spectra is critical to their application as ground truth. Analysis with the Modified Gaussian Model (MGM) [22] is an established method for quantifying absorption features [e.g. 23-25], and MGM analysis of the LRMCC spectroscopy results is planned.

Summary: The LRMCC has conducted coordinated mineralogy/petrology/spectroscopy analyses of four lunar basalt samples, including mineral composition, modal abundance, and high-quality reflectance spectra of bulk samples and prepared mineral separates. These data are critical for nonlinear spectral mixture models, and for remote analysis of the lunar crust with optical spectrometers.

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References: [1] Burns, R.G. (1974) *AM*, **59**, 5. [2] Adams, J.B. (1974) *JGR*, **79**, 4829. [3] Cloutis, E.A. et al. (1986) *JGR*, **91**, 11641. [4] Burns, R.G. (1993) *Mineralogical applications of crystal field theory*. [5] Adams, J.B. and Goullaud, L.H. (1978) *PLPSC*, **9**, 2901. [6] Pieters, C.M. (1978) *PLPSC*, **9**, 2825. [7] Pieters, C.M. (1986) *Rev. Geo. Sp. Phys.*, **24**, 557. [8] Lucey, P.G. et al. (2000) *JGR*, **105**, 20297. [9] Gillis, J.J. et al. (2003) *JGR*, **108b**, 3-1. [10] Lucey, P.G. et al., in *New Views of the Moon*, 83. [11] Taylor, L.A. et al. (2001) *JGR*, **106**, 27985. [12] Pieters, C.M. et al. (2008) *LPSC*, **39**, 1900. [13] Sarbadhikari, A.B. et al. (2008) *LPSC*, **39**, 1290. [14] Taylor, L.A. et al. (1996) *Icarus*, **124**, 500. [15] Hiroi, T. et al. (2009) *LPSC*, **40**, 1723. [16] Riner, M.A. et al. (2008) *GRL*, In Press. [17] Klima, R.L. and Pieters, C.M. (2008) *LPSC*, **39**, 1756. [18] Mustard, J.F. and Pieters, C.M. (1987) *JGR*, **92**, 617. [19] Clark, B.E. (1995) *JGR*, **100**, 14443. [20] Hiroi, T. and Pieters, C.M. (1992) *LPSC*, **22**, 313. [21] Poulet, F. and Erard, S. (2004) *JGR*, **109**, E02009. [22] Sunshine, J.M. et al. (1990) *JGR*, **95**, 6955. [23] Sunshine, J.M. and Pieters, C.M. (1993) *JGR*, **98**, 9075. [24] Klima, R.L. et al. (2007) *MAPS*, **42**, 235. [25] Klima, R.L. et al. (2008) *MAPS*, **43**, 1591.