INVENTORY OF FeO AND TiO_2 COMPOSITIONS FOR MARE DEPOSITS ON THE FAR SIDE OF THE MOON.

Jeffrey J. Gillis[1] and Paul D. Spudis[2], 1. Dept. of Geology and Geophysics, 6100 S. Main Street, MS-126, Rice University, Houston, TX, 77005. Gillis@lpiip2.jsc.nasa.gov 2. Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, 77058.

Introduction: Luna 3 forever changed our global perception of the Moon, when it sent back the first images of the lunar far side, Oct. 1959. The difference in the surface distribution of mare basalt between the Earth facing and far side of the Moon was immediately obvious. The dichotomy is probably caused by an asymmetrical crustal thickness between the two hemispheres of the Moon [1]. Ascending mantle melts are more easily prevented from erupting onto the surface by the thicker crust on the lunar far side. Lavas that erupt on the Earth facing side, would be well within the crust on the lunar far side [2]. Studies of how crustal thickness influence eruptive conditions have been conducted [3]. Previous to the Clementine mission [4], the same could not be done with respect to composition. Reflection spectroscopy studies using Earth-based telescopic observations were conducted for basalts covering most of the near side of the Moon [5, 6]. These studies have revealed that basalt composition varies over local and regional scales. Basalts in the eastern hemi-sphere are higher in Ti and Fe relative to those in the western hemisphere [6]. It also has been noted that two-thirds of the basalt spectral types are not represented in the return sample collection [6]. Spectral analysis of far side basalts could reveal compositions that are different than those found on the near side of the Moon and in the present sample collection.

The inaccessibility of the far side of the Moon to Earth-based analysis has impeded chemical and mineralogical information for the far side basalts. Apollo X-ray and γ-ray chemical analysis data covered only a fraction of the far side basalts and have very poor spatial resolution [7]. Galileo spectral data covered the western far side basalts, at moderate resolution [8]. Using the global Clementine multispectral data, we have calculated the chemical composition (FeO and TiO_2) for all mare basalts on the far side of the Moon. Our inventory of basalt compositions was created using data from the 415, 750 and 950 nm bandpasses from Clementine and newly developed spectroscopic methods [9, 10, 11] to ex-tract quantitative abundances of iron and titanium for the Moon. Images were processed using software developed by the USGS, Flagstaff, Arizona (ISIS) [12]. Final image mosaics are in sinusoidal projection and processed with a resolution of 250m per pixel.

Petrologic models, that describe the evolution of primary and secondary crust of the Moon [13], hinge on the Moon's bulk composition. As samples of the mantle, basalts allow us to determine the composition of the interior of the Moon. Although the far side mare deposits are volumetrically minor, even in relation to the near side maria, analyzing their chemistry will allow us to gain a better understanding of the bulk composition of the Moon. Some studies suggest that a thicker crusts would produce flows higher in titanium [14]. Other studies have searched for correlations between the mare deposit geologic position and composition [15]. A thicker crust requires the source of melting to be deeper [16] and therefore bring about changes in melt composition. To test whether lunar basalts have evolved with time, we have observed the timing relationships and chemistry for basalt deposits. Finally, we aim to determine the distribution of pyroclastic deposits of the lunar far side.

Analysis & Discussion: Table 1 shows a selected subset of FeO and TiO_2 compositions for basaltic soils on the lunar far side. Mare basalts on the far side of the Moon vary in composition from very-low to moderate titanium abundance and from moderate to high-iron content. Comparison of basalt composition with crustal thickness and elevation yield no apparent correlations. One noticeable apparent correlation is that older basalts tend to have lower FeO and TiO_2 contents. This is not the result of melt source evolution or differentiation, but is produced by vertical and horizontal impact mixing [17] of low-iron highlands material with higher iron and titanium basaltic material. For instance, two areas within Mare Australe, East of Chamberlin and surrounding Jenner (table 1), are very low in FeO. Both units are among the oldest in the basin. Constant churning of the lunar surface by micrometeorite impacts has mixed the highlands and mare lithologies to a greater extent than nearby, younger deposits.

Similar asymmetrical distribution of FeO and Al_2O_3 is noticed in the highlands surrounding the Smythii basin. The terra material west of Smythii is higher in iron and Mg, and lower Al_2O_3 relative to highlands east of the basin. Previous studies [18] have concluded that material more mafic that average highlands crust was ejected from the Crisium impact and deposited over the western region of Smythii. Using the Clementine data, we interpret the higher iron content of the western highlands the manifestation of numerous basalt ponds that have physically mixed with highlands material. The evidence to support this supposition is in the Clementine iron distribution map. The basalt deposit have a high iron center, 10-16 wt. % FeO, with an annulus of lower FeO, 6-10 wt. %, surrounding them. Similar basalt deposit are noticeably lacking in highlands east of Smythii basin.

Mare Moscoviense displays the largest variation in titanium within an enclosed deposit on the lunar far side [19]. The deposit ranges from a low titanium 1.5 - 2.5 wt. % TiO_2 to moderately high titanium content, 4 - 5.5 wt. % TiO_2. Other deposits that show multi-compositional flows are in the craters Tsiolkovsky, Oris, and Oken (later 2 within Mare Australe). This demonstrates that although these deposits are small, they have been filled by more than one flooding event. Assumptions that areally small deposits like these are filled by only single eruptive event would yield to over estimates of eruption volumes. While Lyot (50°S, 85°E), which is known to contain two different age units [20], maintains a comparable composition for both units.

Conclusions: The range in FeO and TiO_2 composition of the lunar far side basalts is similar to those found on the near side with the exception of the very high-titanium basalts in Mare Tranquillitatis. Small basalt deposits (e.g. Tsiolkovsky, Oris and Oken) are filled by two or more flows of differing composition. The tendency for mare deposits on the far side to be thinner and less extensive has contributed to their higher contamination by underlying and adjacent highlands material. There is a paucity of regional pyroclastic deposits on the far side of the Moon. Localized volcanic glass deposits do exists in Mare Smythii, Moscoviense [21], Apollo [22], Oppenheimer [22] and Orientale [23]. Each deposit is identified by it's very red spectra relative to surrounding deposits and therefore suggest that they are made up of a very high glass content. Their association with nearby basaltic material also suggest that these glassy deposits are volcanic in origin.

References: [1] Kaula W. M. et al. (1972) PLSC 3rd, 3049. [2] Head J. W. (1992) Geochem. et Cosmochem. Acta, **56**, 2155. [3] Yingst A. R. & J. W. Head (1997) JGR, **102**, 10909. [4] Nozette S. et al. (1994) *Science*, **266**, 1835-1839. [5] McCord, T. B. (1969) JGR, **74**, 4395. [6] Pieters C. & T. B. McCord (1978) PLSC 7th, 2677. [7] Davis, P.A. (1980) JGR, 85, 3209. [8] http://wwwflag.wr.usgs.gov/cgi-bin/isis.cgi [9] Greeley R. et al. (1993) JGR, **98**, 17183. [10] Lucey, P. L. et al. (1995) *Science*, **268**, 1150. [11] Lucey, P. L. et al. (1996) LPSC XXVII, 781. [12] Blewett et al. (1997) JGR, **102**, 16319. [13] Taylor, S. R. & P. Jâkes (1974) PLC 5th, 1287. [14] Schonfeld, E. (1979) Conference on Luna 24, 164. [15] Lucchitta, B. K. & J. M. Boyce (1979) PLPSC 10th, 2957. [16] Solomon S. C. (1975) PLSC 6th, 1021. [17] Rhodes, J. M. (1977) Philos. Trans. R. Soc. London, **A285**, 293. [18] Andre C. G. et al. (1977) PLSC 8th, 925. [19] Gillis J. G. & P. D. Spudis (1996) LPSC XXVII, 413. [20] Wilhelms D. E. et al. (1979) Geologic Map of the south side of the Moon, I-1162. [21] Craddock R. A. et al. (1997) LPSC XXVIII, 265. [22] Morrison, D. A. & D. B. J. Bussey (1997) LPSC XXVIII, 987. [23] Bussey, D. B. J. & P. D. Spudis (1997) GRL, **24**, 445.

Mare Deposit	Location	FeO ± <1 Wt. %	TiO2 ± 1 Wt. %
Buys Ballot	21°N, 175°E	8 - 15	0 - 2
Campbell	45°N, 151°E	10 - 14	0.5 - 1.5
Compton	56°N, 105°E	6 - 12	0 - 1
Kohlschütter	15°N, 154°E	10 - 16	1 - 2
Lacus Solitudinis	27°S, 104°E	10 - 16	1.5 - 2.5
Mare Marginis	20°N, 84°E	12 - 16	2.5 - 3.5
Mare Moscoviense	28°N, 148°E	10 - 14	1.5 - 2.5
Mare Moscoviense	27°N, 150°E	12 - 16	4 - 5.5
Mare Orientale	20°S, 95°W	10 - 16	1.5 - 4.5
Lacus Veris	15°S, 86°W	6 - 12	1 - 2.5
Lacus Autumni	10°S, 84°W	6 -12	1 - 3
Mare Smythii	2°S, 87°E	12 - 16	2.5 - 3.5
Tsiolkovsky	20°S, 129°E	12 - 16	0.5 - 3.0
Australe Basin			
East of Chamberlin	59°S, 105°E	8 - 12	0.5 - 1.5
East of Abel	35°S, 92°E	12 - 16	2.5 - 3.5
Jenner	42°S, 96°E	10 - 14	1.5 - 2.5
Surrounding Jenner	42°S, 96°E	8 - 15	1 - 2
Lyot	50°S, 85°E	10 - 14	1 - 2.5
Oris	53°S, 72°E	12 - 16	3 - 4
South of Hanno K	55°S, 78°E	10 - 14	1 - 2
South Pole-Aitken Basin			
Aitken	17°S, 173°E	8 - 15	1 - 2
Apollo	36°S, 152°W	12 - >16	3.5 - 4.5
Crétien	46°S, 162°E	12 - 16	1.5 - 2.5
Ingenii/Thomson	34°S, 164°E	12 - 16	0 - 1 ?
Leibnitz	38°S, 179°E	12 - > 16	0.5 - 1.5
North of Bose	52°S, 167°W	14 - >16	3 - 4
Poincaré	58°S, 162°E	12 - 16	0.5 - 2
Van de Graaff	27°N, 173°E	10 - 14	0 - 1.5
Von Kármán	46°S,175°E	12 - 16	1.5 - 2.5
West of White	47°S, 175°W	12 - 16	1 - 2

Table 1. An inventory of chemical compositions (FeO and TiO_2) for a selected subset of mare deposits on the far side of the Moon. The range in chemistry reflects the variability of that deposit not the uncertainty. Quantitative abundance of FeO and TiO_2 were calculated using the Clementine 415, 750, and 950 nm bandpasses and equations developed by [11, 12 ,13]. These analysis are for the surface regolith layer, therefore the abundance of both chemical components is lower than chemical analysis of a rock sample.