

SOME ISSUES RELATED TO LUNAR FeO AND TiO₂ MULTISPECTRAL MAPPING. P. G. Lucey and D. T. Blewett - Planetary Geosciences, HIGP, Univ. of Hawaii, 2525 Correa Rd., Honolulu, HI 96822, lucey@kahana.pg.d.hawaii.edu.

Introduction. This abstract addresses some of the uncertainties and questions associated with recently developed algorithms [1-3] for the multispectral determination of the FeO and TiO₂ content of the lunar surface. Among these are the ability of the techniques to separate effects caused by composition from those caused by changes in maturity, the applicability of the methods to soils rich in impact-melt glass, the effect of opaque phases, changes in the mode of occurrence of ferrous iron, the success of extrapolating FeO to values lower and higher than that at the sample-return sites, the uncertainty introduced by topography, and comparison of Clementine FeO and TiO₂ maps with those derived from Apollo γ -ray spectrometer data. These topics are all addressed at greater length in [3].

Maturity. The key problem in deriving a measure of iron content from spectral measurements in the extended visible wavelength range is distinguishing between the effects of changing Fe²⁺ abundance in minerals and glasses from effects related to maturity differences [e.g., 4]. The method developed by Lucey and coworkers achieves this separation by identifying trends on a plot of 950/750 nm ratio vs. the 750 nm reflectance for lunar samples [1] or remote measurements of the sample-return sites [5]. Because most of the lunar surface is mature, algorithms for compositional mapping would be extremely useful even in the absence of a means to compensate for maturity differences. However, the utility of maturity-insensitive algorithms would be all the greater.

The success of the method in suppressing maturity variations can be tested by constructing an FeO image for a young crater. The figure shows albedo and FeO profiles across Linne, a 2-km crater in Mare Serenitatis. The young crater, its ejecta, and the background mare basalts differ greatly in maturity. Here "maturity" encompasses a number of potentially troublesome phenomena: (1) regolith grain size variations, from the blocky near-rim ejecta to fine-grained particles in the rays, (2) differences in the abundance of sub-microscopic metallic Fe grains produced by reduction of Fe²⁺ during micrometeorite bombardment, (3) differences in agglutinate abundance, (4) differences in the abundance of impact glass. The FeO profile is essentially flat from the background mare, through the continuous ejecta, and across the bright walls and crater interior. The scatter of $\sim\pm 1$ wt.% seen along the profile is caused by the noise inherent in the Clementine data, and is within the uncertainty of the technique.

Impact Melt Glass. Another factor which could potentially confound multispectral composition mapping is the abundance of impact glass. Glass-rich

halos are common at large craters, so it is important to determine if this presents a problem. This can perhaps be best evaluated at Tycho crater. Tycho has a well-known dark impact melt halo [6]. A profile across the FeO image constructed for Tycho shows no large anomaly, despite the great differences in visible albedo associated with the crater. This suggests that impact melt glass is not a problem.

Opacques. It might be expected that variations in the abundance of opaque phases might confuse the FeO algorithm. An increase in opacques decreases the albedo, which would be interpreted as an increase in FeO. However, for lunar samples no systematic error in predicted FeO is found as the modal abundance of opacques increases. The reason for this is that on the Moon the chief opaque phase is ilmenite, which is a high-iron mineral. The result is a compensating effect which insures that the predicted bulk soil FeO content is accurate.

Mode of Occurrence of Fe²⁺. The methods [1] and [2] were calibrated using returned samples or remote measurements of the sample-return sites. Thus the application of this calibration to areas far from the sample-return sites requires the assumption that the derived composition is insensitive to mineralogy. For example, the Fe-rich mare-derived soils have mafic assemblages dominated by clinopyroxene, in contrast to orthopyroxene-dominated highland soils. The spectral properties of these two pyroxenes are substantially different. At locations distant from those sampled, there may be soils of quite different mineralogy - as indicated by the diversity of unusual rock types in the sample collection and by analysis of near-IR spectra of numerous locations on the nearside [e.g., 7].

This topic was addressed by [1], who applied the FeO calibration based on lunar samples to laboratory spectra of powdered pure minerals, including feldspars, ortho- and clinopyroxenes, glass, and olivines. The findings were that the error in estimating Fe was $\sim 2\%$ for iron contents < 30 wt.%. The small increase in the error is significant because it indicates that it is variation in Fe²⁺ that is important, with changes in modal mineralogy or mineral chemistry much less so.

Extrapolation of FeO. The landing site calibration curve [5] is linear over the range of FeO found at the sample-return sites (~ 4 -20 wt.% FeO), but how reliable is extrapolation beyond these values? Near-IR reflectance spectrometry has been used to identify a number of areas composed of pure anorthosite, based on the lack of a detectable Fe²⁺ band near 1 μm [e.g., 7, 8]. The upper limit of pyroxene abundance at these locations is ~ 3 wt.%, corresponding

to 1 wt.% FeO. Maps of FeO constructed from Clementine images of some of these features (e.g., Gassedi E and K [9]) indicate that the algorithm has the ability to accurately determine the FeO contents of Fe-poor areas. A comparable test at high FeO cannot be made. The highest FeO values found in our data are ~25 wt.%, in Oceanus Procellarum. This is not inconsistent with some mare basalt glasses (24 wt.%), and suggests that the algorithm is giving reasonable results at high FeO.

Topography. The profile in the figure is roughly perpendicular to the Moon-Sun line. If a profile parallel to the Moon-Sun line was measured, it would exhibit the effects of topography. This is because the FeO algorithm assumes that the surface is flat at and above the image pixel scale (subpixel shading is accounted for in phase and photometric functions). Sun-facing slopes would appear to have a high albedo, and thus produce a low-iron anomaly. Shadows or slopes facing away from the Sun are too dark and so give erroneously high FeO values. We have quantified this topographic error as a function of phase angle (which for Clementine is closely related to latitude). At small phase angles (low latitudes), topography can be largely ignored, but the error becomes significant towards the poles. However, stereo coverage at high latitudes permits the construction of digital elevation models [10], and such models can be used to eliminate the topographic error in FeO. Until models are available, common sense should be applied to determine the validity of compositional interpretations in areas of high slope.

Comparison with Apollo GRS. An important test is to compare the spectrally-determined element maps with independent measurements. The Apollo 15 and 16 service modules each carried a γ -ray spectrometer (GRS) in lunar orbit. The resulting data has been processed into coarse spatial resolution (~100 km/pixel) maps of Fe and Ti abundance [e.g., 11] along the spacecraft groundtracks.

As noted [12], the correlation between the GRS FeO map and the global Clementine FeO map [1] is generally good, but important differences exist, particularly on the farside. The GRS map has excursions of roughly 6 wt.% FeO in several locations on the eastern and western farside that are not present in the Clementine map, and in at least one area (Grimaldi) the GRS map has a low-iron anomaly where the Clementine map indicates high FeO. Also the GRS failed to detect Mare Tranquillitatis in FeO, and values for the other nearside maria are significantly lower than those of the multispectral map. These differences are intriguing, because it is difficult to understand how large amounts of FeO could be hidden in a phase that does not produce an optical signature (albedo or spectral difference). The Lunar Prospector mission will be of great help in this dilemma. If it reports variations like

those seen in the Apollo GRS data, then something interesting and unexpected is going on.

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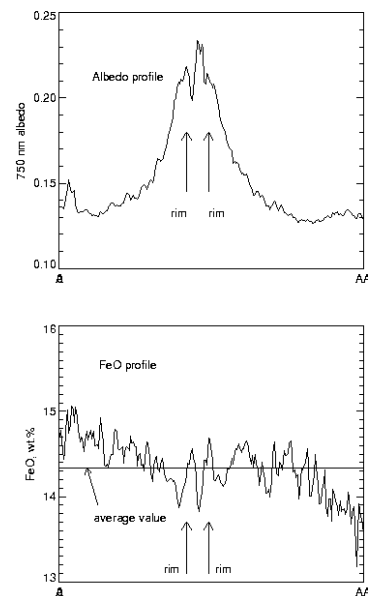


Figure. Albedo (750 nm) and FeO profiles across Linne crater.