

DERIVATION OF FE ABUNDANCE WITH 1-2wt% PRECISION FROM
CLEMENTINE MULTISPECTRAL IMAGING, Paul G. Lucey, G. Jeffrey Taylor, Hawaii
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We have developed a method for derivation of the abundance of the element Fe at high precision (1-2 wt%) from visible wavelength multispectral imaging and applied this method to data obtained recently by the Clementine mission to the Moon. This mission provides 100% coverage of the lunar surface at 100-300 meter resolution(1). Of this coverage we have processed Fe abundance data for 93% of the lunar surface between latitudes of 70degrees S to 70degrees N at 35 km resolution(2).

Iron dominates the reflectance properties of the lunar surface. In its divalent form the presence of Fe is revealed in reflection spectra of minerals and glasses by ultraviolet and near-infrared overlapping absorptions. The strength of these absorptions are proportional to the iron content of a compound and together they dictate the broadband reflectance of the compound and the shape of its absorption spectrum. Increasing Fe decreases the reflectance of minerals and glasses and increases spectral contrast for fine grained powders characteristic of most of the lunar surface. The derivation of mineralogical or elemental abundances from reflectance spectra of powdered materials is complicated by the effects of mineral mixing and grain size differences which also affect band contrast and overall reflectance. The spectral properties of the lunar surface are further strongly effected by the maturation process which alters lunar soil by exposure to the space environment. Lunar materials darken, redden and lose spectral contrast with maturity most likely due to accumulation of reduced iron via a process of reduction of ferrous iron in minerals and glasses aided by the presence of protons implanted by the solar wind. The presence of the extremely fine-grained reduced iron dominates the changes observed in spectra as soils mature. The spectral effects of reduction of Fe-bearing minerals are clearly observed in spectra of lunar samples.

Figure 1 plots reflectance at 750 nm versus 950/750 nm ratio of spectra of soils from Apollos 15 and 16 from the collection of John Adams(3). Apollo 15 soils represented in John Adams spectral collection have two clusters of Fe content, around 9 and 13 wt.%, and Apollo 16 soils have much lower Fe contents of about 4 wt.%. The major variation observed within each cluster is due to differences in maturity of soils in the cluster and to a lesser degree, variation in bulk Fe content. This coupling of the spectral effects of bulk Fe-content and reduced iron has frustrated previous attempts to derive accurate total iron or maturity from multispectral imaging of the Moon or spectra of lunar samples(4). While this figure shows that maturity has a marked effect upon these two spectral parameters, note that the initial iron content of the materials has an orthogonal effect, with low iron soils showing high reflectance and high ratio values and high iron soils having low reflectance and low ratio values. Note also that while each trend tends to point in the direction of low reflectance and high ratio values, the trends have distinctly different slopes, and indeed seem to intersect at a low reflectance, high ratio value. This intersection is consistent with mixing trends of immature starting material with a hypothetical, pure reduced iron component which is dark and spectrally red. We used these systematics to construct an algorithm, depicted in Figure 1, to decouple the effect of maturity and total Fe. The position of the origin depicted in Figure 1 was optimized to maximize the correlation between the parameter theta as defined in the figure, and bulk Fe content.

The result of this process is shown in Figure 2. The correlation between theta and Fe content of 40 Apollo soils from all landing sites is .969, with a 1 sigma scatter of .95 wt. %. In order to test the robustness of this correlation, we predicted Fe contents based on the lunar soil correlation for 25 pure minerals and one glass, all sieved to less than 75 micron grain size ranging in Fe content from 0.3 to 30 wt. % (5,6,7). The accuracy of the determination of Fe from spectra of these materials is shown in Figure 3, where 1sigma error in predicted iron is 2.16% up to for iron contents up to 20wt% Fe. Above 20wt% iron band saturation eliminates the correlation.

To further test this method for derivation of Fe from spectral data, we calibrated a global mosaic of data obtained from Clementine with 35 kilometer spatial resolution, corrected for phase

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To further test this method for derivation of Fe from spectral data, we calibrated a global mosaic of data obtained from Clementine with 35 kilometer spatial resolution, corrected for phase effects and photometric geometry(2) to the reflectance of soil 62231 obtained from Apollo 16 according to the methods of McCord et al. (8). We applied the algorithm for prediction of iron described above to this data set. We then extracted the predicted iron for the Apollo and Luna landing sites which occurred in relatively uniform areas. The result is plotted in Figure 4. The correlation of measured landing site Fe(9) and predicted Fe is excellent, with somewhat greater systematic error for the mare sites. Fe in these areas seem to be under predicted. This under-prediction could be due to stray light in the Clementine cameras, mixing of highland material into these sites, or a reflection of the effect seen in Figure 4 as mare soils contain some pyroxenes with Fe contents greater than 20 wt. %. The overall agreement is good and the agreement with the highlands sites especially is excellent. Based on these experiments we believe that the calibration to Fe from the spectra based upon this new algorithm is accurate to 1-2%, with a likely relative accuracy somewhat higher (.5-1%). With these data we can address fundamental questions in lunar science. References; 1) Nozette et al, Science, in press; 2) Lucey et al, Science, in press; 3) Adams, J.B. and T.B. McCord, Proc. Lunar Sci. Conf. 4th, Geochimica Cosmochim. Acta Suppl. 4, 163-177, 1973; 4) Fischer, E.M. and C. M. Pieters, Icarus 111, 475-488, 1994; 5) Cloutis E.A. and M.J. Gaffey, J. Geophys. Res.. 96, 22809-22826, 1991; 6) King, T.V.V. and W.I. Ridley, J. Geophys. Res.92 B11, 11,457-11,469,1987; 7) Allen C.C., R.V. Morris, H.V. Lauer Jr., and D.S. McKay, Icarus 104, 291-300, 1993; 8) McCord, T.B., R.N. Clark, B.R. Hawke, C.M. Pieters, L.A. McFadden, PD. Owensby, C.M. Pieters, and J.B. Adams, J. Geophys. Res.. 86, 10883-10892, 1981; 9) Lunar Sourcebook (G.H. Heiken et al., eds.), (1991).

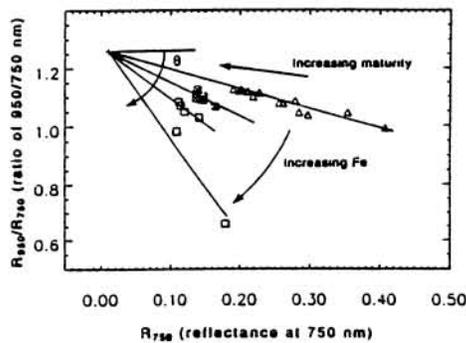


Figure 1. Triangles are Apollo 16 soils; crossed boxes are low iron Apollo 15 soils, unfilled boxes are high iron Apollo 15 soils.

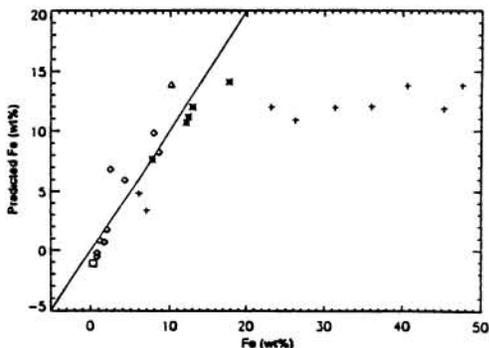


Figure 3. Predicted vs. measured Fe for pure minerals. The box is a plagioclase from Allen et al., diamonds are orthopyroxenes; asterisks are clinopyroxenes; the triangle is a glass; crosses are olivines. All samples are sieved to <75 μ m. Data from (5,6,7).

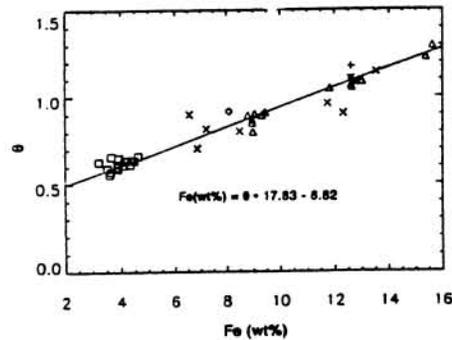


Figure 2. Correlation of spectral parameter θ with total Fe for 40 lunar soils. Boxes are Apollo 16 soils, cross is an Apollo 11 soil, triangles are Apollo 15, crosses are Apollo 17, asterisks are Apollo 12 and the diamond is Apollo 14.

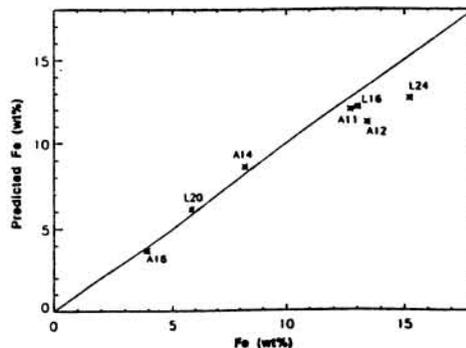


Figure 4. Correlation of predicted and measured Fe for Apollo and Luna Landing sites(13). Diagonal line is perfect correlation.