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Determination of Lunar Ilmenite Abundance from Remotely Sensed Data

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Abstract

Of fundamental importance in the utilization of indigenous resources for a future permanently manned lunar base is the identification and mapping of the abundance distribution of the mineral ilmenite, which is currently considered the most readily identifiable and most easily accessible source of oxygen needed for human consumables and spacecraft propellant. Solid state detector array technology now permits the use of groundbased multispectral remote sensing techniques to produce maps with better than one kilometer spatial resolution and uncertainties of about two weight-percent TiO_2 abundance. We have used an empirical relationship between the weight-percent abundance of titanium dioxide and the 400/560 nm spectral ratio measured in returned lunar samples. Because this abundance correlation is valid only for mature lunar mare regolith, we have also qualitatively mapped the distribution of immature mafic minerals which we have found to be correlated primarily with steep slopes exposing bedrock. The first mapping phase focussed on the entire lunar nearside at 5.3 km per pixel (Johnson et al, 1991a), and on experiments with more sensitive spectral ratios. Relative spectrophotometry was employed to aid in identifying wavelengths that provide greater spectral contrast. We found that the 400/730 nm ratio improved the abundance sensitivity by 37% (Johnson et al, 1991b), while the 950/730 nm ratio improved mafic mineral contrast about 100% (Larson et al, 1991). The second mapping phase utilized a large experimental CCD at 280m per pixel to map the high titanium regions identified in the phase one mapping. The high resolution maps provide data on the small scale (500m) variations in abundance and their relationship to morphological units (Melendrez et al, submitted to *JGR*).

Recent Results

Efforts over the past year have been aimed at defining the peak abundance levels of high TiO_2 deposits on the highest spatial scales achievable from the ground (~500 m), and investigating possible phase function effects on the image ratios used to generate our maps. Photometrically calibrated multispectral imaging data were obtained over four months at the Tumamoc Hill Observatory to obtain a full lunation of phase angles of five areas containing high and low abundance TiO_2 regions, representative highland material, pyroclastic deposits and the standard reference MS-2. A spin-off of this major observing effort was the acquisition of several excellent image sets with essentially pixel-limited (440m) resolution. Although previous data with a 2048 x 2048 pixel CCD on two nights at the Catalina 1.5m telescope had 280m pixels, the atmospheric seeing limited the resolution to 0.5-1.0 km. Our new data provides important new confirmation of the complex small scale morphology of the high TiO_2 bearing deposits in the lunar regolith, and more precise abundance maps because of improved photometric controls. The higher resolution maps show TiO_2 abundances of 14 weight-percent (or more) in regions as large as 20 square km. in Mare Tranquillitatis (see *Figure 1*). The complex spatial distribution of the highest TiO_2 units appear to be a result of specific flow episodes which have overlaid, and later been partly covered by low TiO_2 basalt flows in a complex manner dictated by local topography and vent location.

The lunar phase function had been previously determined for the integrated disc and for some small areas, but in very limited spectral bandpasses. We used our standard 340, 400, 560, 730 and 950 nm filters in this phase function study to quantify effects on various spectral ratios used to define the TiO_2 abundance and soil maturity. Although past mapping efforts were concentrated near full moon (phase angle < 10 degrees), this range contains the major effects of the lunar opposition "surge". With the help of Jim Collins, a student using the complex data reduction process as a class project in Singer's remote sensing class, we measured the brightness of 36 points in the five bandpasses at 13 phase angles. The sampled 1 km square points covered a broad range of TiO_2 abundances, and we now know that in spite of the appreciable phase angle wavelength dependence, it has minimal effect on the relative abundance values. The greatest phase effect is in the 950nm band which contains the major absorption band of crystalline pyroxene and is used as a qualitative indicator of agglutinate content. The results of this work, which is currently being prepared for publication, are highly applicable to the design of orbital and surface optical remote sensing experiments.

Future Work

We anticipate expanding this work into near-infrared wavelengths (0.7-2.6 +m) to facilitate mapping abundances of Fe, Ca and Mg in the lunar regolith. We are also interested in better characterizing optical effects of the pyroclastic deposits which do not follow the empirical TiO_2 calibration we use, but may still contain very high amounts of ilmenite. This work will require the use of a new near-IR CCD array sensitive to the 0.7 - 2.6 micron region. As before, telescopic data will be obtained at kilometer resolution to determine the surface abundance distribution. Deriving abundances of other potential resources will require supporting laboratory spectral measurement of returned lunar samples and terrestrial laboratory analogs to provide calibration of appropriate spectral bands. We anticipate establishing a spectrogoniometer facility to provide the optical characterization and calibration needed for quantitative remote sensing in this mineralogically diagnostic spectral region.

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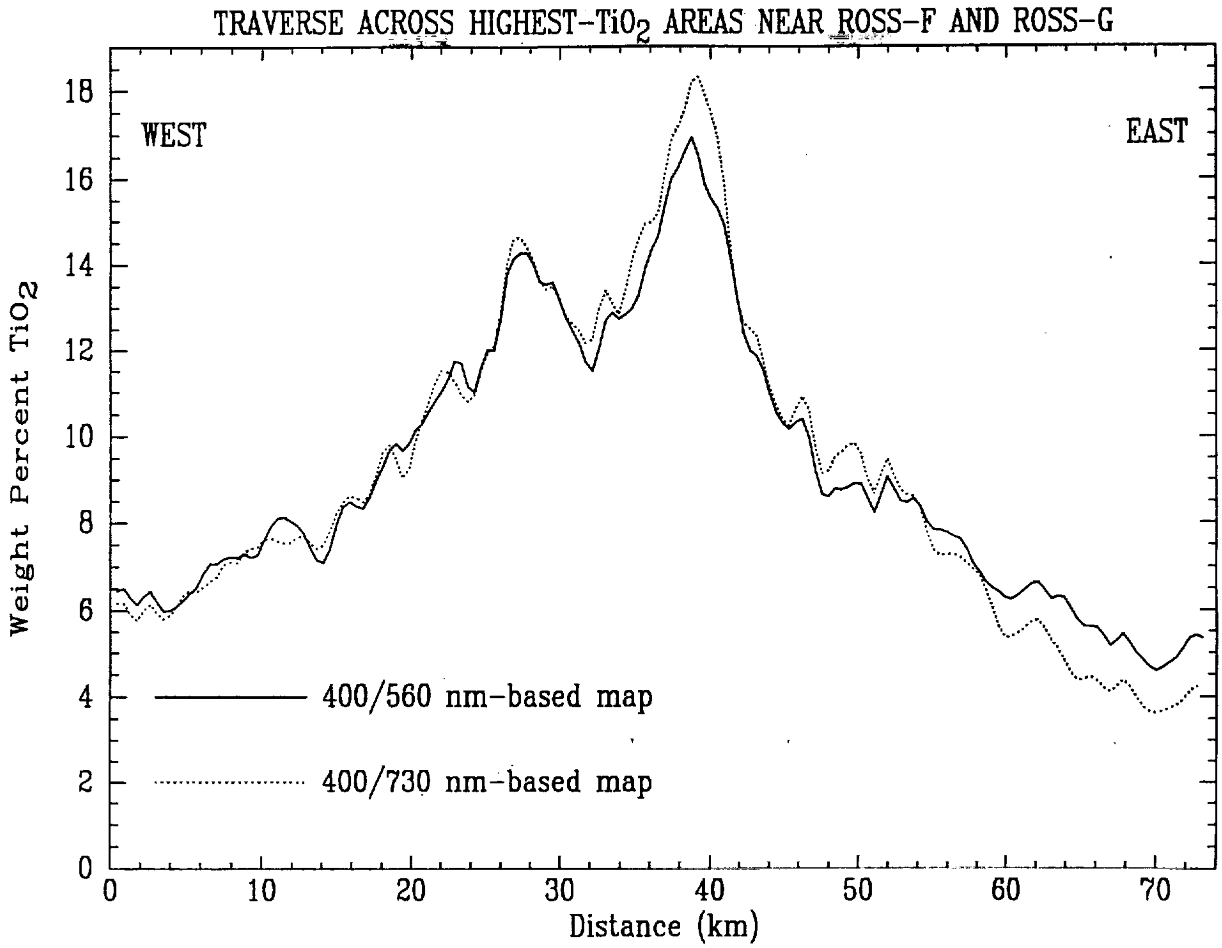
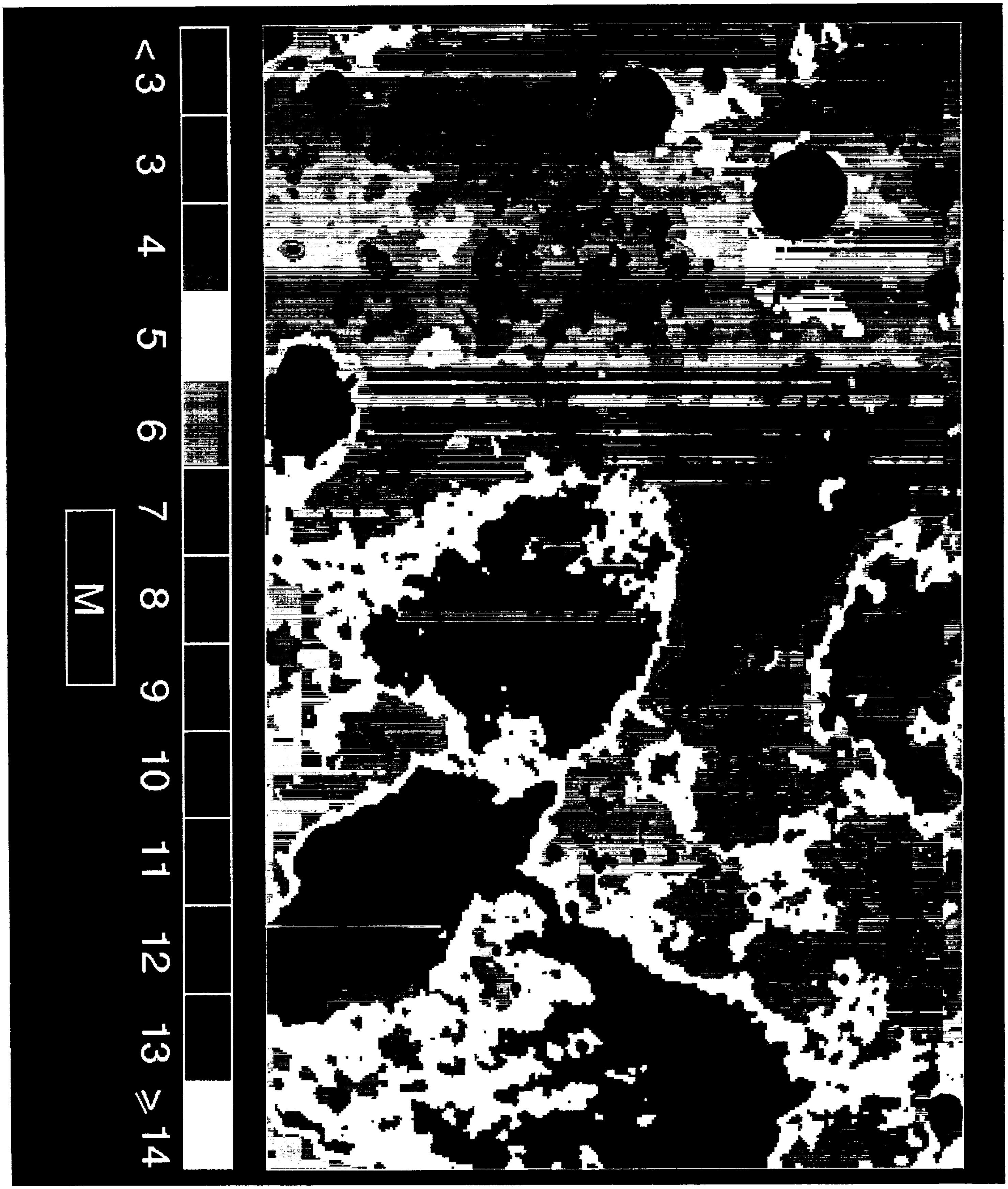


Fig.1 Traces of the weight-percent of TiO_2 across the high abundance region in central Mare Tranquillitatis showing the generally good correspondence between the traditionally calibrated 400/560 nm ratio, and the 400/730 nm ratio. At a scale of 440 meters per pixel, this trace shows the localized nature of the high TiO_2 bearing regolith.

Fig.2 (next page) High resolution TiO_2 abundance map for central mare Tranquillitatis. The frame height is about 140 km. Areas not applicable to the TiO_2 calibration have been blacked out.



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