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DETERMINATION OF LUNAR ILMENITE ABUNDANCES FROM REMOTELY SENSED DATA

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The mineral ilmenite ($FeTiO_3$) was found in abundance in lunar mare soils returned during the Apollo project. Lunar ilmenite often contains greater than 50 weight-percent titanium dioxide (TiO_2), and is a primary potential resource for oxygen and other raw materials to supply future lunar bases. Chemical and spectroscopic analysis of the returned lunar soils produced an emperical function that relates the spectral reflectance ratio at 400 and 560 nm to the weight percent abundance of TiO_2 (Charette et al., 1974). This allowed mapping of the lunar TiO_2 distribution using telescopic vidicon multispectral imaging from the ground (Johnson et al., 1977). However, the time variant photometric response of the vidicon detectors produced abundance uncertainties of at least 2-5%. Since that time, solid-state charge-coupled device (CCD) detector technology capable of much improved photometric response has become available.

We have been carrying out an investigation of the lunar TiO_2 distribution utilizing groundbased telescopic CCD multispectral imagery and spectroscopy. The work has been approached in phases to develop optimum technique based upon initial results. The goal is to achieve the best possible TiO_2 abundance maps from the ground as a precursor to lunar orbiter and robotic sample return missions, and to produce a better idea of the peak abundances of TiO_2 for benefaction studies. These phases and the results thus far are summarized below.

A. Low spatial resolution global survey producing a photometrically homogenous TiO_2 map of the entire lunar near-side using the traditional 400/560 nm ratio. This involved constructing a Newtonan focus on the Tumamoc Hill 0.5 m telescope to produce an appropriate scale on the CCD, and a filter wheel to facilitate rapid cycling between filters. With this arrangement, the visible lunar disc could be covered with a mosaic of 5 CCD fields with 5.3 km pixels on the moon. The resulting map (fig. 1) shows that the highest TiO_2 regions are in Mare Tranquillitatis and Oceanus Procellarum. Where they overlap, most of this map is consistent with the Apollo Gamma Ray Spectrometer data, but with much better spatial resolution.

Maps based on 950/560 nm ratios were also made to define the location of mature mare soil for which the spectral TiO_2 abundance relation is considered valid. In this ratio, fresh craters appear dark because of abundant pyroxene grains which produce strong absorption near 950 nm due to Fe^{2+} crystal field transitions. Micrometeoroid impacts over time increases the agglutinate content and a weakening of the 950 nm pyroxene absorption band. We obtained substantial differences from previous 950/560 nm ratio maps which seem to result from inexact correction of scattered light in the silicon vidicon tubes. The silicon substrate becomes transparent at wavelengths longward of 800 nm, and because of the high index of refraction causes "light piping" within the CCD. This scattering can substantially alter the effective modulation transfer function of the detector preferentially for the longer wavelengths. Previous investigators attempted to correct for this by subtracting a constant "DC level" from the 950 nm image. Studies of the lunar limb profiles and laboratory testing of our CCD shows that the thinned silicon substrate does not exhibit significant scattering. Because of this, we feel that we can better identify regions of various relative soil maturity.

B. Medium resolution (1 nm) 330-870 nm spectrophotometry of high TiO_2 regions to investigate a broader spectral range and identify spectral signatures which might alter the interpretation of the image ratio values. Using the all-reflecting Larson IHW CCD spectrograph on the Tumamoc Hill 0.5 m telescope, we adopted a technique of dividing the spectrum of the region of interest by a spectrum of the standard area "MS-2" taken within 10 - 30 seconds to correct for terrestrial atmospheric extinction, instrumental response, solar Fraunhofer absorption lines and the general red spectral slope of the moon. With relative photometric uncertainties of only 0.1%, the resulting spectra can be readily compared and show may new spectral features, especially in the near-ultraviolet region. Figure 2 shows examples of these ratio spectra. Follow-up spectrophotometry has been made with better spatial resolution on the Catalina 1.5 m telescope of all of the Apollo sites (for "ground truth" checks with returned samples), the high TiO_2 areas and other interesting and relevant locations on the moon.

C. Absolute spectral calibration of the standard area MS-2 with respect to flux calibrated solar analog stars is underway with data obtained with the Catalina 1.5 m telescope to convert the ratio spectra to absolute refectivity for more direct comparison with the laboratory spectra of Apollo samples. The long slit spectra also permitted determination of the spatial extent of the spectrally uniform MS-2 standard area, and what errors are introduced by imprecise pointing of the spectrograph slit aperture.

D. Investigation of laboratory spectra of lunar samples in the Brown University RELAB database to clarify apparent inconsistencies and uncertainties in the emperical abundance relationship. High spatial resolution groundbased spectra of the Apollo landing sites are needed to test the consistency between spectra of returned spectra and groundbased data.

E. As a result of B and D, we have found that the use of 400/730 nm image ratios appear to show the same feature distribution as the 400/560 nm ratios but at higher spectral contrast. The 400/730 nm image ratios may thus yield better TiO_2 abundance accuracy due to 40% greater spectral contrast. .This is being studied in more detail, but it promises to provide greater accuracy, especially in the medium TiO_2 regions.

F. To make the best possible TiO_2 abundance maps from the ground, we have applied an experimental 2048 by 2048 pixel CCD built by Photometrics Ltd. of Tucson. A successful observing run on the Catalina 1.5 m telescope on 1990 Dec. 1-2 yielded good images with 240m pixel size of 7 areas on the moon at .36, .40, .56, .73 and .95 nm. These selected areas include all of the Apollo landing sites, MS-2, and the high TiO_2 regions in Mare Tranquillitatis and Oceanus Procellarum. These very large images (16 Mb) are currently being reduced, and some of them appear to be as good as the best full moon photographic images yet obtained from the ground. The resulting ratio images should provide TiO_2 abundance maps to 500 m resolution and help determine the sharpness of composition boundaries and compositional variations in the Apollo landing sites. An example of the effect of increased resolution is shown in figure 3, where TiO_2 abundance maps with 5.3 and 1.2 km pixels are compared. The smaller sample size shows more localized areas of higher TiO_2 abundance.

Many of these results have been included in a major paper submitted to the Journal of Geophysical Research (Johnson et al., 1991), and have been presented at the 21th Lunar and Planetary Science Conference (Johnson et al., 1990a) and the meeting of the Division of Planetary Sciences of the American Astronomical Society (Johnson et al., 1990b). Subsequent papers are in preparation and planned which will cover all aspects of this research. We believe that this work represents a very useful contribution to understanding the potential resource distribution on the moon as well as developing improved detection techniques that may be applied to future spacecraft experiments.

CITED REFERENCES

Charette, M.P., McCord, T.B., Pieters, C and Adams, J.B. (1974). Application of remote spectral reflectance measurements to lunar geology classification and determination of titanium content of lunar soils. *J. Geophys. Res.*, **79**, 1605.

Johnson, J.R., Larson, S.M., and Singer, R.B. (1990a). Estimates of lunar mare titanium and ilmenite abundances from CCD imaging and spectroscopy. *Abstracts of the LPSC XXI*, 567-568.

Johnson, J.R., Larson, S.M., and Singer, R.B. (1990b).Remote compositional mapping of potential lunar resources. *Bull. Am. Astron. Soc.* , **22**, no. 3,1048.

Johnson, J.R., Larson, S.M., and Singer, R.B. (1991). Remote sensing of potential lunar resources: I. Global compositional mapping. Submitted to J. Geophys. Res.

Johnson, T.V., Saunders, R.S., Matson, D.L. and Mosher, J.A. (1977). A TiO_2 abundance map for the northern maria. Proc. Lunar Sci. Conf. 8th, 1029-1036.

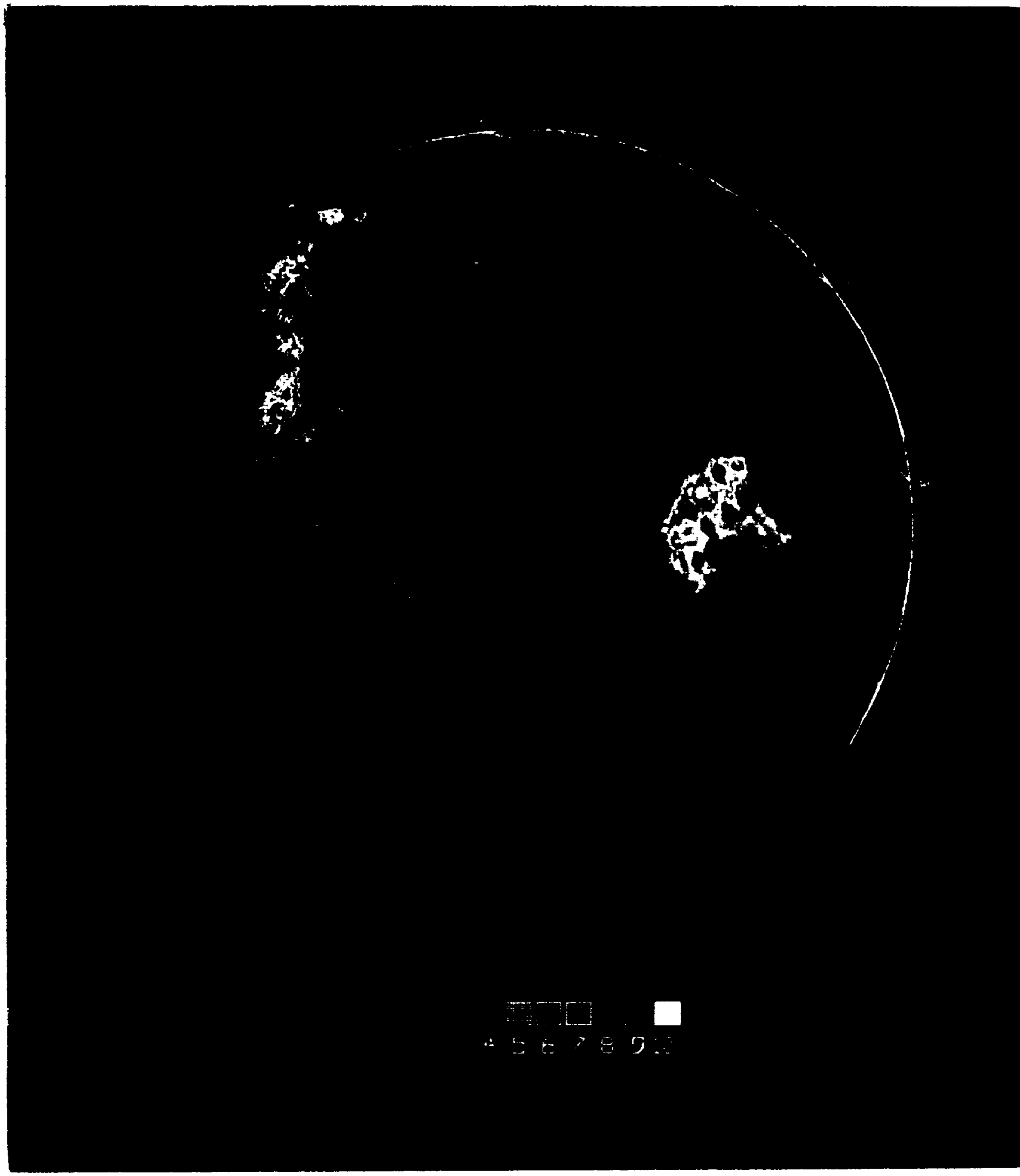
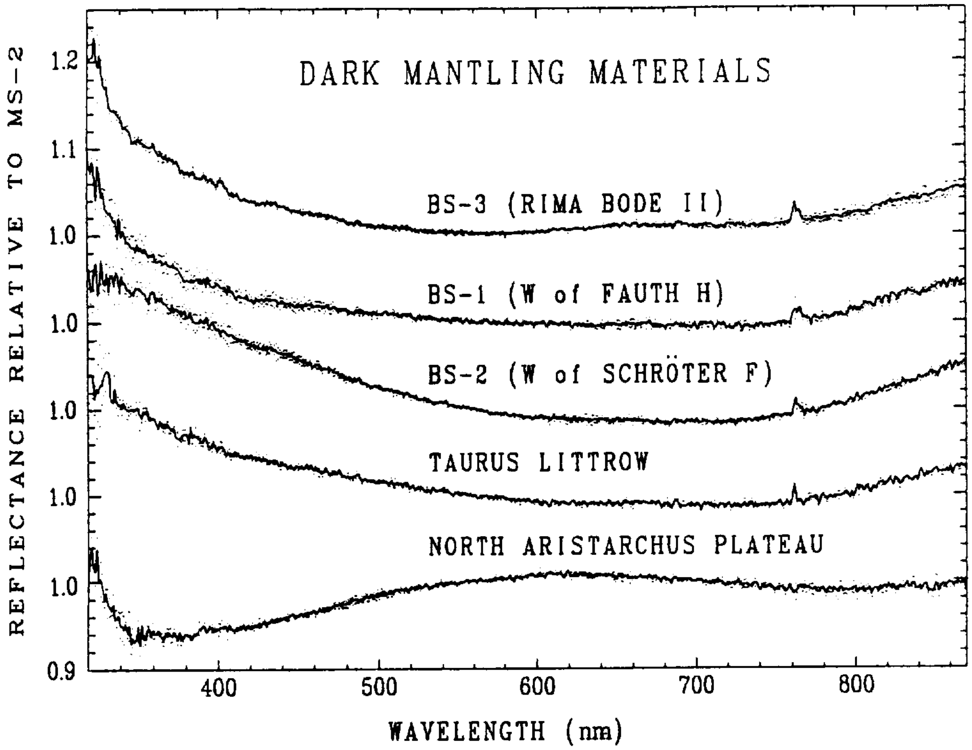


Figure 1. Color encoded TiO_2 abundance map for the near-side lunar maria with units expressed in weight percent TiO_2. The masked areas (unit H) include highland regions and major regions of dark mantle materials where the emperical abundance relation does not apply.



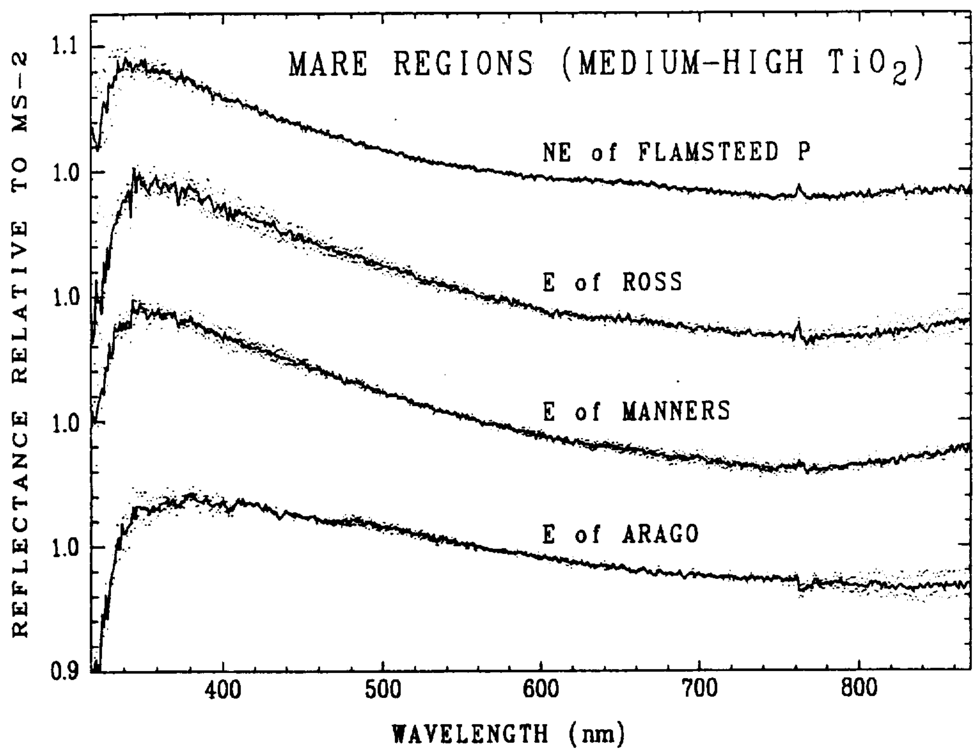


Figure 2. Representative 330-870 nm spectra (all relative to MS-2) of various areas composed of dark mantle materials (top) and maria regions of medium to high TiO_2 (bottom). Dots are 1 standard deviation between samples along the slit at the same wavelength.

Figure 3. Comparative TiO_2 abundance maps with resolutions of 5.3 (top) and 1.2 km per pixel (bottom) of the high TiO_2 region in Mare Tranquillitatis. The general boundaries are consistent, but the smaller pixels may yield locally higher concentrations of TiO_2.