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MEASURING TRACK DENSITIES IN LUNAR GRAINS USING IMAGE ANALYSIS; G.E. Blanford[1], D.S. McKay[2], R.P. Bernhard[3], and C.K. Schulz[1], [1]University of Houston-Clear Lake, Houston, TX 77058, [2]NASA/JSC SN, Houston, TX 77058, [3]Lockheed, 2400 NASA Rd. 1, Houston, TX 77058

We have used digitized scanning electron micrographs and computer image analysis programs to measure track densities in lunar soil grains. Tracks were formed by highly ionizing solar energetic particles and cosmic rays. We used sample 60009, 6049 that was previously studied by Blanford *et al.* (1979) [1]. Back-scattered electron images produced suitable high contrast images for analysis. The images were digitized to 512 x 512 pixels with gray scale 0-255 (8 bit). We ascertained gray-scale thresholds of interest: 0-230 for tracks, 231 for masked regions, and 232-255 for background. We used computer counting and measurement of area to obtain track densities. We found an excellent correlation with manual measurements for track densities below 1×10^8 cm^{-2}. For track densities between 1×10^8 cm^{-2} to 1×10^9 cm^{-2} we found that a regression formula using the percentage area covered by tracks gave good agreement with manual measurements

Measurement of track densities in lunar samples has been a very rewarding technique for measuring exposure ages and soil maturation processes [2]. However measuring track densities is labor intensive because quantitative scientific results require counting tracks and measuring areas on micrographs. The sophistication and ready availability of image processing software can reduce this tedious labor.

To establish analytical conditions we used a polished section from Apollo 16 double drive tube 60009, 6049 at a position estimated to be 546 mm below the lunar surface. This sample had been etched for 15 hours in 1 N NaOH at 118°C. We used an ISI SEM with the polished sample oriented perpendicular to the electron beam. The same condenser lens setting and aperture were used for all images. The microscope is not equipped with a Faraday cup and we could not be sure of reproducing the same beam current for each microscope session. We set a fixed working distance of 8 mm and coarse focused by adjusting the sample height. We calibrated magnification with a stage micrometer and verified that it remained consistent within 1.5%. Back-scattered electron (BSE) images naturally showed a high contrast between tracks and background. We purposely chose to exploit this property and took digital images that appeared to the naked eye to be almost binary. Using the computer we could set the contrast and brightness to numerically reproducible settings.

We produced digital images and analyzed them using an eXL computer manufactured by Oxford Instruments, formerly Link Analytical. Digital images were collected as a Kalman average for 90 sec. We worked at 4 different magnifications, 4600x, 6800x, 10000x, and 15000x. After acquiring the image, we created a mask for the image to obscure parts of the image we did not wish to analyze such as areas off the edge of the grain, large cracks, *etc*. We could "paint" the image using this mask to some useful gray-scale level.

We used a set of procedures referred to as "feature scan" to count tracks. A "feature" is defined in terms of connected areas (pixels) within defined limits of gray-scale. Because we took high contrast images, it was relatively simple to define these limits. By trial and error the limits were set to obtain track counts that were consistent with manual track counts on several standard images. The program counted every connected "feature" within the gray-scale thresholds, but it distinguished some as too big and others as too small. Trial and error were used to set these size criteria.

The "single image phase analysis" subset of routines prepares a histogram of pixel number versus the image gray-scale levels and allows the user to interactively set thresholds that are color coded. The routine displays the area covered by each threshold region in pixels, in square micrometers, and percentage of total area. Using this routine, we could determine the total area of the image, the area of the mask, and the percentage area covered by tracks.

Figure 1 shows a correlation diagram of track density measurements using image analysis with conventional measurements from a photomicrograph. The correlation is excellent for track densities below 1×10^8 cm^{-2}. Furthermore, the correlation is not sensitive to the magnification used within the range tested (but there is better statistical accuracy for lower track density grains when measured at lower magnifications). However, above track densities of 1×10^8 cm^{-2} the image analysis technique shows saturation. It is not hard to understand why this is true because tracks overlap at high densities. The human counter can distinguish overlapping tracks to some extent. The software however lumps many tracks into single "features" on the digital image and the computer under counts. However, the area covered by the tracks should be proportional to the number of tracks. We performed a linear regression between track density versus the percentage area covered by tracks for images taken at 10000x. There was a correlation coefficient r = 0.98. Consequently, we used this regression line to determine track densities from 1×10^8 cm^{-2} to 1×10^9 cm^{-2}. Even this method is likely to fail at higher track densities. Figure 2 shows the 10000x data from Fig. 1 together with corrected points using the regression formula. The rectangles surrounding each point represent one standard deviation statistical uncertainty.

We have shown that we can reliably measure track densities in lunar grains using image analysis techniques. It is difficult to assess exactly how much more time efficient this method will be, but we believe it will be very significant. When conditions had been established, we collected and analyzed 125 images in ~12 hours. Even during these sessions, however, we keystroked the procedures rather than use macros to speed up the process. Automating track counting may allow application of this technique to important problems in regolith dynamics including the ratio of radiation exposure to reworking in various surface and core samples and in regolith breccias.

[1] Blanford G.E. *et al.* (1979) *Proc. Lunar and Planetary Sci. Conf. 10th*, 1333. [2] Heiken G. *et al.* (ed.) (1991) *Lunar Sourcebook: A User's Guide to the Moon.*

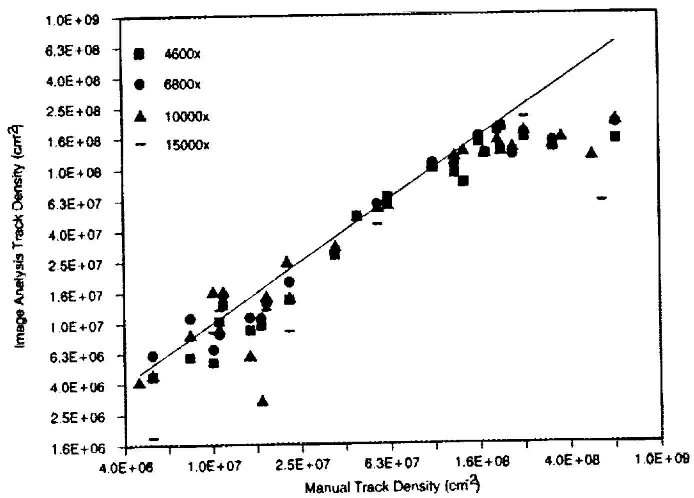

Figure 1. Graph of track densities in lunar soil grains from sample 60009, 6049 at a depth of 546 mm from the lunar surface from images taken at 4600x, 6800x, 10000x, and 15000x. The ordinate has values determined from counts using "feature scan." The abscissa has values determined by manual counting.

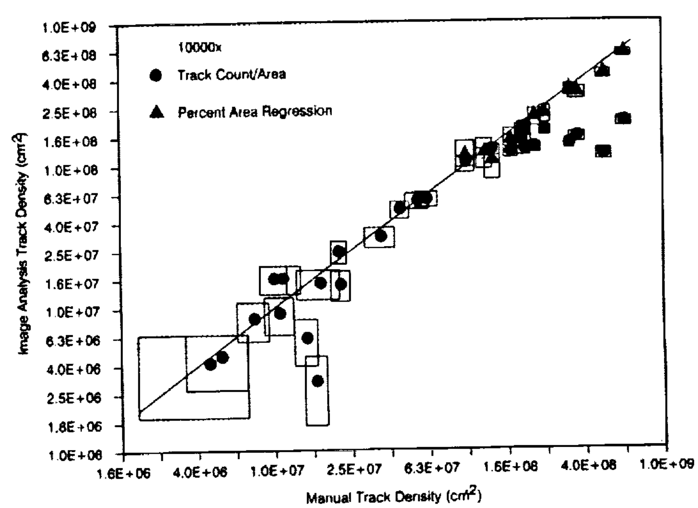

Figure 2: The correlation of manually counted and image analysis determined track densities for data taken at 10000x. Circles represent data obtained using feature scan and triangles represent data using a linear regression formula of the percentage area. Rectangles give one standard deviation uncertainty based on counts or the error in the regression formula.