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Computer Image Analysis of Etched Tracks from Ionizing Radiation

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ABSTRACT

I proposed to continue a cooperative research project with Dr. David S. McKay concerning image analysis of tracks. Last summer we showed that we could measure track densities using the Oxford Instruments eXL computer and software that is attached to an ISI scanning electron microscope (SEM) located in building 31 at JSC. To reduce the dependence on JSC equipment, we proposed to transfer the SEM images to UHCL for analysis. Last summer we have developed techniques to use 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 during near surface exposure on the Moon. The track densities are related to the exposure conditions (depth and time). Distributions of the number of grains as a function of their track densities can reveal the modality of soil maturation. As part of a consortium effort to better understand the maturation of lunar soil and its relation to its infrared reflectance properties, we worked on lunar samples 67701,205 and 61221,134. These samples were etched for a shorter time (6 hours) than last summer's sample and this difference has presented problems for establishing the correct analysis conditions. We used computer counting and measurement of area to obtain preliminary track densities and a track density distribution that we could interpret for sample 67701, 205. This sample is a submature soil consisting of ~85% mature soil mixed with ~15% immature, but not pristine, soil.

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INTRODUCTION

Solar wind, solar energetic particles, galactic cosmic rays, and meteoroid impacts hit regolith grains on the Moon, asteroids, some planets and satellites, and interplanetary dust particles producing measurable forms of "weathering.". Research has shown that these measurable effects correlate in lunar soils (McKay *et al.*, 1991). Nevertheless, the correlations are very crude because the weathering effects on the Moon are usually measured as a bulk average for a given soil. Most weathering measurements are not very useful for making quantitative predictions of exposure age or even giving a relative measure of maturity for the soil. Furthermore, regolith soils mature by at least two distinct processes: by *in situ* weathering and by mixing. Bulk average measurements cannot distinguish the maturation processes. To improve our understanding of space weathering, we should find these correlations on a grain by grain basis. During work on this proposal, we concentrated principally on one form of weathering, the formation of tracks in individual soil grains caused by solar energetic particles and galactic cosmic rays.

Price and Walker (1962) discovered that very ionizing radiation, such as fission fragments and cosmic rays, produces a trail of damage in dielectric materials that can be etched with a reagent to form visible tracks (cf. Fleischer *et al.*, 1975). Their discovery has led to practical applications such as Nuclepore filter paper and cosmic ray dosimeters used by astronauts. Scientific applications include fission track dating of geological samples and, the subject of our research, cosmic ray-solar energetic particle weathering effects on lunar samples. From the beginning quantitative scientific results have followed from counting tracks on micrographs and by micrographically measuring track morphological characteristics. The sophistication and ready availability of image processing software can reduce this tedious labor.

Etching lunar soil grains in a suitable reagent reveals tracks by producing pits at the track locations. We used a scanning electron microscope (SEM) to make digital images of the etched surfaces of polished grain mounts. We are developing procedures to rapidly measure track densities with image processing software. We applied these techniques to determine the track density distribution of a lunar soil sample that is being studied by a consortium of scientists to better understand lunar soil maturation processes.

PROPOSAL ACTIVITIES

In the interim report submitted in January, I stated that Ms. Cynthia K. Schulz had been hired as a graduate assistant, that a spare water bath had been installed in JSC building 31 for sample etching, that lunar samples had been requested, that problems had been found with the *Khoros* software installed at UHCL, and that we had ordered a Macintosh Quadra computer to use the *NIH Image* software. I also attached an abstract

to the interim report which had been submitted for presentation at the 25th Lunar and Planetary Science Conference (Blanford, *et al.*, 1994). The abstract was accepted for poster presentation which took place at the Lunar and Planetary Science Institute on the evening of March 17, 1994.

Two lunar samples, 67701,205 and 61221,134, were received in mid-January. The first was etched on Jan. 20 and the second on Mar. 22. Each sample was etched for 6 hours in 6 N sodium hydroxide at 118°C. Sample 67701,205 was coated with a conducting coat of AuPd and prepared for electron microscopy in early February. SEM observations began at that time and are continuing to the present on this sample. Unfortunately, the SEM was under repair for about two months from mid-March to mid-May and no observations could be made.

We obtained images on an ISI SEM. The sample was oriented perpendicular to the electron beam. The same condenser lens setting and aperture were used for all images. Nevertheless, the microscope is not equipped with a Faraday cup and we could not be sure of reproducing the same beam current exactly for each microscope session. The working distance knob was set at 8 mm, the focus knobs were set at 5 turns clockwise, and the image was brought into focus initially by adjusting the sample height. This procedure assures that magnification and resolution will be consistent from one session to another. We determined magnification calibration with a stage micrometer and verified that it remained consistent within 1.5%. The SEM is capable of making conventional secondary electron images (SEI) and it is also equipped with a back-scattered electron (BSE) detector. Secondary electrons produce a gray scale micrograph that looks very much like a regular black and white photograph. If SEI were used, we felt that fairly sophisticated image processing would be necessary to use the computer to distinguish tracks from background. BSE images, however, 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 with very little gray. Using the computer we could set the contrast and brightness to numerically reproducible settings.

We produced digital images using an eXL computer manufactured by Oxford Instruments, formerly Link Analytical. The computer has a proprietary operating system and software. The system is designed to be used with electron microscopes and it controls energy dispersive x-ray analysis as well as digital imaging. There are a wide variety of image processing options and analytical options. I will describe only those procedures that were useful to us. Digital images were collected as a Kalman average for 90 sec. The images were 512 x 512 pixels at a 256 gray-scale (8 bit). We consistently worked at 10000x.

Image analysis was done on a Macintosh computer running *NIH Image* software. The Macintosh computer arrived in mid-February and the *NIH Image* software was immediately installed. Initially, we used floppy disks to transfer images from the eXL computer in building 31 to the Macintosh. This was very slow because the eXL computer takes nearly 5 minutes to copy a file to a floppy disk (these image files are about 300 kbytes in size). An additional piece of hardware was purchased to attach the Macintosh to the local area network. This arrived and was installed in late April. It took several weeks

to get the protocols straightened out, but now we can transfer files from the eXL to the Bldg. 31 network and later from this network to the Macintosh in just tens of seconds per file.

Because *Khoros* is such a powerful image analysis program, we have not yet given up on it. We have bought software that will allow us to access *Khoros*, which is on a Sun workstation attached to the local area network, from the Macintosh. However, we have still not located the problem which prevents it from doing the analyses we want to do. We have also bought some other small antivirus and utility programs for the Macintosh.

RESULTS

Despite the success that we had last summer in analyzing track densities using image analysis software, the technology has not been completely transferred to the Macintosh. There is not a software problem. Although *NIH Image* functions somewhat differently than the eXL image analysis software, it will do everything that I found was necessary to do last summer and it is faster. The software allows the user to mask out cracks, *etc.* from the images, it will count isolated items after establishing a binary threshold, and it will measure the area of the image occupied by tracks. The problem has been with the conditions for taking the digital images on the SEM. It has taken a long time to discover the problem because of the nature of sample 67701, 205. This sample, although categorized as a submature soil, is very close to being a mature soil. Only about 15% of the grains have track densities that are low enough to be suitable for calibrating conditions. We had to look at 100 grains to get enough for good calibration work.

Sample 67701, 205 was etched for 6 hours whereas the sample that was used last year had been etched for 15 hours. The difference in etching time is the primary reason we have had trouble establishing the best conditions for contrast, brightness, threshold, and minimum pixels per track. The larger tracks from the 15 hour etch turned out to be much easier to establish proper conditions for. The downside to long etching, however, is that you cannot measure the highest density grains. This is clearly demonstrated in Fig. 1 which compares histograms of lunar sample 60009, 6049 etched for 6 and 15 hours. The downside to short etching is that the small tracks require much more sensitive analysis conditions. If the contrast and brightness are not just right, then the computer misses the track. In Figs. 2 and 3 we show the calibration data as it existed at the end of May. In Fig. 2 we see that the computer is consistently under counting tracks at the higher track densities. It is necessary to work with the contrast, brightness, threshold, and minimum pixel settings to improve the correlation. Because the correlation is poor we do not expect the regression line in Fig. 3, that is used for obtaining track densities when they are very high, is suitable. Nevertheless, the histogram of track densities for 67701, 205 looks quite reasonable (Fig. 4). This histogram will change when we have collected better calibration data, but even in its present state I have a very good idea of what we will learn about the maturity of this sample.

Lunar soil 67701 is a submature soil. It is comprised of a mixture of two components. About 85% of the sample is a mature soil with the other 15% being an immature, but not pristine, soil.
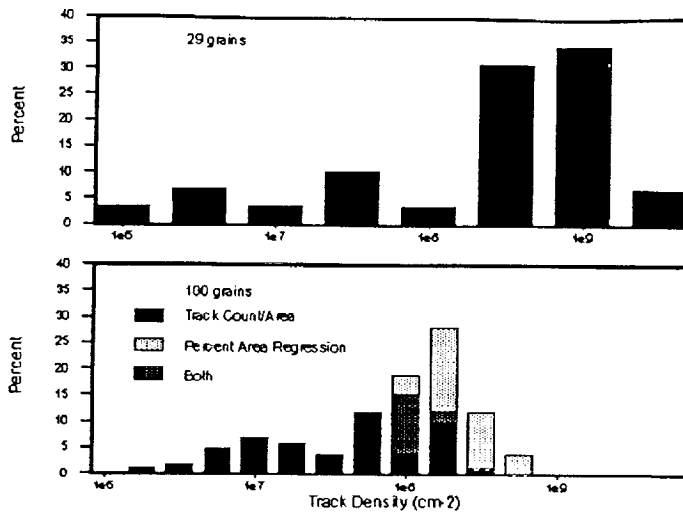
Figure 1. Histograms of the track density distribution at 546 mm below the lunar surface in sample 60009,6049. The upper histogram is based on manual measurements in 29 grains after etching for 6 hours. The lower histogram is based on 100 grains using image analysis techniques after etching for 15 hours. Note how it was possible to measure grains of much higher track density for the shorter etching time.
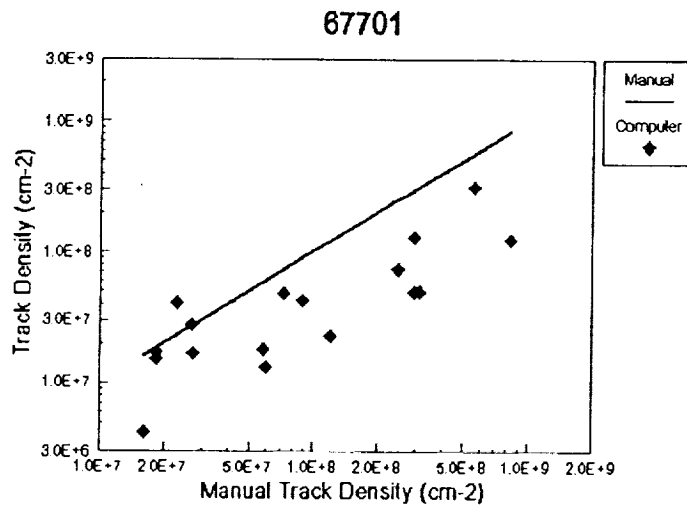

Figure 2. Correlation of track densities measured manually in plagioclase grains in lunar sample 67701, 205 with track densities measured using computer image analysis. Clearly the correlation is not very good and we are trying to vary analysis conditions to improve agreement.
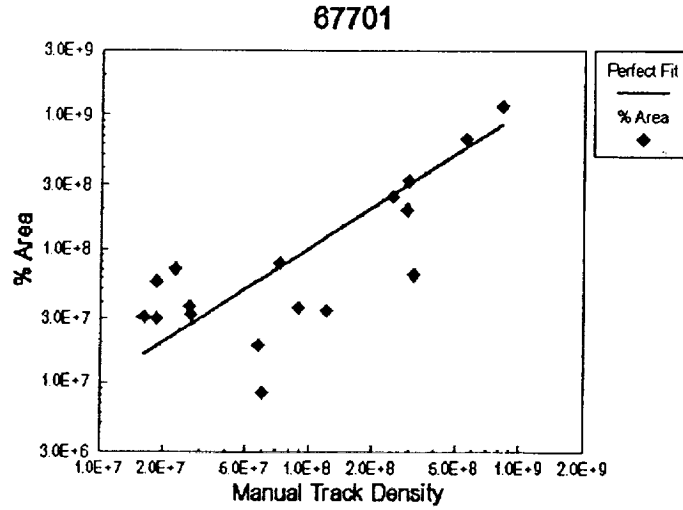
67701

Figure 3. Linear regression line used to convert percent area measurements into high track density measurements. Not only is the fit of data points widely scattered around the regression line, the fact that the correlation shown in Fig. 2 is so poor means that using the regression line will give results that are only suggestive of the true results.
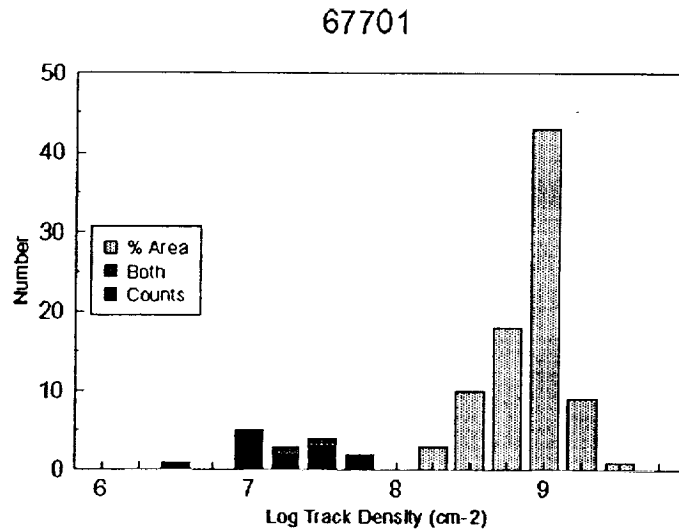
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Figure 4. Histogram of track densities in 99 grains from the 90-150 μm fraction lunar sample 67701, 205. The histogram indicates that this sample is submature, but very close to being mature. The immature fraction (~15% of the sample) has been mixed into a mature fraction.

CONCLUSION

Although we have not completed the calibration of our new set up, we have all the physical parts of the system in place and working. The calibration problem will take several weeks of concentrated effort to solve, but I am convinced we have that problem just about licked. One possibility may be that we will have to etch the samples for a longer time, but certainly not as long as 15 hours. When we have established correct imaging and analysis conditions, sample 61221,134 can then be completed in about a week.

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MEASURING TRACK DENSITIES IN LUNAR GRAINS USING IMAGE ANALYSIS; G.E. Blanford[1],
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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. On the other hand, 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 55 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.

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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.
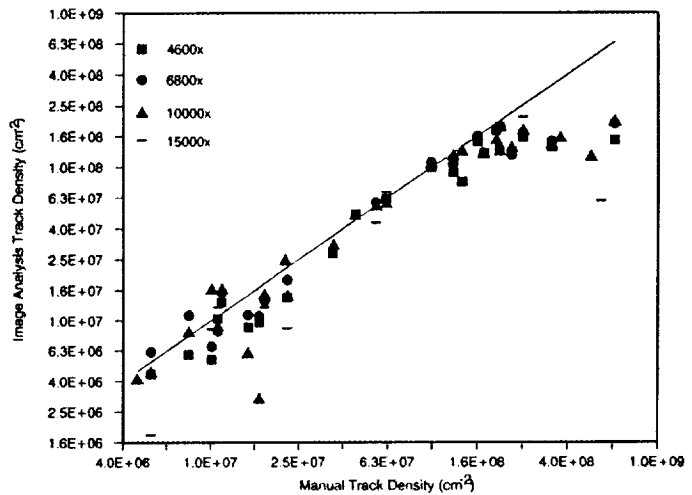

Figure 2: The correlation of manually counted and image analysis determined track densities for data taken at 10000x. Circles represent data obtained using feature scan and triangles represent data using a linear regression formula of the percentage area. Rectangles give one standard deviation uncertainty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