ROCK 72315: A NEW LUNAR STANDARD FOR SOLAR FLARE AND MICROMETEORITE EXPOSURE. I.D. Hutcheon, D. Macdougall and P.B. Price, Physics Dept., Univ. of Cal., Berkeley, Ca. 94720; and F. Hörz, D. Morrison and E. Schneider, Johnson Space Center, Houston, Texas 77058

For two years the profile of solar flare Fe tracks in the Surveyor glass filter has served as the standard from which surface exposure ages and erosion rates of lunar rocks, as well as micrometeorite fluxes, have been derived. In this paper we show that lunar rock 72315, from an Apollo 17 boulder, promises to become a new standard for solar flare spectra during the last $\sim 10^5$ years. Our track profile was measured in a mm-sized feldspar crystal at the surface of the rock. Crater counts were made on two areas near the crystal. Both studies show that a large fraction of the present surface of the rock was freshly exposed about 10^5 years ago. In fact, astronaut Jack Schmitt thought the rock was a large clast because of its lighter (fresher) appearance than the surrounding material of the boulder.

A section of the feldspar crystal ~normal to the exposed surface was etched in a boiling solution of 1g NaOH:2gH_2O for times of 2 min for TEM (+ replica), 7 min for SEM, and 20 min for optical microscopy (+ silvering). The solid points in Fig. 1 are the combined track data obtained by the three techniques. The maximum etched track length for the optical counts was ~5μm, but this is not the correct value of ΔR (the recordable range) to use in computing the energy spectrum. To estimate ΔR we continued etching for up to 5 hours and found that the 5μm-long tracks grew to ~30μm and that TINTs reached maximum lengths of almost 40μm before their growth rates became very low. Previously used values of $\Delta R \approx 10$ to 15μm are too low. For rock 72315 we adopt the value $\Delta R = 40$μm, which means that anywhere along the last 40μm of the trajectory of an Fe ion a visible track can be etched.

The dashed curve in Fig. 1 gives the current best estimate of the etch pit density per steradian vs true depth in the Surveyor glass. We used an average of the measurements of (1) and (2) instead of the measurements of (3), which were made on the horizontal surface of the glass and require corrections that depend critically on a knowledge of the etch pit cone angle as a function of energy. The scale of the ordinate for the curve assumes a 10^5 year exposure at the same average rate as for the 2.6 year Surveyor exposure. Storzer et al (4) found that glass with the same composition as the Surveyor glass records Fe ion tracks at an energy of 9.6 MeV/nucleon, corresponding to a range of at least 75μm. Because of possible annealing on the lunar surface, it is better to look at actual flare tracks in the glass. By observing the growth of Fe ion etch pits during a sequence of etches we find that $\Delta R \approx 100$μm is a more realistic estimate of the recordable range than the value 30μm used previously.

The triangles in Fig. 1 are the data previously reported (5) for a steep track gradient in a pyroxene crystal at the bottom of a vug in rock 15499. At that time we pointed out that the profile was nearly as steep as that in Surveyor glass and that normal erosion processes apparently had been thwarted, perhaps because the crystal was shielded by the vug walls from micrometeorites orbiting in the ecliptic plane. A background of $\gtrsim 10^8$ tracks/cm^2 from galactic cosmic rays made it impossible to extend the profile to depths

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greater than ~200μm. For this reason the vug crystal is not as useful as rock 72315, for which we have data down to ~800μm and in a future column of which we expect to obtain data at even greater depths.

Because of the different values of ΔR and range-energy relations for glass, feldspar, and pyroxene it is safer to compare energy spectra computed from track profiles than the profiles themselves. As a first approximation, however, note that the profile in rock 72315 fits the Surveyor profile quite well at depths ≳100μm and allows an exposure age of $\sim 10^5$y to be computed, <u>if we assume the Surveyor profile to represent a 2.6y average rate</u>. Note further that the profile in 72315 can be made to fit the Surveyor profile at all depths from ~25 to 800μm if we assume either that the crystal came from a depth of ~20μm or that it was eroding at an average rate of ~2.5Å/y. (The location of the crystal was not well documented.) With the same assumption we infer an exposure age of $\sim 2\times10^5$y for the vug crystal in 15499 and an erosion rate of no more than ~1Å/y.

Fig. 2 shows the energy spectra computed for Surveyor glass and for rock 72315. To extract the correct energy spectrum from a track profile, one must realize that tracks observed at a given depth are produced by particles having residual ranges from ~0 (in practice 1 or 2μm) to ΔR. Denoting the track profile by $N(R)$ (tracks/cm^2 ster), the (measured) slope of the track profile by $dN/dR \equiv (N/R)\, d\ell nN/d\ell nR$, the differential range spectrum by $j(R)$ (particles/cm^2 micron ster), and the differential energy spectrum by $j(E)$ (particles/cm^2 ster MeV/nucleon), we can determine $j(R)$ from the relation

$$j(R_o)=j(R_o+\Delta R)-(dN/dR)_{R_o} = -\sum_{j=o}^{n} (dN/dR)_{R_o+j\Delta R}$$

and $j(E)$ from the relation $j(E)=j(R)/dE/dR$ (the correction for spallation being negligible for solar flare energies). In principle one must integrate over all solid angles. In practice, for a typical steep flare spectrum the tracks are strongly collimated toward the nearest surface and we have restricted our measurements to those tracks within ~15° of the direction of the nearest surface. At depths $R_o \ll \Delta R$ the relation $j(R_o) \approx -(dN/dR)_{R_o}$ is adequate; at depths $R_o \gtrsim 3\,\Delta R_o$ one can use the approximate relation $j(R_o) \approx N(R_o)/(\Delta R - \alpha(\Delta R)^2/2R_o)$, where α is the exponent of the empirical expression $N(R)=AR^{-\alpha}$.

At energies ≳10 MeV/nucleon erosion is unimportant during 10^5y and the spectra are very similar, with slopes increasing in steepness to ~-3.66. With decreasing energy the slope of the Surveyor spectrum decreases to ≲-2.

Fig. 3 shows the results of cumulative crater counts made on two ~5cm^2 areas of the rock. The distribution is still in production but the difference in slopes of the counts from the two regions is puzzling. The absolute counts suggest an age of 1.2×10^5 years, consistent with the value 10^5 years based on an assumed constant solar flare rate. Measurements at a higher magnification of pits in the 1 to 25μm diameter interval may raise the frequency at the low-diameter end of the distribution.

Laboratory sputtering experiments (6) indicate that the erosion rate of the solar wind hardly exceeds 0.02Å/y. From Fig. 3 it seems unlikely that micrometeoritic erosion could have flattened the spectrum of 72315 at low energies. We are optimistic that a documented crystal from the true surface of our track column will yield a steep spectrum even at energies as low as

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1 MeV/nucleon. In order for rock 72315 to serve as a solar flare standard that is completely independent of Surveyor glass it would be necessary to date its exposure time by ^{26}Al.

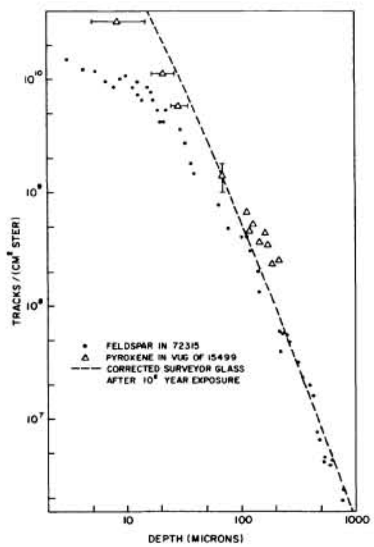

Fig. 1

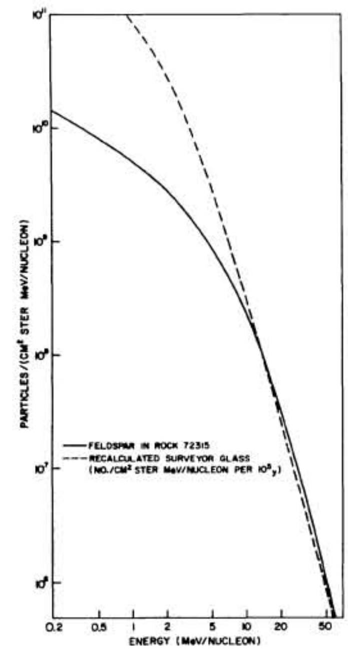

Fig. 2

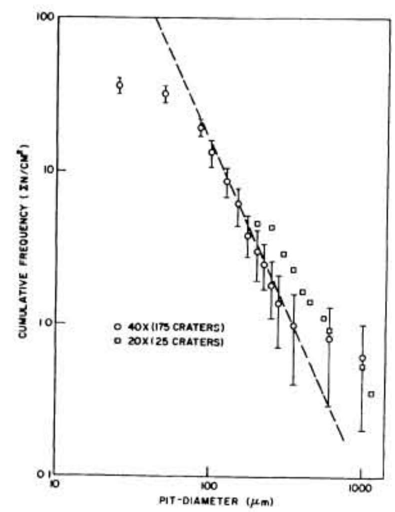

Fig. 3

References

1. G. Crozaz and R.M. Walker, Science 171, 1237 (1971).
2. R.L. Fleischer, H.R. Hart, Jr., and G.M. Comstock, Science 171, 1240 (1971).
3. P.B. Price, R. Cowsik, I. Hutcheon and D.J. Barber, Phys. Rev. Letters 26, 916 (1971).
4. D. Storzer, G. Poupeau and W. Krätschmer, Proc. Fourth Lunar Science Conf. 3, 2363 (1973).
5. I.D. Hutcheon, D. Braddy, P.P. Phakey and P.B. Price, Apollo 15 Sample Studies, p. 412 (1972).
6. J.A.M. McDonnell, D.G. Ashworth, R.P. Flavill and R.C. Jennison, Proc. Third Lunar Science Conf. 3, 2755 (1972).