Cosmic Ray Exposure History at Taurus-Littrow, R. J. Drozd, C. M. Hohenberg, C. J. Morgan, F. A. Podosek and M. L. Wroge, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130 USA.

Lunar features formed in events which bring to the surface material previously shielded from cosmic ray effects can often be dated by calculation of the cosmic ray exposure age of this material. For example, we have previously reported cosmic ray exposure ages for a number of Apollo 17 samples which contained a cluster near 100 m.y., evidence for a site-wide event at that time, interpreted as the arrival of Tycho ejecta (1). In this paper we report new data to strengthen the interpretation of a site-wide event and make some observations relating surface dynamics and apparent exposure ages.

Figure 1a is a histogram of apparent exposure ages for all available Apollo 17 data (coarse fines to boulder fragments) including published data, personal communication (2), and 8 new $^{81}$Kr-Kr ages (this work). It shows a rather broad grouping of exposure ages between 90 and 150 m.y., with a prominent peak around 110 m.y. This grouping includes representatives from Camelot, the Sculptured Hills, the Bright Mantle (South Massif landslide), and nearly all of the samples from Central Cluster (stations 0 and 1). We believe that such a grouping reflects the emplacement of the Central Cluster and Bright Mantle material and demonstrates the site-wide nature of the event. For comparison, Figure 1b is a histogram of exposure age data for the Apollo 14 and 16 sites. It shows similar clustering defining the ages of South Ray, North Ray and Cone Craters (3).

The clustering of Apollo 17 ages is obviously real, but the spread is substantially greater than for clusters dating South Ray, North Ray and Cone Craters; in particular the spread of ages is much larger than can be accounted for by experimental uncertainty. This spread thus requires consideration of second order effects in the interpretation of basic exposure age data.

An apparent exposure age is calculated from the amount of the cosmic-ray product and an assumed production rate, which in turn depends on target chemistry and shielding. Uncertainty in the production rate is alleviated by use of the $^{81}$Kr-Kr method, in which the $^{81}$Kr activity determines the production rate of $^{83}$Kr. Even for the self-calibrating $^{81}$Kr-Kr method, however, modification of exposure conditions, as by erosion, geometry change, or catastrophic fracture, will cause apparent exposure ages to deviate from the actual exposure time.

Figure 2 shows the relationship between the apparent $^{81}$Kr-Kr exposure age which would be calculated for samples exposed for a true time of 100 m.y. but subject to both continuous surface erosion of 1 mm/m.y. (4) and a discrete shielding change, occurring at time $T_i$, which either removed (-) or added (+) the indicated amount of shielding $\Delta$ (in g/cm$^2$). The calculations are based on the depth dependence of cosmogenic krypton production from solar (100 MV rigidity) and galactic cosmic rays as computed by Reedy (5) and a target chemistry similar to sample 70035. The two families of curves relate to two values of S, the present distance to the nearest surface (in g/cm$^2$). Note that shielding changes can increase as well as decrease the apparent age, since the production rate maximum from galactic cosmic rays occurs at finite depth rather than at the surface. Due to solar flare effects, samples
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recovered from within a few g/cm² of a surface that once was up have apparent exposure ages that depart the most from the true exposure age. To better evaluate the time of the site-wide Apollo 17 event we will consider only those samples taken from 10 g/cm² or more from the surface.

As seen in Figure 2, pure erosion \( T_i = 0 \) results in a ratio of apparent to true exposure age of 0.975. The displayed \( \Delta \) range corresponds roughly to typical sample size, and so reasonably represents the range of shielding changes that would be expected either by turnover or fracture of larger rocks. The corresponding range in apparent age is from 0.7 to 1.2 times the true age. The span is approximately that seen in Figure 1a, so we conclude that the shielding changes considered can plausibly account for the observed spread in apparent exposure ages of Apollo 17. Since such geometry changes defeat the self-calibration feature of \(^{81}\text{Kr-Kr}\) ages, other methods such as Ca-Ar exposure dating are equally as accurate and, in fact, contribute substantially to the exposure age cluster at Apollo 17.

Comparison of the Apollo 17 results with the much more sharply peaked exposure age cluster of North Ray Crater is instructive. Erosion and fracture rates are presumably the same at both sites. However, the North Ray age is defined primarily by samples from relatively large boulders, while the Apollo 17 cluster is defined primarily by relatively small isolated rocks. This suggests that for the range of rock sizes characteristic of Apollo 17 (tens of centimeters), shielding change by tumbling or turnover is a more frequent phenomenon than comparably sized fracture events among rocks of the size characteristic of the North Ray boulder field (tens of meters).

If the arguments presented above are correct, the most precise age for emplacement of Central Cluster, The Bright Mantle, and other Apollo 17 features will be found by \(^{81}\text{Kr-Kr}\) exposure ages of the large boulders. There are six such samples, 70135 (Geophone rock), 71055, 71135, 75015, 75035 and 75055, with \(^{81}\text{Kr-Kr}\) exposure ages of 106±4, 110±7, 103±4, 92±5, 89±3, and 106±2 m.y. respectively. These samples are indicated by solid dots in Figure 1a. There is some evidence (1) that 75015 and 75035 may have been part of the same boulder, subsequently fractured while on the surface. Excluding these two rocks, the remaining four give an average apparent exposure age of 106±3 m.y. which, when corrected for erosion (Figure 2), yields a true exposure age of 109±4 m.y. In our opinion this age represents the most reliable estimate of the emplacement time for the Apollo 17 features.

These considerations suggest that none of the approximately six boulder samples dating North Ray crater show signs of major fracturing events during their 50 m.y. surface residence time and one of five boulders at Apollo 17 indicates a possible fracture event during 100 m.y. surface residence. All of these are boulders in the one meter to tens-of-meter size range. Such data should be an important input to models describing rock fracturing on the lunar surface.

REFERENCES

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Figure 1a (top) & 1b (bottom): Histograms of cosmic ray exposure ages obtained from a number of Apollo 14, 16 and 17 samples. The arrow on the 100 m.y. cluster at Apollo 17 shows the spread in apparent exposure ages produced by shielding changes (see text and figure 2).

Figure 2: Apparent 81Kr-Kr exposure ages resulting from a true surface residence of 100 m.y., an erosion rate of 1 mm/m.y., and a single shielding change of Δ g/cm², occurring at time t₁. The solid curves are for shielding removal (whether by fracturing or by geometry change); the dashed curves are for shielding addition by geometry change. S refers to the distance to the nearest surface in g/cm².