THE SATURATED ACTIVITY OF ^{26}Al IN LUNAR SAMPLES AS A FUNCTION OF CHEMICAL COMPOSITION AND THE EXPOSURE AGES OF SOME LUNAR SAMPLES. J.E. Keith and R.S. Clark, NASA Johnson Space Center, Houston, TX 77058.

It has long been recognized that measurements of the activity of cosmic ray and solar proton induced radionuclides provides the most unequivocal evidence for recent exposure (as opposed to cumulative exposure, provided by tracks, etc.) in extraterrestrial objects. However, in order to calculate an exposure age some estimate of the saturated ^{26}Al activity must be made. Such estimates have been made from internal evidence (1,2) for meteorites, and we present here an analogous estimate for the saturated ^{26}Al activity in lunar samples derived only from lunar data.

Since Apollo 12, some lunar samples have been described as unsaturated in ^{26}Al - 12054, 12062, 12064, 15475 and 15495 by O'Kelley et al. (3,4), 15205, 15206 and 15501,2 by Rancitelli et al. (5), and 14045, 15086, 15426 and 15431 by Keith et al. (6). No method of identification of unsaturation that was free of assumptions about the appropriateness to lunar samples of non-lunar data was available, however. In this paper we present such a method; we remove the variation in the ^{26}Al specific activities of a selected set of lunar samples due to the variation in their chemical composition and their surface to volume ratios, leaving only the errors in the measurements and the variation in the activity due to the variations in the conditions of irradiation to vary randomly. In the process of finding a subset of the original set of samples we shall use internal consistency arguments as well as physical intuition to guide us in improving the regression model and in selecting samples to eliminate from the saturated set.

In selecting our original set of samples we look for those samples that have as little as possible non-random (man-made) alteration, that might reasonably be expected to have maintained their shape for the last few million years (no fines) and for which the chemical composition is known and the ^{26}Al activity was measured on the whole rock. As a result of the search, 28 such cases were found and are shown in Table 1.

The internal consistency arguments mentioned above will involve our requirement of good behavior on the part of the residuals; that neither the observed value, nor the predicted value of ^{26}Al activity, nor any of the independent variables display a significant correlation with the residuals. We shall start by regressing the observed value of the ^{26}Al activity of the Apollo 11, 12, 14 and 15 samples on the silica, alumina and magnesia contents of these samples. The results appear in Figure 1. There appears to be a rather compact group of points with four conspicuously low - those due to 12034, 12064, 14301 and 15265. The first three of these four have previously been described as unsaturated. We discard them and try again. In order to obtain good behavior in the residuals we are forced to add three more variables to the model which accommodate the variation in the ^{26}Al activity due to variation in the surface to volume ratios in the samples: $[SiO_2]\ w^{-1/3}$, $[Al_2O_3]\ w^{-1/3}$ and $[MgO]\ w^{-1/3}$ (where w is the weight of the sample in kg and $[M_xO_y]$ is the percent oxide). Since the exposed surfaces of lunar samples are known to have strong activity gradients due to solar proton bombardment, this is not an unexpected result. Proceeding in this fashion through many trials which we do not have room to describe, we show that the saturated ^{26}Al specific activity of our saturated subset (see Table 1) can be represented by: $^{26}Al(dpm/kg) = 0.652[SiO_2] + 2.50\,[Al_2O_3] + 0.560\,[Al_2O_3]\,w^{-1/3} + 2.28\,[MgO]\,w^{-1/3}$. Sy/x = 5.54, F = 1670. Other independent variables (e.g. [MgO]) turn out to be not significant, and the residuals (see Figure 2) are well-behaved. Note also that no member of the original set identified as unsaturated failed to also be so identified by our selection process.

We have developed a systematic method of predicting the saturated ^{26}Al specific activity of lunar rock samples from various readily observable variables. From this two major consequences flow: by postulating a one-step elevation to the surface from depths sufficient to produce only negligible ^{26}Al activity, one can calculate the most probable length of time that these samples have been exposed on the lunar surface. These "exposure ages" should be regarded as upper limits (because the ^{26}Al production rate may have been nonnegligible, as in the case of 12034 which was found in a trench) and are shown in Table 2. A new, more quantitative measure of the recent deep gardening of the lunar regolith is also made available: since 6 of 27 samples found on the lunar surface have been shown to be unsaturated, the probability of choosing another unsaturated sample is $0.22^{+.18}_{-.11}$ (90% confidence limits).

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Table 1. A list of the lunar samples whose data is used in this paper.

10003* A	12002 H	12064* O	15265* V
10017 B	12004 I	12065 P	15415* W
10018 C	12010 J	12073 Q	15418 X
10019 D	12013 K	14053 R	15558 Y
10021 E	12034* L	14066 S	60315*
10057 F	12053 M	14301* T	60335
10072 G	12063 N	15256 U	62235

*Indicates samples found not be be members of the saturated set. All unstarred samples are members of that set.

The letter after each sample number identifies the corresponding point in Figure 1.

Figure 1. Scatter plot of residuals vs. observed values for initial model.

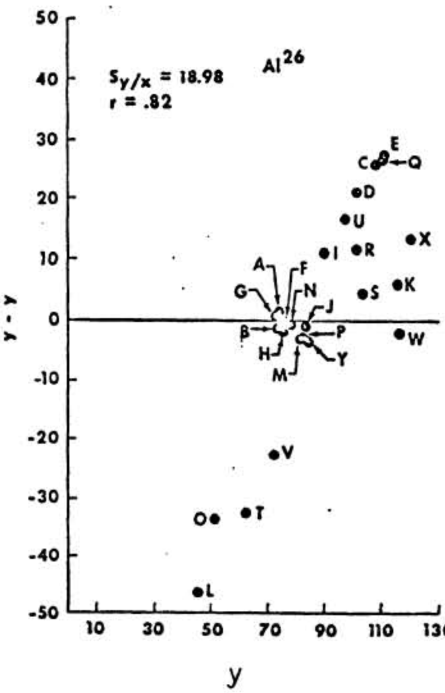

Table 2. Residuals and exposure ages of unsaturated lunar samples.

Sample	Observed ^{26}Al activity (dpm/kg)	Difference between obsv. and predicted ^{26}Al activity‡ (dpm/kg)	Exposure age† $t^{+\sigma}_{-\sigma}$ (m.y.)
10003	74 ± 8	-14.8 ± 9.84	$1.91^{+1.1}_{-.52}$
12034*	45 ± 5	-81.5 ± 8.03	$0.47^{+.07}_{-.09}$
12064	51 ± 5	-24.8 ± 7.91	$1.19^{+.32}_{-.25}$
14301	62 ± 18	-38.3 ± 19.1	$1.03^{+.70}_{-.42}$
15265	72 ± 8	-26.8 ± 9.92	$1.39^{+.44}_{-.31}$
15415	116 ± 9	-32.8 ± 14.3	$1.61^{+.51}_{-.34}$
60315	92 ± 9	-23.8 ± 11.0	$1.69^{+.61}_{-.38}$

*The exposure age of 12034 may be presumed to be zero, since it was dug up, but it was not buried deeply enough to have a negligible ^{26}Al activity.

‡The standard deviations in this column are calculated from those of the observed value and those of the predicted value.

†The increments to the age listed here correspond to one standard deviation in the activity ratio D_0/D_∞.

Figure 2. Scatter plot of residuals vs. observed values for final model.