The Irradiation History of Lunar Samples

Lunatic Asylum*

Division of Geological Sciences
California Institute of Technology
Pasadena, California 91109

Abstract

The galactic cosmic ray and solar wind exposure of lunar samples has been investigated by means of rare gas and Gd isotopic measurements.

Neutron exposures obtained from Gd isotopic measurements for various Apollo 11 and Apollo 12 soil samples are the same to within 10%. This is difficult to understand in view of stated differences in the regolith thickness at the Apollo 12 and Apollo 11 sites. The regoliths at different mare sites appear to be well-mixed seas from the point of view of nuclear bombardment.

The measured neutron exposures for soil samples permit regolith mixing depths to be calculated for the Apollo 11 and Apollo 12 sites. Assuming total mixing down to a depth, L, values of L = 10-20 meters are obtained using new theoretical calculations of the neutron flux gradient by Lingenfelter and Canfield. This is distinctly higher than regolith thicknesses estimated from crater depths. Use of partial mixing models and the effect of known uncertainties in the calculations would tend to make the discrepancies larger. Smaller mixing depths are obtained from spallation Xe^{126} in soil samples for a total mixing model.

The Apollo 12 double core shows only a small, but significant, gradient in neutron exposure (~ 10% larger at the bottom). The observed stratification is thus comparatively recent (within the last 50 m.y.). Limits on deposition times can be set for various layering models.

---

* In alphabetical order, the nuclear active inmates are A. L. Albee, D. S. Burnett, A. A. Chodos, E. L. Haines, J. C. Huneke**, D. A. Papanastassiou, F. A. Podosek, G. Price Russ, F. Tera and G. J. Wasserburg.

** Speaker

Apollo 12 rocks have neutron exposures which are similar to the Apollo 11 rocks. No variations in neutron exposure are observed for samples from different depths in 12002.

Strong evidence for a range in irradiation depths for lunar rocks is obtained both from the relative yields of rare gas spallation products and from neutron fluxes calculated from the measured Gd isotopic variations. The fraction of the total exposure time spent on the lunar surface is small for most of the Apollo 11 rocks.

Cosmic ray exposure ages calculated for different spallation products with production rates obtained from measurements of radioactive nuclei in lunar samples are in better agreement than those calculated with meteoritic production rates. This suggests that, although finite, the average irradiation depths were not large (probably $\leqslant$ 60 cm).

An internally consistent set of spallation product exposure ages has been calculated for 14 Tranquillity Base rocks. Four, possibly five, of seven "low-K" rocks appear to be grouped with an exposure age of around 100 m.y. At least five major impacts are required to produce the 14 rocks.

High precision (better than 0.1% for the major isotopic ratios) Xe and Kr analyses of grain size fractions from Apollo 11 and Apollo 12 soils have been carried out. These data are interpreted in terms of a "SUCOR"(surface correlated; primarily solar wind) and a volume correlated (primarily spallation) component. The Apollo 11 data have been analyzed in detail and are consistent with this model. The derived spallation Xe spectrum is in good accord with that observed for lunar rocks; however, the Kr spallation spectrum has excess Kr^{82} and Kr^{84} compared to lunar rocks or meteorites. Independent evidence exists for a Kr spallation spectrum of this type. SUCOR Kr is related to atmospheric Kr by a mass fractionation of 0.7% per mass unit favoring the lighter isotopes in the atmosphere. SUCOR Xe appears to be complex and may contain, in addition to solar wind, additional components from the lunar atmosphere (for example, fission Xe) which have been implanted by solar wind action.