SCR and GCR Exposure Ages of Plagioclase Grains from Lunar Soil 61501.

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Goal and Approach: The concentrations of solar wind implanted 36-Ar in mineral grains extracted from lunar soils show that they were exposed to the solar wind on the lunar surface for an integrated time of 10E4 to 10E5 years (1,2). Down to a depth of 2-3 cm spallogenic Ne and Ar are produced more efficiently by the solar cosmic radiation (SCR) than by the galactic cosmic radiation (GCR)(3). At a depth larger than about 10 cm SCR produced spallogenic gases amount to less than 0.1% of those produced by the GCR. 38-Ar GCR exposure ages of plagioclase grains from lunar soils computed with nominal mean production rates range from 50 to 500 Ma (1,4). Because the knowledge of the residence time of a soil sample at different depth could serve as an experimental test of models for the regolith dynamics (e.g. 5), it is of interest to resolve the spallogenic products into the SCR and GCR produced fraction. Several such attempts, predominantly based on the isotopic composition of Ne, have been reported (6-11).

Difficulties: In principle it is possible to resolve the spallogenic nuclides detected in a given sample into the SCR and GCR produced portions because of the differing energy and target element dependencies of the production rates of the various spallogenic nuclides. Therefore, the decomposition requires the knowledge of the chemical composition of the sample as well as its shielding history. The latter constitutes the first difficulty encountered, because this information is intrinsically not available and has to be modeled appropriately.

The second difficulty arises in the precise determination of the concentrations and isotopic ratios of the spallogenic elements in lunar materials because of the presence of implanted gases. In constituents of lunar soils, the concentrations of implanted gases generally exceed those of the spallogenic gases by several orders of magnitude. Even in samples from lunar rocks very fine soil particles blown into the pore space of the rock on the first exposure to atmospheric pressure may lead to difficulties in the determination of the spallogenic component. Thus, in both cases, the implanted gases must be experimentally depleted to such a degree that the isotopic ratios and concentrations of the spallogenic gases can be determined without impairing corrections or assumptions.

The third difficulty concerns the experimental separation of the two types of spallogenic gases. Because the grains -or samples- investigated are small in comparison to the attenuation length of even the SCR interaction, attempts for experimental separation of the two spallogenic components, such as stepped heating or etching, are bound to fail.

Our Study: From the bulk soil 61501 ~~we prepared~~ plagioclase separates of 8 grain size ranges. The depletion of the implanted gases was achieved by etching aliquot samples of 4 grain sizes to various degrees ~~(nominal thickness of the removed layers: 1 - 40 µm)(12)~~. The experimental results pertinent to the present discussion are ~~as follows~~: The spallogenic 38-Ar concentration is (68+-9) x 10E-8 ccSTP/g. The concentration of spallogenic Ne is, as in most plagioclases from lunar soils, affected by diffusive losses and of no use here. The 36-Ar of solar wind origin amounts to (2030 +- 100) x 10E-8 ccSTP/g in the 150 - 200 µm size fraction and shows that these grains were exposed to the solar wind for at least 10'000 years. The 21-Ne/22-Ne ratio of the spallogenic Ne is 0.75 +- 0.01 and in very good agreement with the value of this ratio in a plagioclase separate from rock 76535 (13). This rock has had a simple exposure history and its plagioclases have a chemical composition quite similar to those studied here. In addition to the noble gases, we also investigated the heavy particle tracks in an aliquot of the 150 - 200 μm plagioclase separate and found 92% of the grains to contain more than 10E8 tracks/cm^2(14,15). According to (2,15) this corresponds to a mean track density of (5 +- 1) x 10E8 tracks/cm^2.

To evaluate these results with respect to possible shielding histories, we modeled two exposure scenarios:

1. In addition to the 10'000 years of solar wind exposure, the sample resides for the rest of its effective exposure time at only one constant depth.
2. The sample is excavated -or burried- with a constant rate of 1mm/Ma (5). This is equivalent to the assumption of a random up-and-down motion with equal residence time at each depth interval.

Taking into account the chemical composition of our plagioclases, we computed the Ne and Ar production rates as a function of shielding depth (3) for SCR and GCR exposures. Furthermore, the track densities at the center of 150 - 200 μm plagioclase grains were computed (16). The comparison of the experimental results and the computed values show that for both scenarios appropriate depth-time histories can be found:

* An exposure for some 400 Ma at a depth of about 10 cm (or 20g/cm^2) in the first scenario or an excavation from a depth of 43 cm (taking 430 Ma) in the second scenario produce the observed spallogenic 38-Ar concentration, the infered track density as well as spallogenic Ne with a 21-Ne/22-Ne ratio close to the measured one.
* The first exposure history leads to a SCR contribution to the total of the spallogenic gases of less than 1 % and even in the second scenario merely 4 and 8 % of the spallogenic Ne and Ar, respectively, are SCR produced.

Conclusions: The exploration of the exposure history of the plagioclase separates from the soil 61501 do not contradict the model for the regolith dynamics (5) but also fail to prove it. The evidence for a comparatively short (<5 %) SCR exposure is compelling. During this stage, all solar wind gases, a large fraction of the tracks but very little spallogenic Ne and Ar were accumulated. This is in sharp contrast to the conclusions reached for other soils (8-11). Spallogenic Ne with a 21-Ne/22-Ne ratio lower than commonly found in meteorites is not necessary an indication for a significant SCR exposure; it may be the result of chemical differences.

The exercise reported here demonstrated to us: To unravel the depth-time history of samples exposed to SCR and GCR, real high accuracy of the experimental and theoretical input data about the spallogenic and solar gases, the sample chemistry as well as the track data are of crucial importance.

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