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Nitrogen and Noble Gases in the 71501 Bulk Soil and Ilmenite as Records of the Solar Wind Exposure: Which is correct? P. Signer, H. Baur, Ph. Etique and R. Wieler. ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland.

The N determination in mg sized mineral separates from lunar soils by static mass spectrometry (1,2) is an experimental break-through likely to contribute to the deciphering of the records left in the mineral grains by the exposure to the solar wind. In this discussion we focus on some comparisons of the results of N (2) and noble gas analyses of the 71501 bulk soil and an ilmenite separate thereof. Conclusions from noble gas data obtained on mineral separates from some 20 soils (3,4,5) are summarized in a companion paper (6) and will be also considered here.

The N/36-Ar ratios in the bulk soil and 100-150 μm sized ilmenites are 720 and 520, respectively. Both values are much above the value of 26 (7) for the solar abundance and indicate that Ar is severely depleted not only in the mature bulk soil but also in the ilmenite. Apparently, lunar soil grains and even ilmenite retain only about 5 % of the total impinging solar wind Ar. This conclusion is, of course, based on the assumptions of a solar wind origin of the N and quantitative retention.

The N concentration in the ilmenite grains allows to compute the minimum duration of their exposure to the solar wind. This minimum exposure is the sum of all individual exposure episodes, assuming that the grains are always exposed to acquire solar wind on their full geometric cross section. To compute the mean acquisition rates of solar wind species on the lunar surface, one has to account for the shielding of the moon from the solar wind by the geomagnetic tail, the day-night cycle and the angle of incidence. On the lunar equator and at zero longitude the mean acquisition rates amount to 9.3 % of the free-space flux of the solar wind at 1 AU (8). With these rates, a free-space solar wind particle flux of 2.7×10^8 particles/cm²,sec, a H/N ratio of 11'500 (7) and the measured N concentration, a minimum SW exposure time of the ilmenite of 110'000 years is computed. Similarly, one derives a minimum SW exposure time from the 36-Ar concentration of 5400 years by using a H/36-Ar ratio of 298'000 (7). The real surface exposure time is certainly longer than the minimum exposure time, may be about a factor of 10, because the grains are bound to be partly buried during their exposure episodes. Thus, the real SW exposure of the ilmenite grains deduced from the N data is likely to be on the order of 1 Ma. Such a long residence time of grains on the surface of the regolith leads to the following conflicts:

* The track density at the center of 150-200 μm plagioclase grains acquired during the 1 Ma of real surface exposure is about 3×10^9 tracks/cm² (9). During the residence of the grains in the uppermost cm of the regolith, the track density is further increased. Yet, the actually measured mean track density is only 6.7×10^8 tracks/cm² (5). For this argument, similar evolutions of the ilmenite and plagioclase grains are presumed.

* The extrapolation of the destruction probabilities for rocks in the 10 g to 10 kg mass range (10) to the masses of the grains studied here (about 3 μg) yield a 99 % destruction probability by a primary impacts of about 20'000 years. Thus, the real exposure times of mineral grains as deduced from the N concentration appear much longer than the mean life times of the grains.

* Based on Ar and He analyses of single grains it was concluded that the Ar concentrations in plagioclase grains are not determined by saturation (4). Furthermore, the erosion rate of such grains appears to be less than 2 $\mu\text{m}/\text{Ma}$ (4). If the erosion rate is governed by ion sputtering, the much larger SW

dose implied by the N concentrations may cause larger erosion. This is not only conflicting with the above conclusion but also leads to the release of implanted N to the lunar atmosphere. Freed N is then recycled to the lunar surface by the Gold-Manka-Michel process as proposed for 40-Ar. Because of the low trapping yield ($\leq 5\%$, (11)) the recycling leads inevitably to a net loss of N. Therefore, the SW dose necessary to account for the retained N is further increased and one is led into a vicious circle.

The N concentrations not only in the 100-150 μm ilmenite grains but also in the bulk soil are uncomfortably high, especially if the present-day solar wind flux is used to deduce SW exposure times. To account for the N concentrations in bulk soils an enhanced flux of SW nitrogen in past times has been postulated (12,13). The new data (2) of N in the 71501 bulk soil and ilmenite accentuate this problem in two respects:

* A regolith having a thickness of 3 m, a density of 2 g/cm² and the same N and Ar concentrations as the soil 71501 requires 44 Ga to accumulate its N from the solar wind with a present-day flux. Therefore, the mean N flux seen by this soil must have been at least 10 times higher than the present-day N flux in the solar wind.

* The N concentration of the ilmenites requires that they were exposed while the N flux was still high. Because the 38-Ar GCR exposure age of the 71501 ilmenites is about 100 Ma (3) and because we contend that mineral grains from most surface soils have acquired their solar species essentially in the last 10-100 Ma, the high mean flux should have lasted until about 10 Ma ago.

We now turn to the discussion of the isotopic composition of N, Ne and Ar. From the studies of olivine/pyroxene and ilmenite separates from some 10 soils we conclude that the 20-Ne/22-Ne ratio of solar wind Ne retained in Ne retentive minerals remained constant within $\pm 2\%$ during the last 1 to 3 Ga (5). Thus, a possible temporal change of this ratio in the solar wind (14) is less than 2%. N appears thus, besides Ar, to be the only element where substantial changes ($\sim 30\%$) of the isotopic composition with time are observed (c.f.12). Ar in mineral separates shows variations of the 40-Ar/36-Ar ratio, possibly also time correlated, in excess of 1000% (5).

Summary and Conclusions. The newly reported N concentrations in the soil 71501 and its ilmenites (1,2) have not only aggravated the problem of the disparity of the N/Ar ratios in lunar soils and the assumed solar ratio but also the question of the high fluxes of N in the solar wind. It appears that the mean flux of N was more than 10 times larger than it is since 10 Ma. Otherwise, N in lunar soils must have other sources besides the solar wind. Indigenous lunar N has recently been considered as one alternative source (2,15). The remarkable fact that the gases with the largest isotopic variations in lunar soils are also comparatively abundant in the terrestrial atmosphere may indicate still other sources.

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