

# Trapping of atmospheric gases during crushing of lunar samples

A. B. Verchovsky (1), J. Mortimer (1), A. I. Buikin (2) and M. Anand (1, 3)

(1) The Open University, Milton Keynes UK, (2) Vernadsky Institute RAS, Moscow, Russia, (3) Natural History Museum, London, UK ([sasha.verchovsky@open.ac.uk](mailto:sasha.verchovsky@open.ac.uk))

## Abstract

Experimental simulation of trapping of atmospheric noble gases and nitrogen during crushing of lunar samples using an electromagnetic metal crusher demonstrates that nitrogen is trapped much more efficiently than noble gases. This observation is in sharp contrast with lunar samples that display trapped terrestrial atmosphere-like noble gases, but do not contain terrestrial N, thereby suggesting another source for the atmosphere-like noble gases.

## 1. Introduction

The presence of terrestrial atmospheric noble gases in lunar samples has been known since the early analyses of lunar samples delivered by the Apollo program [1-4]. Some lunar samples contain trapped gases with clear terrestrial atmosphere Xe isotopic signatures [3, 4]. As part of the sample preparation procedure some of them have been crushed before analyses. Therefore, it was thought that trapping of the atmospheric gases occurred at this stage. However, the terrestrial atmospheric gases have been found also in the samples that have not been crushed prior to analysis [3]. Nevertheless, even in these cases the origin of the trapped gases has been attributed to terrestrial contamination, though the mechanism by which they are trapped remains unclear.

In the present study, we investigated this issue by taking into consideration nitrogen, which is the most abundant atmospheric constituent, and is also more chemically active than noble gases. Along with analyses of N in lunar samples which have an excess of atmospheric noble gases [5], we performed several crushing experiments to see in what proportion noble gases and nitrogen can be trapped and compared this with their abundance in the lunar samples.

## 2. Experimental

For the analyses of noble gases, nitrogen and carbon we used the 'Finesse' instrument [6], which allows

simultaneous measurements of abundances and isotopic compositions of different species present. First, we analysed each sample as it is, using stepped combustion and then in the second experiment we employed vacuum crushing. More than 10000 strokes cumulatively were applied during crushing, resulting in production of a fine-grained powder. The crushed samples were subsequently removed from the crusher and an aliquot of the sample was then analysed by stepped combustion. The transfer from the crusher to the combustion furnace includes brief exposure of the crushed material to the atmosphere. In a third experiment, we crushed (3000 strokes) one of the samples (69921) under atmospheric conditions i.e. without evacuation of air from the crusher, and then analysed the crushed material using stepped combustion.

Altogether, three lunar soils (12070, 14141 and 69921) were used in this study. The nitrogen, carbon and noble gas step-combustion data for these samples have been published previously [7].

During crushing a metal powder has also been produced due to friction between the movable insertion and the walls of the crusher. This metal powder was mixed with the sample so tightly that it was not possible to separate them from each other using physical methods of separation. Perhaps the metal and sample particles have coalesced as a result of extreme heating and pressure raised at strokes. In order to account for the N contribution from the metal we have analysed the metal parts of the crusher and also performed a crushing experiment under vacuum with an empty crusher and collected the formed metal particles for further analysis. Analyses of the metal samples showed elevated concentrations of N in the metal.

## 3. Results and discussion

Based on our initial analysis of nitrogen in the lunar rock, 12064, which showed a clear excess of atmosphere-like Ne, we found [5] that the  $(N_2/Ne)_r$  ratio is lower than the terrestrial atmospheric ratio by

a factor of  $6 \times 10^4$ . This indicates that atmospheric nitrogen is much less efficiently trapped by crushing than Ne, contradicting the general idea that chemically active atmospheric species should be trapped during crushing of silicate materials in air with higher efficiency than the inert ones. This result can be considered as evidence for a non-atmospheric origin of the trapped Ne in this sample.

The most important result of the crushing experiments is that in both cases, exposing the crushed material to air after crushing and crushing in air, shows a significant increase in N (by a factor of 6-14) concentrations in the crushed residues compared to the original samples. One of the most important questions is whether or not these high N concentrations can be explained by contribution from the crusher metal only. Analysis of possible concentrations of metal in the lunar soils after crushing and release patterns of N in the samples compared to that in the metal allows us to conclude that metal can explain a significant portion, but not all of the observed concentrations of N in the crushed lunar samples. A fraction of N significantly higher than that present in the original samples has been trapped during crushing.

The majority of solar noble gases are lost during both types of crushing, but the amounts of trapped atmospheric noble gases are extremely low and can barely be seen in the residual materials (Fig. 1). The  $^{36}\text{Ar}/^{40}\text{Ar}$  ratio is a very sensitive indicator of the presence of atmospheric Ar, since this ratio in the samples analysed is significantly different from that in the atmosphere. The results shown in Fig. 1 indicate almost no difference in the  $^{36}\text{Ar}/^{40}\text{Ar}$  ratio between the original and crushed samples in spite of a huge difference in  $\text{N}_2/^{40}\text{Ar}$  ratio. N is trapped much more efficiently, however.

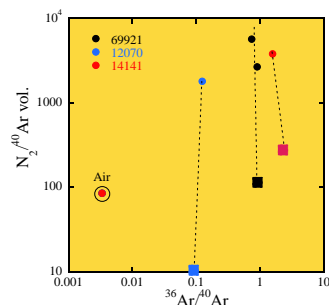


Figure 1: Bulk compositions of the original (squares) and crushed (circles) lunar soil samples.

## 4. Summary and Conclusions

Our crushing experiments demonstrated a very high efficiency of trapping for N, compared to that of noble gases. The mechanism of trapping and the source of N (apart from the fact that it comes from air) is not clear. However, what is clear is that lunar rocks with trapped atmosphere-like noble gases do not show such high concentrations of N and, therefore, their noble gases do not seem to have been trapped from air as a result of crushing.

## Acknowledgements

The authors thank CAPTEM for the allocation of Apollo samples. This work was partially funded through a UK Science and Technology Facilities Council studentship to JM and a research grant to M.A (# ST/L000776/1).

## References

- [1] Lightner B. D. & Marti K.: Lunar trapped xenon, *Proc. 5<sup>th</sup> LPSC*, 2023-2031, 1974
- [2] Leich D. A. and Niemeyer S.: Trapped xenon in lunar anorthositic breccia 60015 *Proc. 6<sup>th</sup> LPSC*, 1953-1965, 1975.
- [3] Niemeyer S. and Leich D. A.: Atmospheric rare gases in lunar rock 60015, *Proc. 7<sup>th</sup> LPSC*, 587-597, 1976
- [4] Niedermann S. and Eugster O.: Noble gases in lunar anorthositic rocks 60018 and 65315: Acquisition of terrestrial krypton and xenon indicating an irreversible adsorption process, *GCA 56*, 493-509, 1992.
- [5] Mortimer J. et al.: Simultaneous analysis of abundance and isotopic composition of nitrogen carbon, and noble gases in lunar basalts: Insight into interior and surface processes on the Moon, *Icarus 255*, 3-17, 2014.
- [6] Verchovsky A. B. et al.: Separation of planetary noble gas carrier from bulk carbon in enstatite chondrites during stepped combustion, *EPSL 199*, 243-255, 2002.
- [7] Mortimer J. et al.: Predominantly non-solar origin of nitrogen in lunar soils, *GCA 193*, 36-53, 2016.