ATMOSPHERIC XENON IN ROCK 60015. S. Niemeyer and D. A. Leich, Dept. of Physics, University of California, Berkeley, California 94720.

Recent reports documenting the presence of trapped Xe of terrestrial-like composition in lunar rocks (1,2) have led to an as yet unresolved question regarding the origin of this trapped Xe. The terrestrial-like isotopic composition certainly suggests terrestrial atmospheric contamination as the source, but several arguments have been put forth as prima facie evidence against such an origin: (a) The high temperatures (>900°C) necessary to extract the trapped Xe are well in excess of temperatures normally thought to be adequate for the release of adsorbed atmospheric Xe. (b) The relative elemental abundances of trapped 36Ar, Kr, and Xe are not atmospheric, nor are they consistent with a Henry's law solubility model for the sorption of rare gas atoms from a terrestrial atmospheric reservoir. (c) Two rocks with great petrological similarities (60015 and 60025) yielded order-of-magnitude differences in the measured abundances of trapped terrestrial-type Xe. Leich and Niemeyer (2) concluded it was unlikely that a terrestrial contamination process would have distinguished so strongly between two such similar samples. It appeared more tempting to conclude that rock 60015 simply lost most of its original trapped-gas contents along with the radiogenic Ar in an impact event 3.5 b.y. ago, as determined by 40Ar-39Ar dating of this rock (3,4). (d) A possible correlation of terrestrial-type trapped xenon contents with abundances of other lunar volatiles has been suggested (1) but has never been established.

It has been our opinion that, while convincing on some counts, the above arguments really represent only circumstantial evidence against a terrestrial origin. We report here on the results of the first stage of an experimental program designed to provide more definitive answers to the question of the role of terrestrial atmospheric rare-gas contamination in lunar sample analyses.

If the source of the trapped Xe is indeed atmospheric contamination, contrary to the arguments summarized above, then rock 60015 can be considered as a relatively uncontaminated sample compared to rock 60025, and therefore might be subject to further contamination. Thus, our experimental approach was to subject splits of the 60015,73 sample to various types of exposure and handling and then to determine the extent and character of the resulting terrestrial contamination. Two subsamples of 60015,73, an interior chip, had already been separated by crushing a 1-gram chip in a panner mortar and hand-picking a total of 0.7 g of millimeter-sized fragments. One of these subsamples was irradiated for 40Ar-39Ar dating (4) and the other, which we shall here call 60015,73A, was used for the analysis of trapped rare gases (2). The remaining sample (60015,73B) consisted of 0.26 g of the crushed chip, ranging from millimeter-sized fragments down to a small quantity of fines, plus a single large (1.14 g) chip. This entire sample was alternately crushed and sieved to remove particles smaller than 160 µm. After all of the available material had been crushed to <160 µm, the homogenized sample was split into eight aliquots, three of which were used in the present work. One aliquot (B-1) was covered with distilled water and agitated ultrasonically, and a second aliquot (B-2) was covered with reagent acetone and subjected to
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ultrasonic agitation. These two samples, plus a third aliquot (B-3) to serve as a control sample, were then analyzed in the mass spectrometer using a two-step temperature program (925° and 1650°C). The isotopic compositions of the rare gases vary from our previous analysis of 60015,73A (2) only in the relative proportions of the trapped and cosmogenic components. The trapped gas contents, however, are an order of magnitude higher in the 60015,73B samples than in 60015,73A (Table 1). Apparently, crushing the sample has increased the rare-gas concentrations by incorporation of atmospheric rare gases, but has not altered the temperature release pattern, as temperatures in excess of 900-1000°C are necessary to release ~80% of the trapped Xe. The only way such a result can be explained in terms of a lunar trapped Xe component is to conclude that the collection of millimeter-sized fragments constituting 60015,73A were extremely non-representative of the bulk sample, i.e. that the lunar trapped gases were strongly concentrated in some minor phase which was excluded in the sampling of 60015,73A. We regard this possibility as extremely unlikely.

Comparing the three 60015,73B samples, we note that while the acetone and H2O treatments did not affect the high-temperature release pattern, the gas contents of these samples are somewhat lower than in the control sample. The lower rare-gas abundances of samples B-1 and B-2 relative to the control sample B-3 may be due to a loss of the finer grain sizes during handling, although sample inhomogeneity or the partial removal of occluded rare gases cannot be ruled out. In any case, it can be concluded that the H2O and acetone treatments have introduced no detectable atmospheric contamination above the levels already present in the crushed sample. The almost inescapable conclusion that the increased trapped gas contents of the crushed samples, 60015,73B, are due to atmospheric contamination, casts strong doubts on some of the arguments which have been used to suggest a lunar origin for terrestrial-like Xe in lunar rocks: (a) Apparently, atmospheric rare-gas contamination can be occluded in some unknown way requiring high release temperatures

Table 1. Xenon from rock 60015,73.*

<table>
<thead>
<tr>
<th>Sample</th>
<th>Reference</th>
<th>132Xe (×10^-12 cm^3 STP/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low-Temp.</td>
<td>High-Temp.</td>
</tr>
<tr>
<td>A</td>
<td>(2)</td>
<td>1.2</td>
</tr>
<tr>
<td>B-1</td>
<td></td>
<td>5.7</td>
</tr>
<tr>
<td>B-2</td>
<td></td>
<td>15.5</td>
</tr>
<tr>
<td>B-3</td>
<td></td>
<td>13.2</td>
</tr>
<tr>
<td>60025</td>
<td>(1)</td>
<td>16.4</td>
</tr>
</tbody>
</table>

*Low-temperature data are for extractions up to 1000°C for 60015,73A; 925°C for the three 60015,73B samples; and 900°C for 60025. The remaining extractions to 1650°C for 60015 samples and 1700°C for 60025 constitute the high-temperature data. A 1650°C reextraction of 60015,73B–3 released no detectable rare gases above blank amounts (0.1 × 10^-12 cm^3 STP/g).
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(>925°C). (b) Such a contamination process does not preserve atmospheric elemental ratios, but results in enhanced Xe abundances with elemental ratios close to those observed for 60015,73A, well off the line representing the bulk of terrestrial sample analyses in Figure 1. While analyses lying off of this line have been widely interpreted as implying non-atmospheric rare-gas components, this conclusion has recently been criticized on theoretical grounds by Ozima & Alexander (5) and is contrary to the present experimental results.

We now believe the trapped gases observed in all of our 60015 analyses are atmospheric contaminants. This conclusion is strengthened by the observation that relatively large amounts of chemically active gases, especially mass 28 (CO and/or \(N_2\)), survived the clean-up of the 60015,73B temperature extractions, in a manner similar to that reported by Bogard and Gibson (6) for samples of rock 68115. The origin of the large trapped gas contents of rock 60025 remains a difficult problem, however, since the sample analyzed by Lightner and Marti (1) was a collection of several small chips while we were able to incorporate comparable amounts of atmospheric gases into 60015 only by crushing to a very small particle size. However, we emphasize that arguments based on high extraction temperatures and non-atmospheric elemental ratios should no longer be used to rule out atmospheric contamination as a possible source of terrestrial-type Xe in lunar samples.

REFERENCES


Fig. 1. Elemental ratios of trapped rare gases in lunar rocks with terrestrial-type Xe. The 60015 points "A" and "B" are for 60015,73A (2) and for the three 60015,73B samples analyzed in the present work. For explanation of other data points and fields, see Fig. 6 of reference (2).