Krypton and xenon from a large coherent white clast and the low metamorphic grade matrix of lunar breccia 14307 were analyzed by the step-wise heating technique. Drozd et al. (1) reported that both contain fission xenon in excess of that expected from the spontaneous fission of $^{238}$U. It has now been determined that the fission xenon in the clast and possibly the matrix is due to the neutron-induced fission of $^{235}$U (2,3). The large size of this effect in the clast requires that it has been near the lunar surface for a substantial fraction of its history. The presence or absence of similar neutron effects in the matrix can be used to determine whether the breccia was formed early in lunar history or relatively recently.

Figure 1 is a standard light isotope correlation diagram for the xenon data of 14307-clast. The data for temperature fractions below 900°C lie on a line which is consistent with the interpretation of mixing between a trapped component and a single spallation component. The data above 1000°C do not lie on a single line through the trapped component, indicating multiple spallation components. When the high temperature points are compared with known spallation components determined from other lunar samples, they appear to be pure spallation with little, if any, trapped gas present.

Figure 2 is a three-isotope correlation diagram of the fission isotopes of xenon; the lines are drawn arbitrarily (in the direction of the spallation component) through (0.18,0.265) and the respective fission components. The high temperature points lie close to the line connecting spallation and neutron-induced fission of $^{235}$U; clearly this line does not go near the trapped component (BEOC 12), indicating no trapped xenon in those fractions. Thus the high temperature fractions seem to be a two-component mix of spallation and fission. From the measured U concentration of 4.65 ppm in the clast (4), and an assumed age of 3.95 AE, one can predict that 6% of the measured $^{136}$Xe should be due to spontaneous fission of $^{238}$U with the remainder due to neutron fission of $^{235}$U. This corresponds to a predicted $^{134}$Xe/$^{136}$Xe fission ratio in the clast of 1.223.

Figure 3 is a correlation diagram with three components nominally present: fission ($^{134}$Xe and $^{136}$Xe), spallation ($^{130}$Xe and $^{134}$Xe), and trapped (all). Since there is little or no trapped xenon in the high temperature fractions of 14307-clast, the system reduces to one of only two components, spallation and fission. Spallation can be eliminated by extrapolating along the correlation line through the high temperature points to $^{130}$Xe = 0, yielding the $^{134}$Xe/$^{136}$Xe ratio in fission. This ratio is $1.214 \pm 0.015$, in agreement with that predicted above, implying that $(0.14 \pm 0.06) \times 10^{-10}$ cm$^3$ STP/g $^{136}$Xe is due to $^{238}$U fission and $(1.57 \pm 0.06) \times 10^{-10}$ cm$^3$ STP/g $^{136}$Xe is due to $^{235}$U neutron fission. A fission rate of 3.4 fissions/sec·g of $^{235}$U was obtained from the Apollo 17 Lunar Neutron Probe.
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Experiment (5) at a depth of 150 g/cm² (the peak of the fission rate profile). Assuming the clast had remained at that depth until the present, it would take ~3 AE to accumulate the measured fission $^{136}$Xe. Since the clast is presumably not older than >4 AE, it must have remained near the surface of the regolith for a long period. If the fission were due to thermal neutrons only, a fluence of $1.3 \times 10^{17}n/cm^2$ would be necessary to account for the measured fission $^{136}$Xe. Since fission by neutrons of higher energy will be important in a lunar sample (6,7), the above fluence should be regarded as approximate; however, even after correction it will be among the highest measured in a lunar sample (6).

Further support for a heavy neutron irradiation of 14307-clast comes from the examination of anomalies at $^{86}$Kr, $^{82}$Kr, and $^{128}$Xe, due to capture reactions on $^{79}$Br, $^{81}$Br, and $^{127}$I, respectively. Concentrations of Br and I based upon the neutron fluence obtained from uranium fission are 257 ppb and 18.5 ppb, respectively. These agree well with concentrations found in other Apollo 14 gas-rich breccias (8).

The trapped xenon content of the matrix of 14307 is 20 times that of the clast and is typical of other gas-rich Apollo 14 breccias (8). Because the xenon is dominated by trapped gas, it is difficult to determine an accurate fission excess. Assuming that spallation $^{126}$Xe/$^{130}$Xe = 0.95 ± 0.15 implies that $(0.7 ^{+0.4}_{-0.3}) \times 10^{-10}cm^3STP/g$ of excess fission $^{136}$Xe exists in the >1100°C temperature fractions of the matrix. It is difficult to determine if this excess is due to $^{235}$U neutron fission. There are no obvious neutron capture anomalies at $^{80}$Kr, $^{82}$Kr, or $^{128}$Xe because the low temperature fractions (<600°C) of the matrix are relatively enriched in spallation with respect to the intermediate (700°C-1100°C) fractions (Fig. 4), obscuring the possible neutron effects. If the excess fission $^{136}$Xe is due to the neutron-induced fission of $^{235}$U, the matrix received a neutron fluence 0.65 ± 0.36 times that of the clast.

If the matrix did not experience the same neutron irradiation as the clast, then, given the long exposure to neutrons of the clast, 14307 must have brecciated after the clast existed in some coherent form. On the other hand, if both experienced the same irradiation, then it is likely that the breccia formed >3 AE ago. For the latter case, the normal cosmic ray exposure ages of the clast and matrix should be the same. This appears to be the case for other clasts and the matrix of 14307 with reported exposure ages of ~180 my (9,10). Our clast has an apparent $^{81}$Kr-Kr age of 610 my and approximately the same concentration of spallogenic $^{126}$Xe as the matrix. The Kr age does not reflect the true period of time which the sample was exposed to cosmic rays since it has had at least a two-stage irradiation history, nor do the similar concentrations of spallogenic $^{126}$Xe imply the same exposure since target element abundances are unknown and possibly different. Thus, the rare-gas studies are not conclusive.
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about the time of brecciation of 14307; investigation of neutron capture effects in Gd or Sm should determine if the clast and matrix experienced the same neutron irradiation.

REFERENCES


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