FISSION TRACK RECORD OF APENNINE FRONT KREEP BASALTS

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Lunar KREEP components are present in many lunar materials, and the location, age, and nature of the primary source is of great interest to investigators of lunar evolution. Fragments of primary KREEP basalt are found in soils collected at the base of the Apennine Front. Particle track studies may be used to investigate the distribution of the actinide elements among mineral phases of such materials, and provide information on their crystallization and radiation histories. At the Fifth Lunar Science Conference we reported on observations of large and variable fission track densities (>10⁹ cm⁻²) in primary KREEP basalt fragments from the Apennine Front (1). We concluded that the excess track component was about eight times greater than the ²³⁸U spontaneous fission component, and that if this excess was due to ²⁴⁴Pu spontaneous fission, then the initial Pu/U varied greatly from one whitlockite grain to another. Because of our wish to measure the Th/U ratios of the individual grains by a fission track method then being developed, we had not yet carried out the etching experiments required to verify that the features observed in plastic replicas were indeed fission tracks, experiments which would destroy the phosphates. Since that time we have successfully measured the Th/U ratios of the whitlockites with limited accuracy. We have also carried out experiments which conclusively prove that the features are fission tracks, and which suggest that the fission track densities are even higher than we reported earlier (1).

The Th/U ratios were determined by combining two independent experiments. In the first the polished sample was irradiated by thermal neutrons which induce fission in ²³⁵U. In the second the sample was irradiated by fast neutrons produced by 800 MeV protons in the beam stop of the Los Alamos Meson Physics Facility (LAMPF). Fast neutrons induce fission in ²³⁸U and ²³²Th. Mica detectors recorded fission tracks from each whitlockite grain in each experiment. Simultaneous equations relating the track densities in the two experiments were solved for the Th/U ratio of each grain (see table). The large uncertainties of these ratios are due mostly to counting statistics - low track densities due to low beam intensities at LAMPF. (When LAMPF resumes operation in mid-1975 its beam is expected to be 100 times more intense.) Thermal neutron contamination of the fast flux increased the uncertainty by increasing the U fission rate. This effect makes the solution matrix more nearly singular and the statistical error is multiplied in the Th/U ratio. The thermal contamination will be controlled in future experiments.

To establish the authenticity of the fossil fission tracks observed in the whitlockite grains, we etched the neighboring plagioclase crystals, destroying all phosphates and mesostases in the process. Tracks were
FISSION TRACKS IN KREEP BASALT

Haines, E. L. et al.

revealed by etching in a boiling solution of 6g NaOH in 20g H2O for 20 min., and observed on plastic replicas by means of a scanning electron microscope. Plagioclase crystals showed a uniform background density caused by galactic cosmic rays. Where a plagioclase crystal was in contact with a whitlockite grain, the track density within about 10μ of the boundary displayed a clear gradient, increasing sharply up to the plagioclase/whitlockite interface. The existence of this gradient proves that a source of tracks exists inside the whitlockite grain and does not extend into the plagioclase. This source can only be fissioning U, Th, and perhaps Pu. If the tracks were due to cosmic rays or shock, alone or in combination, this gradient would not exist. What is more, the strength of the fission source may be estimated by comparing the density observed near the plagioclase/whitlockite boundary with the uniform background density. Because the plagioclase at the boundary is exposed to only one hemisphere of fissionable material, the difference between these densities represents one-half of the fission track density expected well inside the whitlockite.

Two features of the density gradients deserve attention: 1) the densities at the crystal boundaries are higher than we would expect from our earlier observations in whitlockite, and 2) the gradients vary from grain to grain. The second feature can be understood in terms of the dip of the whitlockite/plagioclase interface with respect to the plane of the polished surface. The first feature may be understood retrospectively when we consider that plagioclase is less susceptible to thermal fading than whitlockite. What is more, the whitlockite grains were etched very lightly (0.1 N HNO3 for 10 sec. at 25°C) and the tracks may not have been fully developed.

In order to arrive at the excess track densities for four whitlockite grains, we have subtracted from the observed plagioclase densities (projected to the whitlockite interior) the measured and calculated contributions from all known sources of tracks. These contributions include the directly measured cosmic ray densities, reactor and lunar neutron induced fission of 235U, cosmic ray induced fission of 232Th and 238U, and spontaneous fission of 238U. With these contributions subtracted the excesses range from 1.8 to 8.0 x 10^9 cm^-2, compared with the previously measured excesses of 0.3 to 1.5 x 10^9. If we assume that the excess density is due to the spontaneous fission of 244Pu, then dividing the excess by the calculated 238U spontaneous fission density provides a measure of the variation in Pu/U because all the whitlockite grains have the same age. This ratio ranges from 4 to 29.

The usual explanation of such large track excesses is the presence of 244Pu in near-meteoritic abundances and a very great age. However, other investigators have measured 40Ar/39Ar release ages (2, 3) and Rb/Sr internal isochron ages (4) of primary KREEP fragments from the Spur Crater station, and report ages near 3.9 Gy. It is difficult to see how such similar
FISSION TRACKS IN KREEP BASALT

Haines, E. L. et al.

fragments residing only 300 meters away from the 15272 fragment could have entirely different histories. On the other hand, if the age of the 15272 fragment is about 3.9 Gy, improbably high initial ratios of Pu/U would be required to produce the observed track excesses. The origin of these track excesses must remain unresolved until the fission track record of a KREEP fragment of known age has been unfolded.

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<table>
<thead>
<tr>
<th>Sample</th>
<th>U (µg/g)</th>
<th>Th/U</th>
<th>(\rho(\text{obs'd at plag. boundary}))</th>
<th>(\rho(\text{cosmic rays}))</th>
<th>(\rho(\text{total fission in whit.}))</th>
<th>(\rho(\text{known fission comp.}))</th>
<th>(\rho(\text{Ratio}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>15272</td>
<td>70±7</td>
<td>14±10</td>
<td>2.7</td>
<td>0.62</td>
<td>4.2</td>
<td>0.64</td>
<td>3.5  22</td>
</tr>
<tr>
<td>33D</td>
<td>120±12</td>
<td>9±6</td>
<td>5.2</td>
<td>0.75</td>
<td>8.9</td>
<td>0.92</td>
<td>8.0  29</td>
</tr>
<tr>
<td>33FA</td>
<td>200±45</td>
<td>11±7</td>
<td>2.5</td>
<td>0.75</td>
<td>3.5</td>
<td>1.68</td>
<td>1.8   4</td>
</tr>
<tr>
<td>33FG</td>
<td>148±46</td>
<td>12±12</td>
<td>3.2</td>
<td>0.75</td>
<td>4.9</td>
<td>1.28</td>
<td>3.6   11</td>
</tr>
</tbody>
</table>

All track densities (\(\rho\)) in units of \(10^9 \text{ cm}^{-2}\)

**Ratio** refers to \(\rho(\text{excess})/\rho(\text{spon. fis. }^{238}\text{U for 3.9 Gy})\)