EXCESS FISSION TRACKS IN APENNINE FRONT KREEP BASALTS

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Whitlockite grains from two small Apennine Front KREEP basalt fragments have been found to contain extremely high densities of fission tracks. The observed track densities exceed the contribution from spontaneous fission of ^{238}U by factors ranging from ~ 6 to 20 times. Track excesses are not correlated with the measured uranium contents of individual phosphates. This behavior suggests large variations in the Pu/U ratios among phosphates within a single basalt fragment.

The apparent upper limit on crystallization ages of lunar rocks of 4 Gy has been interpreted as the result of the wide distribution of material excavated during the Imbrium impact or as the termination of very heavy meteorite bombardment. The Apennine Front appears to have been uplifted during or subsequent to the Imbrium event, e.g. as a crater rim or subsidence scarp. As such, the Front may contain material crystallized before the Imbrium event whose track record was not erased during the uplift.

Our whitlockite grains were found in basalt fragments selected from the 1-2 mm size fraction of soil 15272 (station 6) recovered from the Apennine Front. Three hundred nineteen fragments were originally selected from eight Apollo 15 and 16 soils for mounting, polishing, and microprobe examination. Only twenty of these fragments contained phosphates of adequate size ($\gtrsim 40\mu$ large dimension) and only two fragments, both KREEP basalts, had phosphates with decipherable fission track records. Tracks were revealed in the whitlockites by etching with 0.1% HNO_3 for 10 sec. Tracks typically 0.5 - 1.0μ in length were counted on plastic replicas of the grains with a scanning electron microscope (SEM). Track densities in the 15 whitlockites studied varied from $13.4 \times 10^8/cm^2$ to $\gtrsim 60 \times 10^8/cm^2$ and were generally uniform. Areas with large gradients or poorly developed tracks were not analyzed. Tracks were also revealed in accompanying apatite grains (after longer etching times) but were heterogeneously distributed and exhibited large and irregular variations in track length. We attribute this behavior to thermal annealing in apatite. Uranium concentrations of individual phosphates were measured by fission track activation before etching, and electron microprobe analyses were performed on newly polished surfaces after etching. A summary of track data for 8 whitlockite grains is presented in Table I.

Two aspects of the particle track record are apparent and merit special attention: (1) The observed track densities (ρ_{obs}, column c in Table I) are extremely high, about an order of magnitude higher than track densities in typical lunar phosphates. (2) The observed track densities in individual phosphate grains <u>do not</u> correlate with the respective uranium contents. The normalized ratios (column d) vary by a factor of ~ 4 among the grains within one fragment.

To obtain the track density excess in these unique samples, we subtracted the contributions of all known sources (column e) from ρ_{obs}. The density of heavy cosmic rays was measured in U-poor plagioclase lathes in a sister grain. It varies from $\lesssim 1 \times 10^8/cm^2$ at the center of a 1 mm grain to $\sim 4 \times 10^8/cm^2$ 70 μ from the surface. No phosphate listed in Table I was closer than ~ 70μ from the surface. Spallation was estimated to be $\lesssim 3 \times 10^8/cm^2$ from the ^{38}Ar exposure age of a similar soil fragment (1). Reactor induced fission was measured but insignificant. The contributions from thermal neutron-induced fission of ^{235}U and high energy cosmic ray induced fission of ^{232}Th and ^{238}U are more difficult to estimate due to uncertainties in the exposure history of our soil fragments and in the Th/U ratio in whitlockite (2). The observed track record cannot be dominated by any source whose contribution is proportional to the uranium concentration. Thus, barring unexpectedly large values for the Th/U ratio (~100) or a very long exposure history (~ 4 Gy), induced fission cannot account for the observed track density. Similarly the record cannot be dominated by a source which is uniform throughout the rock. The normalized track excesses remaining after the subtraction of these contributions (column f) vary by an order of magnitude. The most conservative position we may take is that the entire ρ_{obs} for the two whitlockites with lowest excesses, 33A and 33FA, is due to known sources. We define these two excesses ≡ 0 and calculate a uranium correlated and an uncorrelated source (column g). The normalized excesses thus derived (column h) range from ≡ 0 to 13.

Normalized track excesses average ~ 8, or ~ 7 for the conservative position, which may be compared with a normalized excess of 0.5 in 14321 reported by Hutcheon and Price (3). The magnitude of the excess is suggestive of a substantial contribution from the spontaneous fission of ^{244}Pu. If we postulate an initial Pu/U = 0.02, the average excess is consistent with a track retention age for these fragments of 4.3 Gy.

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(1) A. Stettler et al, Proc. 4th LS Conf. 2, 1865 (1973).
(2) D. Burnett et al, Proc. 2nd LS Conf. 2, 1503 (1971).
(3) I. D. Hutcheon and P. B. Price, Science 176, 909 (1972).

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Table I

Sample 15272	a U $\mu g/g$	b ρ^U_{sf} *	c ρ_{obs} *	d $\frac{\rho_{obs}}{\rho^U_{sf}}$	e ρ_Σ *	f $\frac{\rho_{xs}}{\rho^U_{sf}}$	g ρ'_Σ *	h $\frac{\rho'_{xs}}{\rho^U_{sf}}$
33A	81±11	2.00	13.4	6.7	10.4	1.50	≡13.4	≡0
33D	70± 7	1.73	18.7	10.8	9.5	5.0	12.0	3.8
33FA	120±12	2.96	18.2	6.1	13.8	1.49	≡18.2	≡0
33FB	63±14	1.55	>25	>16	8.9	>10.4	11.1	>8.9
33FE	138±31	3.38	>60	>18	15.3	>13.2	20.4	>11.7
33GA	42± 8	1.02	21.9	21.5	7.1	14.5	8.5	13.1
33GC	58± 7	1.43	22.5	15.7	8.5	9.8	10.5	8.4
35A	51± 5	1.25	20.5	16.4	7.9	10.1	9.6	8.7

*Track density in units of $10^8/cm^2$