Fission Track Ages of Mica Minerals

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Price and Walker [1] and also Fleisher et al. [2,3] discussed the origin and nature of fossil fission tracks in natural mica samples and attributed them to the spontaneous fission of Uranium-238. The distribution of these spontaneous fission tracks in these samples could be studied by selective etching and counting in an optical microscope and these data were successfully used for the determination of their solidification ages. The fission track ages, determined by Fleischer et al. [2] for several varieties of mica samples agreed reasonably well with the K—Ar ages and Pb—P ages of these samples in some cases but disagreed considerably in other sets of samples. This stiuation appeared interesting and it is thought worthwhile to have an independent check on the correlation of ages determined by fission track counting method and by other radioactive decay methods.

Experimental

Freshly cleaved mica samples from Bancroft, Ontario; Faraday Township, Ontario; Keystone, South Dakota and Magnet Cove, Arkansas, having a thickness of $\approx 20\ \mu m$ and an area of 1 cm^2 are selectively etched with 12—24% hydrofluoric acid till the characteristic features of the fission tracks are clearly developed in these samples. These fossil damage trails were counted in a Zeiss Universal Photomicroscope, equipped with "Nomarski" phase-contrast and interference-contrast optical system, at a magnification of 400×. Each sample needed about 6 hours for complete scanning and it was scanned twice to avoid manual errors. The average value (P_s) of the spontaneous fission track density determined for each sample is given in Table 1.

In order to determine the induced fission track density due to U^{235}, the samples were sealed in quartz ampoules and were irradiated in the Swimming Pool Reactor of the University of Missouri at Rolla at an integrated thermal neutron flux of $\approx 10^{16}$ neutrons/cm^2, along with both gold and uranium monitors. U^{235} undergoes thermal neutron-induced fission and gives rise to a new generation of freshly created fission tracks. The samples were re-etched with HF under the same conditions as before and the new generation of fission tracks were counted in the optical microscope. The correction due to the fast neutron induced fission contribution to thermal neutron induced fission was found to be $< 4\%$. The average value of induced-fission track density ($2 P_i$) measured in each sample is given in Table 1.

Sample type and location	Sample No.	P_s	$2 P_i$	Fission track age (10^6 y)	Estimated age of the region (10^6 y)
Biotite-A	1 a	915	4897	170	
(Bancroft,	1 b	1049	4367	188	≈ 1000
Ontario)	1 c	1368	5151	226	[Wetherill [6]]
	2 a	1532	4734	308	
			Average	223 ± 20	
Biotite-B	2 a	1743	6391	279	
(Bancroft,	2 b	1706	6214	297	
Ontario)	2 c	1541	6143	233	≈ 1000
	2 d	894	3896	220	
	2 f	1364	5314	239	
	2 g	1076	4311	233	
			Average	248 ± 25	
Biotite	3 b	74	2044	35	
(Magnet Cove,	3 c	89	1230	70	96
Arkansas)	3 d	99	2021	48	[Ericson and
			Average	50 ± 10	Blade [5]]
Lepidomalane	4 a	1363	12830	103	
(Faraday	4 b	1480	12601	112	≈ 1800
Township,	4 c	743	8491	84	[Wetherill [6]]
Ontario)	4 d	961	21371	50	
			Average	87 ± 20	
Muscovite	5 b	91	7883	11	
(Keystone,	5 c	952	19001	49	
South Dakota)	5 d	201	10865	18	≈ 1500
	5 e	111	5954	18	[Wetherill [6]]
	5 f	114	4539	25	
	5 g	151	5996	25	
			Average	24 ± 8	

a) Except 5 b—5 g, the rest of the samples were etched with 12% HF for one minute at 25 °C. Samples 5 b—5 g were etched with 24% HF for 2 hours at 25 °C.
b) The thickness of the samples were $\approx 20\ \mu$.
c) Biotite-B from Bancroft, Ontario contained some quartz impurities.

Table 1. Fision track ages of several mica samples.

In order to determine the neutron flux (Φ) to which the maca samples were exposed in the reactor, the Au monitor was gamma-counted with a NaI(Tl) crystal, using Nuclear Data 512-channel analyser (dead-time losses $< 2\%$). The area under the photopeak 0.412 MeV was used to calculate the absolute disintegrations per sec by standard methods and the thermal neutron

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flux was calculated. Also, Mo^{99} was radiochemically isolated from the U-monitor and it was beta-counted using and end-window gas-flow proportional counter. The neutron flux calculated by both these methods are in good agreement. An average value of 1.33×10^{12} neutrons/cm^2/sec was used for the neutron flux (Φ) in the calculations given below.

The ratio of spontaneous fission tracks (P_s) to the induced fission tracks ($2\,P_i$) is a function of the age of the mica mineral and using the following equation, the age, T, of the micas are calculated.

$$\frac{P_s}{2\,P_i} = \frac{\lambda_f}{\lambda_f + \lambda_\alpha}\,[e^{(\lambda_f+\lambda_\alpha)\,T} - 1] \cdot \frac{1}{\Phi\,\sigma\,I\,t}$$

where λ_f = spontaneous fission decay constant, RAO and KURODA [4],
λ_α = alpha-decay constant of U^{238},
σ = thermal neutron induced fission cross-section for U^{235},
$I = U^{235}/U^{238}$ isotope ratio today,
t = total time of reactor irradiation.

By using the $P_s/2\,P_i$ ratio, the uncertainties in the fission fragment ranges and the etching effeciencies of the mica samples are eliminated.

Results and Discussion

The ages obtained for several micas are given in Table 1. For comparison, the estimated ages of the regions from which the samples were collected were also given in Table 1. The details about the etching conditions and sample thicknesses are given below the table.

The biotite from Magnet Cove, Arkansas yielded a solidification age of $\approx 10^8$ years by the fission track counting method. Of those samples studied here, the muscovite from Keystone, South Dakota seems to be the youngest, having an age of $\approx 25 \times 10^6$ years. On the other hand, the biotite from Bancroft, Ontario and the lepidomalane from Ontario appear to be old samples which yielded about $\approx 225 \times 10^6$ years and $\approx 90 \times 10^6$ years, respectively.

The solidification age for the Magnet Cove biotite was independently determined by the K – Ar method to be $\approx 95 \times 10^6$ years [ERICKSON and BLADE [5]]. The sample used in this work was the same sample used for K – Ar dating. The close agreement between the fission-track counting method and K – Ar method in determining the age of this sample is good.

Also, FLEISCHER et al. [2] studied the biotite samples from Bancroft, Ontario and found a solidification age of 355 ± 40 million years. In this work, the biotite samples from the same region yielded an average age of ≈ 225 million years. Within experimental errors, the agreement between the ages from this work and those of FLEISCHER et al. [2] is good. However, it needs to be pointed out that the estimated age of this region (by Pb – Pb dating) is about 10^9 years and is well above the values obtained here.

The fission track ages for muscovites from Keystone, South Dakota and for lepidomalane from Faraday Township, Ontario are not available to us in literature so that a comparison could be made. However, the estimated age for Faraday Township, Ontario is about 1800 million years and it is well above the fission track age found here. The case is similar with Keystone, South Dakota.

One interesting conclusion seems to be apparent in this study. In case of relatively young biotite ($T \approx 10^8$ y) from Magnet Cove, Arkansas, the fission track ages agreed very wel with the K – Ar ages, whereas in case of relatively old ($T \approx 10^9$ y) micas – biotite from Bancroft, Ontario and lepidomalane from Faraday Township, Ontario, the fision track ages are comparatively lower to the K – Ar ages estimated for these regions. Also, FLEISCHER et al. [2] found that several old lepidolites (Africa) and some muscovites (Canada) yielded considerably smaller fission track ages than ther ages of $\approx 10^9$ years, obtained by other radioactive decay methods. This discrepancy seems to be related to the fading of fission tracks at relatively high temperatures. If the samples were subjected to relatively high temperatures for long times ($\sim 10^6$ years) or suddenly if the environmental temperatures raised very high, at some stage in the thermal history of the sample, it is possible that the fission tracks could be easily annealed. The experimental data indicate that in case of young samples ($T \approx 10^8$ y) the track-fading effect seems to be negligible whereas in case of old micas, the track-fading seems to have played a key role.

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