FISSION-TRACK AGES OF INDIAN MICAS

S. S. KERE
Department of Physics, Indian Institute of Technology, New Delhi-29 (India)

INTRODUCTION

MANY natural micas contain a large background of charged particle tracks which were first observed by Price and Walker in an electron microscope study of the mineral.[1] Considering various possible origins for the tracks they showed that the most likely source is the slow, spontaneous fission of the U-238 isotope of uranium present in traces.[2] They can be rendered visible under the optical microscope by etching the mica with hydrofluoric acid.[3] The age of the mineral can be determined from the density of such fossil tracks, and of uranium atoms in the mineral.[2] Various minerals have been dated using this method.[4-6]

The author has found fossil fission-tracks in three samples from the Nellore mica belt, Andhra Pradesh, and applied this method of dating to two of them from Gudur. Since these tracks anneal out at temperatures above some 200° C., such dating only gives a lower limit to the age of the mineral. This limit of about 500 million years for the samples studied is to be compared to the estimate of about 1,570 million years obtained for this region by other methods.[9]

THEORY

In brief, the theory of fission-track dating as presented by Price and Walker[2] is as follows: Let ρ_s be the density of background tracks due to spontaneous fission of U-238 on a freshly cleaved and etched surface of mica. The U-content of the mineral can be accurately determined by exposing it to a known dose of thermal neutrons, and measuring the density ρ_i of the fresh tracks produced by induced fission of U-235. From the ratio ρ_s/ρ_i one can determine the age A, assuming that the isotopic ratio of U-235/U-238 in the mica is the same as that in natural uranium. For specimens younger than a billion years the relation simplifies to

$$\frac{\rho_s}{\rho_i} = \frac{A\lambda_f}{n\sigma I}$$

where λ_f = Decay constant for spontaneous fission of U-238 ($6 \cdot 85 \times 10^{-17}$ year^{-1});

σ = Cross-section for thermal neutron-induced fission of U-235 (582×10^{-24} cm.^{2});

I = Isotopic ratio U-235/U-238 ($7 \cdot 26 \times 10^{-3}$);

n = Total thermal dose of neutrons. (It is $9 \cdot 15 \times 10^{16}\ n$/cm.^{2} in this experiment.)

EXPERIMENT

A muscovite and a biotite from Gudur, Andhra Pradesh, were examined. The small pieces were about 1 sq. cm. in area, and 40-60 μ in thickness. They were cleaved into nearly equal slices and their internal surfaces were etched (Table I) with HF acid at room temperature. They were area-scanned under high magnification (1,500 ×) to determine ρ_s.

TABLE I

Sample	Etch before irradiation	Etch after irradiation	ρ_s/cm.^{2}
Biotite (Gudur)	1 min. in 20% HF at 32° C.	1 min. in 20% HF at 30° C.	$2 \cdot 10 \pm 0 \cdot 09 \times 10^3$
Muscovite (Gudur)	30 min. in 40% HF at 34° C.	1 hr. in 40% HF at 30° C.	$2 \cdot 48 \pm 0 \cdot 35 \times 10^2$

The following facts in confirmation of earlier results were noted[2,3,8]

(*i*) The track-length is typically $\sim 10\,\mu$.

(*ii*) The track-width is proportional to the etching time at a given temperature and a given concentration of acid.

(*iii*) The etching rate is very sensitive to temperature and increases rapidly with it.

(*iv*) It is much easier to etch biotite than muscovite.

The density of background tracks in the muscovite was found to be less than that in the biotite by an order of magnitude. But preliminary examination of a greenish track-density in this muscovite is of the same order, *i.e.*, $\sim 10^3$/cm.^{2}, as in the biotite studied.

EXPOSURE

After scanning for background tracks the two halves of each specimen were put together, wrapped in an aluminium foil, and exposed in a reactor to a dose of about 10^{17} neutrons. This dosage was chosen so as to make the ratio $\rho_i/\rho_s \sim 10$, assuming the geological age of the specimens to be about 500 million years, from the dating results for the mineral from other parts of the world.[4-8] After irradiation, the specimens were etched out for a proper time, and their internal surfaces were area-scanned for induced tracks.

In the muscovite, the two counts were made on different pieces which came from adjacent portions of a bigger piece. In the biotite, the etching conditions before and after irradiation were nearly the same. It was found that the background tracks were twice as wide as the new ones, since the former had been etched for twice as long. Thus simultaneous track-count could be made for ρ_s and ρ_i over the same area.

Dating Results

The ρ_i data and results are presented in Table II. The atomic concentration of uranium was calculated from the formula:

$$C_u = \frac{1}{N_0 R_0 \sigma I}\left(\frac{\rho_i}{n}\right)$$

where N_0 = number of atoms/cm.[3] in mica; where R_0 = range of fission fragments in mica ($\sim 10\,\mu$).

Table II

Age and uranium concentration of mica

Specimen	ρ_s/cm.^{2}	ρ_i/cm.^{2}	A 10^6 yrs.	Cu atom/atom
Biotite (Gudur)	$2 \cdot 10 \pm 0 \cdot 09 \times 10^3$	$2 \cdot 405 \pm 0 \cdot 047 \times 10^4$	494 ± 24	2×10^{-8}
Muscovite (Gudur)	$2 \cdot 48 \pm 0 \cdot 35 \times 10^2$	$3 \cdot 385 \pm 0 \cdot 240 \times 10^3$	411 ± 65	3×10^{-9}

The errors quoted in Table II are statistical errors due to the counting of a finite number of fission-tracks.

Discussion

I note that the ages of the two varieties from the same location are consistent with each other. The age of pegmatites in the region has been determined to be 1,570 million years by other methods.[9] Ages determined by the fission-track method tend to err on the young side when compared to other radioactive dating results.[4-8] This is a consequence of track-fading at high ambient temperatures. It has been estimated that at about 145° C. tracks in muscovite would be stable over the entire age of the earth, while at about 200° C. they would be stable for only a million years.[4] Hence our dating result gives the time since the mica cooled down to a temperature in the neighbourhood of 145° C. The results seem to indicate that this cooling has taken about a billion years; and also they set a lower limit to the age of the pegmatites of the Nellore mica belt.

Acknowledgements

I should like to thank Dr. S. Lokanathan, Physics Department, for his advice and criticism. I am grateful to Prof. W. E. Duncanson, formerly Head of the Physics Department, for suggesting the problem, and making this work possible. I am indebted to Dr. P. Kumar, Department of Civil Engineering, for giving us his laboratory mica specimens for dating, and for helpful discussions. My thanks are due to the Atomic Energy Establishment, Trombay, for irradiation of the samples in their Apsara reactor.

1. Price, P. B. and Walker, R. M., *Nature*, 1962, **196**, 732.
2. — and —, *J. Geophys. Res.*, 1963, **68**, 4847.
3. — and —, *J. Appl. Phys.*, 1962, **33**, 3407.
4. Fleischer, R. L., Price, P. B., Symes, E. M. and Miller, D. S., *Science*, 1964, **143**, 349.
5. — and —, *Geochim. Cosmochim. Acta*, 1964, **28**, 1705.
6. —, — and Walker, R. M., *J. Geophys. Res.*, 1964, **69**, 4885.
7. — and —, *Phys. Rev.*, 1964, **133 B**, 63.
8. Maurette, M., Pellas, P. and Walker, R. M., *Bull. Soc. France Miner. Crist.*, 1964, **87**, 6.
9. Holmes, A., *Proc. Geol. Assocn. Canada*, 1955, **7**, 81; quoted in M. V. N., Murthy's *Mica Fields of India* (Internat. Geol. Congress, 22nd Session, India, New Delhi, 1964).