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Fission track annealing and age determination of hornblende

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Abstract. Hornblende which occurs in igneous and metamorphic rocks is well suited for age determination by the fission track method. The tracks which are readily etched in hydrofluoric acid are annealed in 1 hr at 530° C. Extrapolation of the experimentally determined temperatures suggest that a temperature of 200° C for one m.y. will erase all the tracks present before the heating. Fission track ages of hornblende agree with the main orogenic metamorphic cycles.

Keywords. Fission track annealing; age determination; hornblende.

1. Introduction

Fission track geochronology introduced by Fleischer and Price (1964) and developed by Fleischer *et al* (1964), Naeser (1967), Mehta and Rama (1969), Naeser and Faul (1969), Mehta and Nagpaul (1970), Gupta *et al* (1971) and Burnett *et al* (1971), is an inexpensive tool for dating terrestrial and extra-terrestrial minerals and glasses. But fission track ages, in general, are found to be either lower or at best equal to other radiometric ages. High thermal sensitivity of the tracks is responsible for the discrepancy. An extensive study of minerals like mica, zircon, sphene, apatite, epidote and glasses has already been reported but only a few samples of hornblende have been studied (Fleischer and Price 1964). This paper presents the results of track annealing experiments on hornblende and describes its usefulness for fission track dating.

2. Experimental technique

A thin section of the specimen is prepared along the plane m (110) (Nagpaul *et al* 1974). The thin section is etched in 48% HF at 60°–70° C for a time varying from 20–30 sec. The tracks are revealed in an optical microscope only when the specimen is etched along the plane m (110). A photomicrograph of the tracks in m (110) plane is shown in figure 1.

Annealing experiments—For successful annealing, the sample should have (*a*) well defined m (110) plane, and (*b*) uniform distribution of uranium which can be verified by etching and rough scanning of fossil tracks for a number of thin sections. In the present study, the hornblende sample which fulfilled these criteria was of the green variety collected from Sidha Valley, Karnataka State. The grains of the sample were heated at 600° C for 12 hr for complete erasure of fossil tracks, and

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Figure 1. Fission tracks in hornblende (Etched for 25 sec at 60° C in 48% HF)

then irradiated in CIRUS Atomic Reactor at Trombay with a dose of thermal neutrons ranging from 10^{16} to 10^{17} nvt. Thin sections of these samples were etched and scanned for induced tracks.

The annealing procedure used by Naeser *et al* (1969 *b*) was modified by sandwiching the thin section between two aluminium strips (1″ × 1″) smoothly fixed by means of screws, as no epoxy resin can stand the high temperatures used. This way the thin sections remained in their respective positions and could be remounted easily. The pair of strips was placed on an iron block in a furnace whose temperature could be controlled within ± 5° C. Temperatures were monitored with a thermocouple that was inserted into a hole in the block. The annealing temperature ranged from 420° to 540° C at an interval of 30° C in each step. At each temperature the samples were heated for different times, ranging from a few minutes at high temperatures to several hours at low temperatures. In each case track density of repolished and etched samples was determined. The percentage of tracks faded after each run at a fixed temperature versus log of time are drawn in figure 2. Figure 3 shows the annealing data of hornblende plotted on an Arrhenius diagram. Individual points on this graph represent 0%, 25%, 50%, 75% and 100% track reductions determined at various temperatures corresponding to different times of figure 2. The data are extrapolated to geologically significant times and temperatures.

Determination of ages—Fission track ages of four samples of hornblende from pegmatites were determined by the technique followed by Mehta *et al* (1970), with a slight modification in the method of preparing thin sections as mentioned earlier.

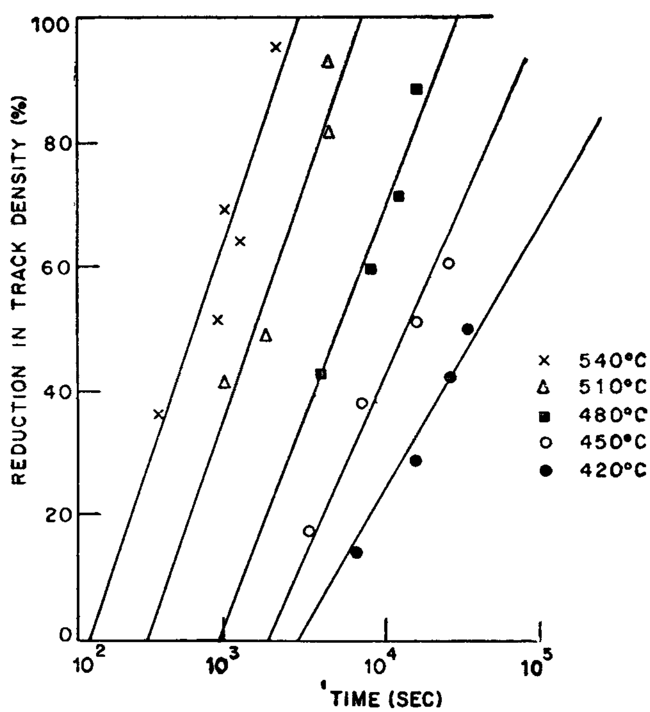

Figure 2. Experimental results for annealing of fission tracks in hornblende.

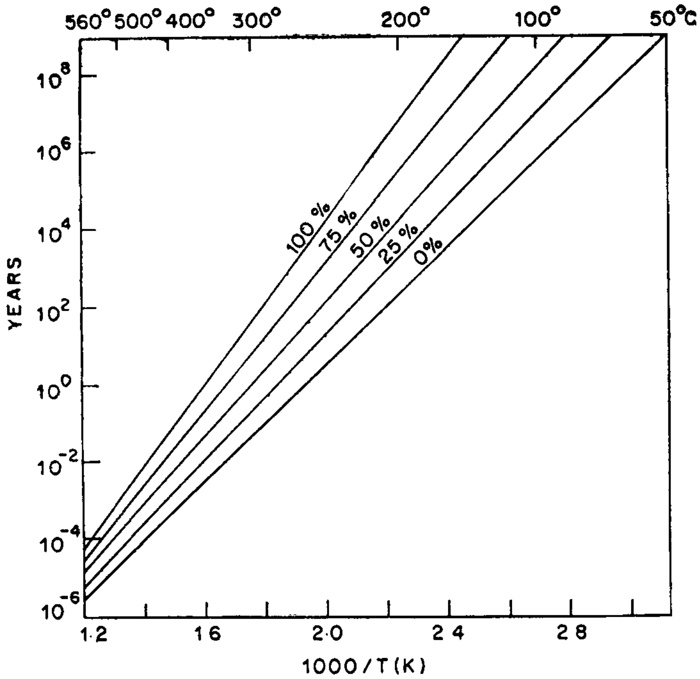

Figure 3. Arrhenius plots for hornblende.

Since the size of the sample available was too large to be handled singly, a number of transparent thin sections were made from a single grain of size 0·5 to 5 mm. They were etched and the densities of tracks were determined under total magnification of 1,500 x. The number of total fossil tracks in sample HR was found to be low and hence it was again grinded, polished and etched for the track counting in order to make the results statistically significant.

After determination of fossil track densities, the samples were exposed to thermal neutrons in CIRUS Atomic Reactor at Trombay and the induecd track densities and neutrons doses were calculated. Ages are determined by using the formula (Mehta *et al* 1970):

$$T = 6 \cdot 57 \times 10^9 \ln\left(1 + 9 \cdot 25 \times 10^{-18} \frac{\rho_s}{\rho_i} \phi\right) \text{yr}$$

where ρ_s, ρ_i and ϕ are fossil track density, induced track density and neutron dose respectively.

The calculated ages are shown in table 1. The errors indicated with the ages refer only to statistical errors in the density determination.

3. Discussion

3.1. *Annealing*

It is not possible to estimate annealing effects on samples over geological times. Laboratory experiments can be performed at high temperatures for a few hours and annealing behaviour of tracks in the sample can be studied. Extrapolating the information thus obtained, the past history of the sample can be assessed. A linear extrapolation of Arrhenius plot of hornblende shown in figure 3, gives

Table 1. Fission track ages of hornblende

Sl. No.	Location	Laboratory symbol	Nature of sample	Total neutron dose, nvt	Fission track age m.y.
1.	Saladipura, Rajasthan	HR	Hornblende green crystals	$2 \cdot 27 \times 10^{16}$	967 ± 53
2.	Sidha Valley, Karnataka State	S	do.	do.	1530 ± 61
3.	Banavar in the south of Karnataka State	B	do.	do.	840 ± 33
4.	Unknown (supplied by Stark and Co.)	HA	do.	do.	1107 ± 133

information about the thermal history of the region. It shows that the mineral will start losing tracks when heated to a temperature of 100° C for one m.y., while a temperature of 200° C for one m.y. will erase all the tracks present in it. It is also evident that if the fission track age of the hornblende coincides with the age determined by other radioactive methods like Rb–Sr and K–Ar, etc., the rock temperature must have remained to the right of the zero per cent track reduction curve and if it is less than the youngest event recorded by other methods, the fission track age will represent some cooling event. Further, the mixed fission track ages will result if the rock had been heated to a temperature for a length of time which falls within the fields between 0% and 100% loss curves.

The experimental points in figure 3 lie on a straight line expressed by the relation

$$\log t = \log a + (E/kT)$$

where t and T are the annealing time and temperature respectively. E is the activation energy, a is a constant and k is the Boltzmann constant.

3.2. *Ages*

Fission track ages have been determined for two specimens drawn from different areas of Karnataka State. The age of the sample B concurs with Rb–Sr mica age of the region (Venkatasubramaniam *et al* 1971 *c*). The apparent discrepancy between the ages of samples S and B may be corroborated by the fact that the Karnataka region has undergone quite a number of orogenic metamorphic cycles, the effect of which is found to be increasing towards the south, accompanied by some igneous activity (pegmetisation, grantisation and alkali-gabro syenite complex) (Sarkar 1968). The younger age 840 ± 30 m.y. of the sample B may be due to the latest thermal event during the Indian Ocean cycle or may be due to some later igneous activity.

The Rb–Sr isochron for whole rock indicates an event of metamorphism accompanied by granitic and pegmatitic activity during 1450–1850 m.y. representing the Eastern Ghat orogenic cycle in the area. The age of the sample S is thus representing the Eastern Ghat cycle (Sarkar 1968).

In conclusion it may be suggested that the broad time gap between the two ages of the samples S and B probably indicates events in the middle proterozoic time.

The age of the sample HR is in conformity with K–Ar age of the region and indicates the closing stage of the Aravalli–Delhi orogenic metamorphic event (Sarkar *et al* 1964). Although the pattern of metamorphism which is further complicated by some igneous activity, seems to be irregular, the fission track ages of the hornblende were not lowered by these events.

Conclusions

(i) The widespread abundance of hornblende in igneous and metamorphic rocks coupled with its annealing characteristic makes the mineral an important tool for fission track dating. The present study has confirmed that the fission track method can be successfully applied for dating pre-Cambrian hornblende samples.

(ii) Fission track ages determined with due precautions agree with the period of main orogenic metamorphic cycles and also other radiometric ages. The lowering of the ages may be due to some local thermal events which are not recorded by other methods.

(iii) It has a high potential for unfolding the thermal history or uplift of the region if measurements are made on co-existing or cogentic minerals.

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