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Anisotropic track annealing in apatite

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Abstract

Systematic annealing experiments on fission tracks in different planes of apatite are carried out in order to observe its anisotropic behaviour. The anisotropic effect is found to increase with annealing rate. It is observed that the fission tracks parallel to the c-axis in apatite crystal exhibit a far greater resistance to annealing than those registered in any other orientation. The annealing rate, Va and the activation energy, Ea, are also found to vary with the crystallographic orientation.

Introduction

The anisotropic track annealing studies in crystalline minerals have drawn considerable attention in recent years (Laslett et al., 1984; Watt et al., 1984). Green and Durrani (1977) have studied the anisotropic track annealing effects in some natural crystals. Gegusin et al. (1968) observed that in case of muscovite mica the fission fragment tracks registered parallel to the cleavage planes are much more resistent to thermal annealing than those registered perpendicular to the cleavage planes. This type of effect has great significance in case of fossil tracks, since these have passed through the geothermal history of the region. In the present investigation an attempt is made to study the anisotropic track annealing behaviour in apatite procured from the Laval University Museum (Quebec) and collected from Wakefield area in Canada.

Since the atomic spacing is very variable along different crystallographic orientations in the anisotropic mineral, it follows that the annealing rate, Va, and the activation energy, Ea, for annealing might be different for tracks in different orientations.

Apatite is the most widely investigated mineral for fission track age determinations because of the ease with which it can be polished and etched for track revelation.

Experimental procedure

a. Sample preparation:

Three different natural planes (relative to the c-axis of the apatite crystal) were selected for the study. These are:

1. The plane perpendicular to the c-axis of the crystal ((0001) plane).

2. The plane inclined at an angle of 49° to the c-axis of the crystal ((1$\bar{1}$01) plane).
3. The plane parallel to the c-axis of the crystal ((10$\bar{1}$0) plane).

Apatite samples from each plane were separated and prepared after grinding and polishing as described earlier (Singh et al., 1986).

b. Standardisation of etching conditions:

In order to determine the optimum etching time for fission tracks in apatite, one sample of each plane was irradiated with ^{252}Cf fission fragment source in 2π geometry for 10 min each. These samples were then etched in 2% HNO_3 at 25°C for various time intervals ranging from 30 to 300 s. The projected track length was measured after each time interval for each plane using an optical microscope at a magnification 1,500 X (+oil immersion). These measurements were made using a calibrated ocular scale provided in the microscope. The optimum etching time corresponding to maximum track length was found to be 3 min for all the planes of apatite.

c. Angular distribution of etched tracks:

Two samples from (10$\bar{1}$0) plane of the apatite crystal, one containing fossil tracks and other containing fresh induced tracks were taken and etched simultaneously for 3 min in 2% HNO_3 at 25°C (hereafter termed as the standard etching condition). The angular distribution in fossil and induced tracks was obtained by measuring the inclinations of the ends of the tracks relative to a fixed but arbitrary direction (Khan,1977). The results along with the reference lines are shown in Figs. 1 and 2. Another sample

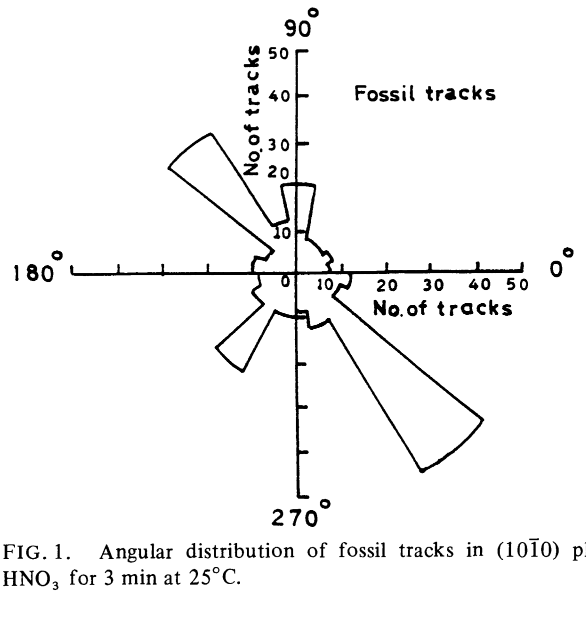

FIG. 1. Angular distribution of fossil tracks in (10$\bar{1}$0) plane of apatite etched in 2% HNO_3 for 3 min at 25°C.

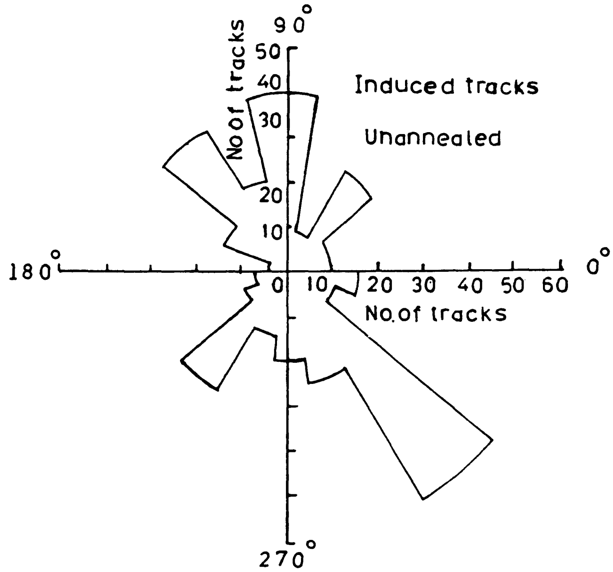

FIG. 2. Angular distribution of induced tracks in (10$\bar{1}$0) plane of apatite etched in 2% HNO_3 for 3 min at 25°C.

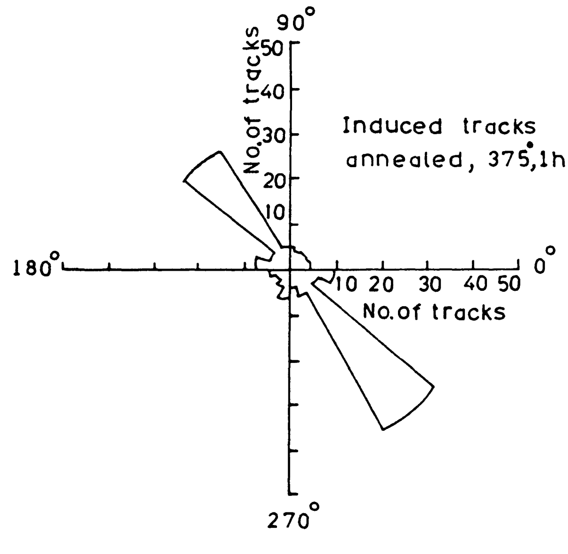

FIG. 3. Angular distribution of induced tracks in (10$\bar{1}$0) plane of apatite, annealed at 375°C for 1 hour and etched in 2% HNO_3 for 3 min at 25°C.

from the same plane $(10\bar{1}0)$ containing induced tracks was heated at 375°C for 1 hour and etched for 3 min in 2% HNO_3 at 25°C. The angular distribution of these tracks is shown in Fig. 3.

d. Variation of etchable length of induced tracks with angle to the c-axis:

The length (L) and orientations (ϕ) of induced fission tracks at various angles to the c-axis in $(10\bar{1}0)$ plane were measured for an unannealed control sample and the

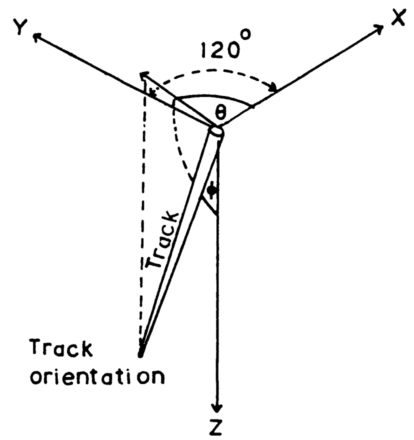

FIG. 4. The coordinate system used to denote track orientations.

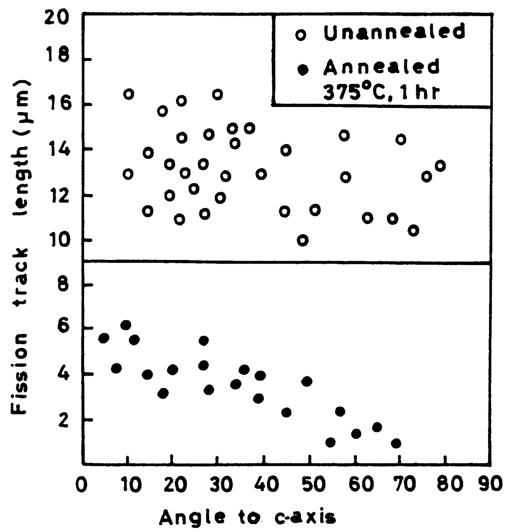

FIG. 5. Variation of track length of induced fission tracks ($(10\bar{1}0)$ plane) with angle to the c-axis in an unannealed control sample and a sample annealed at 375°C for 1 hour.

sample annealed at 375°C for 1 hour. The coordinate system used to denote track orientations is shown in Fig. 4 (Laslett et al., 1984). Fig. 5 shows the measured track length plotted against the track orientation relative to the c-axis for the apatite crystal.

e. Track annealing rate and activation energy:

The annealing experiments were carried out to study the effect of temperature on the fission track annealing rate, Va, for different planes of apatite. The samples from different planes of the crystal were exposed to ^{252}Cf fission fragments at 15±2° angle of incidence and were heated at 300, 325, 350, 400 and 425°C for 10 min each. The samples were etched and the mean track length was measured at each heating event (Fig. 6). The following empirical relation (Modgil and Virk, 1985),

$$Va = At^{-n}\, e^{-Ea/kT} \qquad (1)$$

is used to determine the activation energy, Ea, for different planes of apatite.

The track annealing rate, Va, is calculated from the relation:

$$Va = \frac{dL}{dt} \qquad (2)$$

assuming that Va remains constant over the first 10 min of heating. Plot of ln

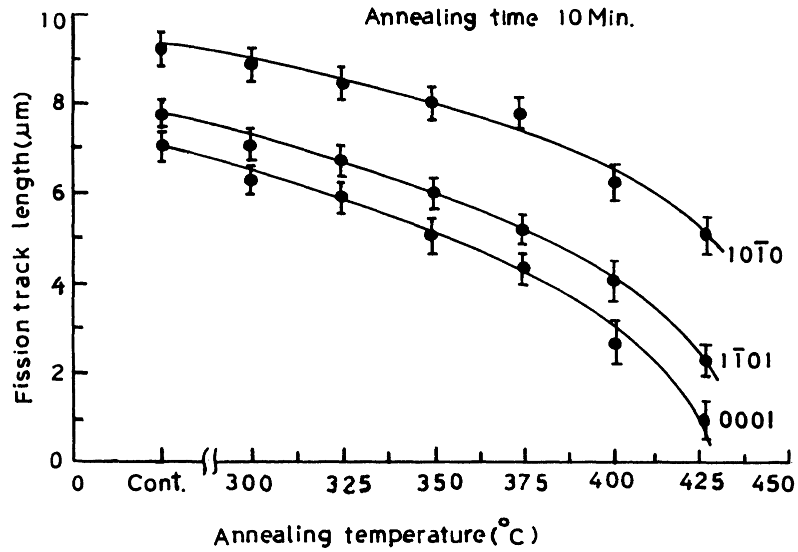

FIG. 6. The variation of mean track length with annealing temperature for heating time of 10 min each.

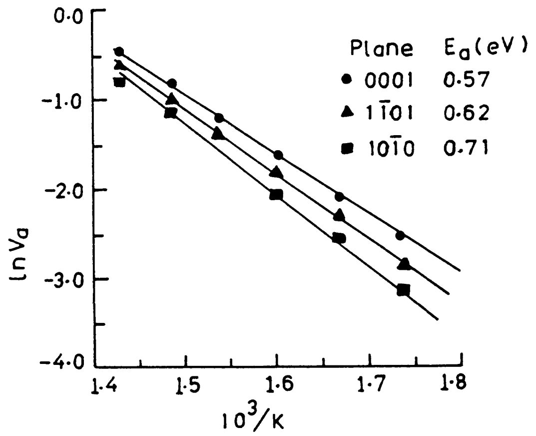

FIG. 7. Plot of ln Va vs l/T for different planes of apatite.

TABLE 1. The values of Va and Ea for different planes of apatite.

Annealing Temperature °C	10$\bar{1}$0 plane		1$\bar{1}$01 plane		0001 plane	
	Va μm/min	Ea eV	Va μm/min	Ea eV	Va μm/min	Ea eV
300	0. 04	0. 71	0. 06	0. 62	0. 08	0. 57
325	0. 08		0. 09		0. 12	
350	0. 12		0. 17		0. 20	
375	0. 15		0. 25		0. 28	
400	0. 31		0. 37		0. 45	
425	0. 41		0. 55		0. 61	

Va vs 1/T for different planes is shown in Fig. 7. The values of Va and Ea are given in Table 1.

Results and discussion

Fig. 1 shows the angular distribution of etched fossil tracks in (10$\bar{1}$0) plane. The distribution of fossil fission tracks is quite non-isotropic as compared to fresh induced tracks (Fig. 2). The anisotropy is increased when the induced fission tracks are subjected to annealing (Fig. 3). This clearly indicates that the annealing augments anisotropy of track revelation in the crystal. As the fission fragment track in apatite are very sensitive to thermal effects the only reason for the high degree of anisotropy in case of fossil tracks is the annealing to tracks during the geological history of the sample. From Fig. 5 it is evident that the effect of annealing is to make the distribution of fission tracks anisotropic. It is also observed (Fig. 5) that the fission tracks parallel to the c-axis in apatite exhibit a far greater resistance to annealing than those registered in any other orientation. The tracks which are perpendicular to the c-axis are annealed at a much faster rate.

Also the annealing of fission tracks occurs faster (Fig. 6) for samples cut perpendicular (0001) to the optical axis than for ones cut parallel to it. Since the annealing is a diffusion of interstitial atoms and atomic vacancies, it must be a function of interatomic spacing between different planes. The value of activation energy, Ea, for track annealing in a plane parallel to the c-axis is higher (0.71 eV) than that in a perpendicular plane (0.57 eV). This indicates that the interstitial atoms require less amount of energy to start the process of annealing in a plane perpendicular to the c-axis. The difference in Ea may be due to the different total point defect concentration in different orientations.

Conclusions

1. The annealing of fission tracks makes their distribution more anisotropic.
2. The fission track age should be determined on that plane which is highly resistent to annealing.
3. In case of apatite, a plane parallel to the c-axis (i.e. $(10\bar{1}0)$ plane) is found to be most suitable for fission track dating purpose.

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