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# SHORT COMMUNICATION

# FISSION TRACK ANNEALING IN MINERALS

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**Abstract**—Studies have been made concerning the annealing behaviour of nuclear tracks in some crystalline minerals, namely: quartz, zircon, chlorite and muscovite mica. Annealing experiments were carried out in the temperature range 300–1000°C. The activation energy, $E_a$, for track annealing is determined in the frame of a model involving a unique value of $E_a$ for a given detector.

## INTRODUCTION

A knowledge of the annealing mechanism of fission tracks in crystalline minerals has had increasing interest in recent years, due to their wide applications in geochronology (Fleischer *et al.*, 1975; Green *et al.* 1985, 1986; Sandhu *et al.*, 1987). A considerable number of laboratory annealing studies have been made of the stability of fission tracks in a variety of minerals and glasses. A number of models (Mark *et al.*, 1973; Dartyge *et al.*, 1981; Green *et al.*, 1985) have been proposed to explain the kinetics of annealing in solid state nuclear track detectors (SSNTDs).

Most workers have interpreted their annealing experiments on the basis of the Boltzmann equation, and have obtained a series of fanning lines or Arrhenius plots yielding a spectrum of activation energies for different degrees of annealing. However, there is considerable disagreement on the form of this equation. Green *et al.* (1985) tried to explain the annealing behaviour and their model predicts parallelism of lines of equal track length reduction on the Arrhenius plot and hence, as a consequence, a single activation energy of annealing.

Modgil and Virk (1985) proposed a single activation energy model relating annealing rate, $V_a$, with activation energy, $E_a$, as

$$V_a = At^{-n}\exp(-E_a/\mathrm{k}T) \qquad (1)$$

where $A$ is a proportionality constant which depends upon the type of detector and incident ion and $n$ is the exponent of annealing time, $t$. The annealing rate, $V_a$, is defined as the rate of change of track length and can be approximated as

$$V_a = (L_0 - L)/t \qquad (2)$$

where $L_0$ and $L$ are the mean track lengths before and after annealing, respectively. To determine the activation energy, equation (1) can be written in the form

$$\ln V_a = \ln A - n \ln t - E_a/\mathrm{k}T. \qquad (3)$$

The model (Modgil and Virk, 1985) predicts that a plot of $\ln V_a$ vs $1/T$ will give a unique straight line, with a slope equal to the activation energy. The purpose of this work is to find the activation energy ($E_a$) of some crystalline minerals on the basis of this single activation energy model.

## EXPERIMENT

Different sets of polished samples prepared from 1010 plane of quartz and 100 plane of zircon were irradiated with a collimated beam of fission fragments from a Cf-252 source in a vacuum chamber at 15° angle of incidence. A few samples prepared from chlorite and muscovite were exposed to Ca-40(15.0 MeV $n^{-1}$), La-139(14.6 MeV $n^{-1}$) and U-238(16.53 MeV $n^{-1}$) ion beams from the UNILAC accelerator at GSI Darmstadt, F.R.G., at 15° angles of incidence with respect to the detector surface. Irradiated samples of quartz, zircon, chlorite and muscovite were heated in a muffle furnace at temperatures varying from 650–950, 700–900, 300–650 and 350–650°C, respectively, using intervals of 50°C and heating times of 10 min for each sample.

The annealed and unannealed (reference) samples of quartz, zircon, chlorite and muscovite were etched in 15 N KOH (125°C, 12 h); HF:$H_2SO_4$ (175°C, 14 h); 40% HF (25°C, 50 min) and 48% HF (25°C, 120 min); respectively. The process of etching and microscopic observations was repeated till the maximum track length (unannealed and annealed), became invariant with further etching. The track

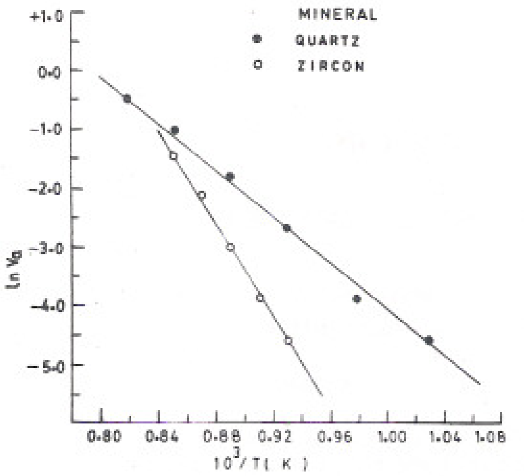


FIG. 1. Plot of $\ln V_a$ vs $1/T$ for quartz and zircon.

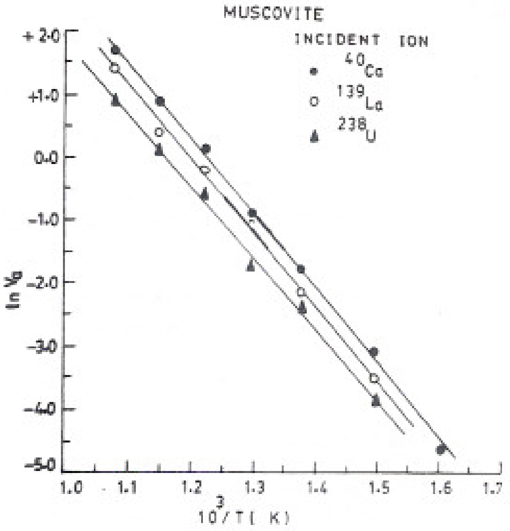


FIG. 3. Plot of $\ln V_a$ vs $1/T$ for different ion beams in muscovite.

lengths (corrected for dip) were measured at each temperature and the annealing rate $V_a$ was calculated (equation 2). The plot of $\ln V_a$ vs $1/T$ for these detectors are shown in Figs 1–3.

Table 1. Activation energy of track annealing for different track detectors

| Detector | Incident ion | Activation energy $E_a$(eV) |
|---|---|---|
| Quartz | Fission fragments ($^{252}$Cf) | 1.73 |
| Zircon | Fission fragments ($^{252}$Cf) | 3.60 |
| Chlorite | $^{40}$Ca (15.0 MeV $n^{-1}$) | 0.80 |
| | $^{139}$La (14.6 MeV $n^{-1}$) | 0.78 |
| | $^{238}$U (16.53 MeV $n^{-1}$) | 0.77 |
| Muscovite | $^{40}$Ca (15.0 MeV $n^{-1}$) | 0.98 |
| | $^{139}$La (14.6 MeV $n^{-1}$) | 0.98 |
| | $^{238}$U (16.53 MeV $n^{-1}$) | 0.96 |

## RESULTS

The experimental data on annealing of heavy ion tracks in quartz, zircon, chlorite and muscovite fully satisfies the empirical relation proposed by Modgil and Virk (1985). The activation energies as deduced from the respective plots in $\ln V_a$ against $1/T$ are 1.73 eV and 3.60 eV for quartz and zircon crystals, respectively, for fission fragments (Table 1). Also, it is interesting to note that all categories of heavy ions, even of different beam energies, yield almost identical values of activation energy of annealing in chlorite as well as in muscovite (Table 1). This shows that the minimum energy required to start the annealing process in a given SSNTD is independent of the nature and energy of the track-forming ion. This further supports the proposal that the activation energy of track annealing is a characteristic property of the detector material. Dartyge *et al.* (1981) have also found a single value for activation energy for muscovite mica. Moreover, the value they obtained for muscovite mica, with a very different technique (small angle X-ray scattering), is similar to that reported in the present work (0.8 eV, as compared to 0.96–0.98 eV).

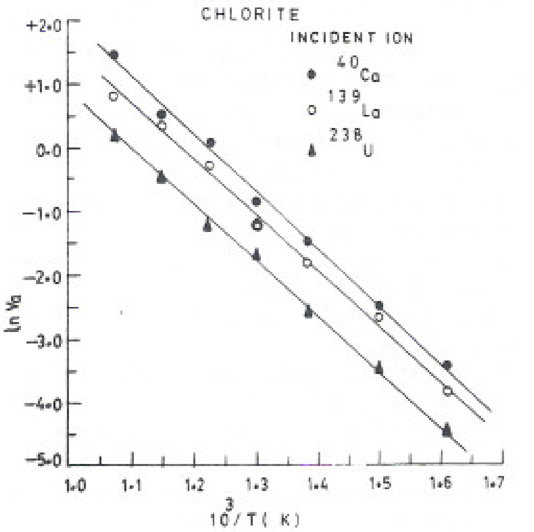


FIG. 2. Plot of $\ln V_a$ vs $1/T$ for different ion beams in chlorite.

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