MINERALOGICAL JOURNAL, VOL. 13, NO. 5, PP. 254–259, JANUARY 1987

Annealing of fission fragment tracks in micaceous minerals

A. S. SANDHU, Surinder SINGH and H. S. VIRK

Department of Physics, Guru Nanak Dev University, Amritsar-143005, India

Abstract

The annealing model proposed by Modgil and Virk (1985) for inorganic solids has been tested for some micaceous minerals being used as track detectors. Annealing experiments have been carried out in the temperature range of 200–700°C, on chlorite, biotite, muscovite and phlogopite, and it has been found from the results that the annealing rate Va is fitted well by the Modgil-Virk relation, $Va=At^{-n}\exp(-Ea/kT)$. Here t and T are the annealing time and temperature; the activation energy, Ea, and the values of constants n and A for these minerals have been determined. The activation energy varies from 0.63 to 0.96 eV. It has been observed that the activation energy is independent of the annealing rate.

Introduction

The annealing of radiation damage in solid state track detectors has wide applications in diverse fields (Storzer and Wagner, 1969; Khan and Durrani, 1973; Nagpal *et al.*, 1974; Singh and Virk, 1977). Different interpretations have been given for track density retention in solid state track detectors (Gentner *et al.*, 1969; Storzer, 1970; Fleischer and Hart, 1970; Naeser and Faul, 1969; Reimer and Wagner, 1972; Modgil and Virk, 1982; Haack and Potts, 1972; Haack, 1976; Mantovani, 1974). Mark *et al.* (1973) proposed that the annealing of fission-tracks in apatite can be better explained by an exponential time dependence, with a single activation energy and parallel lines on an Arrhenius plot for different degrees of annealing. Green *et al.* (1985) suggested that an Arrhenius plot for a single apatite composition is parallel or nearly parallel, characterized by a single activation energy.

Recently, Modgil and Virk (1985) proposed a three step annealing model which explains the annealing behaviour of radiation damage in the bulk material. The authors introduced the concept of a single individual track annealing and found a reciprocal power law relationship between annealing rate and heating time. According to the proposed model, it is the annealing rate, Va, and not the activation energy, which varies with the temperature and time. In the present study, annealing experiments are carried out in order to check the validity of the new model for micaceous minerals.

Experimental procedure

2.1 Va dependence on temperature

Annealing experiments were carried out in order to study the effect of temperature on the track annealing rate. Samples were prepared from chlorite mica. These samples were irradiated with Cf^{252} fission fragment source in a 2π geometry.

Annealing of fission fragment tracks was carried out by heating the irradiated chlorite samples in a Muffle furnace at each of the temperatures 200, 300, 400, 450, 475, and 500°C for 10 min successively. These samples were etched simultaneously with 40% HF for 5 min at 25°C after thermal annealing. Track lengths were measured at each temperature with an Olympus binocular microscope at a magnification of 1500.

The projected track length, L, as a function of annealing temperature is plotted in Fig. 1. Track annealing rate, Va, has been calculated using the relation:

$$Va = \frac{dL}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

assuming that Va remains constant over the first 10 min of heating. Plot of ln Va vs $\frac{1}{T}$ (Fig. 2) shows an exponential dependence of Va on the annealing temperature for chlorite. The similar annealing experiments were also conducted for biotite,

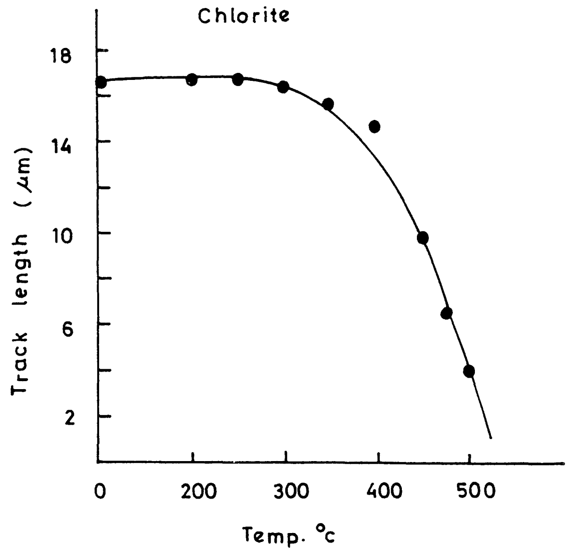

FIG. 1. The variation of mean track length with annealing temperature in chlorite for heating time of 10 min each.

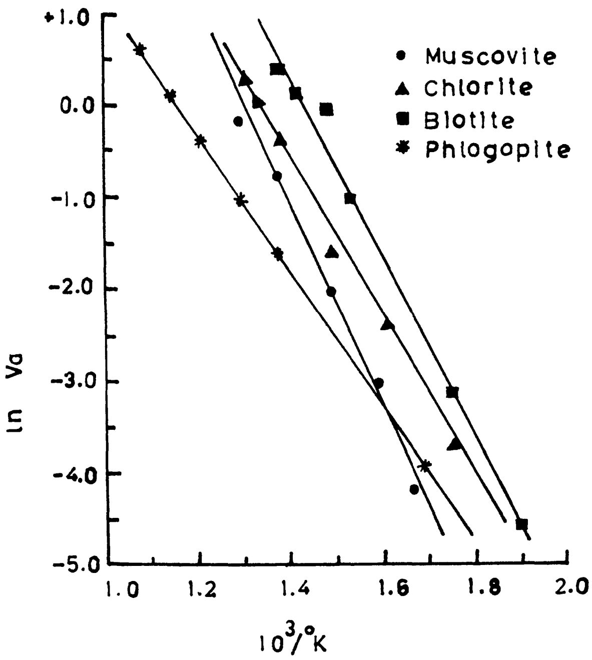

FIG. 2. Plot of ln Va vs $\frac{1}{T}$ for chlorite, biotite, muscovite and phlogopite.

muscovite, and phlogopite samples over the temperature range from 200 to 450, 200 to 500 and 450 to 700°C respectively, using intervals of 50°C and heating time of 10 min for each sample. The results are shown in Fig. 2.

2.2 Va dependence on annealing time

A few samples of chlorite were prepared to study the effect of annealing time on the track annealing rate. These samples, after irradiation with Cf^{252} source, were heated in a Muffle furnace at a temperature of 450°C for the intervals of 10, 20, 30, 40, 50, 70, 90 and 120 min successively. Annealed samples were etched with 40% HF for 5 min at 25°C and track length was measured with the binocular microscope at a magnification of 1500. The mean track length as a function of annealing time is plotted in Fig. 3. Annealing rate, Va, has been calculated for different durations of annealing from the plot of Fig. 3.

The plot of log Va vs log t is shown in Fig. 4. The annealing experiments were repeated for biotite, muscovite and phlogopite at temperatures of 425, 450 and 500°C for the same heating intervals as for chlorite. The results are shown in Fig. 4.

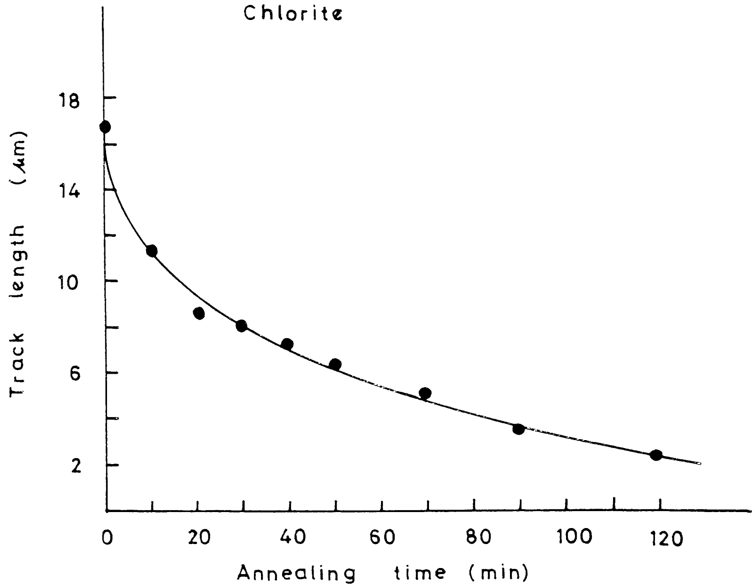

FIG. 3. Variation of mean track length with annealing time in chlorite at 450°C.

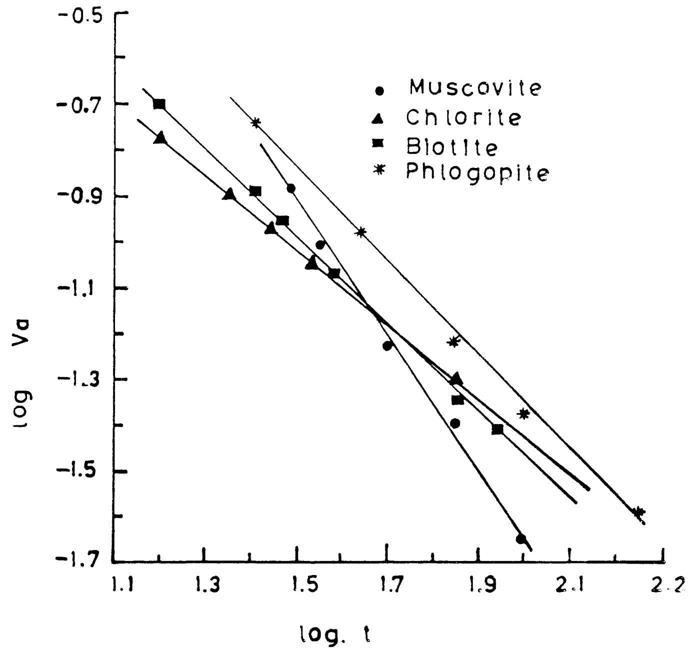

FIG. 4. Plot of log Va vs log t for chlorite, biotite, muscovite and phlogopite.

Results and discussions

We have used the following empirical relation (Modgil and Virk, 1985):

$$Va = At^{-n} e^{-Ea/kT} \quad \ldots \quad (2)$$

as a fitting function to the experimental data. Here k is the Boltzmann constant, T, the absolute temperature, A, the proportionality constant and n, the exponent of the annealing time, t. The values of A, n and Ea are calculated for these detectors from their respective plots and are summarized in Table 1.

The track annealing rate, Va, has been calculated for chlorite, biotite, muscovite and phlogopite using eq. (2) at different temperatures and heating times (Tables 2a, b). It is evident that the computed values of Va for different detectors are in close agreement with the values obtained from the experimental data. Thus the proposed

TABLE 1. Activation energy for annealing, n-value and A-value for micaceous minerals.

Mineral	Etchant	Activation energy of annealing (eV)	n-value	A-value (μm/min)
Muscovite	HF	0.96	1.60	9.25×10^7
Chlorite	HF	0.78	0.84	1.31×10^6
Biotite	HF	0.82	0.91	9.78×10^6
Phlogopite	HF	0.63	1.00	5.85×10^4

TABLE 2a. Annealing rate as a function of temperature and time in micaceous minerals.

Muscovite				Chlorite			
Temp. (°C)	Heating time (min)	Annealing rate Va (μm/min) Exp.	Cal.	Temp. (°C)	Heating time (min)	Annealing rate Va (μm/min) Exp.	Cal.
375	10	0.070	0.080	375	10	0.120	0.160
	15	0.043	0.040		20	0.086	0.090
	20	0.017	0.014		30	0.069	0.060
					60	0.032	0.036
425	10	0.220	0.270	425	10	0.410	0.440
	30	0.040	0.050		30	0.160	0.180
	60	0.017	0.020		60	0.092	0.098
					100	0.059	0.064
475	10	0.830	0.790	475	20	0.510	0.590
	20	0.280	0.260		60	0.290	0.230
	30	0.120	0.140		100	0.120	0.150

TABLE 2b. Annealing rate as a function of temperature and time in micaceous minerals.

Biotite				Phlogopite			
Temp. (°C)	Heating time (min)	Annealing rate Va (μm/min) Exp.	Cal.	Temp. (°C)	Heating time (min)	Annealing rate Va (μm/min) Exp.	Cal.
375	10	0.470	0.500	500	25	0.188	0.185
	20	0.230	0.270		45	0.104	0.102
	30	0.210	0.190		70	0.059	0.065
	60	0.079	0.098		100	0.043	0.045
400	10	0.870	0.870		135	0.034	0.034
	20	0.410	0.470		180	0.027	0.026
	60	0.210	0.170				
	100	0.100	0.110				
450	30	0.970	0.850				
	60	0.410	0.450				
	75	0.290	0.370				
	100	0.240	0.280				

formula holds good for micaceous minerals also, and is capable of measuring annealing rate at a particular temperature and duration of annealing.

References

FLEISCHER, R. L. and HART, H. R. (1970) *General Electric Research Report,* **70-C-328**, 1-25.

GENTNER, W., STORZER, D. and WAGNER, G. A. (1969) *Geochim. Cosmochim. Acta,* **33**, 1075-1081.

GREEN, P. F., DUDDY, I. R., GLEADOW, A. J. W., TINGATE, P. R. and LASLETT, G. M. (1985) *Nucl. Tracks,* **10**, 323-328.

HAACK, U. K. and POTTS, M. J. (1972) *Contr. Mineral. Petrol.,* **34**, 343-345.

HAACK, U. (1976) *Earth Planet. Sci. Letters,* **30**, 129-134.

KHAN, H. A. and DURRANI, S. A. (1973) *Nucl. Inst. and Meth.,* **113**, 51-54.

MANTOVANI, M. S. M. (1974) *Earth Planet, Sci. Letters,* **24**, 311-316.

MARK, E., PAHL, M., PURTSCHALLER, F. and MARK, T. D. (1973) *Min. Petr. Mitt.,* **20**, 131-154.

MODGIL, S. K. and VIRK, H. S. (1982) *Int. J. Appl. Radiat. Isot.,* **33**, 779-780.

MODGIL, S. K. and VIRK, H. S. (1985) *Nucl. Instruments Methods in Physics Research,* **B12**, 212-218.

NAESER, C. W. and FAUL, H. (1969) *J. Geophys. Res.,* **74**, 705-710.

NAGPAL, K. K., MEHTA, P. P. and GUPTA, M. L. (1974) *Pure and App. Geophys.,* **112**, 131-139.

REIMER, G. M. and WAGNER, G. A. (1972) *Rad. Effects,* **15**, 273-274.

STORZER, D. and WAGNER, G. A. (1969) *Earth Planet. Sci. Letters,* **5**, 463-468.

STORZER, D. (1970) *Earth Planet Sci. Letter,* **8**, 55-60.

SINGH, Surinder and VIRK, H. S. (1977) *Curr. Sci.,* **46**, 376-378.

Received June 5, 1986; revised September 2, 1986.