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Fission track dating and uranium mineralization in pegmatites of Bhilwara area, Rajasthan State (India)

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ABSTRACT

Uranium estimation studies on muscovites occurring as pegmatites in the Bhilwara area, Rajasthan State (India) give an evidence of second-phase intrusions of uranium in the mica matrix. The uranium content of mica varies from 10^{-10} atom/atom to 10^{-5} atom/atom. The mean fission track age for this region was found to be 1069 ± 51 m.y. The pegmatites are of Precambrian origin but the uranium inclusions belong to a much later stage in the geothermal history of the samples.

Introduction

There are various techniques for estimating the age and uranium concentration of natural rocks and minerals such as mass spectrometry, auto-radiography, fluorimetry and activation analysis. Fission track technique is a recent addition to this field. It has been developed by Price and Walker (1963), Fleischer and Price (1964), and Virk and Koul (1974, 1975 a, b).

It is a matter of common knowledge in mineralogy that most of the igneous rocks greatly enriched in uranium and thorium belong to late-stage differentiates of granite or syenites. The major host minerals for the uranium are zircon, monazite, allanite and apatite. Micaceous minerals have been found to contain very low quantities of syngenetic uranium (10^{-10} atom/atom). On the contrary pegmatites in which mica generally occurs are unusually radioactive as they are associated with uranium and thorium bearing minerals. This uranium is deposited epigenetically by hydrothermal solutions and is of later origin.

The muscovite samples studied have been separated from pegmatites in which they occur in the form of tight books. The samples were collected from the 3rd and 5th horizons of Bhunas mica mine (Distt. Bhilwara, Rajasthan State) by the authors. The mica books separated from parent rock, have been classified into three distinct varieties i.e. colourless, light yellow and copper brown.

Experimental details

The experimental details regarding preparation, etching, mounting and irradiation of mineral samples have been given elsewhere (Virk and Koul, 1974, 1975a). However, a brief mention of a few important steps is given here.

The etching conditions were determined for all the three types of muscovites. The fossil tracks are rendered visible under an optical microscope by an etch of 40 minutes at room temperature in 48% HF acid in case of colourless and yellow varieties. The etching time for brownish variety was found to be 5 minutes under identical conditions.

On examination under a binocular Carl Zeiss microscope using a magnification of 600×, it has been observed that the fossil track density is highest in the colourless variety and lowest in the yellow. The brown variety contained a large density of tracks in certain regions. On close examination, it was found that these tracks appear in certain uranium-rich inclusions (Fig. 1). This effect has also been reported by Price and Walker (1963).

Yellow and colourless samples were irradiated with a thermal neutron dose of 10^{16} (nvt) in a CIRUS Reactor of Bhabha Atomic Research Centre, Trombay. The irradiated samples were etched as before and the induced fission track density was recorded in all the samples. It has been confirmed that uranium is not only segregated

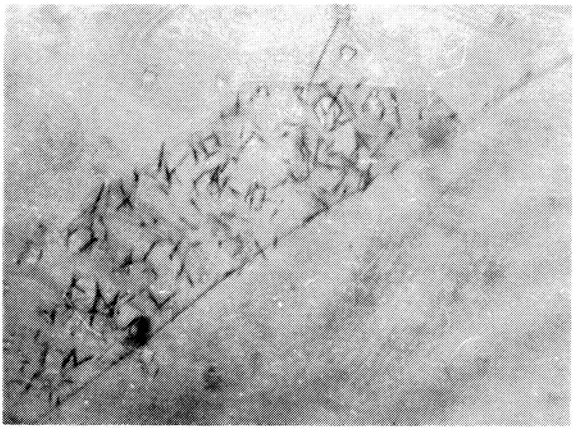

Fig. 1. Fossil fission tracks in a uranium inclusion in a copper brown variety of mica. It shows segregation of uranium due to second phase mineralization in the mica matrix.

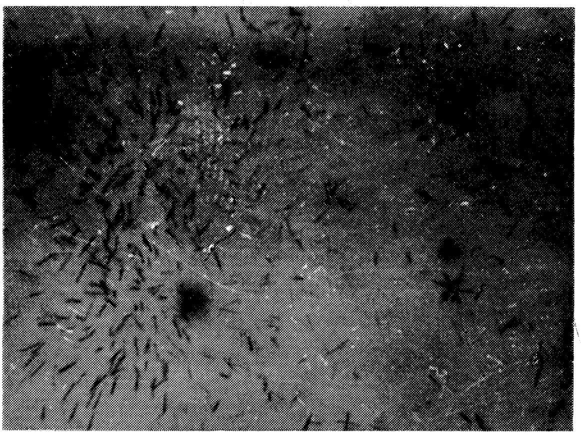

Fig. 2. Cluster formation of induced fission tracks in colourless variety of mica. Such samples are to be eliminated for f. t. dating.

Fig. 3. Induced fission tracks in yellow variety of mica showing heterogeneous distribution due to uranium of epigenetic origin.

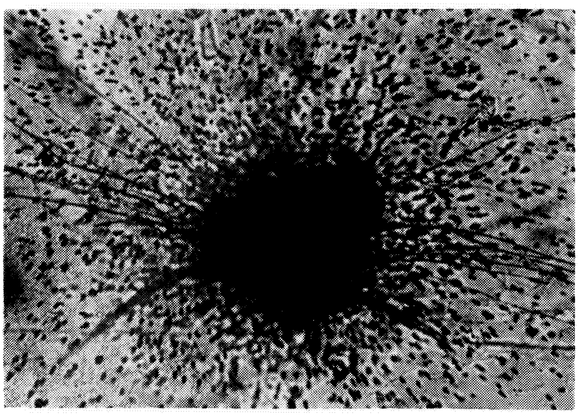

Fig. 4. Induced fission tracks of uranium producing a sunburst pattern.

in the form of inclusions in the brown variety but even in colourless and yellow varieties the track density shows a non-homogeneous distribution of uranium (Figs. 2 and 3). The induced fission tracks appear in the form of clusters and sunbursts (Figs. 2 and 4).

Age determination

The fission track (f.t.) age of the mineral depends upon the ratio of the number of fossil tracks registered due to spontaneous fission of U^{238} and the number of induced fission tracks due to U^{235} when the sample is irradiated with a known thermal neutron dose ϕ. The age formula has been derived by Fleischer and Price (1964) and applied with success by Virk and Koul (1974) for age determination. The f.t. age T is given by

$$\frac{\rho_s}{\rho_i}=\left[\exp\left(\lambda_D T\right)-1\right]\left(\lambda_f/\lambda_D\sigma\phi I\right), \qquad (1)$$

where λ_f=fission decay constant for $U^{238}=7.03\times10^{-17}\,yr^{-1}$ (Robert *et al.*; 1968),

λ_D=total decay constant of uranium$=1.54\times10^{-10}\,yr^{-1}$,

σ=cross section for thermal neutron-induced fission of U^{235} $=582\times10^{-24}\,cm^2$,

ϕ=total thermal neutron dose$=10^{16}$ (nvt), and

I=isotopic ratio of U^{235} to $U^{238}=7.26\times10^{-3}$.

The observed values of ρ_s, ρ_i and the f.t. ages calculated by using equation (1) in case of colourless variety are summarized in the Table 1. The age data for the other two varieties of muscovite

Table 1. Fission track ages of pegmatites of Bhilwara area, Rajasthan State (India).

Sample location	Sr. No.	ρ_s (cm^{-2})	ρ_i (cm^{-2})	T fission track age m.y.	U conc. (atom/atom) $\times10^{-10}$
Muscovite Bhunas mica mines, Bhilwara district	1	1384	746	1073 ± 52	2.2
	2	1383	768	1048 ± 50	2.2
	3	1400	770	1059 ± 51	2.2
	4	1410	765	1071 ± 51	2.2
	5	1430	760	1094 ± 53	2.2
			Mean	1069 ± 51	

Total neutron dose $(\phi)=1.04\times10^{16}$ (nvt)

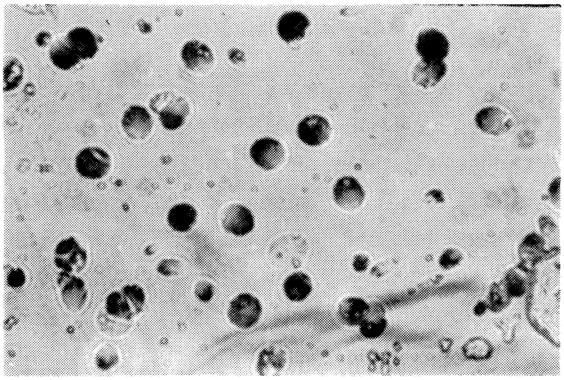

Fig. 5. Induced fission tracks in glass dosimeter (Etching time 5 sec., 48% HF).

have not been obtained with reliable degree of accuracy due to non-homogeneous distribution of uranium in the samples (Figs. 1 and 3).

The integrated neutron dose ϕ to which the samples were exposed is determined by irradiating a calibrated glass slide (supplied through the courtesy of Price and Fleischer) alongwith the muscovite samples. The glass dosimeter is etched for 5 seconds in 48% HF acid. The track density, ρ_d, of induced fission tracks in glass dosimeter (Fig. 5) is recorded and the total thermal neutron dose is calculated by using the following relation (Fleischer *et al.*, 1965),

$$\phi = 2.26 \times 10^{11} \rho_d . \tag{2}$$

Uranium distribution

The study of fossil and induced fission tracks in natural minerals may be used to measure the past and present uranium distribution and thereby one can detect migration of uranium over geological time. Fossil tracks if uniformly distributed provide information about U^{238} which has decayed by spontaneous fission since the time of solidification of the mineral provided it has remained cool enough to retain the radiation damage events producing the tracks. The induced track density, ρ_i, helps to estimate the uranium distribution in the mineral at present. All those samples which included uranium-rich inclusions and other features showing non-homogeneous distribution of uranium have to be eliminated from reliable samples for fission track age determination. Only colourless variety has been found suitable for fission track dating.

The uranium concentration of muscovite samples has been calculated by using the relation (Nagpaul, 1974; Virk and Koul, 1975 b):

$$C_U = \frac{n}{n_m} = \frac{2\rho_i}{\sigma\phi R_0 I n_m}, \tag{3}$$

where R_0 is the mean range of induced fission tracks in muscovite $= 18.5\ \mu$ and n_m, the number of atoms/c.c. of the mineral $= 8.84 \times 10^{22}$ atom/c.c.; the other quantities being same as defined in equation (1). The values of $U_{conc.}$ for colourless variety given in Table 1 are quite low ($\sim 10^{-10}$ atom/atom).

The induced track density for yellow variety has been found to be 26850/cm^2, yielding $U_{conc.}$ of 8×10^{-9} atom/atom. The highest track density has been observed in the uranium-rich inclusions of brown muscovite which give a fossil track count of 36×10^5/cm^2 as compared to 15 tracks/cm^2 in the inclusion-free area of the samples. Assuming the uranium inclusions of the same age as the syngenetic uranium in brown variety, the $U_{conc.}$ in them is a$\sim 10^{-5}$ atom/atom. If, as generally accepted, the uranium-rich inclusions belong to second phase intrusion of uranium in the mica matrix, the $U_{conc.}$ will increase by an order of magnitude.

The dating of uranium inclusions has not been reported so far in the fission track literature. However, the use of lexan plastic detector as an 'overlay' (Fisher, 1970) to record the induced fission tracks may solve the problem in near future.

Discussion of results

1) If one is concerned only with distribution of uranium, the fission track technique is more rapid and more sensitive than autoradiography and other radiometric techniques. We can detect extremely low uranium concentrations ($\sim 10^{-14}$ atom/atom) by this method.

2) The mica samples from the same mine can differ so much in the uranium distribution that it leads to erroneous age results if proper care is not taken to eliminate those samples which contain uranium of epigenetic origin.

3) In addition to syngenetic uranium there are large variations of uranium in pegmatites due to epigenetic introduction of uranium through the agency of juvenile waters or hydrothermal solutions which precipitate a second phase uranium inclusion in the mica matrix.

4) The f.t. age of muscovite pegmatites of Bhilwara area (Rajasthan State, India) indicated clearly that they belong to Precambrian era. Our age results are in good agreement with those of Crawford (1970) and Nagpaul and Nagpaul (1974).

5) The errors shown in the f.t. age results are counting statistical errors which are less than 5%.

6) Geothermal history of the region may be delineated from an analysis of annealing of radiation damage in the co-genetic minerals occurring in pegmatites.

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