SPHENE AND ZIRCON FISSION TRACK ANALYSIS OF SYENITE ROCKS OF THE 
SUSHINA HILLS, PURULIA-BANKURA SHEAR ZONE (TPSZ)

Amal Kumar Ghosh¹
Bhagwant University Ajmer, Rajasthan India

ABSTRACT

Sushina hills are situated in the Purulia-Bankura Shear Zone. This is tectonically 
disturbed narrow zone nearly 100 Km long having WNW-ESE trend. Two different 
rock assemblages namely Chhotanagpur Gneissic Complex and rocks of Singhbhum 
Group occur on the two sides of this shear zone. In this paper, I have used fission track 
ages of two cogenetic minerals and their corresponding closure temperatures to 
describe the denudation history. The difference of their fission track ages provides the 
rate of denudation 4 m/Ma during the period 970Ma-1458Ma due to tectonic activity. 
The youngest age of zircon of 970Ma represents the timing of the initiation of 
denudation.

1. INTRODUCTION

Sushina hills is the pocket occurrence in the Purulia-Bankura Shear Zone (TPSZ) within Singhbhum Group (SG) of rocks. This shear zone is developed between the Chhotanagpur Gneissic Complex (CGC) and the Singhbhum Group of rocks as a consequence of lithospheric stretching under extensional regime. The CGC has undergone three phases of deformation. In Singhbhum region, the rock formation has suffered higher degree of compression. Acharya et al. (2006); Basu (1993) TPSZ was thus affected by the intense deformation in the area adjoining it. Denudation history is, therefore, found to be exciting topic. Furthermore, F.T. age is believed to be 
younger than other radiometric method and it fits best for the analysis of denudation history (Dodge and Ross, 1971; Gleadow et al., 2002; Donelick et al., 2005).

2. GEOLOGICAL EVOLUTION

Sushina hills in Purulia - Bankura Shear Zone lies within Singhbhum Group (SG) of rocks. The Singhbhum Group of rocks and the Chhotanagpur Gneissic Complex are linked by a narrow lineament, viz. Purulia-Bankura shear zone.
The rock formation in this area exhibit a trend that varies from E-W to ESE-WNW. Prominent evidences of shearing, dips, cross faults, oblique faults and brecciations are noticed in this area. From a study of the minor folds and the lineations marked by puckering and mineral parallelism the rocks appears to involved in a series of folds. In addition to this, the rocks of CGC and Singbhum Shear Zone has suffered several phases of deformations. Thus a large scale tectonic significance is evident in this area.

3. METHODOLOGY

Every solid material, once it is penetrated by nuclear particles, will obtain linear trails of disrupted atoms, which also reflect damage on the atomic scale. Fission tracks are such a damage feature. The emerged features are produced by spontaneous fission of 238U. Foster and Gleadow (1993); Foster and Gleadow (1996); Foster et al. (1994); Foster et al. (1993); Foster and John (1999) In general, fission track dating is similar to the other dating methods that rely on the same equation of radioactive decay, i.e., estimating the abundance both of the parent and the daughter isotope. In fission track analysis, the age corresponds to the number of 238U atoms and the number of spontaneous tracks per unit volume. To obtain the number of spontaneous tracks, we simply count the number of spontaneous fission tracks on a given surface of a mineral grain. Meanwhile, the abundance of 238U can is determined by irradiating the samples with low energy thermal neutrons to induce fission of 238U. By controlling the thermal neutron flux, we obtain the number of ‘induced tracks’, which also signified the abundance of 238U. Because the ratio of the 235U/238U is constant, we are able to estimate the abundance of 238U (Fuchs, 1962; Galbraith, 1990; Foster et al., 1991; Gallagher, 1995; Gallagher and Brown, 1997; Gleadow et al., 2000; Foster and Raza, 2002).

4. EXPERIMENTAL PROCEDURE

The samples for this study were processed in the laboratory of the Geological Survey of India, Kolkata, after obtaining permission from the Director General, GSI, Kolkata, West Bengal. The samples were prepared using standard separation, grinding and polishing techniques (Galbraith and Laslett, 1993). In our experiment, we collected sand size crystals of zircon and sphene. Zircon was light brown in color and rice-shaped, and sphene was resinous yellow, observed under binocular microscope. All the samples were prepared for the external detector.
method. Sphenes were etched in 50N NaOH at 130˚C for 30 min. Zircons were mounted in PFA Teflon. Zircons were etched in KOH-NaOH eutectic etchant at 215 ˚c on Spinot digital hot plate for 8 hrs. The sample was placed in 48% HF for 2 hrs to clean up grains. After etching, mica sheets were firmly attached on the sample mounts. The samples were irradiated in the thermal facilities of FRMII at Garching, Germany together with dosimeter glass IRM-540R (15ppm). Mica sheets were etched using 48% HF at room temperature for 19 min. The neutron flux was determined by placing a calibrated dosimeter glass (IRM-540R, 15ppm) in the irradiation package with the samples. The neutron doses calculated on zircon and sphen are $1.75 \times 10^{15}$ neutron/cm$^2$ and $2.5 \times 10^{15}$ neutron/cm$^2$ respectively. The fission tracks were counted under a total magnification of 1000x. The calibrated area of one grid is $0.64 \times 10^{-6}$ cm$^2$.

### Table-1. Analytical data for fission track analysis

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Rock Type</th>
<th>No of Grains</th>
<th>Dosimeter Spontaneous</th>
<th>Induced</th>
<th>$P(\chi^2)$</th>
<th>U (ppm)</th>
<th>Mean Age (Ma)</th>
<th>MTL (µm)</th>
<th>SD</th>
<th>No. of Tracks</th>
<th>$D_{par}$</th>
<th>Error(%) on Mean Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPH</td>
<td>Syenite</td>
<td>18</td>
<td>$\rho_s$</td>
<td>$N_s$</td>
<td>$\rho_i$</td>
<td>$N_i$</td>
<td>$N_{tr}$</td>
<td>145</td>
<td>15</td>
<td>24.40</td>
<td>1.68</td>
<td>20.7</td>
</tr>
<tr>
<td>SZR</td>
<td>Syenite</td>
<td>18</td>
<td>0.73</td>
<td>1168</td>
<td>17.66</td>
<td>452</td>
<td>1.57</td>
<td>244</td>
<td>15</td>
<td>41.65</td>
<td>85</td>
<td>1.54 14.7</td>
</tr>
</tbody>
</table>

Source: Donelick et al. (2005)

Results of AFT analyses : ages calculated using dosimeter glass IRMM-540R with 15ppm U, calibrated by external detector method, N=Number of grains, $\rho$ – track densities given in $10^6$ tr cm$^-2$, $\rho_0$- dosimeter track density, $N_0$ – number of tracks counted on dosimeter, $\rho_p$ – spontaneous (induced) track densities, $N_p$ – number of counted spontaneous (induced) tracks, $P(\chi^2)$ – probability for obtaining $\chi^2$ value for n degrees of freedom, where n=no. of grain – 1, MTL – mean track length, SD – Standard deviation.

### Table-2. Analytical data for uplift rate

<table>
<thead>
<tr>
<th>Region</th>
<th>Closure Temperatures</th>
<th>Time Span (Ma)</th>
<th>Cooling Rate ($Q_C$/Ma)</th>
<th>Uplift Rate (m/Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sushina hills in TPSZ</td>
<td>300 °C for sphen</td>
<td>970 - 1458</td>
<td>0.123</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>240 °C for zircon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Nagpaul (1981)

### 4.1. Statistical Test of Single-Grain Data and Error Calculation of Sample Mean Age

Routinely 10–30 single-grain ages are determined for a single FT analysis. If the grains within the sample have a common age, the variation in single grain ages is governed only by the Poissonian statistics concerned with the determination of $\rho_s$,$\rho_i$ and $\rho_d$ (table 1). In this case, $\rho_s$ and $\rho_i$ are obtained from

$$\rho_s = \frac{\sum N_{sp}}{\sum A_j}$$

$$\rho_i = \frac{\sum N_{in}}{\sum A_j}$$

(Naeser, 1967; Turner et al., 1983; van der Beek, 1997; Tagami and O’Sullivan, 2005) where $N_{sp}$ is the number of spontaneous fission tracks in area $A_j$ of the jth crystal and $N_{in}$ is the number of induced fission tracks in the same area of the corresponding grain print on the muscovite detector. Then, the error in the mean age $t$ is given by the

$$\sigma = \pm \frac{N_{sp}}{N_{in}} \left( \frac{1}{N_{sp}} + \frac{1}{N_{in}} \right)^{1/2}$$

(Fleischer and Price, 1964; Fleischer et al., 1964; Fleischer et al., 1965b; Fleischer and Hart, 1972; Fleischer et al., 1975; Fitzgerald et al., 1993; Fitzgerald et al., 1995; Fletcher et al., 2000)

where $N_{sp}$ and $N_{in}$ are the total numbers of counted tracks for $\rho_s$ and $\rho_d$ respectively. Errors in mean age of sphen and zircon were calculated as 20.7% and 14.7% respectively (table 1). A statistical procedure, called $\chi^2$ -test...
was developed to assess the validity of data. It was shown that results from the conventional formula give the best estimate of \( \left( \rho_S / \rho_t \right) \) and \( \sigma(\rho_S / \rho_t) \), as long as the observed track counts are acceptable under a \( \chi^2 \) – Criterion:

\[
\chi^2 = \sum \left( \frac{(N_S - P_S)^2}{P_S} \right) + \sum \left( \frac{(N_I - P_I)^2}{P_I} \right)
\]

where \( P_{ SJ } = N_S (N_S + N_I) / (N_S + N_I) \), \( P_{ II } = N_I (N_S + N_I) / (N_S + N_I) \). If the \( \chi^2 \) -value is unacceptable, it suggests that the data suffer from extra-Poissonian variation(s) due to a variety of experimental and geological factors (Feinstein et al., 1989; Fitzgerald and Gleadow, 1990; Fitzgerald et al., 1991; Fitzgerald, 1994; Fitzgerald et al., 1999).

Fission track age determinations were made on 18 sphene, and 18zircon separates from syenite rocks from the Sushina hill shown in figure 1. The mean fission track ages of sphene, and zircon are 1458 Ma, and 970 Ma respectively as shown in table1. The uplift rate has been calculated according to the equation:

\[
\text{Uplift rate} = \frac{\text{Cooling rate}}{\text{Geothermal gradient}}
\]

Where, Cooling rate = \( \frac{T_1 - T_2}{A_1 - A_2} \)

\( T_1, T_2 \) = Closure temperatures of cogenetic minerals,
\( A_1, A_2 \) = Mean FT ages of cogenetic minerals,

Average geothermal gradient of the order of 30˚C/km has been adopted. Closure temperatures for sphene and zircon have been adopted 300˚C and 240˚C respectively. FT ages have been calculated according to the equation without zeta value:

\[
T = \frac{1}{\lambda_d} \ln \left[ \left( 1 + \frac{\rho_{SD}}{\rho_{DF}} \right) \phi \sigma I \right]
\]

Where, \( \phi = \) Neutron flux
\( I = 7.25 \times 10^{-3} \)
\( \sigma = 580.2 \times 10^{-24} \text{ cm}^2 \)
\( \lambda_d = (7.03 \pm 0.11) \times 10^{-17} \text{ yr}^{-1} \)
\( \lambda_d = 1.55 \times 10^{-10} \text{ yr}^{-1} \)

\( \rho_s \) is the surface density of etched spontaneous fission racks, \( \rho_t \) is the surface density of etched induced fission tracks. \( \lambda_d = 1.55 \times 10^{-10} \text{ yr}^{-1} \) is the total decay constant of 238U, \( \rho_{SF} \) is the induced fission-track density for a uranium.

In our study, fission-track ages were determined on two cogenetic minerals. I took two co-genetic minerals from Syenite rocks in the Sushina hill, targeting a possible denudation history to be revealed, which could be reflected by an offset ages of two cogenetic minerals (Fuchs, 1962; Galbraith, 1990; Foster et al., 1991; Gallagher, 1995; Gallagher and Brown, 1997; Gleadow et al., 2000; Foster and Raza, 2002).

The low temperature of thermal history of rock in rifting-related heating versus denudation cooling environments is primarily controlled by their vertical displacement relative to the earth’s surface along a near-steady-state geotherm. Denudation is therefore the major controlling process in this context, so the rate of cooling is determined by the rate of denudation (Wagner and Storzer, 1970; Wagner and Reimer, 1972; Vineyard, 1976; van der Beek et al., 1994; van der Beek et al., 1995; van der Beek et al., 1996).

The rate of uplift of 4m/Ma (table2) in our study is therefore inferred as the rate of denudation due to tectonic activity.
Table 1 shows that sphene has a mean age of 1458 Ma with mean track length 11.2µm and zircon has a mean age of 970 Ma with mean track length 14.6µm. Given that there is sphene age older than zircon age, the youngest age of 970 Ma for the zircon must represent the timing of the initiation of tectonic denudation.

5. CONCLUSION

The largest age error (20.7%) occurs in sample SPH. This high error is probably due to a very low uranium concentration (20.40 ppm). It is known that low uranium is hindrance to calculation of accurate age of the samples. In low uranium samples, an exact match between the areas counted in the grains and the mica is often hard to achieve. In this study, closure temperatures for sphene and zircon have been adopted 300˚C and 240˚C respectively. For determining FT ages, zeta calibration was not performed. This delimits an exact calculation of FT ages.

Syenite rocks of the Sushina hill in TPSZ had suffered denudation at the rate of 4 m/Ma in the range from 970 Ma-1458 Ma. The youngest age of zircon of 970 Ma represents the timing of the initiation of tectonic denudation.

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