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Uplift History of Syenite Rocks of the Sushina Hill, Tamar Porapahar Shear Zone (TPSZ), Purulia: Constraints from Fission-track Ages of Two Cogenetic Minerals

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Abstract

Fission-track ages of cogenetic minerals namely apatite, and zircon from syenite rocks of the Sushina hill, Tamar Porapahar Shear Zone (TPSZ), coupled with the corresponding closure temperatures of the minerals have been used to reveal the uplift history of syenite rocks. Offset of their FT ages indicates that the samples uplifted at the rate of 9.97 m/Ma during the period 535 Ma-970 Ma.

Keywords: Metamorphic minerals; Cogenetic minerals; Syenite rocks; Uranium samples

Introduction

It is widely accepted that radiometric ages determined on metamorphic minerals from orogenic belts reflect their cooling history rather than their primary crystallization [1-5]. Cooling histories obtained using different radiometric techniques on cogenetic minerals from a single sample often include zircon and apatite fission track ages as low-temperature bounds to a temperature interval of several hundred degrees [6-15].

Fission-track ages were determined on cogenetic minerals from syenite rocks of the Sushina hill, TPSZ. Sushina hill in TPSZ lies within Singhbhum Group (SG) of rocks. The North Singhbhum Mobile Belt (NSMB) in its northern margin has a tectonic boundary with the Chhotanagpur Gneissic Complex (CGC) along the TPSZ [16-22]. Singhbhum Shear Zone (SSZ) is located 40 km south of the TPSZ. At places, TPSZ passes either through rocks of SG or CGC. Singhbhum orogenic cycle experienced three major phases of deformation. CGC underwent four phases of deformation [23-28]. TPSZ witnessed reactivation near 500 Ma due to overthrusting and suffered rapid exhumation near 600 Ma [29-34]. TPSZ was thus affected by the intense deformation in the area adjoining this shear zone. With this background of geological events, it was thought that fission track dating on cogenetic minerals might help unravel the uplift history of syenite rocks of the Sushina hill.

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 [35]. All the samples were prepared for the external detector method. AFT mounts were etched with 70% HNO_3 at room temperature for 30 s. Zircons were mounted in PFA Teflon. Zircons were etched in KOH-NaOH eutectic etchant [36-39] 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 IRMM-540R (15 ppm). Mica sheets were etched using 48% HF at room temperature for 19 min [40-43]. The fission tracks were counted under a total magnification of 1000X. The calibrated area of one grid is 0.64×10^{-6} cm^2. Durango apatites were used as the age standard mineral, which was provided by Prof. Barry Paul Kohn, University of Melbourne, Australia. FT age of zircon was determined using equation without zeta value. Zeta calibration was not performed on zircon because of the unavailability of age standard minerals [44-48].

Interpretation and Results

Fission track age determinations were made on 15apatite, and 18 zircon separates from syenite rocks from the Sushina hill shown in Figure 1. The mean fission track ages of apatite and zircon are 535.25 Ma, and 970 Ma respectively as shown in Table 1.

The uplift rate has been calculated according to the equation:

$$\text{Uplift rate}=\frac{\textit{Cooling rate}}{\textit{Geothermal gradient}} \quad (1)$$

Where, $\text{Cooling rate}=(T_1\text{-}T_2)\div(A_1\text{-}A_2)$

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 apatite and zircon have been adopted 110°C and 240°C respectively.

FT age of apatite sample namely SAP has been calculated according to the equation [49]:

$$T=1/\lambda_D \ln\{1+\lambda_D Z.G\rho_d p_s/\rho_i\} \quad (2)$$

Where, is the surface density of etched spontaneous fission racks, ρ_i is the surface density of etched induced fission tracks, and G is the integrated geometry factor of etched surface. $\lambda_d=1.55\times10^{-10}yr^{-1}$ = total decay constant of ^{238}U, Z = calibration factor based on EDM of fission-track age standards. ρ_d = induced fission-track density for a uranium standard corresponding to the sample position during neutron irradiation.

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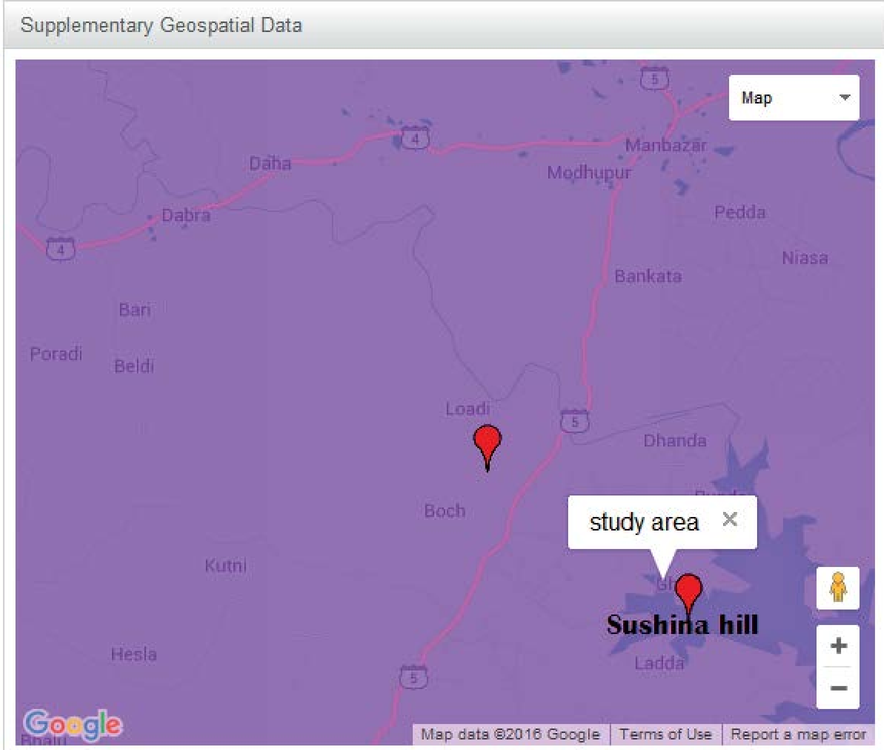

Figure 1: Location map of the Sushina hill.

Sample name	Rock type and Mineral	P_d×10⁶	N_d	P_s×10⁶	Ns	P_i×10⁶	N_i	P{×}2(%)	U(ppm)	Mean age ± 1б (Ma)	No. of grain
SAP	Syenite, Apatite	1.925	1232	0.325	156	0.146	70	0.33	0.68	535.25 ± 14.52	15
SZR	Syenite, Zircon	1.82	1168	17.66	452	1.773	244	15.39	41.65	970 ± 7.94	18

Table 1: Results of AFT analyses : ages calculated using dosimeter glass IRMM-540R with 15 ppm U, zeta = 250, irradiated at FRMII, calibrated by traditional zeta approach and external detector method for apatite sample SAP, N=Number of grains, ρ – track densities given in 10^6 tr cm^{-2}, ρ_d – dosimeter track density, N_d – number of tracks counted on dosimeter, $\rho_s(\rho_i)$ – spontaneous (induced) track densities, $N_s(N_i)$ – number of counted spontaneous (induced) tracks, P(²א) – probability for obtaining ²א value for n degrees of freedom, where n=no. of grain – 1, Neutron flux(Φ) for zircon sample SZR = 1.75×10^15 neutron/cm².

Region	Closure temperatures	Time Span (Ma)	Cooling rate (°C/Ma)	Uplift rate (m/Ma)
Sushina hill in TPSZ	110°C for apatite 240°C for zircon	535-970	0.299	9.97

Table 2: Cooling and uplift rate of the Sushina hill.

FT age of zircon sample namely SZR has been calculated according to the equation without zeta value [50]:

$$T = 1/\lambda_d \ln\left(1 + 9.25\times 10^{-18} p_s / \rho_i.\Phi\right) \text{years} \quad (3)$$

Where, Φ = Neutron flux

The large age errors, e.g. 14.52% are found in sample SAP. As already known, low Uranium samples present a problem because of low induced track densities [51-55]. The P (X^2) test was performed to measure the uranium variation in the samples. A value of P(X^2) larger than 5% means that the grains are assumed to be a single age. Sample SAP failed the X^2 test, which may indicate bimodal distributions for the sample.

By applying apatite fission track analysis, the possible uplift rate of the Sushina hill was attempted to be revealed, which could be reflected by an offset age of two cogenetic minerals (Table 2).

Conclusion

The largest age error (14.52%) occurs in sample SAP. This high error is most likely due to a very low uranium concentration (0.68 ppm). As already known, low uranium samples place limits on how robust the ages could be. In low uranium samples, an exact match between the areas counted in the grains and the mica is often hard to achieve. An adjustment by eye is difficult and subjective because the outline of the induced tracks on the mica does not reflect the shape of the analyzed grain. In this study, closure temperatures for apatite and zircon have been adopted 110°C and 240°C respectively. In reality, the closure temperature concept cannot be straight forward applied.

For determining zircon FT age, zeta calibration was not performed. It places limit on precise calculation of FT age. Syenite rocks of the Sushina hill in TPSZ uplifted at the rate of 9.97 m/Ma in the range from 535 Ma-970 Ma.

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