check for updates

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

Amal Kumar Ghosh[1]   [1]*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.

Contribution/Originality: Apatite fission-track (AFT) analysis has been widely used to constrain the low-temperature thermal histories of many igneous, metamorphic and sedimentary rocks in a wide range of geological settings. This study is one of very few studies which have investigated the rate of denudation 4m/Ma and 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 streching 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 breeciations 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.
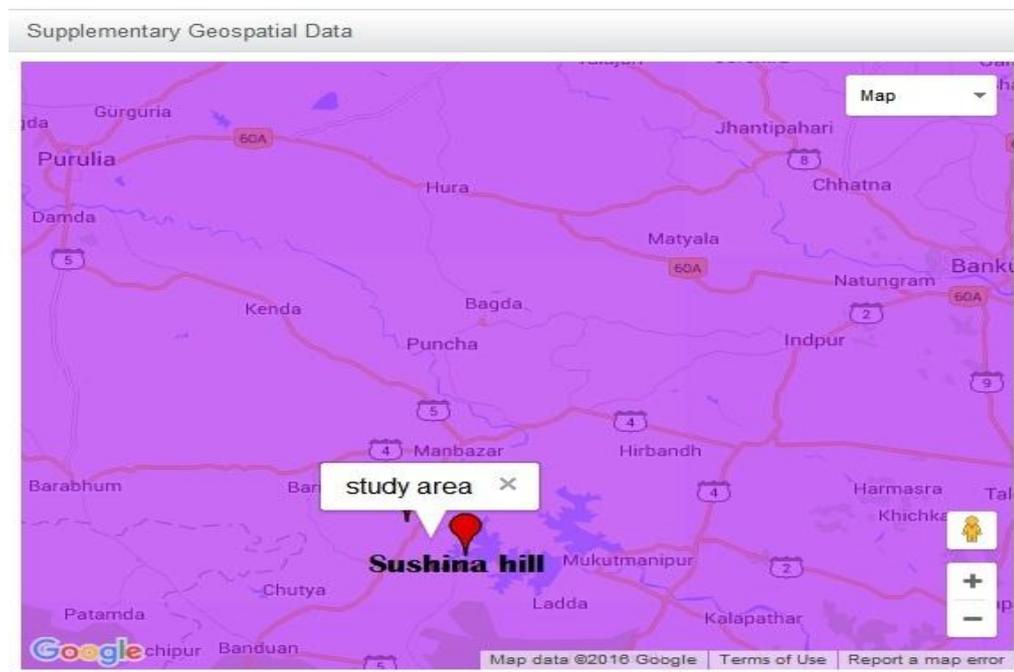

Fig-1. Location map of Sushina hill
Source: Generated by KML files using GIS technique

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 238Ucan 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 sphene are 1.75×10^{15} neutron/ *cm2* and 2.5×10^{15} neutron/ *cm2* respectively. The fission tracks were counted under a total magnification of1000x. The calibrated area of one grid is 0.64X 10**-6** cm**2**.

Table-1. Analytical data for fission track analysis

Sample No.	Rock Type	No of Grains	Dosimeter		Spontaneous		Induced		$P(\chi^2)$	U (ppm)	Mean Age (Ma)	MTL (µm)	SD	No. of Tracks	D_{par}	Error(%) on Mean Age
			ρ_d	N_d	ρ_s	N_s	ρ_i	N_i								
SPH	Syenite	18	1.045 409	11.37	291	1.04	143	18.8	24.40	1458	11.2	NA	90	1.68	20.7	
SZR	Syenite	18	0.73	1168	17.66	452	1.77	244	15.4	41.65	970	14.6	NA	85	1.54 14.7	

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, ρ – track densities given in 10^6 tr cm^{-2}, ρ_d- dosimeter track density, N_d – number of tracks counted on dosimeter, ρ_s(ρ_i) – spontaneous (induced) track densities, N_s(N_i) – number of counted spontaneous (induced) tracks, P(χ2) – probability for obtaining χ2 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

Region	Closure Temperatures	Time Span (Ma)	Cooling Rate (0_C/Ma)	Uplift Rate (m/Ma)
Sushina hills in TPSZ	300 °C for sphene 240 °C for zircon	970 – 1458	0.123	4

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 ρ_s, ρ_i and ρ_d (table 1). In this case, ρ_s and ρ_i are obtained from

$$\rho_s = \frac{\sum N_{sj}}{\sum A_j} \qquad \rho_I = \frac{\sum N_{Ij}}{\sum A_j}$$

(1)

(Naeser, 1967; Turner *et al.*, 1983; van der Beek, 1997; Tagami and O'Sullivan, 2005) where N_{sj} is the number of spontaneous fission tracks in area Aj of the jth crystal and N_{ij} 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

$$\sigma = \pm \frac{Ns}{Ni}\left(\frac{1}{Ns} + \frac{1}{Ni}\right) 1/2$$

(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_s, and N_i are the total numbers of counted tracks for ρ_s and ρ_d respectively. Errors in mean age of sphene and zircon were calculated as 20.7% and 14.7% respectively (table 1). A statistical procedure, called χ2 -test

was developed to assess the validity of data. It was shown that results from the conventional formula give the best estimate of (ρ_S/ρ_i) and $\sigma(\rho_S/\rho_i)$), as long as the observed track counts are acceptable under a $\chi 2$ − Criterion:

$$\chi^2 = \Sigma \left\{ \frac{(N_{Sj} - P_{Sj})^2}{P_{Sj}} \right\} + \Sigma \left\{ \frac{(N_{Ij} - P_{Ij})^2}{P_{Ij}} \right\} \qquad (3)$$

where $P_{SJ} = N_S(N_{SJ} + N_{IJ})/(N_S+N_I); P_{IJ}=N_I((N_{SJ} + N_{IJ})(N_S+N_I)$. 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:

$$\text{Uplift rate} = \frac{Cooling\ rate}{Geothermal\ gradient} \qquad (4)$$

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 :

$$\text{T} = \frac{1}{\lambda_d}\ \ln\left[\left(1 + \frac{\rho_s \lambda_d}{\rho_i \lambda_F}\right)\varphi\sigma\text{I}\right] \qquad (5)$$

Where, φ = Neutron flux

I = $7.25 \times 10-3$

σ = $580.2 \times 10-24$ *cm2*

$\lambda_F = (7.03 \pm 0.11) \times 10-17\ yr-1$

$\lambda_d = 1.55 \times 10^{-10}\ yr-1$

ρ_s is the surface density of etched spontaneous fission racks, ρ_i is the surface density of etched induced fission tracks. $\lambda_d = 1.55\times 10^{-10} yr-1$= total decay constant of 238U, ρ_d = induced fission-track density for a uranium standard corresponding to the sample position during neutron irradiation.

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 1shows that sphene has a mean age of 1458 Ma with mean track length 11.2μm and zircon has a mean age of 970Ma with mean track length 14.6μm. Given that there is sphene age older than zircon age, the youngest age of 970Ma 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 970Ma-1458 Ma. The youngest age of zircon of 970Ma represents the timing of the initiation of tectonic denudation.

REFERENCES

Acharya, A., S.K. Basu, S.K. Bhaduri, B.K. Chaudhury, S. Ray and A.K. Sanyal, 2006. Proterozoic rock suites along South Purulia Shear Zone, Eastern India; Evidence for rift-related setting. Geological Society of India, 68(6): 1069-1086. *View at Google Scholar*

Basu, S.K., 1993. Alkaline-carbonatite complex in Precambrian of South Purulia Shear Zone, Eastern India: Its characteristics and mineral potentialities. Indian Minerals, 47(3): 179-194. *View at Google Scholar*

Dodge, F.C.W. and D.C. Ross, 1971. Coexisting hornblendes and Biotites from granite rocks near the San Andreas fault, California. Journal of the Geological, 79(2): 158-172. *View at Google Scholar | View at Publisher*

Donelick, R.A., P.B. O'Sullivan and R.A. Ketcham, 2005. Apatite fission-track analysis. Reviews in Mineralogy and Geochemistry, 58(1): 49-94. *View at Google Scholar*

Feinstein, S., B.P. Kohn and M. Eyal, 1989. Significance of combined vitrinite reflectance and fission-track studies in evaluating thermal history of sedimentary basins: An example from Southern Israel. In NaeserND, McCulloh TH (Eds), Thermal history of sedimentary basins: Methods and case histories. Berlin: Springer- Verlag. pp: 197-216.

Fitzgerald, P. and A.J.W. Gleadow, 1990. New approaches in fission track geochronology as a tectonic tool: Examples from the transantarctic mountains. Nuclear Tracks and Radiation Measurements, 17(3): 351-357. *View at Google Scholar | View at Publisher*

Fitzgerald, P.G., 1994. Thermochronological constraints on the post-Paleozoic tectonic evolution of the central transantarctic Mountains, Antarctica. Tectonics, 13(4): 818-836. *View at Google Scholar | View at Publisher*

Fitzgerald, P.G., J.E. Fryxel and B.P. Wernicke, 1991. Miocene crustal extension and uplift in Southeastern Nevada: Constraints from fission track analysis. Geology, 19(10): 1013-1016. *View at Google Scholar | View at Publisher*

Fitzgerald, P.G., J.A. Munoz, P.J. Coney and S.L. Baldwin, 1999. Asymmetric exhumation across the Pyrenean orogen: Implications for the tectonic evolution of a collisional orogen. Earth and Planetary Science Letters, 173(3): 157-170. *View at Google Scholar | View at Publisher*

Fitzgerald, P.G., S.J. Reynolds, E. Stump, D.A. Foster and A.J.W. Gleadow, 1993. Thermochronologic evidence for timing of denudation and rate of crustal extension of the South Mountain metamorphic core complex and Sierra Estrella, Arizona. Nuclear Tracks, 21(4): 555-563. *View at Google Scholar | View at Publisher*

Fitzgerald, P.G., R.B. Sorkhabi, T.F. Redfield and E. Stump, 1995. Uplift and denudation of the central Alaska Range: A case study in the use of apatite fission track thermochronology to determine absolute uplift parameters. Journal of Geophysical Research, 100(B10): 20175-20191. *View at Google Scholar | View at Publisher*

Fleischer, R.L. and H.R. Hart, 1972. Fission track dating: Techniques and problems. In Calibration of hominid evolution. Bishop WW, Miller DA, Cole S (Eds). Edinburgh: Scottish Academic Press. pp: 135-170.

Fleischer, R.L. and P.B. Price, 1964. Techniques for geological dating of minerals by chemical etching of fission fragment tracks. Geochimica et Cosmochimica Acta, 28(10-11): 1705- 1714. *View at Google Scholar | View at Publisher*

Fleischer, R.L., P.B. Price and E.M. Symes, 1964. On the origin of anomalous etch figures in minerals. American Mineralogist, 49(5-6): 794-800. *View at Google Scholar*

Fleischer, R.L., P.B. Price and R.M. Walker, 1965b. The ion explosion spike mechanism for formation of charged particle tracks in solids. Journal of Applied Physics, 36(11): 3645-3652. *View at Google Scholar | View at Publisher*

Fleischer, R.L., P.B. Price and R.M. Walker, 1975. Nuclear tracks in solids. Berkeley: University of California Press.

Fletcher, J.M., B.P. Kohn, D.A. Foster and A.J.W. Gleadow, 2000. Heterogeneous Neogene cooling and uplift of the Los Cabos block, Southern Baja California: Evidence from fission track thermochronology. Geology, 28(2): 107- 110. *View at Google Scholar | View at Publisher*

Foster, D.A. and A.J.W. Gleadow, 1993. Episodic denudation in East Africa- a legacy of intracontinental tectonism. Geophysical Research Letters, 20(21): 2395- 2398. *View at Google Scholar | View at Publisher*

Foster, D.A. and A.J.W. Gleadow, 1996. Structural framework and Denudation history of the flanks of the Kenya and Anza Rifts, East Africa. Tectonics, 15(2): 258-271. *View at Google Scholar | View at Publisher*

Foster, D.A., A.J.W. Gleadow and G. Mortimer, 1994. Rapid Pliocene Exhumation in the Karakoram, revealed by fission-track thermochronology of the K2 gneiss. Geology, 22(1): 19-22. *View at Google Scholar | View at Publisher*

Foster, D.A., A.J.W. Gleadow, S.J. Reynolds and P.G. Fitzgerald, 1993. The denudation of metamorphic core complexes and the reconstruction of the Transition Zone, West-Central Arizona: Constraints from apatite Fissiontrack thermochronology. Journal of Geophysical Research, 98(B2): 2167-2185. *View at Google Scholar | View at Publisher*

Foster, D.A. and B.E. John, 1999. Quantifying tectonic exhumation in an extensional orogen with thermochronology: Examples from the Southern Basin and Range Province. Geological Society, London, Special Publications, 154(1): 343-364. *View at Google Scholar | View at Publisher*

Foster, D.A., D.S. Miller and C.F. Miller, 1991. Tertiary extension in the old woman Mountains area, California: Evidence from apatite fission track analysis. Tectonics, 10(5): 875-886. *View at Google Scholar | View at Publisher*

Foster, D.A. and A. Raza, 2002. Low-temperature thermochronological record of exhumation of the Bitterroot metamorphic core complex, Northern Cordilleran Orogen. Tectonophysics, 349(1-4): 23-36. *View at Google Scholar*

Fuchs, L.H., 1962. Occurrence of whitlockite in chondritic meteorites. Science, 137(3528): 425-426. *View at Google Scholar | View at Publisher*

Galbraith, R.F., 1990. The radial plot: Graphical assessment of spread in ages. Nuclear Tracks and Radiation Measurements, 17(3): 207-214. *View at Google Scholar | View at Publisher*

Galbraith, R.F. and G.M. Laslett, 1993. Statistical models for mixed fission track ages. Nuclear Tracks and Radiation Measurements, 21(4): 459-470. *View at Google Scholar | View at Publisher*

Gallagher, K., 1995. Evolving temperature histories from apatite fissiontrack data. Earth and Planetary Science Letters, 136(3-4): 421-435. *View at Google Scholar | View at Publisher*

Gallagher, K. and R.W. Brown, 1997. The onshore record of passive margin evolution. Journal of the Geological Society, 154(3): 451-457. *View at Google Scholar | View at Publisher*

Gleadow, A.J., D.X. Belton, B.P. Kohn and R.W. Brown, 2002. Fission track dating of phospate minerals and the thermochronology of apatite. Reviews in Mineralogy and Geochemistry, 48(1): 579-630. *View at Google Scholar | View at Publisher*

Gleadow, B.K., V.F. Brown, M. Grivet, M. Rebetez, C. Dubois, A. Chambaudet, N. Chevarier, G. Blondiaux, T. Sauvage and M. Toulemonde, 2000. Damage morphology of Kr tracks in apatite: Dependence on thermal annealing. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 168(1): 72-77. *View at Google Scholar | View at Publisher*

Naeser, C.W., 1967. The use of apatite and sphene for fissiontrack age determinations. Geological Society of America Bulletin, 78(12): 1523-1526. *View at Google Scholar | View at Publisher*

Nagpaul, K.K., 1981. Fission track geochronology of India. Proceedings of the Indian Academy of Sciences-Earth and Planetary Sciences, 90(3): 389-401. *View at Google Scholar | View at Publisher*

Tagami, T. and P.B. O'Sullivan, 2005. Fundamentals of fission-track thermochronology. Reviews in Mineralogy and Geochemistry, 58(1): 19-47. *View at Google Scholar | View at Publisher*

Turner, D.L., V.A. Frizzell, D.M. Triplehorn and C.W. Naeser, 1983. Radiometric dating for ash partings in coal of the Eocene Puget Group, Washington: Implications for paleobotanical stages. Geology, 11(9): 527-531. *View at Google Scholar | View at Publisher*

van der Beek, P.A., 1997. Flank uplift and topography at the central Baikal Rift (SE Siberia): A test of kinematic models for continental extension. Tectonics, 16(1): 122-136. *View at Google Scholar | View at Publisher*

van der Beek, P.A., P.A.M. Andriessen and S. Cloetingh, 1995. Morphotectonic evolution of rifted continental margins: Inferences from a coupled tectonic surface processes model and fission-track thermochronology. Tectonics, 14(2): 406-421. *View at Google Scholar | View at Publisher*

van der Beek, P.A., S. Cloetingh and P.A.M. Andriessen, 1994. Mechanisms of extensional basin formation and vertical motions at rift flanks: Constraints from tectonic modelling and fission track thermochronology. Earth and Planetary Science Letters, 121(3-4): 417-433. *View at Google Scholar | View at Publisher*

van der Beek, P.A., D. Delvaux, P.A.M. Andriessen and K.G. Levi, 1996. Early Cretaceous denudation related to convergent tectonics in the Baikal region, SE Siberia. Journal of the Geological Society, 153(4): 515-523. *View at Google Scholar | View at Publisher*

Vineyard, G.H., 1976. Thermal spikes and activated processes. Radiat Effects, 29(4): 245-248. *View at Google Scholar | View at Publisher*

Wagner, G.A. and G.M. Reimer, 1972. Fission track tectonics: The tectonic interpretation of fission track apatite ages. Earth and Planetary Science Letters, 14(2): 263-268. *View at Google Scholar | View at Publisher*

Wagner, G.A. and D. Storzer, 1970. Die interpretation von Spaltspurenaltern (fission Track Ages) am Beispiel von naturlichen Glasern, Apatiten und Zirkonen. Eclogae Geologicae Helvetiae, 63(1): 335-344. *View at Google Scholar*