Jour. Fac. Sci., Hokkaido Univ., Ser. IV,
vol. 20, nos. 2-3, Feb., 1983, pp. 195-202.

# GEOMETRY FACTOR IN FISSION TRACK DATING

*by*

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(with 5 text-figures and 3 tables)

*Abstract*

An analysis of geometry factor on fission track dating using both the external and internal surfaces of zircon with external detectors is made in this note. The present experimental results suggest that the geometry ratio of track density of an external to that of an internal surface takes $G = 0.52$. This experimental value agrees with the value of $G = 0.53$ obtained from the minimum track length proposed by Green and Durrani (1978). A series of experimental results yields that the value of $g'$ (i.e. the ratio of track density in an external detector to that in an external surface) takes 0.98. The fission track ages calibrated by using both G and $g'$ values obtained from track density of internal surface, are approximately coincident with the ages calibrated by only $g'$ value obtained from external surface.

## Introduction

In fission track dating, the employment of an internal surface for counting spontaneous fission tracks and an external detector for counting induced tracks has become more common. External surface ($2\pi$) will receive fission fragments on only one side of sample surface. Internal surface ($4\pi$) revealed by polishing will record the fission fragments on both upper and bottom surface of sample. Accordingly, the ratio of fission track density between external surface and internal surface will be ideally 0.5. This value has been often used for fission track dating. However, Fleisher et al. (1964, a) and Edward (1967) suggested that the ratio took more higher value in case of track densities obtained from hornblendes and glasses. Reimer et al. (1970) also indicated that a large correction must be necessary for this ratio especially in case of apatite, sphene and zircon on the basis of the following two reasons; 1) The geometry is greater than $2\pi$ on account of destruction of external surface of mineral with bulk etching. 2) Due to limited resolution of optical microscope, it is impossible to identify the tracks less than $2\mu$m in diameter.

On the other hand, Gleadow and Lovering (1977) insist that these ratios are stationary as ideal value (0.5). They indicated two effects for explanation on this value. 1) The etching efficiency on particular mineral (apatite, sphene and zircon) surface should be very similar to that of mica. 2) Both internal surface and external detector have similar minimum length track and efficiency for counting will be essentially the same. Lately, Green and Durrani (1978) also show the following points about geometry factor. 1) Prolonged etching will affect both the external and internal surfaces identically and thus can not enhance the ideal ratio. 2) Practically, prolonged etching is not important in minerals, as once Nishida and Takashima (1975) described. They showed geometry factors as follows;

$$G = \rho 2\pi / \rho 4\pi; \quad g = \rho \text{e.d.} / \rho 4\pi; \quad g' = \rho \text{e.d.} / \rho 2\pi \quad (1)$$

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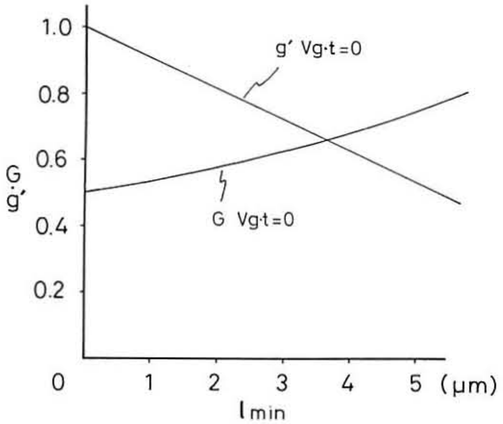
where $\rho 4\pi$, $\rho 2\pi$ and $\rho$e.d. are etched fission track densities on internal surface, external surface and external detector respectively. Ideal values of those ratios as defined above are;

$$\mathbf{G} = 0.5; \quad \mathrm{g} = 0.5; \quad \mathrm{g}' = 1.0 \qquad (2)$$

Practically, these values are influenced by the following three effects, 1) the limitation of $\theta$c and $\theta$e.d., critical angles of etching in sample and in the external detector, 2) the presence of tracks that are shorter than the minimum observable track length, 3) removal of each surface by bulk etching. Of them, the second effect is the most significant factor. The variation of **G** and g′ ratios shown by the minimum observable track length are defined in Text-fig. 1.

Among them, **G** and g′ ratios participate directly in fission track dating. Therefore, **G** represents geometry factor between external surface and internal surface in minerals, and g′ represents geometry factor between mineral surface and external detector (Table 1). In this paper, the results of investigation of geometry factors for calibration of fission track ages, based on analysis of track densities and track length on each surface are discussed.




**Text-fig. 1** The theoretical variation of the ratios G and g′ in zircon with the minimum track length, 1 min, assuming the effect of surface removal (vg·t) is zero. Based on the Green and Durrani equation (5) (1978: pp. 209).

**Table 1** The geometry factor among various different etching surfaces.

| | | |
|---|---|---|
| External surface ($2\pi$ geometry) | $\boxed{\rho 2\pi/\rho 4\pi = \mathrm{G}}$ | Internal surface ($4\pi$ geometry) |
| $\boxed{\rho\mathrm{e.d.}/\rho 2\pi = \mathrm{g}'}$ | | $\boxed{\rho\mathrm{e.d.}/\rho 2\pi = \mathrm{g}'}$ |
| External detector | | External detector |

## Experimental procedure

Zircon crystals separated from the Tertiary volcanic rocks in Sado island, Niigata Prefecture, Central Japan were selected for the present determination. The experiment was carried out by using the method of Gleadow et al. (1976). The present experiment processes are the following;

The zircon crystals mounted on teflon sheet, are separated into two groups. One group is polished by diamond paste in order to expose an internal surface; the other group is placed for determination of external surface (100) without polishing. Each mounted zircon is etched to reveal the spontaneous fission track using KOH (11.5g) and NaOH (8.0g) molten mixed etchant and keep the temperature constant at 200°C for about 23 – 25 hours for the internal surface, and 25 – 30 hours for the external surface. After etching, muscovite external detctor is attached to each given surface, and then these samples are pressed with acrylic plates. On the other hand, the following samples are prepared for determination of g′ value. Some zircon crystals are annealed in order to remove spontaneous fission track completely under the temperature condition at 1,000°C for 2 hours. After annealing, these zircons are mounted on teflon sheets and their surfaces polished. Then, muscovite detector is attached to polished surface and is holded in between the acrylic plates. All the zircon samples and standard glass (NBS 613) are covered with external muscovite detector, and are irradiated in the Triga type reactor of Musashi Institute of Technology, for 20 minutes (total thermal neutron flux; 0.94 – 1.08 x $10^{15}$ n/$cm^{-2}$ ). After radioactive cooling, the muscovite detectors are etched for 25 minutes at room temperature with 46% HF solution. The spontaneous fission track density (Ns) is then counted on the both external and internal surfaces and the induced track density (Ni) is obtained from the external detector. Neutron doses are monitored using calibrated uranium bearing glass (NBS613). Counting is carried out under the 1,000 magnification microscope with immersion oil. After counting fission track densities, length of fission tracks are measured on both external, internal surfaces and external detector.

## Result and discussion

Length of fission track

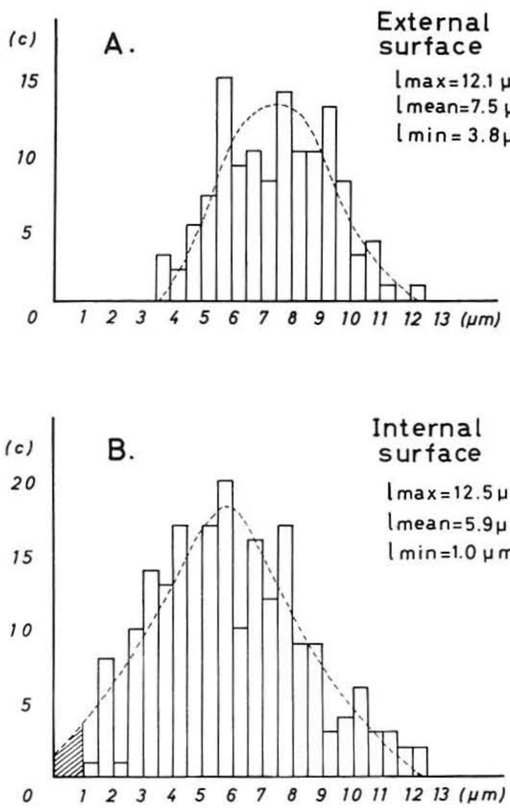
The minimum track length on each surface is most effective to the geometry factor. Text-fig. 2 indicates the measurements of length distribution of tracks on each surface. This result may represent the following consequence;

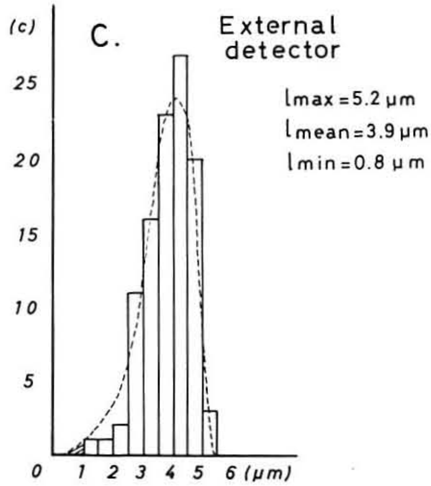
1) The distribution pattern shown in Text-fig. 2 coincides well with the ideal distribution pattern of track lengths proposed by Gleadow and Lovering (1977) (Text-fig. 3).

2) The data obtained from the internal surface (Text-fig. 2, B) show the widest distribution, ranging from 1.0μm to 12.5μm. The presence of unobservable tracks, less than 1.0μm illustrated by hatched area in Text-fig. 2, B will be obvious. The distribution of track length obtained from the external surface (Text-fig. 2, A) takes place a somewhat limited range between 3.8μm and 12.1μm. The minimum track length is 3.8μm. This suggests that correction for the geometry factor is not necessary for external surface. Most detected track lengths in external detector (Text-fig. 2, C) distributes in a limited range between 1.0μm and 5.0μm, and are especially concentrated to a limit ranging from 3.0μm to 5.0 μm. Unobservable tracks, less than 0.8μm shown by hatched area in Text-fig. 2, C are inferred in the track distribution pattern.

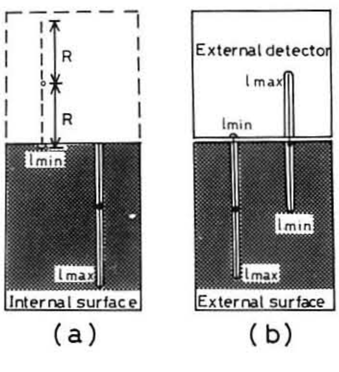
Discussion on geometry factor

Text-fig. 2 shows that **G** and g′ values are directly related with the ratio of the



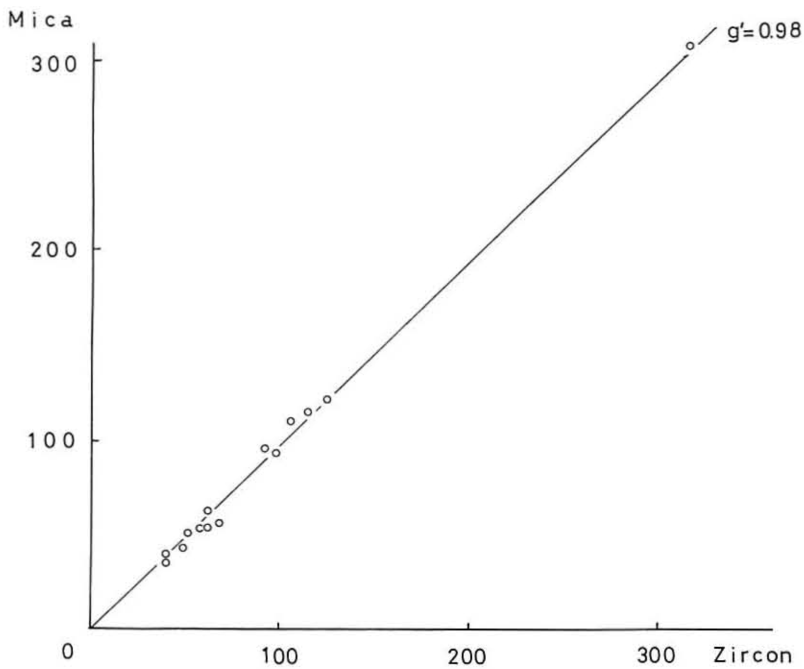




**Text-fig. 2** Range distribution of fission track length on each surface indicating the longest (1 max), shortest (1 min) and mean track length (1 mean). Shaded area indicates supposed portion of unobservable tracks.




**Text-fig. 3** Diagram showing the longest (1 max) and the shortest (1 min) possible fission tracks on various different etching surfaces. (a) illustrate the case of spontaneous tracks etched on the internal surface ($4\pi$ geometry). (b) shows tracks etched on the external surface of U-bearing mineral itself and on the external detector ($2\pi$ geometry). R indicates the range of fission fragment. (after Gleadow and Lovering, 1977)

unobservable track density to the total actual track density. On the basis of the histogram as illustrated in Text-fig. 2, B, supposed unobservable tracks are estimated to be approximately 9. The total actual track count obtained from the sample B is 219. Therefore, **G** value is given as 0.52. On the other hand, supposed unobservable tracks are estimated to be about 3 based on the histogram obtained from the external detector; while the total actual count is observed to be 105. Therefore, g′ value is given as 0.97. Text-fig. 4 represents the ratio g′ between the induced fission track density on annealed zircon surface ($\rho 2\pi$) and the induced track density on muscovite detector ($\rho$e.d.). Exerimental result suggests that the g′ ratio is 0.98. In fact, this value is indistinguishable from the result shown in Text-fig. 2, C. These results suggest that almost 98% of induced tracks produced in zircon are recorded on muscovite detector and the rest 2% is not recorded. Therefore, the results of these experiments may suggest that some correction for geometry factor should be necessary for fission track dating technique in the case of using internal surface of zircon and external detector.




**Text-fig. 4** Diagram showing the variation of **g′** ratio between the induced fission track density on annealed zircon surface ($\rho 2\pi$) and the induced track density on muscovite ($\rho$e.d.), Most plots are close to the line (g′ = 0.98).

Fission track dating

The fission track ages are calculated based on the following equation proposed by Fleisher et al. (1964, b).

$$T1 = \frac{1}{\lambda f} \times \frac{Ns}{Ni} \times \frac{\phi\sigma}{\eta} \qquad (3)$$

where; ($\lambda$f) = decay constant by fission of $^{238}U$, ($6.85 \times 10^{-17}$ $yr^{-1}$)

($\sigma$) = thermal fission cross section of $^{235}U$, ($577 \times 10^{-24}$ $cm^2$)

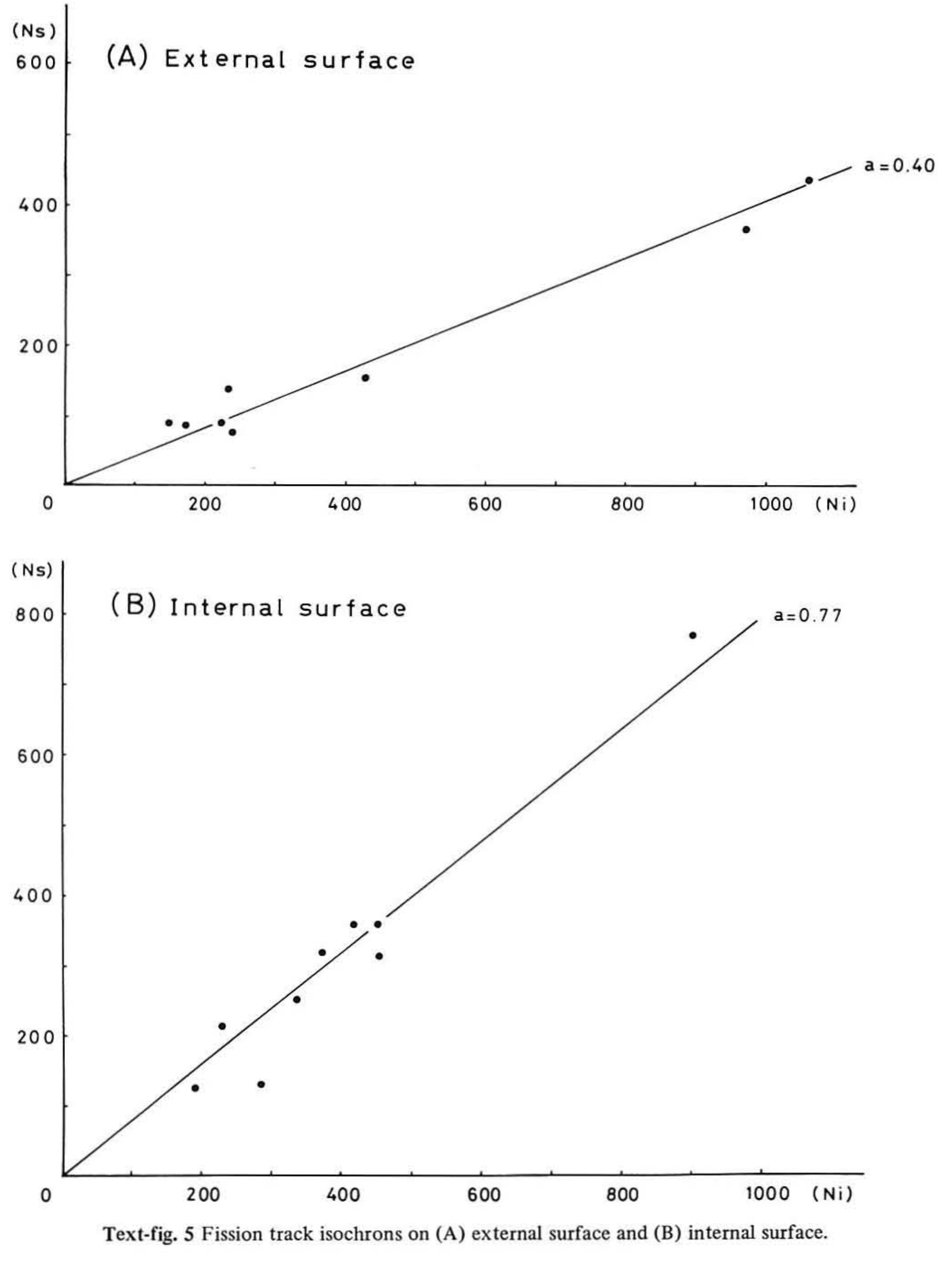
($\eta$) = the present-day ratio of the abundance of $^{238}U$ and $^{235}U$, (138)

(Ns) = spontaneous fission track density

(Ni) = induced fission track density

($\phi$) = thermal neutron flux (n/cm$^2$)

More precisely, the above equation (3) should be written as follows in the case of calculating




**Text-fig. 5** Fission track isochrons on (A) external surface and (B) internal surface.

fission track ages (T2) from the internal surface.

$$T2 = \frac{1}{\lambda f} \times \frac{Ns \cdot \mathbf{G}}{Ni/g'} \times \frac{\phi/g' \cdot \sigma}{\eta} = T1 \cdot G \qquad (4)$$

In short, geometry factor **G** correction should be made on the apparent age (T1). In the above equation, (Ns/Ni) is determined by experimental results (Text-fig. 5). Text-fig. 5(A) and 5(B) represent the results of fission track isochron using data from the external and internal surfaces. The results of the present fission track age determinations are given in Table 2. The age (T1) obtained from the external surface is about 4 – 10 percents older than that obtained from internal surface. The difference between the two may be due to geometry factor. In the case of OD-82 (Table 2), after calibration by using **G** ratio, the T2 age obtained from the internal surface approximately coincides with T1 age obtained from the external surface. On the other hand, T2 age obtained from the internal surface is still a little different from T2 age from the same surface especially in the case of IW-1 sample (Table 2). The difference in this latter case must be affected by some unknown error than the geometry factor.

**Table 2** Measurments of fission track dating, T1, apparent ages; T2, ages after geometry factor G correction.

| Sample code | Surface | Ns tracks/cm² (×10⁶) | Ns tracks | Ni tracks/cm² (×10⁶) | Ni tracks | neutrons ($\times 10^{14}$) | Ns/Ni | Number of grains | T1 | T2 |
|---|---|---|---|---|---|---|---|---|---|---|
| IW-1 | External ($2\pi$) | 1.39 | 1645 | 3.37 | 3524 | 7.25 | 0.47 | 8 | 23.1 | |
| | Internal ($4\pi$) | 2.99 | 2826 | 4.03 | 3709 | 7.25 | 0.75 | 9 | 20.9 | 21.7 |
| OD-82 | External ($2\pi$) | 2.73 | 1387 | 5.91 | 2953 | 7.25 | 0.47 | 9 | 28.6 | |
| | Internal ($4\pi$) | 4.38 | 14593 | 4.25 | 13933 | 6.91 | 0.81 | 41 | 27.6 | 28.7 |

Comparison between geometry ratios

In the present study the minimum track length in the case of the internal surface is 1.0$\mu$m (Text-fig. 2,B). From the graphic presentation of Green and Durrani's formula (Text-fig. 1) **G** value would be accordingly 0.53 (Table 3). This value is quite close to **G** = 0.52 obtained in the present study. Further, this value (0.52) is also close to the ideal value of **G** (0.50) proposed by Gleadow and Lovering (1977). While, the minimum length of tracks in the external detector (mica) measured in the present study is 0.8$\mu$m (Text-fig. 2,C). We can similarly deduce the $g'$ value out of Text-fig. 1. $g' = 0.93$ thus obtained is approximately coincident with the exerimental result in which $g' = 0.98$. The minor difference may probably be due to the presence of tracks less than 0.8$\mu$m.

**Table 3** Comparison between geometry ratios of authors. *Data deduced from Text-fig. 1.

| | Reimer et al. (1970) | Gleadow and Lovering (1977) | Green and Durrani (1978) | This paper |
|---|---|---|---|---|
| G | 0.60 – 0.69 | 0.5 | 0.53* | 0.52 |
| $g'$ | | | 0.93* | 0.97~0.98 |

## Conclusion

1) It is required to correct the fission track ages by geometry factors of $\mathbf{G} = \rho 2\pi/\rho 4\pi$ and $g' = \rho e.d./\rho 2\pi$ in the case of using internal surface of mineral and external detector (Table 1).

2) The track less than 1.0$\mu$m and 0.8$\mu$m on the internal surface of zircon and the external muscovite detector are indistinguishable under the microscope. Both **G** and g′ values are calculated as the number of actual track count divided by total track count which is the sum of actual track count and estimated unobservable tracks.

3) The value of **G** = 0.52 obtained from the present experimental result agrees with the value of **G** = 0.50 or 0.53 recommended by Green and Durrani (1978) and Gleadow and Lovering (1977). While, the value of g′ = 0.98 agrees fairly well with that of g′ = 0.93 deduced from Green and Durrani (1978).

4) The fission track ages obtained from track density of internal surface of zircon and calibrated by **G** and g′ factor are in better coincidence with those obtained from track density of external surface of zircon.

*Acknowledgements*

The auther would like to thank Professor M. Kato and Dr. Y. Fujiwara for useful discussions and suggestions during the development of this work. Thanks are due to Professor S. Hirai for the use of reactor facilities of the Musashi Institute of Technology.

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(Manuscript received on Oct. 5, 1982)