FISSION-TRACK AGE DETERMINATION OF ACCESSORY ZIRCON FROM THE NEOGENE-TERTIARY TUFF SAMPLES, AROUND SENDAI CITY, JAPAN

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Introduction and Previous Works

Since PRICE and WALKER (1962) and FLEISCHER and PRICE (1963) showed that fission-track could be observed under the optical microscope after chemical etching, the methods of fission-track dating of minerals have progressed greatly. Minerals available for this dating are zircon, apatite, biotite, hornblende and muscovite (FLEISCHER and PRICE, 1964d). Particularly, zircon is one of the best minerals because of its high uranium content and its high-temperature stability (FLEISCHER, PRICE and WALKER, 1964). Recently, the fission-track dating has been applied to geology by many workers (PRICE and WALKER, 1963, FLEISCHER and PRICE, 1964a, b, FLEISCHER *et al.*, 1964, NAESER and DODGE, 1969, NAESER and MCKEE, 1970, CALK and NAESER, 1973, MACDOUGALL, 1971, BIGAZZI *et al.*, 1972, BURCHART, 1972, WAGNER and REIMER, 1972). The fission-track method is also useful to cosmology, archaeology, nuclear physics and other branches of study. These studies of particle tracks were summarized by FLEISCHER *et al.*, (1965b) and FLEISCHER *et al.*, (1972).

In Japan this dating method was first tried by SHIMA *et al.* (1966), and advanced by NISHIMURA (1969, 1970a, b), NISHIMURA and SASAJIMA (1970), NISHIMURA and ISHIDA (1972), NISHIMURA and MIYACHI (1973), SHIMA *et al.* (1967, 1969, 1969 (II)), YABUKI and SHIMA (1970), SUZUKI (1969, 1970),

WATANABE and SUZUKI (1969), SUZUKI and YAMANOI (1970), KANEOKA and SUZUKI (1970), MACHIDA and SUZUKI (1971), NAGAI (1970), and SATO *et al.* (1972). This dating method was summarized by SHIMA (1967, 1970). Studies on the nuclear track and its applications were summarized by SAKANOE (1973).

The purpose of the present work is to establish a time scale for the stratigraphic succession in and around Sendai based upon the age determination on zircon crystals collected from tuffs. The fission-track ages were obtained, in this study, by the procedure of the track densities of population registered on zircons of the each sample (BURCHART, 1972).

Stratigraphy

Stratigraphical studies of the area around Sendai City have been done by many workers (cf. HANZAWA *et al.*, 1953). The Neogene-Tertiary formations widely exposed in this area intercalate undated many pyroclastic flows and pyroclastic fall deposits. Therefore, to know the precise ages for the chronostratigraphy of this area, it is necessary to date these tuffs.

In this area the following units are developed, from the older to the younger, namely Tsukinoki, Takadate Volcanics, Moniwa, Hatatate, Tsunaki, Yumoto, Shirasawa, Mitaki, Kameoka, Tatsunokuchi, Kitayama, Hirosegawa Tuff, Yagiyama and Dainenji Formations. The Tsukinoki Formation consists of granule conglomerate, acidic pumiceous tuff, tuff breccia and lignite. The Takadate Volcanics

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comprises basaltic lava and agglomerate and rhyolite lava. These volcanics interfinger with the upper part of the Tsukinoki Formation and the lower part of the Moniwa Formation. In the Moniwa district the Takadate Formation is covered with unconformity by the Moniwa Formation which is composed of green coarse-grained sandstone and marine-fossil-bearing volcanic conglomerate. The molluscan fauna (NOMURA, 1940, MASUDA, 1969) of the Moniwa Formation is stated to be lower Middle Miocene in age. The K-Ar age of the glauconite of the Moniwa Formation is obtained by UEDA and SUZUKI (1973), as 12.4 m.y. This value is lower than the age suggested from the marine fossils. The Moniwa Formation is covered with conformity by the Hatatate Formation which comprises tuffaceous and micaceous sandstone, acidic tuff, tuffaceous siltstone and which yielded abundant foraminifera fossils (TAKAYANAGI, 1952). Recently detail biostratigraphic zoning has been studied by means of these planktonic foraminifera (IKEBE *et al.*, 1973). The Tsunaki Formation, conformable with the Hatatate Formation, consists of pumiceous and pearlitic tuff breccia, agglomerate and tuffaceous sandstone. In the Tomiya area, in the northern part of Sendai City, the Ootsutsumi Formation, a correlative of the Tsunaki Formation, contains sandstone, acidic tuff and calcareous granule conglomerate with marine fossils. In the western part of the Sendai area, the Yumoto Formation, considered to be a correlative of the upper part of the Tsunaki Formation, includes massive pumiceous tuff breccia. The Shirasawa Formation, covering the Yumoto Formation with unconformity comprises acidic tuff, cross-bedded tuffaceous sandstone and plant fossil-bearing laminated tuffaceous siltstone. These plant fossils, called the Nenoshiroishi Flora (OKUTSU, 1955), are Late Miocene to Pliocene in age (KITAMURA and TAKAYANAGI, 1971). Obsidian fragments are also abundant in this formation. This obsidian was dated as 13 m.y. by the K-Ar method (KAWANO and UEDA, 1964)*. The Mitaki Formation, the lower part of

which interfingers with the Shirasawa Formation, contains andesitic basalt lava, agglomerate, tuff breccia and volcanic sandstone. This formation is overlain with unconformity by the Kameoka Formation with which it interfingers in part. It includes cross-bedded sandstone, lignite and pisolitic tuff. Plant fossils occur in the lignitic seams. The Tatsunokuchi Formation with abundant molluscan fossils is conformable with the Kameoka Formation, and comprises massive siltstone, tuffaceous silty sandstone and acidic tuff. These molluscan fossils, called the Tatsunokuchi Fauna, are thought to be Pliocene (HANZAWA *et al.*, 1953, KITAMURA, and TAKAYANAGI, 1971). The Kitayama Formation which overlies the Tatsunokuchi Formation with unconformity consists of cross-laminated granule conglomerate, sandstone and lignitic siltstone. It is overlain conformably with the Hirosegawa Tuff. The Hirosegawa Tuff, composed of pisolitic fine-grained tuff and massive pumiceous tuff with various lithic fragments, is overlain with conformity by the Yagiyama Formation, of which compositions are white tuff, sandstone and lignite beds. The Dainenji Formation conformably covered the Yagiyama Formation; siltstone, sandstone, conglomerate, lignite and tuff. Many plant fossils occur in the lignitic siltstone of the Kameoka, Tatsunokuchi, Kitayama, Yagiyama and Dainenji formations, and are reported as the Sendai Flora; the age is Pliocene (OKUTSU, 1955, KITAMURA and TAKAYANAGI, 1971).

Sampling points

One rhyolite and 14 tuff samples were collected. The sampling sites are shown in Fig. 1 and their stratigraphic positions are marked in the generalized columnar sections in Fig. 2. The samples were classified into 5 groups based on the sampling area. Group I consists of 6 samples (No. 1—6), Group II of 2 samples (7—8), Group III of 2 samples

* It is still doubtful whether this dated obsidian is included in the Shirasawa Formation or not.

Fig. 1. Map showing the sample localities.

1-15: sample number, I-V: group number

(9-10), Group IV of 2 samples (11-12) and Group V of 3 samples (13-15). The lithological character and stratigraphic position of each sample are also listed as follows.

Group I

Sample No. 1: rhyolite lava (lower part of the Takadate Volcanics)

No. 2: bedded acidic tuff breccia (upper part of the Tsukinoki Formation)

No. 3: acidic coarse-grained tuff (lower part of the Hatatate Formation)

No. 4: acidic coarse-grained tuff (upper part of the Tsunaki formation)

No. 5: massive pisolitic pumiceous tuff (upper part of the Tsunaki Formation)

No. 6: laminated sandy pumiceous tuff (the Shirasawa Formation)

Group II

No. 7: pumiceous tuff (the Yumoto Formation)

No. 8: massive pumiceous tuff with pearly lapilli (middle part of the Shirasawa Formation)

Group III

No. 9: massive acidic tuff (middle part of the Ootsutsumi Formation)

No. 10: massive pumiceous tuff (upper part of the Ootsutsumi Formation)

Group IV

No. 11: bedded acidic tuff breccia (the Shirasawa Formation)

No. 12: massive pisolitic fine-grained tuff (the Kameoka Formation)

Group V

No. 13: pumiceous coarse-grained tuff (upper part of Tatsunokuchi Formation)

No. 14: pisolitic fine-grained tuff (basal part of Hirosegawa Tuff)

Fig. 2. Columnar sections of each locality.

No. 15: coarse-grained pumiceous tuff with lithic fragments (lower part of the Hirosegawa Tuff)

Principle of fission-track dating

One of trace elements, ^{238}U , contained in the zircon crystal, makes spontaneous nuclear fission and produces radiation damage to the crystal structure. This damage is called fossil track. If the zircon crystal is irradiated with thermal neutrons, ^{235}U makes induced nuclear fission and produces similarly radiation damage. This damage is called n-induced track. These damages are eroded by chemical etchant and can be observed as fission-fragment track under the optical micro-

scope (PRICE and WALKER, 1962, FLEISCHER and PRICE, 1963). Thus fission-track numbers per unit area can be counted under the microscope. Through such counting, spontaneous fission-track density (ρ_s) and induced fission-track density (ρ_i) are calculated. The age of crystallization of zircon (T) is determined by means of the decay constant (λ_f) for the spontaneous fission of ^{238}U , the ratio (ρ_s/ρ_i) of track densities of spontaneous fission and induced fission, the present-day ratio (η) of the abundances of ^{238}U and ^{235}U , the thermal fission cross section (σ) of ^{235}U and total fluxes (ϕ) of thermal neutron. The ages in years are calculated by the following formula (FLEISCHER *et al.*, 1964).

$$T = \frac{1}{\lambda_f} \times \frac{\rho_s}{\rho_i} \times \frac{\phi \sigma}{\eta}$$

Adopting the values $(\lambda_f) = 6.85 \times 10^{-17} \text{yr}^{-1}$, $(\sigma) = 577 \times 10^{-24} \text{cm}^2$ and $(\eta) = 138$, the formula is expressed as $T = 6.12 \times 10^{-8} \times (\phi) \times (\rho_s/\rho_i)$.

The uranium content of a zircon crystal is determined by the induced fission-track numbers per cm^2 (P_i) and the total fluxes of thermal neutron (ϕ) through the following equation

$$C = \left(\frac{P_i}{\phi} \right) \times \left(\frac{\eta}{N_v \sigma R} \right) \approx 5 \times 10^{10} \times (P_i/\phi)$$

where $(N_v) = 9 \times 10^{22} \text{atoms/cm}^3$ is the atomic density of zircon and (R) is the effective fission fragment range in zircon, which can be taken as nearly 4μ (FLEISCHER, PRICE, and WALKER, 1964).

Concentration of zircon crystals

Volcanic rock and tuff are proper dating samples, because the fission-track age of minerals in these rocks may be equal to the age of sedimentation. First, a few kilograms in weight of the rock sample collected from the field are crushed, washed and passed through sieves of 120 and 250 mesh. After drying, the heavy minerals are separated by heavy solution of tetrabromoethane. Next the heavy minerals are magnetically separated on an isodynamic separator and the nonmagnetic minerals are assembled. Finally the zircon crystals are picked up under the optical microscope ($\times 16$).

Chemical etching

Suitable etching conditions are varied sensitively for various minerals. For zircon, three etching conditions have been reported (FLEISCHER and PRICE, 1964d, FLEISCHER, PRICE and WALKER, 1964, NAESER, 1969). In this work, the zircon crystal grains were etched for one minute and a half at 490°C in conc. phosphoric acid in 15 cc platinum crucible on an electric furnace. Then the fission-tracks on the crystal become of sufficient size for observation under the optical microscope.

Fig. 3. Typical forms in zircon crystals and difference of track density on each plane of one crystal.

S, D, C: crystal habits (after KARAKIDA, 1954). N: spontaneous fission-track numbers per $50 \times 50 \mu^2$.

Irradiation with thermal neutron

The samples were placed in a plastic tube with a low uranium content, sent to a reactor and exposed to a dose of thermal neutron. The total flux number of thermal neutron (ϕ) was determined by counting the radioactivity of gold foil monitors. In this experiment the crystals were irradiated with nearly $(\phi = 2 \times 10^{15} \text{n/cm}^2)$.

Observation of fission-tracks

The fission-tracks can be observed under the scanning electron microscope. Etched fission-tracks are observed under the optical microscope of 400 magnification. Track density was counted by using oil immersion under the optical microscope ($\times 1500$).

(a) Form of fission-tracks

The fission-track is straight and its length does not exceed about 10μ . Fission-tracks

Fig. 4. Distribution patterns of spontaneous fission-track density.

N: spontaneous fission-track numbers per $50 \times 50 \mu^2$, logarithm scale.

G: grain numbers counted.

have no preferred orientation, whereas dislocation solution channels are often parallel in direction. Therefore fission-track damages are distinguished from other defects and dislocation with their morphologies and lengths (Pl. 1).

(b) Distribution of fission-tracks

Track densities are determined as the number of tracks per $50 \times 50 \mu^2$ on zircon crystals. The track densities on the crystal surface are generally homogeneous, but the clusters of tracks are sometimes reproduced by omnipresence of uranium content in the crystals (Pl. 1). Therefore, it is necessary to count the track densities on the part except

the area where the clusters of tracks are present.

(c) Difference of track densities on each crystal face and each crystal grain

In this paper the zircon crystals are classified into S, D and C type based on their crystal habits (KARAKIDA, 1954), (Fig. 3). Suitable crystal faces for observation are $a(100)$ and $m(110)$, which are extensive prism faces. The track densities on each crystal face within the individual grains were little dispersed but it varied greatly among the grains from the same rock sample (Fig. 3). The results of the measurement of the track densities among the grains of the same

Fig. 5. (ρ_s/ρ_i) determined by two methods.

N/CM^2 : fission-track numbers per cm^2 . G : grain numbers counted.
 ρ_s/ρ_i : ratio of spontaneous fission-track density and induced fission-track density. $\circ$: (ρ_s/ρ_i) determined by each crystal grain. $\bullet$: (ρ_s/ρ_i) determined by the means of track densities of many crystals.
 $\square$: spontaneous fission-track densities. $\blacksquare$: spontaneous and induced fission-track densities. $\overline{7.6}$: average of each population.

rock sample are shown in Fig. 4. This figure also shows that the plots of the track densities on the crystals in igneous rocks such as granodiorite, adamellite and rhyolite show a lognormal distribution pattern and single population. On the contrary that of sandstone are widely dispersed. Track densities on crystals from tuff are mostly concentrated showing a lognormal distribution pattern although dispersion is wide in part. This wide dispersion is thought to be due to acci-

dental crystals in tuffaceous rock. Considering such distribution it is concluded that the means of the spontaneous fission-track densities ($\bar{\rho}_s$) and of the induced fission-track densities ($\bar{\rho}_i$) can be calculated using the lognormal distribution patterns. In this case, it is better that using the normal distribution pattern than using the lognormal distribution pattern, for obtaining the more precise average of track densities.

First, two groups of zircon crystals, each of

Fig. 6. (ρ_s) and (ρ_{i+s}) of all samples.

□: spontaneous fission-track densities. ■: spontaneous and induced fission-track densities. $\uparrow 75$: average of values in this interval. 10: mode number. $N/50\mu^2$: fission-track numbers per $50 \times 50 \mu^2$. G: grain numbers counted.

which is composed of about 30 grains, are prepared. Then $(\bar{\rho}_s)$ is calculated in one of them and $(\bar{\rho}_i)$ from another after irradiation. (d) Comparison between the ratios $(\bar{\rho}_s/\bar{\rho}_i)$ counted on the same crystal surface and calculated as the means of track densities on many crystal surfaces of many grains.

There are two methods for obtaining the ratio (ρ_s/ρ_i) . One of them is that both (ρ_s) and (ρ_i) are counted on the same crystal surface of only one grain. In this case the grain on which (ρ_s) is counted is photographed. After irradiation with thermal neutron and etching the same crystal face of the grain (ρ_{i+s}) should be determined with reference to the photograph. Therefore the grain must be etched twice for spontaneous and induced fission-tracks. Another method is that $(\bar{\rho}_s)$ and $(\bar{\rho}_i)$ are counted as the means of (ρ_s) of many grains and of (ρ_i) of many other grains. $(\bar{\rho}_s/\bar{\rho}_i)$ is assumed as (ρ_s/ρ_i) . The difference between (ρ_s/ρ_i) determined by two methods is shown in Fig. 5. The rock samples used in this experiment are from the Neogene-Tertiary of the Oga Peninsula, Japan. The values of (ρ_s/ρ_i) determined by each crystal grains varied widely. This variation is thought to be due to the variation of the value of (ρ_i) in accordance with the second etching conditions. The second etching for induced fission-tracks is very delicate because the crystal has been already etched once for spontaneous fission-tracks. The minimum value of (ρ_s/ρ_i) determined by each grain is nearly equal to the value calculated by the means of (ρ_s) and (ρ_i) obtained from many grains. Particularly in tuff samples the determination of (ρ_s/ρ_i) by only one grain endangers the possibility of measurement of accidental crystals. Therefore in this work the value (ρ_s/ρ_i) were determined on two groups, each of which is composed of about 30 grains. This method has the following two merits. One is that experimental procedure is simple. Another is that even the sample in which xenocrystal or reworked zircon are mixed, is properly dated. (ρ_s) and (ρ_{i+s}) of all the measured samples are shown in Fig. 6.

Annealing

Fission-tracks become gradually shortened and finally fade out by annealing although there are several grades in track according to the minerals. Fission-tracks of zircon used in this study become completely faded out by 1 hour heating at 700°C in an electron furnace. After consideration of these experimental fading temperatures, the fission-tracks of zircon are estimated to not fade out for ten million years so far as under 300°C (FLEISCHER, PRICE and WALKER, 1965a). Therefore except for the special high geothermal area, track annealing effect is considered to be negligible in the case of zircon.

There are two methods for obtaining $(\bar{\rho}_i)$. In one case, one group of grains without annealing is irradiated and etched chemically. Induced fission-tracks appear with spontaneous fission-tracks. These tracks can not be distinguished. Therefore spontaneous plus induced fission-track density $(\bar{\rho}_{i+s})$ is obtained. Then $(\bar{\rho}_i)$ is calculated as $(\bar{\rho}_i = \bar{\rho}_{i+s} - \bar{\rho}_s)$. In the other case, another group of grains is primarily annealed for fading out spontaneous fission-tracks. After irradiation and etching only induced fission-tracks become visible. Therefore $(\bar{\rho}_i)$ is counted directly. There were no great differences between the values of (ρ_i/ϕ) obtained by the two methods. This result shows that annealed zircon crystals did not vary according to the grade of induced fission-track damage and hardness of fission-track etching (Table 2).

The accuracy of fission-track dating age

Fission-track dating may be misled by including the counting errors of (ρ_s, ρ_i) and (ϕ) and also the uncertainty of the decay constant for the spontaneous fission of ^{238}U (λ_f). The errors of (ρ_i) , (ρ_s) and (ρ_{i+s}) have been calculated by the t-statistics of Student at the confidence level of 95%. In this case, the values greatly deviated from the populations, were excepted from data in calculation of standard deviation. The count-

Table 1. Counting errors.

Sampling No.		σ_s (No.) σ'_s (No.)	$\overline{\rho}_s \pm \varepsilon_s$ $\overline{\rho}_s \pm \varepsilon'_s$	σ_i (No.) σ_{i+s} (No.)	$\overline{\rho}_i \pm \varepsilon_i$ $\overline{\rho}_{i+s} \pm \varepsilon_{i+s}$	$\phi \pm \varepsilon_\phi$	Total errors
Group V	15	59.60 (44) *3.92 (37)	3.5±18.36 *3.5± 1.33	72.55 (25) 60.83 (55)	70±30.57 60±16.64	2.07±0.21 1.4 ±0.14	0.59 0.48
	14	107.52 (52) *1.63 (15)	3.5±29.97 *3.5± 0.93	72.27 (35) 87.74 (34)	66±25.16 64±31.16	2.07±0.21 1.4 ±0.14	0.47 0.56
	13	87.30 (29) *2.34 (13)	4.0±33.79 *4.0± 1.47	72.53 (25) 71.37 (61)	58±30.56 50±18.43	2.07±0.21 1.4 ±0.14	0.65 0.53
Group IV	12	72.03 (57) *3.95 (30)	5.0±19.34 *5.0± 1.50	73.75 (24) 36.98 (18)	85±31.82 100±18.92	2.07±0.21 1.67±0.17	0.49 0.37
	11	80.53 (51) *6.21 (28)	10.0±22.89 *10.0± 2.45	68.28 (40)	100±22.10	1.70±0.17	0.34
Group III	10	*6.93 (38)	*10.0± 2.31	37.40 (16)	96+20.58	1.67+0.17	0.33
	9	8.19 (83) *4.17 (72)	4.0±1.80 *4.0±0.99	26.95 (40) 31.08 (75)	40± 8.72 35± 7.21	1.95±0.20 1.67±0.17	0.34 0.34
Group II	8	56.90 (27) *6.03 (19)	9.0±22.94 *9.0± 2.98	50.74 (33) 41.88 (32)	130±18.30 110±15.36	2.07±0.21 1.90±0.19	0.37 0.37
	7	99.81 (32) *2.12 (12)	10.0±36.57 *10.0± 1.41	68.94 (62) 63.02 (45)	60±17.65 85±19.16	1.80±0.18 1.70±0.17	0.34 0.28
Group I	6	*4.25 (38)	10.0±1.41	44.83 (40) 44.74 (31)	115±14.52 140±16.68	1.80±0.18 1.90±0.19	0.21 0.21
	5	42.42 (40) *6.26 (35)	11.0±13.73 *11.0± 2.18	33.16 (35) 40.26 (39)	96±11.54 100±13.22	2.07±0.21 1.90±0.19	0.25 0.26
	4	*7.08 (38)	*11.0± 2.36	25.56 (37)	98+ 8.64	1.90+0.19	0.25
	3	12.26 (37) *6.39 (36)	10.0±4.14 *10.0±2.19	14.41 (33) 40.90 (23)	50± 5.20 75±18.04	1.80±0.18 1.90±0.19	0.26 0.34
	2	25.40 (47) *3.57 (41)	10.5±7.53 *10.5±1.14	47.74 (41) 32.99 (38)	55±13.65 59±11.01	1.80±0.18 1.70±0.17	0.29 0.23
	1	*4.83 (44)	*16.0±1.49	29.60 (45) 21.76 (19)	76± 8.99 91±10.78	1.80±0.18 1.90±0.19	0.18 0.18

σ_s (No.): standard deviation of ρ_s (grain numbers counted). σ'_s (No.): standard deviation of ρ_s except large dispersed values (grain numbers counted). $\bar{\rho}_s \pm \varepsilon_s$: mean of $\rho_s \pm$ error counted by t-statistics of Student at the confidence level of 95%. σ_i (No.): standard deviation of ρ_i (grain numbers counted). σ_{i+s} (No.): standard deviation of ρ_{i+s} (grain numbers counted). $\bar{\rho}_i \pm \varepsilon_i$: mean of $\rho_i \pm$ error counted by t-statistics of Student at the confidence level of 95%. $\bar{\rho}_{i+s} \pm \varepsilon_{i+s}$: mean of $\rho_{i+s} \pm$ error counted by t-statistics of Student at the confidence level of 95%. $\phi \pm \varepsilon_\phi$: thermal neutron fluxes $\pm$ error counted as 10%.

*: this value is adopted as the error of ρ_s in calculation of total error.

ing error of (ϕ) is estimated to be $\pm 10\%$. (λ_f) differs by different workers, but (λ_f) = $6.85 \times 10^{-17} \text{y}^{-1}$ may be the most practical for geochronology at present (FLEISCHER and PRICE, 1964c, NISHIMURA, 1972). The fis-

sion-track age is calculated by $T = 6.12 \times 10^{-8} \times (\phi) \times (\rho_s / \rho_i)$. Therefore the total errors have been assumed to be the square root of the sum of the squares of the errors in spontaneous fission-track densities (ρ_s), in-

Table 2. Dating errors.

		$\bar{\rho}_s$	$\frac{\bar{\rho}_i}{\bar{\rho}_{i+s}}$	$\phi(\times 10^{15})$ (cm^{-2})	U (ppm)	T(my)
Group V	15	3.5	70 60	2.07 1.40	67.6 80.7	6.3 ± 3.7 5.3 ± 2.6
	14	3.5	66 64	2.07 1.40	63.8 86.4	6.7 ± 3.2 5.0 ± 2.8
	13	4.0	58 50	2.07 1.40	46.4 65.7	8.7 ± 5.7 7.6 ± 4.0
Group IV	12	5.0	85 100	2.07 1.67	82.1 113.8	7.5 ± 3.7 5.4 ± 2.0
	11	10.0	100	1.70	105.9	11.6 ± 3.9
Group III	10	10.0	96	1.67	103.0	11.9 ± 3.9
	9	4.0	40 35	1.95 1.67	41.0 37.2	11.9 ± 4.1 13.2 ± 4.4
Group II	8	9.0	130 110	2.07 1.90	124.6 106.0	8.8 ± 3.3 10.4 ± 3.8
	7	10.0	60 85	1.80 1.70	66.7 88.0	18.4 ± 6.3 13.9 ± 3.9
Group I	6	10.0	115 140	1.80 1.90	127.8 137.0	9.6 ± 2.0 8.9 ± 1.9
	5	11.0	96 100	2.07 1.90	92.8 94.0	14.5 ± 3.6 14.4 ± 3.7
	4	11.0	98	1.90	92.0	14.7 ± 3.7
	3	10.0	50 75	1.80 1.90	55.4 68.0	22.0 ± 5.7 17.9 ± 6.0
	2	10.5	55 59	1.80 1.70	61.2 58.0	21.0 ± 6.0 22.5 ± 5.3
	1	16.0	76 91	1.80 1.90	84.4 78.0	23.2 ± 4.1 24.8 ± 4.4

ρ_s : spontaneous fission-track numbers per $50 \times 50 \mu^2$. ρ_i : induced fission-track numbers per $50 \times 50 \mu^2$. ρ_{i+s} : spontaneous and induced fission-track numbers per $50 \times 50 \mu^2$. ϕ : total thermal neutron fluxes. U: uranium content (cm^{-3}). T: obtained fission-track ages.

duced fission-track densities (ρ_i) and thermal neutron flux (ϕ). These are listed in Table 1. The errors of samples (1—6), (7—12), (13—15) range from 20 to 30%, from 30 to 40%, and from 50 to 60% respectively. Generally speaking, the younger the age of the sample is, the larger the errors become, as the number

Fig. 7. Errors of dating ages.

of (ρ_s) counted become smaller.

Result

The ages with errors and uranium content obtained by the fission-track method are shown in Table 2 and the ages with errors are illustrated in Fig. 7. Generally speaking these ages are in agreement with stratigraphic succession. Only the age of the sample from the Kameoka or the Tatsunokuchi Formation is discordant with that of the stratigraphic succession. It is necessary to reinvestigate the ages of samples collected from the area where the Kameoka Formation is clearly covered with the Tatsunokuchi Formation. The age of Hatatate Formation obtained by fission-track dating is older than that by K-Ar dating. While the age of the Shirasawa Formation dated by fission-track method is slightly younger than the age by K-Ar dating. The fission-track ages of the Tatsunokuchi Formation and the Hirosegawa Tuff

are older than the ages determined by the biostratigraphic method.

The mean uranium content in the samples range from 40 to 130 ppm by weight.

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仙台付近新第三系の飛跡法による年代測定

玉 生 志 郎

(要 旨)

仙台付近に露出する新第三系火山岩、凝灰岩中のジルコン結晶を用いて、飛跡法による鉱物年代測定を試みた。今回の測定では、結晶粒 1 ケ 1 ケで年代を求める方法でなく、同一試料中のジルコンの飛跡密度が対数正規分布することを利用する方法を用いた。即ち、同一試料中の 100 ケ以上の結晶粒を 2 つのグループに分け、1 つのグループで自発核分裂飛跡密度の平均値を求め、他方のグループで熱中性子照射後、誘導核分裂飛跡密度の平均値を求める方法である。この方法は実験操作が簡単であるばかりか、異質岩片や再堆積物質が少量混っているような試料でも妥当な年代が得られる利点をもっている。今回の測定結果を以下に示す。年代の誤差は $\pm 20 \sim 30\%$ 見込む必要がある（但し竜ノ口層、広瀬川凝灰岩では $\pm 50\%$ に達する）。高館火山岩類（流紋岩）：24 m. y., 槻木層（上部凝灰岩）：22 m. y., 旗立層（下部凝灰岩）：20 m. y., 綱木層（上部凝灰岩）：14.7, 14.5 m. y., 湯元凝灰岩：16 m. y., 大堤層（下部凝灰岩）：12.5 m. y., 大堤層（上部凝灰岩）：12 m. y., 白沢層：11.6, 9.6, 9.3 m. y., 亀岡層：6.5 m. y., 竜ノ口層（上部凝灰岩）：8 m. y., 広瀬川凝灰岩：5.9, 5.8 m. y.

この結果では亀岡層・竜ノ口層以外は、層序の上下関係と矛盾することなく、より上位の地層ほど若い年代になっている。これは測定した火山岩・凝灰岩中のジルコン結晶の飛跡年代がほぼ堆積年代として妥当であることを示すものである。

地層名・地名

Tsukinoki	槻木
Takadate	高館
Moniwa	茂庭
Hatatate	旗立
Tsunaki	綱木
Yumoto	湯元
Shirasawa	白沢
Mitaki	三滝
Kameoka	亀岡
Tatsunokuchi	竜ノ口
Kitayama	北山
Hirosegawa	広瀬川
Yagiyama	八木山
Dainenji	大年寺
Nanakita	七北田
Natori	名取
Akashima	赤島
Shinzan	真山
Daijima	台島
Sugoroku	双六
Funakawa	船川
Anzenji	安全寺
Shibikawa	鮎川