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Citation	Kyoto University overseas research reports of new world monkeys (1986), 5: 39-42
Issue Date	1986
URL	http://hdl.handle.net/2433/199623
Right	
Type	Article
Textversion	publisher

Kyoto University Overseas Research
Reports of New World Monkeys (1985) 5: 39–42
Kyoto University Primate Research Institute

Fission Track Dating of the Volcanic Ash Layers in Continental Deposits at Salla, Bolivia: Re-examination

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In the previous report (Hayashida et al., 1984), we presented a study of fission track dating of two volcanic ashes intercalated in the Cenozoic continental deposits around Salla in the Bolivian Andes. The fission track dates, determined by the re-etch method on external surfaces of zircons, were 54.0 Ma and 52.0 Ma. These data suggested that the extinct vertebrate fauna found from the Salla deposits is of the early Eocene in age. MacFadden et al. (1985) subsequently showed that our results are unacceptable as indication of the time of the deposition. They made intense studies of magnetic polarity stratigraphy and radiometric age estimation on the Salla beds. Their results includes fission track dates of zircons from two volcanic ashes at the horizons almost equivalent to our samples. The dates, determined by the external detector method (Naeser, 1979), are 22.2 and 22.0 Ma. They also reported a K-Ar date, 26.4 Ma, of biotites from the tuff at a basal horizon of the section, and assigned the pattern of magnetic polarity reversals to the time scale between 28.5 Ma and 24 Ma. Thus, their work clearly showed that the age of the Salla fauna is the late Oligocene to the early Miocene.

We made re-examination of our results of the fission track dating. The significantly older dates might be obtained if zircon grains of detrital origin had been mixed into the volcanic ashes. The zircon crystals of our samples, however, have euhedral shapes and unworn surfaces, suggesting that they were originated as essential volcanic products. We assumed, therefore, that the older dates are attributed to some inappropriate procedure in the re-etch method, and we newly applied the external detector method to the two samples used in the previous study.

The external detector method was applied to both internal and external surfaces of zircons (ED1 and ED2; Gleadow, 1981). Two aliquots of zircon grains were prepared from each of the two samples (FT1 and FT2), and mounted in PFA (copolymer of tetrafluoroethylene-perfluoroalkoxyethylene) sheets. The zircons in one sheet were polished, and after the etching for 14 or 17 hours in a melt of KOH and NaOH at 225°C, spontaneous fission tracks on the internal surfaces were counted. The zircons in the other mount were also etched in the same conditions, and the spontaneous tracks developed on the external surfaces were counted. The zircons in the two sheets, covered with external fission track detectors of muscovite, were irradiated in the TRIGA II reactor at Musashi Institute of Technology. The neutron dose was monitored with a muscovite detector firmly attached to NBS glass SRM612. The induced fission tracks were counted on the muscovite detectors.

Results of the fission track dating obtained in the present study and the previous one are listed in Table 1. The fission track dates of the two samples (FT1 and ET2) determined with the external detector methods (ED1 and ED2) are all about 25 Ma. These dates are about a

Table 1 Results of fission track dating for volcanic ashes from Salla, Bolivia

Method	N_s tracks	$\rho_s \times 10^6$ tracks/cm^2	N_i tracks	$\rho_i \times 10^6$ tracks/cm^2	N_Φ tracks	$\rho_\Phi \times 10^4$ tracks/cm^2	T Ma	$\varepsilon \cdot T$ Ma	n	r	U ppm
Sample: FT1 (zircon)											
re-etch	2630	1.39	1362	0.722	1095	7.53	54.0	2.4	33	0.707	77
ED1	949	3.97	568	2.38	1296	8.76	27.2	1.6	20	0.773	218
ED2	630	1.76	820	2.29	1296	8.76	25.0	1.5	23	0.897	209
Sample: FT2 (zircon)											
re-etch	1769	1.09	955	0.586	1095	7.53	51.8	2.6	36	0.576	62
ED1	815	2.19	472	1.27	1204	8.14	26.1	1.9	30	0.897	125
ED2	594	1.25	749	1.57	1206	8.15	24.0	1.5	29	0.908	155

N_s and ρ_s: total count and density of spontaneous fission tracks
N_i and ρ_i: total count and density of induced fission tracks
N and ρ_Φ: total count and density of induced fission tracks on neutron flux monitor
n: number of grains
r: correlation coefficient between ρ_s and ρ_i
U: Uranium concentration in zircons
The fission track date was obtained using the following constants:
Calibration constant: $B = 6.23 \times 10^9$ ($= \Phi/\rho_\Phi$, Φ: thermal neutron flux)
Spontaneous fision decay constant: $\lambda_f = 7.03 \times 10^{-17}$ (/year)
Thermal neutron fission cross section for ^{235}U: $\sigma_f = 5.77 \times 10^{-22}$ (cm^2)
Isotope ratio $^{235}U/^{238}U$: $I = 7.253 \times 10^{-3}$
These constants give the ζ-value, $\zeta = 371$, and the fission track date, T (Ma), and counting error, ε, are given as follows:

$$T = \zeta \cdot (\rho_s/\rho_i) \cdot \rho_\Phi$$

$$\varepsilon = \{(1/\sqrt{N_s})^2 + (1/\sqrt{N_i})^2 + (1/\sqrt{N_\Phi})^2\}^{1/2}$$

half of the estimation by the re-etch method, and concordant with the age of the Salla beds determined by MacFadden et al. (1985). The two aliquots of zircons from each sample, subjected to the ED1 and ED2 methods, showed almost identical values of induced fission track densities. The ratio of spontaneous track densities determined by the ED1 and ED2 methods seems concordant with that expected from the geometry factor of the internal and external surfaces.

It appears that the older age results of the re-etch method were deduced from the significantly small estimation of the induced track densities (Table 1). We re-examined the conditions of the spontaneous and induced fission tracks on zircons, using the photographs taken during the course of the previous study. It was then found that the induced fission tracks observed after the second etching are dominant in the direction vertical to the c-axis of the crystal, showing a remarkable anisotropic occurrence. The fact that the diameters of the induced tracks are generally smaller than that of the spontaneous tracks before the second etching also indicates that the zircons were under-etching when the induced tracks were counted. On the contrary, the spontaneous tracks developed by the first etching were found to be directing isotropically on the zircon surface. While it is clear that the spontaneous tracks trending vertically to the c-axis had been developed with the higher etching rate, the tracks parallel to the c-axis were also well observable. As suggested from the spontaneous track densities concordant with the new results, it is inferred that the detection of the spontaneous tracks in the previous re-etch method was made in an approptiate condition.

It has been known that the detection of induced tracks on a re-etched surface is difficult. The difficulty seems to increase significantly in the case that the spontaneous track density exceeds the order of 10^5/cm^3. Fig. 1 shows plots of the spontaneous and induced fission track densities of single zircon grains determined with the re-etch, ED1 and ED2 methods. As

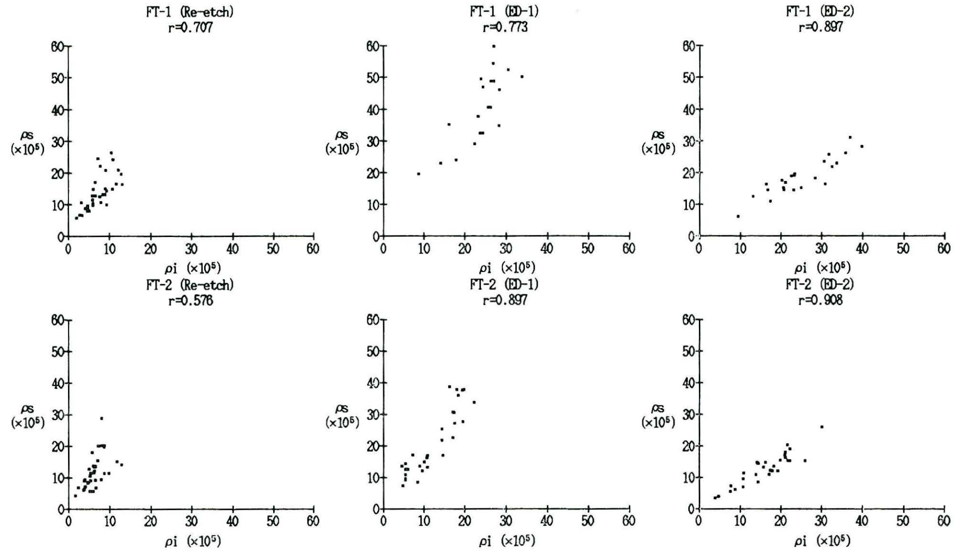

Fig. 1 The correlation diagram between the spontaneous track densities (ρ_s) and the induced track densities (ρ_i) of the single zircon grains from the sample FT1 and FT2, determined with the re-etch method, and the external detector methods (ED1 and ED2). r: correlation coefficient.

shown in these diagrams, the results of the re-etch method are characterized by the small estimation of the induced track densities and the relatively poor correlation between the induced and spontaneous track densities. It is thus suggested that in the re-etch experiments the detection of the induced tracks were also affected by the other factors than the underetching; distortion of the zircon grains and development of the numerous and thick fission tracks after the second etching might cause the significant underestimation of the induced track density of some grains. We infer, therefore, that even if the second etching had been further proceeded, the reasonable estimation of the induced track densities would not have been attained. We thus recognized that the re-etch method has the serious difficulty, especially for dating of zircons with high fission track densities.

We thank Mr. Takahiro Tagami of Kyoto University for his support during this work and for his critical comments to the manuscript.

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