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Independent fission-track ages (ϕ-ages) of proposed and accepted apatite age standards and a comparison of ϕ-, Z-, ζ- and ζ_0-ages: Implications for method calibration

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Abstract

The results of 94 determinations of the independent fission-track ages (ϕ-ages) of proposed and accepted apatite age standards show that the ages of the accepted standards are consistent with their reference ages but that those of the proposed age standards are not. The FCT and DUR data have been used to calculate Z-, ζ- and ζ_0-calibration factors. The ζ_0-values agree with independent measurements and with calculated values. The ϕ-, Z-, ζ- and ζ_0-ages (t_ϕ, t_Z, t_ζ and t_{ζ_0}) of 71 samples dated in the course of geological investigations are, on the whole, consistent, although systematic deviations from the mean (t_M) exceed the statistical uncertainties. These are, however, ≤2% and traceable to statistical variation, including counting statistics and an extra-Poisson component resulting from somewhat inconsistent track identification criteria. The overall agreement between t_Z, t_ζ and t_{ζ_0} implies that measurements of (ρ_s/ρ_i), ρ_d and ϕ are reproducible but says nothing about their intrinsic accuracies. The fact that t_ϕ also agrees with t_Z, t_ζ and t_{ζ_0} ($t_\phi/t_M = 1.000 \pm 0.001$) is inconsistent with the ~10% length reduction of confined spontaneous tracks in the standards; the same applies to the t_ϕ/t_{REF}-ratio (mean: 1.009 ± 0.010). It is concluded that the agreement between t_ϕ and t_{REF} and between t_ϕ and t_Z, t_ζ and t_{ζ_0} is an indication of the fact that the calculated ages are indeed accurate. This implies that the ~10% reduction of the spontaneous track lengths in FCT and DUR has no measurable effect on their fission-track ages, to within the <1% resolution of the present datasets.

Keywords: Apatite; Fission-track dating; Age standards; Age calibration

1. Introduction

Price and Walker (1963) demonstrated that nuclear tracks in terrestrial minerals can be attributed to spontaneous fission of ^{238}U and developed a fission-track

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dating method based on measurements of the track densities and the following equation:

$$t_\phi = \frac{1}{\lambda_\alpha}\ln\left[\frac{\lambda_\alpha}{\lambda_F} I\sigma\phi\frac{N_s}{N_i} + 1\right] \quad (1)$$

wherein λ_α and λ_F are the alpha- and fission-decay constants of ^{238}U, N_s is number of spontaneous tracks per unit volume, N_i is the number of induced fission tracks of ^{235}U per unit volume, produced by irradiation in a nuclear reactor, σ is the thermal neutron fission cross-section of ^{235}U, ϕ is the thermal neutron fluence, and I is the isotopic ratio $^{235}\theta/^{238}\theta$. In dating applications, the fission tracks intersecting a mineral surface are etched (Price and Walker, 1962) and the ratio (ρ_s/ρ_i) of the areal densities of the etched spontaneous and induced tracks are substituted in (1). With the external detector method, ρ_s is measured by counting the etched tracks in a polished internal mineral surface and ρ_i is measured by counting the etched tracks in an external detector, irradiated in contact with the mineral surface (Fleischer and Hart, 1972; Gleadow, 1981). In this case, the induced tracks are counted in a different geometry and in a detector with a different track etching threshold and different bulk etching properties from the mineral, so that $\rho_s/\rho_i \neq N_s/N_i$ and appropriate correction factors must be included in (1). In addition, the etchable length of the spontaneous tracks is reduced if the mineral experienced elevated temperatures during the period of track accumulation. Because the number of spontaneous tracks that intersect a unit area is proportional to their mean etchable length (Fleischer et al., 1975), a length correction is sometimes also included in (1). Different theoretical and empirical geometry factors (Reimer et al., 1970; Gleadow and Lovering, 1977; Green and Durrani, 1978) and procedure factors (Faure, 1986; Wagner and Van den haute, 1992; Jonckheere, 1995) have been written into the age equation to account for these effects. More recently, Jonckheere (2003a) proposed the following formal equation:

$$t_\phi = \frac{1}{\lambda_\alpha}\ln\left[\frac{\lambda_\alpha}{\lambda_F} GQRL\frac{\rho_s}{\rho_i} I\sigma\phi + 1\right]. \quad (2)$$

The geometry ratio G ($g=½$ for the external detector method) accounts for the different registration geometries of the spontaneous and induced tracks. The procedure factor Q ($=[\eta q]_{ed}/[\eta q]_{is}$) accounts for the different track counting efficiencies ($[\eta q]$; Jonckheere and Van den haute, 1996, 2002) of the spontaneous tracks in an internal surface (is) and induced tracks in an external detector (ed). R ($=(l_f/l'_f)(l'_e/l_e)$; l_f and l'_f are the lengths of latent and l_e and l'_e the lengths of etched tracks in the mineral and an external detector, respectively; Jonckheere, 2003a) corrects for the effect of the different length deficits (range deficits; Fleischer et al., 1975) in the mineral and the external detector (external detector method). L is an unspecified correction factor for the length reduction of the spontaneous tracks. Eqs. (1) and (2) refer to age determinations based on a specific λ_F-value and an explicit measurement of the thermal neutron fluence ϕ. Analogous to the ζ-method, we propose to refer to this method as the ϕ-method hereafter.

Fission-track ages determined with the ϕ-method are subject to errors arising from disagreement about the decay constant λ_F (Bigazzi, 1981) and difficulties related to measurements of the neutron fluence ϕ (Hurford and Green, 1981a, 1983). Errors resulting from the fission-track counts have been less emphasized but are perhaps equally important, except for dating apatite with the population method where $G=1$, $Q=1$ and $R=1$. To avoid these errors, Hurford and Green (1981a, 1982, 1983) proposed to calibrate fission-track ages against age standards that have been dated with independent isotopic methods, and presented two calibration schemes, the Z- and the ζ-method. The ζ-method in particular has been instrumental in improving the consistency between laboratories and agreement with the results of other dating methods, and has been recommended by the Fission-Track Working Group of the IUGS Subcommission on Geochronology (Hurford, 1990a,b). The Z- and ζ-methods calculate the fission-track age of a sample as a fraction of the (K–Ar, Ar–Ar, Rb–Sr) reference ages of the standards via track density ratios, but without relying on the nuclear parameters of the fission process. In this sense, the fission-track method has lost its status as an independent dating method. In a formal sense, the Z- and ζ-methods are also untestable: empirical verification of Z- and ζ-ages consists in dating samples with known *fission-track* ages but the samples with known (reference) fission-track ages are used for calibration. A practical problem in the case of apatite is that the available standards do not fulfil all the requirements (Wagner in Hurford and Green, 1981b). In particular, it