Single-track length measurements of step-etched fission tracks in Durango apatite: “Vorsprung durch Technik”

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ABSTRACT

Fossil and induced confined fission-tracks in the Durango apatite do not etch to their full etchable lengths with the current protocols. Their mean lengths continue to increase at a diminished rate past the break in slope in a length vs. etch-time plot. The mean length of the fossil tracks increases from 14.5(1) to 16.2(1) μm and that of the induced tracks from 15.7(1) to 17.9(1) μm between 20 and 60 s etching (5.5 M HNO3; 21 °C); both are projected to converge toward ~18 μm after ~180 s. This increase is due to track etching, not bulk etching. The irregular length increments of individual tracks reveal a discontinuous track structure in the investigated length intervals. The mean lengths of the fossil and induced tracks for the standard etch time (20 s) for the (5.5 M HNO3; 21 °C) etch are thus not the result of a shortening of the latent fission tracks but instead of a lowering of the effective track-etch rate \( v_T \). The rate of length increase of individual fossil confined tracks correlates with their length: older tracks are shorter because they etch slower. Step etching thus makes it possible to some extent to distinguish between older and younger fossil fission tracks. Along-track \( v_T \) measurements could reveal further useful paleo-temperature information. Because the etched length of a track at standard etch conditions is not its full etchable length, geometrical statistics based on continuous line segments of fixed length are less secure than hitherto held.

Keywords: Durango apatite, fission track, step etching, confined-track length

INTRODUCTION

The conventional fission-track method distinguishes itself from other radiometric geothermochronometers in that both the parent- and daughter-isotope concentrations are measured by means of proxies. The fossil tracks stand for the daughters produced by spontaneous nuclear fission of \( {}^{238}\text{U} \). The induced tracks created by thermal-neutron fission of \( {}^{235}\text{U} \) stand for the present concentration of the parent. The damage trails left in the wake of the fission fragments’ flight have dimensions [length: ~21 μm; Bhandari et al. (1971); Jonckheere (2003); diameter: <10 nm; Paul and Fitzgerald (1992)] and structure (Miro et al. 2005; Afra et al. 2011; Li et al. 2014; Schauries et al. 2014; Lang et al. 2015). Latent fission tracks are thus susceptible to changes effected by environmental factors, with temperature as the main factor (Fleischer et al. 1965, 1974, 1975; Kohn et al. 2003; Schmidt et al. 2014). Each fossil track holds a record of the temperature effects it experienced from its formation to the present. Apatite fission-track modeling was developed to exploit this stored information for reconstructing the thermal histories of geological samples.

The temperature record stored in the fossil tracks is read from the length distribution of etched confined tracks. Etching condenses the information in individual tracks into a single scalar value: their etchable length. Tracks that experienced the same environmental conditions are however not all etched to the same length as a result of random factors involved in U fission, track formation, and repair. Their temperature information is therefore reflected in the mean of their etched-length distribution. Length variations due to the possible effects of the anisotropic properties of the track detector on track formation, annealing, and etching are systematic and can be accounted for (Galbraith and Laslett 1988; Donelick 1991; Donelick et al. 1999; Galbraith 2002; Ketcham et al. 2007).

Step-etch experiments show that the mean length of induced fission tracks in apatite increases fast up to an etch strength \( S_E \) [\( S_E = \text{etchant concentration (M)} \times \text{etch time (s)} \)] of ~50 M·s, followed by a slow—or no—increase (Fig. 1). The data scatter prevents us from concluding whether the transition is gradual or not. Etching to just past the transition point (60 \( \leq S_E \leq 90 \)) is considered ideal; tracks on either side are either “under-etched” or “over-etched” (Laslett et al. 1984). The basic model holds that the confined-track length increases at twice the track-etch rate \( v_T \) until the etchant reaches both ends, and the track is revealed over its full etchable length, and at twice the bulk-etch rate \( v_B \) thereafter (Laslett et al. 1984). The lack of experimental evidence of bulk etching (Fig. 1; except f) was explained by the fact that most of the measured tracks at each etch step represent a new sample of confined tracks (Green et al. 1986). Both the Barbarand et al. (2003) data for under-etched tracks (\( S_E < 60 \) M·s; Fig. 1j) and the Carlson et al. (1999) data for over-etched tracks (\( S_E > 90 \) M·s; Fig. 1f) lie above the fitted trend. This could be due to a stricter selection of well-etched tracks for length measurement, compared to the other experiments. This could itself be a bias...