Some geometrical properties of fission-track-surface intersections in apatite

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ABSTRACT

Parallel fission-track-surface intersections identify the grains in an etched apatite mount that have been polished parallel to their prism faces and mark the orientations of their c-axes. Their lengths \( D_{par} \) are a practical kinetic parameter that is indicative of the track annealing rate of apatite. Little is known, however, about their geometrical properties in non-prism faces. We present a model calculation of the frequency distributions of the orientations, lengths, and widths of track-surface intersections in non-prism faces. The current model does not include the effects of surface etching or measurement imprecision. However, as far as it goes, it is consistent with measurements in apatite surfaces up to 30° to the c-axis. Regardless of the model, we submit that the statistical properties of the fission-track-surface intersections have practical uses. The distribution of their orientations is characteristic of the orientation of the etched surface relative to the c-axis. The distribution of their lengths presents a possible tool for investigating track etching, in particular for evaluating the tracks added and lost through surface etching. The distribution of their widths is a potential kinetic parameter independent of surface orientation and less susceptible to the factors, such as the sampling method and surface etch rate, that produce conflicting \( D_{par} \) values.

Keywords: Apatite, fission track, etching, \( D_{par} \), \( D_{perp} \), statistics

INTRODUCTION

Fission-track dating is based on counting the damage trails produced by nuclear fission of uranium isotopes. Fission tracks in apatite have a length of ~20 μm (Jonckheere 2003) and a maximum diameter of ~10 nm (Paul and Fitzgerald 1992; Li et al. 2011, 2012, 2014). The mineral grains are mounted, polished, and etched. Etching widens the tracks to ~1 μm for observation and counting with an optical microscope. So, we do not count the tracks as such but the etched channels that develop along the track axes from their surface intersections.

The model of fission-track etching changed little in five decades (Price and Walker 1962; Price and Fleischer 1971; Tagami and O’Sullivan 2005; Hurford 2019); it describes track development as the result of two etch rates. The track etch rate \( v_T \) along the track axis is the rate at which the damaged material in the track core is removed; the bulk etch rate \( v_E \) is the rate at which the surrounding undamaged material is etched in all other directions. This etch model implies that the etching efficiency \( \eta_E \) is a function of \( v_E \) and \( v_T \); in its simplest form:

\[
\eta_E = 1 - \left[ \frac{v_T}{v_E} \right]^2.
\] (1)

For minerals, with anisotropic \( v_E \), Equation 1 is considered to hold for the value of \( v_E \) perpendicular to the etched surface (surface etch rate \( v_E \)). Often, \( \eta_E \) is taken to also be the fraction of tracks counted (counting efficiency \( \eta_C \); Hasebe et al. 2004; Tagami and O’Sullivan 2005). Although other studies are less explicit about the relationship between the counting and etching efficiencies, Equation 1 is the basis for the common practice of counting the fission tracks in low-\( v_E \) (high \( \eta_C \)) surfaces, such as the prism faces of apatite and zircon, characterized by sharp polishing scratches (Gleadow 1978, 1981). The cleavage planes of muscovite are also considered to have near unit counting efficiencies. In contrast, there is theoretical and experimental evidence that the track counting efficiencies of these surfaces are much lower (Jonckheere and Van den haute 1998, 1999, 2002; Jonckheere 2003; Eikelmann et al. 2005). This is thought to be due to a threshold, which prevents the observation, or the confident identification, of the shallowest etched tracks with an optical microscope. It is thus less than certain that apatite prism surfaces are ideal and other surfaces unsuited for counting tracks. In addition, the focus on prism faces limits the number of grains suitable for fission-track dating. This is most disadvantageous for sediment samples containing grains that seldom present their prism faces to the observer. This is because distinguishing the age components in a sediment sample for provenance studies requires dating a large number of grains (≥117; Vermeesch 2004).

It is useful to investigate the properties of non-prism faces. Here, we examine how we can determine the orientations of non-prism faces relative to the mineral’s c-axis. The outline of a grain section and the orientation of inclusions provide useful information but are not always available or reliable. The grains are often rounded in transport, broken during mineral separation, free of inclusions, or contain inclusions with no preferential orientations. The etched-track-surface intersections provide a more dependable criterion. The track openings in a prism face are a constant length and oriented parallel to each other and the c-axis. Little is known about the track-surface intersections in other faces, other than that they are unlike those in prism faces. Like the shapes of the track channels, those of the track openings are...