Fission-track etching in apatite: A model and some implications

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ABSTRACT

From their formation, fission tracks are complex structures, onto which their thermal histories come to be imprinted. Track etching leaves elongated voids whose lengths and orientations are used for reconstructing these histories. It is thus important to understand etching for interpreting track data. We revive an existing dissolution model that explains the geometries and dimensions of etched fission tracks in apatite. It implies that on continued etching, the track contours come to reflect the minimum and maximum apatite etch rates, at the same time that all trace of the track structure is erased. We cannot derive valid etch rates from the dimensions of the track openings or from the length increase of step-etched confined tracks. The roundedness of the track tips is not a measure of etching progress. Understanding the contours of confined tracks does permit, in most cases, to calculate their true etch times. We propose to exploit this fact to set an etch-time window and to model the confined-track data in this interval. The excluded measurements will be those of the least-etched and most-etched tracks. This numerical loss is offset by the fact that an etch-time window relaxes the requirement of a fixed immersion time, and a longer immersion multiplies the measurable confined tracks. This calls for no changes to existing procedures if the etch-time windows for different protocols give consistent results. The length data for apatites with different compositions could become comparable if their etch-time windows were linked to a compositional parameter.

Keywords: Apatite, fission track, etching, effective etch time, surface track, confined track

INTRODUCTION

Fission tracks in apatite are ~20 μm long (Bhandari et al. 1971; Jonckheere 2003) and ~10 nm wide (Paul and Fitzgerald 1992; Paul 1993; Li et al. 2011, 2012, 2014), too thin to observe with a microscope. Polished grain mounts are therefore etched for fission-track dating and thermal history modeling. Etching creates micrometer-wide channels along the track axes, which can be counted and measured with an optical microscope. The average etchable length of a fission track in apatite is ~16 µm, depending on the temperatures that it has experienced, but also on its orientation, the apatite composition and the etching protocol (Tamer et al. 2019). The effects of temperature, orientation, and composition have been studied and integrated in quantitative models. These studies have become too numerous to list but Tables 5 and 6 of Wauschkuhn et al. (2015) give an overview.

Investigations of apatite (Fleischer and Price 1964; Patel et al. 1967), zircon (Krishnaswami et al. 1974; Gleadow and Levering 1977), and titanite (Naeser 1967; Gleadow 1978) showed that track revelation is anisotropic and that the crystallographic orientations of the etched surfaces influence their etching characteristics and the appearance of the etched tracks. Later studies investigated the influence of etching on the track densities, e.g., for apatite: Green and Durrani (1978), Poupeau et al. (1980), Watt and Durrani (1985), Singh et al. (1986), Sandhu et al. (1988a, 1988b), and Jafri et al. (1990). Interest waned after the ζ-calibration was adopted (Hurford 1990a, 1990b), which obviated explicit counting efficiencies. Its intended application to single-grain dating implies that the tracks should be counted in slow-etching faces with high-etching efficiencies, e.g., the prism faces of apatite (Gleadow 1981). This is a lasting result of the investigations of anisotropic fission-track etching. Beginning before, but for the most part after the ζ-watershed, etching experiments were aimed at defining suitable protocols for etching confined fission tracks in advance of comprehensive annealing experiments, e.g., Laslett et al. (1984), Green et al. (1986), Crowley et al. (1991), Carlson et al. (1999), Barbarand et al. (2003), Ravenhurst et al. (2003), and Telfo et al. (2006). Other studies addressed certain fundamental aspects of fission-track etching in apatite (Hejl 1995; Jonckheere and Van den Haute 1996; Jonckheere et al. 2005, 2007, 2017, 2019; Murrell et al. 2009; Moreira et al. 2010; Sobel and Seward 2010; Tamer et al. 2019; Tamer and Ketcham 2020; Aslanian et al. 2021).

Several models have been proposed to account for the appearance of etched tracks in isotropic and anisotropic detectors. All are based on the premise that the track geometries result from the dissolution of the damaged core at a rate $v_T$ (track etch rate) along the track axis and of the undamaged detector at a rate $v_B$ (bulk etch rate) in all other directions. Etched-track profiles were calculated for isotropic $v_B$ and constant and variable $v_T$ (Fleischer et al. 1969; Henke and Benton 1971; Paretzke et al. 1973; Ali and Durrani 1977; Barillon et al. 1997; Nikezić 2000; Nikezić and Yu 2003; Tagami and O’Sullivan 2005; Hurford 2019). Some models describe bulk etching of anisotropic detectors.