Thermal annealing mechanisms of latent fission tracks: Apatite vs. zircon

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EARTH AND PLANETARY SCIENCE LETTERS 302 (2011) 227–235

Fission tracks in apatite and zircon, the minerals most often used for fission track dating and thermochronology, have been considered to anneal by the same mechanism, essentially epitaxial recrystallization. In this study, direct, atomic-scale observations of thermal annealing of unetched, latent racks at elevated temperatures by transmission electron microscopy (TEM) demonstrate that the annealing behavior of tracks in apatite is entirely different from that of the amorphous tracks in zircon. Remnants of the latent tracks in apatite can be seen after in situ heating at 700 °C for 130 min, in clear contrast to the complete disappearance of tracks after they have been annealed at 360 °C for 1 h and then enlarged by chemical etching. The "fading" or shrinkage of tracks in apatite results from thermo-emission of vacancies from the porous core to the surrounding matrix, in contrast to the recombination of interstitials and vacancies within he amorphous tracks in zircon. The high surface energy and high diffusivity of atoms at the surface of the essentially porous tracks in apatite cause the discontinuity in the tracks by several different mechanisms: Rayleigh instability, Brownian motion, and preferential motion of track segments. The preferential motion of toms along the c-axis accounts for more rapid annealing of fission tracks perpendicular to the c-axis of apatite. In addition to the shrinkage, the discontinuity of fission tracks in apatite prevents solutions from entering into the porous tracks for further etching, thus reducing the etched track length. This accounts for the complete disappearance of etchable tracks in apatite at much lower temperatures, as compared to that of the latent tracks observed by TEM. In contrast, the amorphous tracks in zircon do not segment due to the low surface energy and low diffusivity of atoms at the track-matrix boundary. This explains the similarity between the complete disappearance of latent tracks in zircon at 830 °C after 90 min and that of etchable tracks at 800 °C after 1 h. The very different behavior of fission tracks in zircon and apatite is a direct result of differences in the internal structure of the track — the amorphous domain in zircon vs. the low atomic density void in apatite.