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A long-term natural fission track annealing and helium diffusion experiment: field testing in the deep ocean environment

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Low-temperature geochronometers are applied to a wide field of geosciences, ranging from structural geology to metamorphic geology, and hydrocarbon exploration. The most commonly used method is apatite fission track analysis, and, in more recent times, apatite (U-Th)/He analysis. Fission tracks are damaged zones of the crystal lattice caused by spontaneous nuclear fission of ^{238}U. When exposed to elevated temperatures, fission tracks start to anneal by shortening until above a certain temperature, they completely disappear, resetting the fission track age to zero. The shortening pattern can be used to reconstruct the detailed thermal history of a sample. Most of fission track annealing takes place at temperatures between ∼110 and 60˚C (= Partial Annealing Zone, PAZ). From laboratory annealing experiments, fission tracks are considered to be relatively stable at temperatures below ∼60˚C, but, because of sluggish kinetics, laboratory experiments cannot describe low-temperature ($<$60˚C) annealing over geological time scales. Apatite (U-Th)/He analysis is sensitive to even lower temperatures than fission track analysis. It is based on the alpha-decay of uranium and thorium, generating radiogenic helium. The latter is considered to be retained and accumulated in the apatite crystal lattice at temperatures below ∼40˚C.

For this study, we describe and quantify the effect of long-term exposure to very low temperatures on fission track annealing and helium diffusion in apatite. Our samples are derived from volcanic ash layers of drill cores from the Ocean Drilling and Deep

Sea Drilling Programs. The oceanic setting provides much better control on the thermotectonic evolution than a continental setting and also provides a long-term deep cold environment. Deposition ages of samples studied range from mid-Cretaceous to Middle Miocene. The thermal evolution of the different samples was independently reconstructed by vitrinite reflectance data. These range between 0.17 and 0.3 %, indicating that none of the samples has been heated to temperatures above the fission track PAZ, and most of the samples remained at temperatures below the helium partial retention zone. Fission track ages are within error limits concordant with the deposition ages of their host sediments. Mean fission track lengths range between 15.15 and 14.35 μm, which is substantially shorter than predicted by widely used models. Initial (U-Th)/He data yields ages, which are substantially younger than their corresponding fission track age. This suggests that long-term exposure to temperatures below the helium retention zone in the deep ocean environment has had an important influence on helium diffusion.