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Apatite Fission-Track (FT) Dating by LAM-ICO-MS Analysis

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Fission track (FT) geochronology involves the measurement and analysis of tracks in minerals caused by the spontaneous fission of ^{238}U. The technique is primarily used to determine the exhumation history of active orogenic belts and associated sedimentary basins (e.g. Andriessen and Zeck 1996; England et al. 1997; Blythe and Kleinspehn 1998; Lonergan and Johnson 1998). The method has been applied to many minerals, but the majority of FT-studies focus on apatite, zircon and occasionally titanite. FT-geochronology differs from other methods in that the age is measured by counting linear tracks of damage, revealed by etching the mineral in reagents such as HNO_3 for apatite. The track density can then be counted by using high-power optical microscopes. The FT-age of a mineral is given by the formula:

$$t = 1/A_A \ln [(A_a/A_f)(F_s/_A{}^{238}U)+1]$$

where, F_s is the number of tracks per cubic cm, ^{238}U is the number of atoms/cm^3 in the crystal at the present time and A_a/A_f is the proportion of the number of decay cycles due to spontaneous fission. Thus, to determine the FT-age we need to measure the number of tracks and the number of ^{238}U atoms in a given volume of a crystal. The current method of determining the U-concentration is to place the sample in contact with a plastic detector and subject it to slow-neutron bombardment. ^{235}U is induced to fission, producing tracks which are counted in the plastic detector and converted to ^{238}U concentration. The main causes of error are counting of both the spontaneous and induced tracks, measuring the neutron flux using glass monitors and age standards and the effect of 2-D versus 3-D track geometry. Errors are usually 5-10% of the age, effectively restricting FT-dating to rocks younger than 200Ma.

A laser-ablation microprobe attached to an inductively coupled plasma-mass spectrometer (LAM ICP-MS) allows for detection limits of U of 0.01ppm using small (30μm) spot sizes. U-contents in apatite typically range from 5-100ppm. By utilizing a motorized stage the laser was made to raster over the sample surface allowing the volume of apatite ablated to be determined. The raw ^{238}U signals were corrected for machine drift using Ca as an internal standard, and then converted into the number of ^{238}U atoms per unit volume using the well characterized Durango apatite standard. Etched crystals display only a certain proportion of the total tracks (F_s) on its surface. This relationship can be expressed as:

$$P_s = F_s\theta$$

where, P_s is the number of observed tracks and θ is the relative proportion of total tracks. Thus, to determine the proportion (θ), the track density (P_s) was also measured in the Durango apatite. This means that all the FT-ages calculated are calibrated against this standard. This is done routinely in conventional FT-age determination as a measurement of the neutron flux during irradiation.

The applicability of the FT-LAM technique has been tested by deriving FT-ages on samples with well constrained U-Pb ages. One example is the Palisades sill, New York, which contains abundant, perfectly euhedral crystals of apatite and was emplaced into loosely consolidated sediments where it cooled quickly. This sample has an age (201±1 Ma, Dunning and Hodych 1990) which is at the usual limit for precise conventional FT-ages. The concentrations of U in apatite from the sample vary from 2.3-4.6ppm and have track densities of 1.25-1.5 x 10^6 tracks/cm ^{2}. Calibrated against the Durango standard, the individual crystal FT-ages are within error of the published age and have overall errors of <5% at the 95% the confidence interval (2σ). This represents an overall improvement of 25-50% versus conventional FT-age determinations. The rapid analysis times also allow for a large number of grains to be analyzed per sample which further improves age errors. Thus, the technique may be applied to rocks of late Precambrian age.

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