Detrital zircon fission track thermochronology: practical considerations and examples

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ABSTRACT

Detrital fission track thermochronology involves using FT ages of single grains for stratigraphic correlation, provenance analysis, dating unfossiliferous sediments, and exhumation studies. Revelation of fission tracks in zircon is affected by alpha damage, so detrital suites require an etching procedure designed to reveal a spectrum of grain-damage characteristics. We use a multi-mount technique with a pre-etch in controlled conditions. Different etch times are needed to capture the full range of grain ages, especially in suites with a wide grain-age distribution. Modern suites of zircon shed from the Southern Alps in New Zealand have young to moderate FT ages (2-300 Ma) which are revealed using 15, 30, and 60 hr etch times. Zircons from Eocene flysch in Kamchatka, Russia, have moderate FT ages (40-150 Ma) that are revealed in mounts etched for 15 and 30 hr: both etch times yield similar age distributions. Zircons from Jurassic sandstones of the Taurin Suite (Crimea) have moderate to very old FT ages (~150 to 1000 Ma) and the samples show a clear relationship between age and uranium concentration, emphasizing a clear practical limit in the countability of grains in older samples. FT ages of detrital zircon from the Mohawk River in NY are old to very old (300 to 850 Ma) and the entire suite has uranium concentrations below 100 ppm because higher uranium grains are not countable.

OVERVIEW

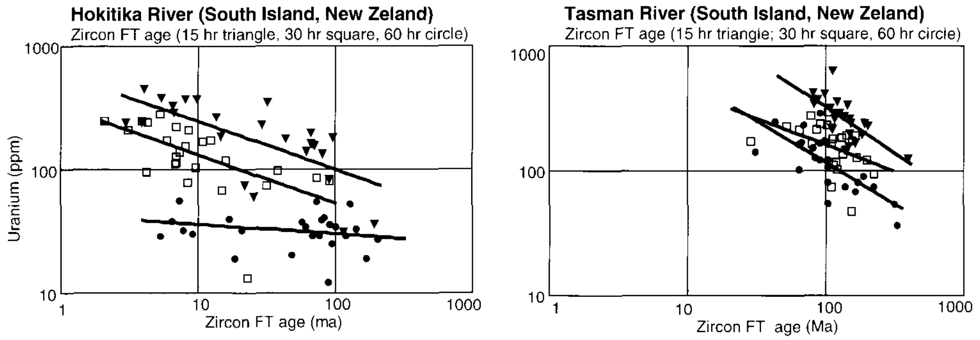
A relatively new field in provenance analysis is detrital fission track thermochronology which utilizes grain ages from sediment shed off an orogen to elucidate its exhumational history (Garver *et al.*, 1999a). Unlike a conventional FT age where dated grains from a single source have a common thermal history, FTGA distributions contain many single grain ages that originated from a variety of thermotectonic source terrains. There are a several techniques used to evaluate grain-age populations (see Brandon, 1996).

Studies using FTGA of detrital zircon show its utility [1] as a means for correlating sedimentary units; [2] for constraining the depositional age of poorly dated or unfossiliferous sediments; [3] as a method of constraining provenance; and [4] for tracking orogenic exhumation (Garver and Brandon 1994a,b). An important goal in these studies is to obtain a data set that has a little bias as possible in terms of capturing a full and quantitative grain-age spectrum (see Bernet *et al.*, this volume). Important practical considerations when using detrital zircon for such studies include uranium concentration and etch time. Single grain-age precision is affected by uranium concentration and age as both directly affect the number of countable tracks. Detrital zircons have a typical range between 100 and 600 ppm U (Garver and Brandon, in prep.).

Accumulated radiation damage, mainly alpha damage, affects the etchability of a zircon so that optimal etch times are not uniform from grain to grain. Radioactive decay of ^{238}U and ^{232}Th results in a-damage, which is mainly a function of uranium, thorium, and grain age. This damage facilitates etching and produces a variation in etch time for most typical zircons between 5 and 100 hours. The onset of a-damage accumulation starts at or below the FT closure temperature, so grains with old FT ages tend to have more accumulated a-damage.

PROCEDURE

Our methodology is similar to that widely used for the external detector method. Zircon grains are mounted in 2 cm^2 squares of PFA Teflon™ using a glass sandwich technique at ~330°C. Each mount is cut with 800 grit wet sandpaper, and then polished successively on 9 pm, and then 1 pm. Mounts are etched for 5 to 60 hours in a NaOH-KOH eutectic at exactly 228°C in a covered Teflon™ dish in an laboratory oven. A 1-5 hr pre etch is used for all mounts. This pre-etch is designed to force the disintegration of metamict grains, and other possible contaminants out of the mount especially iron sulfides which affect etching efficiency (Kowallis *et al.*, 1996). This etchant is then discarded and the etch continues with fresh etchant. Note that the composition of the etchant vessel affects etch times: etch times for the Fish Canyon Tuff vary by a factor of 1.5 to 2.0 between labs that use Teflon™ and those that use platinum dishes (etch time in Pt is shorter).



• 1 and 2 - Relationship between U and FT age for two modern river samples with young to moderate to FT ages (~2 to 300 Ma). Tasman River drains the east side of the S. Alps and the west-flowing Hokitika drains the deeply exhumed core of the orogen.

EXAMPLES

SOUTHERN ALPS, NEW ZEALAND

Rocks uplifted and eroded from the Southern Alps collision zone comprise the Torlesse terrane which is bounded in the west by the Alpine fault. Rivers flowing west erode deeply exhumed rocks of biotite to garnet-oligoclase zones, while those flowing east erode unmetamorphosed sandstone to chlorite schists.

The challenge in comparing zircon FT ages from east side and west side is to reveal both very young and moderately old FT grain ages (2 and 300 Ma) (see Figs 1-2). The dominant population of grain ages in the Hokitika River, which drains to the west into the Tasman Sea, are young (many <10 Ma) reflecting erosion of a recently exhumed crustal section. This FTGA distribution has a wide range of grain ages between about 2 and 80 Ma. In this sample, the FT grain ages from mounts with different etch times are dramatic. Note that the 60 hr etch time revealed essentially the same grain ages, but the average U content is between 30 and 40 ppm as opposed to ~100-300 ppm for the 15 hr etch. Grain ages of zircons from the Tasman River, draining off the west side of the Alps are ~30 Ma to ~200 Ma. In this instance, the difference between the 15, 30, and the 60 hr etch times are not as dramatic, and longer etch times reveal tracks in grains with less uranium and therefore less alpha damage.

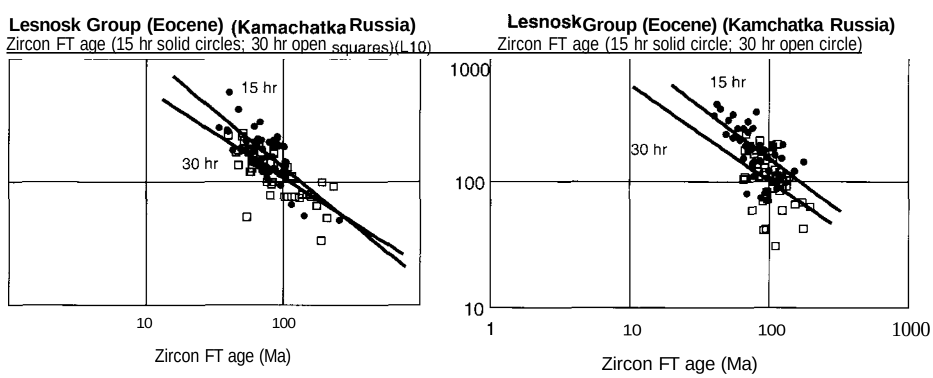
KAMCHATKA PENINSULA, RUSSIA

The Cretaceous-Eocene Ukelayet Flysch represents forearc strata that record the evolution of the continental arc build on the Eurasian mainland. The Ukelayat flysch is a 10-15-km-thick imbricated package of deformed turbidites. These quartzofeldspathic sandstones are uniform in composition, with varying proportions of volcanic detritus (Soloviev *et al.*, 1998).

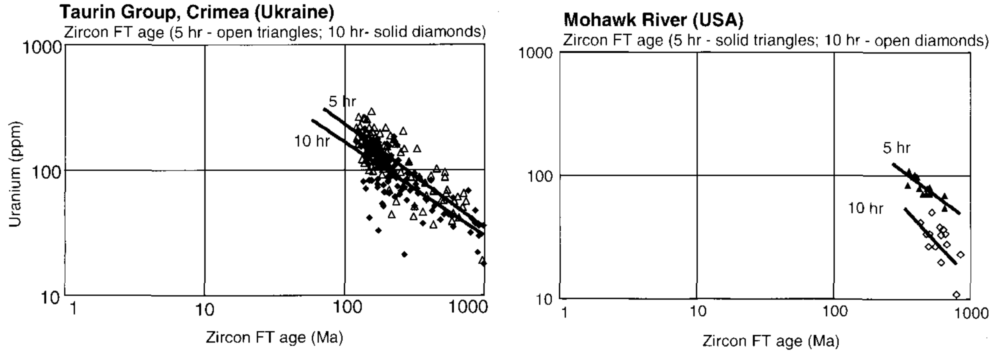
Detrital zircon constrain the timing of flysch deposition and the timing of exhumation of the source (two examples shown in Figs 3-4). The young population (P1) defines a "FT depositional age," which is the maximum age of unit and ranges from ~44 to 88 Ma. A second population (P2), represents progressive exhumation of the basement to the Okhotsk-Chukotka Arc over 50 Myr at rates of ~120-400 m/Myr. Note that in this case, the grain-age distribution includes only moderately old grain ages (~40 to ~150 Ma) and a double etch of 15 and 30 hr captures the principal population. At these uranium concentrations (80-300 ppm) there is not a significant difference in grain ages revealed in the two etch times.

CRIMEA, UKRAINE

The fold and thrust belt in the Crimean sector of the Alpine chain includes poorly dated Triassic to Jurassic flysch deposited along the continental rise derived from local continental basement rocks and a superimposed arc. The Taurin Group is part of the lower plate (Gornokrimsky Complex) and consists of the proximal and distal facies of deep-water flysch. FT ages of zircons from sandstones of the Taurin Group elucidates the provenance of the sediments and constrains their age (Fig. 5). The challenge in this project is to reveal tracks in zircon grains with moderate to very old cooling ages. Etching for 5 and 10



Figs 3 and 4 - Relationship between uranium and FT age for two samples with moderately old FT ages (~40 to 180 Ma). The 30 and 15 hr etch results in about the same grain age distribution.



Figs 5 and 6 - Relationship between uranium and FT age for two samples with moderate to old and very old FT ages (~150 to 1000 Ma for the Taurin Suite; 350 to 850 Ma for the Mohawk River).

hrs revealed grain ages between ~150 Ma and ~1000 Ma and in all cases, grains with fully revealed tracks in the longer etch have lower uranium concentrations. In this study, the strong correlation between U and age reflects the FT counting envelope: any grain older than 400 Ma must have less than 100 ppm U to be countable, otherwise the track density is too high. In such studies, the data set is strongly biased toward low-uranium grains.

APPALACHIAN MOUNTAINS, UNITED STATES

Modern river sediment from the Mohawk River (New York State) drains lower Paleozoic strata in the Catskill Mountains, which are part of the Appalachian mountain chain. Glacial sediments derived from similar lithologies and Proterozoic basement rocks to the north (Adirondacks and from the Canadian Shield) also make up a significant fraction of the modern sediment load. The Lower Paleozoic rocks are unmetamorphosed and therefore the zircons recycled from them retain cooling ages of the original source terrains that cooled in the lower Paleozoic and Precambrain. Similar to the Crimea study, the challenge here is to reveal fission tracks in grains with old to very old cooling ages (350 Ma and 850 Ma). Again, higher U grain are revealed in shorter etch time (10 hr vs. 5 hr., see Fig. 6). A strong bias exists in this data set as almost every grain has below 100 ppm U.

CONCLUSIONS

Studies using FT ages of detrital zircon allow for important insight into problems associated with sediment provenance, and exhumation of orogenic belts. To obtain a nearly unbiased sampling of an entire population of detrital grains, etching procedures must fully account for variation in alpha damage which affects track revelation. Using the multimount technique and etch times of 5,10,15,30, and 60 hours, a full spectrum of grain ages between 2 and 1000 Ma can be obtained.

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