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ABSTRACT PROGRAM

Radiation-damage and cooling ages of Precambrian detrital zircon

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Zircon ($ZrSiO_4$) is a common accessory mineral in siliciclastic sedimentary rocks and because it can be dated by several radiometric techniques it is widely used in provenance studies. These studies are aimed at understanding the age, thermal history, and composition of the source rocks that supplied sediment to the basin. Crystallization ages (U/Pb) can provide critical information about the range of ages of rocks units in an orogenic belt, but the signal can get complicated when there is a significant fraction recycled zircon from sedimentary or metasedimentary rocks. Cooling ages of detrital zircon (ZFT and ZHe) provide information about the integrated cooling history of the source terrain, which in most cases is directly related to tectonic processes that drove source rock exhumation and subsequent accumulation in flanking sedimentary basins. In the last decade or so, we've see that the analyses of detrital suites of zircon has become more or less routine (U/Pb, ZFT, and ZHe). Very old zircon grains, and zircon with significant radiation damage provide analytical challenges, but they also present us with important opportunities that we can use to refine our understanding of zircon provenance.

Most radiation damage in zircon accumulates from alpha-recoil primarily from the decay of ^{238}U. The accumulated damage results in many changes in a zircon including the progressive loss of crystallinity (disorder), the activation of color centers in the pink series, reduction in density, and susceptibility to chemical dissolution. For a zircon with 300-400 ppm uranium and a U:Th of 2, significant change in color and crystallinity typically occurs over 100 to 1000 Myr. When strata have been heated after deposition, the differential annealing of fission tracks in zircon is governed by radiation damage and composition, and this annealing occurs in rocks of prehnite-pumpellyite grade, or higher. Annealing of wide-spectrum radiation damage requires higher temperatures, and occurs over a much broader range of temperatures, and in typical geological setting it requires greenschist facies or higher. Here we present three cases where we can evaluate old, high-damage zircon in sedimentary basins.

1. Detrital zircon with Precambrian fission track ages. In some suites of detrital zircon, some grains have considerable radiation damage, but also very old fission-track ages. In these cases, fission-track ages can only be determined with great difficulty, and data sets tend to rely on relatively low-uranium grains because other grains are too damaged for analysis. High Density Fission Track (HDFT) dating can provide unique insight into exhumation and cooling in Precambrian settings provided the strata have not been significantly heated since deposition[1]. Stratigraphic units are from the Powder River Basin record Laramide tectonism and unroofing of the Precambrian-cored Big Horn Mountains in Wyoming. Analysis of these detrital suites is difficult because they retain such a wide range of cooling ages, and many of the cooling ages are Precambrian. U/Pb ages of detrital zircon from the Eocene Wasatch Formation are almost exclusively Precambrian (93%) with most at ~1800 Ma[3]. HDFT dating of zircon in the Eocene Wasatch Formation show that the majority of grains (80%) having cooling ages of ~950 Ma, but with wide a range and a few grains with Paleoproterozoic cooling ages. The HDFT cooling ages in stratigraphically lower Cambrian Flathead are also almost exclusively Neoproterozoic (c. 790 Ma). For both the Flathead and the Wasatch formations, two populations show dramatic discordance in the U/Pb system with lower intercept of 0 ± 35 Ma, and we conclude that discordance of high-damage grains has occurred since deposition. The Wasatch Formation is unique because it has an abundance of Paleoproterozoic and Archean grains with cooling ages that are mainly Neoproterozoic, but most are undatable because the FT density is too high. Collectively these grains have extremely high radiation damage, which dramatically affects the internal isotopic systems and resistance to in situ weathering and alteration.

2. Annealing of damaged-induced color in detrital zircon. In typical detrital zircon a significant fraction have an internal geochemistry amenable to the accumulation of radiation-damage-induced color in the pink series[2]. The pink color accumulates in intensity with time as a function of increasing disorder and activation of color centers. Field settings and laboratory studies show that annealing occurs at temperatures of about 350-400°C, and this has been well documented in the exhumed crustal section of the Mesozoic Torlesse terrane in the Southern Alps of New Zealand. In this unique setting, graywackes of the Torlesse show a spectrum of metamorphic grade due to differential exhumation. Rocks of prehnite–pumpellyite-grade (and lower) greywacke show no color-annealing and are dominated by pink, radiation-damaged grains (up to 60%). All color appears to be annealed in a rocks originally with temperatures of 350-400°C or higher, and in this case greenschist to amphibolite facies of the Alpine Schist. Annealing of this damage-induced color corresponds to an effect of radiation damage, but the amount of radiation-damage annealing (reordering of the crystalline structure) in this zone is not well known. In suites of detrital zircon with old grains, the absence of color in the pink series may indicate a source with old zircon, but relatively young high-temperature thermal history.

3. Radiation damage ages of Precambrian Detrital zircon. The progressive accumulation of the full spectrum of radiation damage in zircon can be used to understand the high-temperature thermal history of a zircon grain, and this information can complement U/Pb and ZFT dating. The most widely used proxy for measuring disorder in zircon relies on using μ-Raman spectroscopy, which is routine for single grains[5]. Part of the basement of the volcano-plutonic source terrain that supplied clastic sediment to the flysch of the Chugach-Prince William terrane (CPW) in Alaska delivered a small but significant fraction of Precambrian zircon. Using a combined approach of U/Pb dating, Fission-track, and μ-Raman analysis, we discovered[4] the source rocks for the Precambrian grains have two distinct high-temperature thermal histories: (1) western units of the CPW have a wide range of grain ages characteristic of a northern Laurentian source, and these grains have considerable disorder and have likely accumulated radiation damage for 500 to 1000 Myr; (2) zircon from the eastern units of the CPW are similar to southwestern Laurentia, but they have very little disorder and have likely only accumulated significant radiation damage since the late Mesozoic (c. 100 Ma). Thus the low levels of disorder as revealed from μ-Raman analysis of this latter suite of detrital Precambrian zircon indicate derivation from an exhumed metamorphic source where the accumulated radiation damage was reset (annealed) in the Cretaceous. Our laboratory experiments and empirical data from samples in thermal aureoles of plutons indicate: 1) that amphibolite grade metamorphism is required to fully anneal disorder caused by radiation damage; 2) the full spectrum of radiation damage is progressively annealed at temperatures well above that required for the annealing of fission tracks (and helium loss).

References

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