Application of multiple (U-Th)/He geo- and thermochronometers with closure temperatures <~250°C

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Thermochronometric dating techniques are widely used to elucidate the time-depth (exhumation and unroofing) histories of mountain belts, metamorphic terranes, sedimentary basins, stable cratons, et cetera. Some commonly used thermochronometers include $^{40}Ar/^{39}Ar$ dating of K-feldspar, mica and hornblende, fission track dating of apatite and zircon, and Th-U-Pb dating of titanite, rutile, and monazite. (U-Th)/He dating of apatite with a closure temperature of ~65-70°C (-dT/dt = 10°C/myr) is now a well-established and widely employed thermochronological techniques. Besides apatite, (U-Th)/He dating has also focused on zircon (closure temperature, Tc = ~180°C) and titanite (Tc = ~200°C). Additional U, Th-rich phases such as monazite (Tc = ~240°C), xenotime (Tc = ~120°C), rutile (Tc = ~220°C), and other silicate and oxide phases, however, may provide tools for establishing time-temperature paths of rocks. Each of these mineral phases is characterized by distinct closure temperatures and partial retention/annealing zones, ranging from ~70ºC to ~250ºC, offering the possibility of constraining different portions of a rock's low-temperature thermal history. Furthermore, the development of these new thermochronometers (Tc = ~180-245°C) should allow for the evaluation of $^{40}Ar/^{39}Ar$ K-feldspar MDD modeling results.

Thermochronometry has been tradionally applied to study the exhumation of crustal rocks in extensional and contractional tectonic settings. Incorporating these newly developed techniques will enable high-resolution reconstructions of temperature-time paths, in particular when systematically integrated with fission track and $^{40}Ar/^{39}Ar$ thermochronometric techniques. Furthermore, the occurrence of these accessory mineral phases in different magmatic, metamorphic, and sedimenatary environemts will lead to the development of new applications of (U-Th)/He dating. For example, (U-Th)/He dating of rutile or garnet allows to reliably date cooling histories of rocks that have often been traditonally problematic to date using established radiometric techniques (e.g., kimberlites and (ultra-) high-pressure rocks); rocks that either do not contain suitable mineral phases, have undergone significant alteration or are plagued by analytical geochemical complexities such excess ^{40}Ar. Therefore these new higher temperature (U-Th)/He thermochronmeters should have a significant impact.

Titanite and monazite U-Pb dating of high-grade metamorphism and extensional denudation in the mid-Scandinavian Caledonides

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In the mid-Scandinavian Caldeonides, a set of prominent extensional and strike-slip shear zones separate windows of high-grade rocks from nappes of the Upper and Uppermost Allochthons. The extensional shear zones have been recently regarded as the location of major attenuation of middle crust during a late stage of the Scandian collision between Baltica and Laurentia. The ENE-WSW trending Central Norway Basement Window (CNBW) is made of high-pressure amphibolite-facies, locally granulite-facies, Proterozoic gneisses and Neoproterozoic to Paleozoic supracrustal rocks, including metapelite, marble and calc-silicate gneiss. The CNBW is limited to the SW by the Høybakken detachment zone and to the NE by the Kollstraumen detachment zone. Monazite from a garnet-kyanite gneiss yields an age of 426 ±1 Ma interpreted as conspicuous migmatization in the rock and folding with ENE-WSW fold axis. Monazite in two garnet ±kyanite gneisses with minor staurolite yields ages of 420 ±2 and 403 ±5 Ma. Titanite in marble and calc-silicates is an amphibolite-facies mineral. In marble, titanite is rich in U (>150 ppm) and provides accurate U-Pb dates and simple U-Pb systematics. Titanite in four samples of calc-silicate gneiss and marble define a tight cluster between 403 ±2 and 401 ±2 Ma, interpreted as a crystallization age. Monazite and titanite record 25 Myr of high-grade metamorphism in the CNBW followed by exhumation. Titanite in the direct footwall of the Høybakken detachment pre-dates top-WSW ductile extensional shearing and consequently constrains final exhumation of the window along this detachment zone to be younger than 401 Ma.

The nappes of the Upper and Uppermost Allochthons overlying the CNBW are made of greenshist to amphibolite-facies supracrustal rocks and magmatic complexes. In the Helgeland nappes, to the NE of the CNBW, monazite in mica gneiss and titanite in calc-silicate gneis and marble range from 431 ±1 to 429 ±2 Ma. On the island of Hitra, to the SW of the CNBW, titanite in a marble yields an age of 443 ±4 Ma. Analyzed monazite and titanite in these nappes are coeval with the last pulse of local plutonism. This implies that high grade metamorphism in these nappes relates to the pre-Scandian orogenic evolution.