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Extending the time range of apatite (U–Th)/He thermochronometry in slowly cooled terranes: Palaeozoic to Cenozoic exhumation history of southeast Sweden

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Abstract

The use of (U–Th)/He thermochronometry in old slowly cooled terranes has long been debated. Hence, studies of natural setting are needed to verify the expected diffusivity behaviour of helium. Our results demonstrate that the (U–Th)/He method can be applicable to samples older than 200 Ma, and that available helium diffusion models can reproduce the results obtained from the age-vs.-depth trends. In addition, the results shed some light on the cross-validation with the apatite fission-track thermochronometer.

(U–Th)/He thermochronometry on apatites has been applied to samples taken from drill cores in the Precambrian basement in southeast Sweden to unravel the time of exhumation of the uppermost 1–3 km of the crust. Much of the Phanerozoic exhumation history in Sweden is poorly constrained due to a large hiatus in the sediment record. Results from the drill cores yield He ages decreasing with increasing depth from ~270 Ma at the surface down to ~120 Ma at 1700 m depth. The age-vs.-depth trend shows an inflection point at ~1400 m depth, which coincides with the upper boundary of the present Helium Partial Retention Zone. A period of slow exhumation (~17 m/my), probably linked to the isostatic uplift of the Caledonian foreland basin, is revealed by the upper section of the trend in the data. The results demonstrate that the area has not been reheated since the mid-Permian. This argues against the existence of a thick Mesozoic sedimentary cover in this region, which, if present at all, cannot have exceeded 100 m in thickness. Furthermore, the age-vs.-depth trend below the inflection point allows dating the cessation of exhumation at approximately 100 Ma. The area has had no significant amount of sedimentation, erosion or uplift since this time.

Keywords: apatite; (U–Th)/He thermochronology; Caledonian foreland basin; Sweden; Baltic Shield

1. Introduction

Apatite (U–Th)/He thermochronology has a sensitivity range typically between 40 and 80 °C [1]. Hence, it is the only existing dating technique that can provide new information on the "more recent" geological history of crystalline basement areas [2,3]. The dating range accessible by the (U–Th)/He method, however, has been questioned for cooling ages older than 200 Ma (e.g., [1]). Helium diffusivity in apatite for samples with long residence time in and/or below the Helium Partial Retention Zone (HePRZ) might render the conventional diffusion models erroneous [4]. Nevertheless, this issue can be assessed by collecting samples from a vertical profile, since the depth/temperature relationship among samples is set. He ages vs. depth typically reveal an

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inverse correlation. At shallow levels, rock samples yield older ages simply because they crossed the HePRZ during an earlier stage than their lower counterparts. The rate at which He ages increase with decreasing depth yields the rate of cooling.

A large portion of the Phanerozoic exhumation history in Sweden is insufficiently constrained due to a large hiatus in the sediment sequence. Devonian to Permian sediments are completely absent in Sweden, and early Mesozoic sediments are only sparsely preserved. This study focuses on (U–Th)/He dating of drill-core samples to understand the low-temperature geochronology of the Oskarshamn area in southeast Sweden (Fig. 1). The area is one of two chosen by the Swedish Nuclear Fuel and Waste Management Company (SKB) for detailed evaluation of long-term nuclear waste storage underground. (U–Th)/He analyses have been performed from surface samples down to a depth of 1700 m with the aim being to constrain periods and rates of exhumation. Previous low-temperature thermochronological data (apatite fission-track (AFT) analyses) derive from only one of the drill cores studied here. Results yield AFT ages of between 206 and 304 Ma. These ages are interpreted as the record of the late Palaeozoic to Mesozoic exhumation history [5].

2. Geological evolution of southern Sweden

The sub-Cambrian peneplain in southern Sweden developed during the end of the Proterozoic and extends over a larger area of the Baltic Shield [6]. Vendian and Cambrian sediments covered the peneplain during the early Palaeozoic, before the latest collision between Laurentia and Baltica [7]. In the Early Ordovician, the collision initiated the Caledonian Orogeny in the northwestern Baltic Shield, contemporaneously with the building of the Appalachian Mountains on Laurentia. The main phase of the Caledonian Orogeny started in the mid-Silurian and continued into the Early Devonian [8]. Numerous studies have suggested that a sedimentary foreland basin developed over southeast Scandinavia at this time (e.g., [9–11]). Tullborg et al. [10] estimated the sedimentary cover to have been 3 km thick, based on fission-track studies. In addition, Samuelsson and Middleton [11] constrained

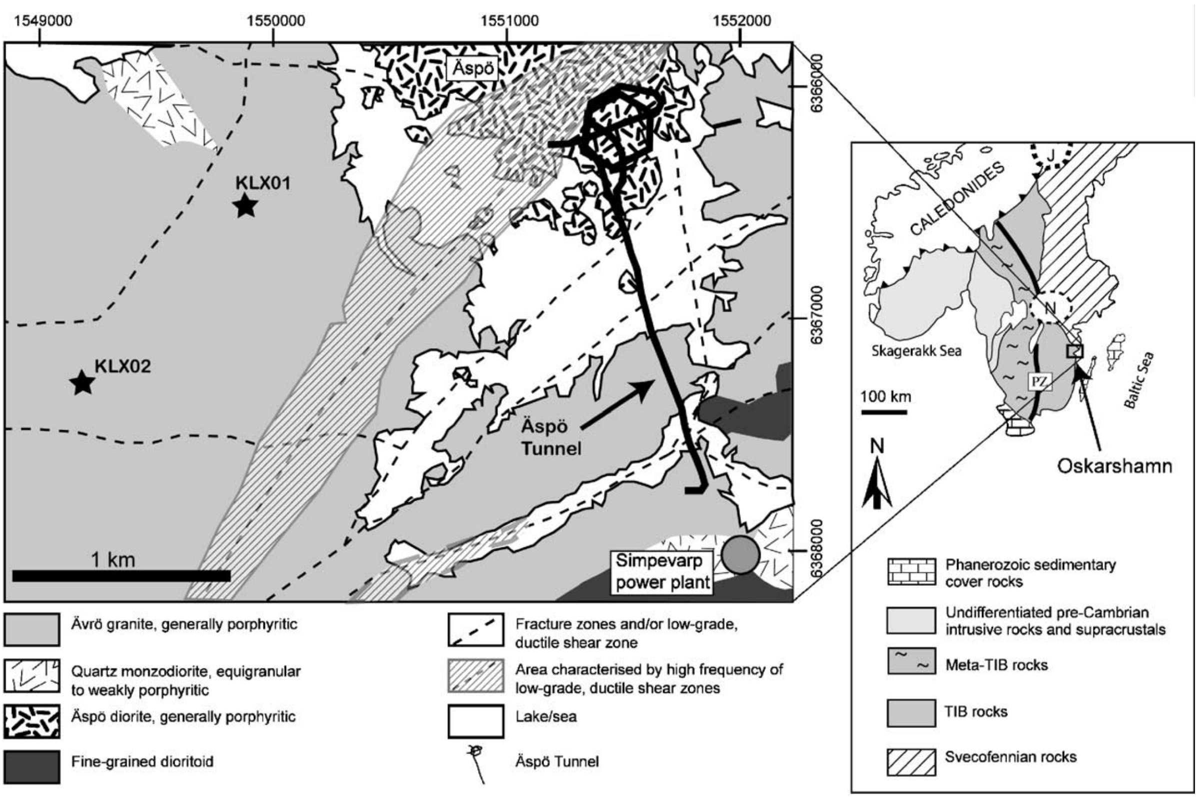

Fig. 1. (Right panel) Simplified geological map of southern Scandinavia. PZ = Protogine Zone; J = Jämtland; N = Närke. (Left panel) Zoom in of the Oskarshamn study area showing the locations of drill cores KLX01 and KLX02, and the Äspö Tunnel (modified from GSD-Fastighetskartan©Lantmäteriet Gävle 2001).