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Discussion

# Comment on "Apatite fission track and (U–Th)/He data from Fennoscandia: An example of underestimation of fission track annealing in apatite" by Hendriks and Redfield [Earth Planet. Sci. Lett. 236 (443–458)]

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**Abstract**

In a recent paper Hendriks and Redfield question the existence of major episodes of burial and subsequent denudation in old cratonic settings. They use Fennoscandia as an example, a continental shield region once covered by foreland basin deposits related to the Caledonian orogen, but today characterized by an exposed Precambrian basement. Hendriks and Redfield argue against a significant Caledonian foreland basin cover, referring to a selection of the numerous thermal indicator studies that have been performed in the region. Furthermore, they discern an inconsistency between previously published fission track and (U–Th)/He results in the region, and suggest an alternative interpretation of the apatite fission-track data from Fennoscandia.

Here we present geological arguments and highlight the numerous studies, only briefly mentioned or not referred to at all by Hendriks and Redfield, that strongly support the former existence of thick and extensive deposits on the Caledonian foreland. Furthermore, we discuss the alleged inconsistency between the different data sets by examining the data referred to more closely. Finally, we evaluate the significance of the suggested inverse correlation between fission track age and $^{238}$U concentration presented by Hendriks and Redfield.

There is, in fact, no published example of an inconsistency between the two methods concerning Paleozoic cooling in Fennoscandia at present, and the inverse relationship stated by the authors is poorly constrained. Therefore, although radiation-enhanced lattice recovery may have an influence on the apatite fission-track age and should be examined further we conclude that the study by Hendriks and Redfield is poorly constrained, their argumentation weakly and sometimes wrongly founded, and that the thermochronology data from Fennoscandia indeed do reflect sedimentary loading.


*Keywords:* FT dating; (U–Th)/He dating; thermochronology; Fennoscandia; foreland basin; Palaeozoic

## 1. Introduction

Hendriks and Redfield [1] discuss the inconsistency which sometimes occurs between (U–Th)/He and fission track (FT) measurements of apatite from old, cratonic

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rocks. The two thermochronology methods detect events in different, but slightly overlapping, temperature ranges (~35–70 °C and ~60–110 °C, respectively), and they are based on two fundamentally different physical processes [2]. They are often successfully combined when studying low-temperature thermal events, yet discrepancies between the methods occasionally emerge, especially when 'old' cooling ages are obtained. Hendriks and Redfield [1] present a theory for this discrepancy based on a selection of previously published apatite data from central Sweden and Finland. An inverse correlation between FT age and $^{238}$U concentration is interpreted as a result of radiation-enhanced crystal lattice recovery, in turn regarded as the main reason for the 'young' Palaeozoic FT ages obtained in eastern Sweden and Finland. This interpretation is based on the assumption that these samples have not experienced any significant reheating during the Phanerozoic due to e.g. sedimentary loading. Hendriks and Redfield [1] claim that the interpretation of a Caledonian foreland basin is based mainly on FT data, which they argue, may be false. They also declare that the absence of an extensive foreland basin is in accordance with "the generally accepted geological history".

The hypothesis of a significant FT annealing mechanism active at surface temperature presented by Hendriks and Redfield [1] is interesting and constitutes important contribution to the discussion of the legitimacy of apatite FT analysis in old geological settings. However, we would like to highlight numerous studies supporting the existence of a substantial Palaeozoic foreland basin in Fennoscandia. Moreover, we discuss the validity of the alleged discrepancy between the data derived from FT and (U–Th)/He measurements in Fennoscandia and the suggested significance of the observed negative correlation between $^{238}$U concentration and FT age, that Hendriks and Redfield [1] base their argumentation on.

## 2. Geological arguments for a Palaeozic foreland basin in Fennoscandia

The formation of the Caledonian mountain range in Fennoscandia at ~400 Ma was due to eastward thrusting, shortening and thickening of the continental crust at the subduction of Fennoscandia beneath Laurentia [3]. The amount of crustal thickening was approximately twice that in the present Himalaya [4]. The overthickened crust is today of normal thickness, which indicates a considerable amount of exhumation and erosion from the elevated parts of the Caledonides [4,5], although late-orogenic extensional collapse took place. The eroded material must have been deposited in the adjacent areas of the Baltic Shield. The fact that Palaeozoic sediments are preserved only in isolated pockets (e.g. [6–9]) on this foreland today does not preclude that sedimentation has taken place in the past. Indeed, thick tilted Paleozoic deposits offshore, being abruptly truncated at sea level [10], indicate previous extension of this sedimentary load also over the present-day onshore areas in Fennoscandia (Fig. 1).

The study referred to by Hendriks and Redfield concerning their 'accepted geological history', i.e. that no Caledonian foreland basin deposits should have existed, actually does suggest that sedimentation in a Caledonian foreland basin took place in Fennoscandia [11]. Nikishin et al. [11] argue for a Late Silurian foreland basin cover extending over eastern Sweden and western Finland for Late Silurian time (Fig. 7j of [11]), subsequently being eroded during Late Permian to early Mesozoic times (p. 46 [11]). They also state that "available stratigraphic information is restricted to tectonic and erosional remnants of these formerly very large shelf and foreland basins" [11]. It has not yet been investigated where the foreland basin sediments, once covering Fennoscandia, are today. It is plausible, though, that the thick Triassic and Jurassic deposits present in the Baltic Sea, at least partly, consist of reworked, foreland basin related sediments [12,13].

The following studies, some briefly summarized but most not referred to at all by Hendriks and Redfield [1], together support the idea of Palaeozoic heating of central Fennoscandia due to a former extensive cover.

### 2.1. Igneous cap rocks and fracture fillings

Thirty to hundred meter thick dolerites cover lower Palaeozoic remnants in central Sweden. They are relatively coarse grained (mostly medium-grained) and show ofitic textures. These cap rocks originally intruded the Palaeozoic sediments as Permian dolerite sills [14], and reached a level where the bedding of sediments may have acted as a magma trap and the driving pressure was much higher than the vertical stress [15]. However, basic magma that maintains a large positive driving pressure at shallow depths has a potential to erupt and will less likely form sill intrusions. It is also known that sills typically intrude at depth of a few km or deeper, and commonly at the end of a period of subsidence [16], which also may be valid for the Swedish Permian sills. The thickness and extent of the Permian sills in south Sweden indicate a forceful injection of magma, which suggests intrusion at considerable depth since they would otherwise have erupted through a thin cover. Additionally, a thin cover would have resulted in rapid cooling and a fine-grained dolerite texture.

Within the Caledonian foreland fractures filled with Cambrian sediments (mostly sand) are widespread (e.g.