Precambrian Research 304 (2018) 110–124

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

# Constraining the timing of brittle deformation and sedimentation in southern Finland: Implications for Neoproterozoic evolution of the eastern Fennoscandian shield

Tuija Elminen[a,*], Horst Zwingmann[b], Anu Kaakinen[c]

[a] Geological Survey of Finland GTK, P.O. Box 96, FI-02151 Espoo, Finland
[b] Department of Geology and Mineralogy, Graduate School of Science, Kitashirakawa Oiwakecho, Sakyo-ku, Kyoto University, Kyoto 606-8502, Japan
[c] Department of Geosciences and Geography, P.O. Box 64, FI-00014 University of Helsinki, Finland

ARTICLE INFO

*Keywords:*
Clay
Fault
K-Ar dating
Neoproterozoic
Thermal event
Sveconorwegian orogeny

ABSTRACT

Sheared sedimentary clay was found in a faulted fracture in crystalline bedrock in a tunnelling site at 60 m depth in southern Finland. Brittle faults are numerous in the Fennoscandian Palaeoproterozoic bedrock, but only some of them have relative age constraints, while absolute ages are nearly lacking. Sedimentary rocks altogether are uncommon in Finland and only sparsely dated by micropaleontological studies. This study reports K–Ar data of fresh, non-weathered authigenic illite and constrains a time framework for the local faulting and sedimentation. The Neoproterozoic Tonian to Cryogenian ages derived from the grains in diminishing grain-size order are c. 967, 947, 809 and 697 Ma. Results indicate that the formation of the extension fracture is related to the collapse of Sveconorwegian orogeny c. 1000 Ma; clay and mature quartz sand were deposited in this extension fracture in shallow water in an intracratonic basin followed by early diagenetic processes and neocrystallization of illite around 967–947 Ma. The Neoproterozoic 1000–700 Ma sedimentation documented in this study is rare in the Fennoscandian shield as a whole. Neocrystallization of authigenic illite in the finest 0.4 and < 0.1 µm fractions c. 809–697 Ma ago is interpreted as resulting from reactivation in the fault due to the continental break-up on the western side of the craton as documented by arenite crosscutting relationships. The younger ages may also be attributed to a Caledonian thermal overprint ca. 410 Ma ago that would influence the 967 Ma age if sufficient thermal energy had been present.

## 1. Introduction

Constraining the timing of fault zone formation is of geotectonic importance to understand structural evolutions and brittle fault processes. Early studies by Lyons and Snellenberg (1971) highlighted the applicability of isotopic dating techniques in constraining the age of brittle faults, and numerous isotopic approaches have since been applied, including the K–Ar method (e.g. Kralik et al., 1992; Vrolijk and van der Pluijm, 1999; Choo and Chang, 2000; Zwingmann and Mancktelow, 2004; Sasseville et al., 2008; Zwingmann et al., 2010a,b; Zwingmann et al., 2011; Pleuger et al., 2012; Hetzel et al., 2013; Viola et al., 2016), the $^{40}$Ar–$^{39}$Ar method (e.g. van der Pluijm et al., 2001; Solum et al., 2005; Haines and van der Pluijm, 2008; Duvall et al., 2011) and the Rb/Sr method (Kralik et al., 1987, 1992). Viola et al. (2013) extended this approach to date complex brittle faults in the Palaeoproterozoic basement of southwestern Finland aiming at also directly dating fault reactivation.

Brittle faulting is ubiquitous in the Fennoscandian basement, but the common lack of dated sedimentary marker horizons makes it difficult to constrain absolute timing or link the faults to specific geological events. Only limited absolute ages from a few locations have been reported in the literature. In Forsmark in central Sweden fracture fillings related to brittle deformation and hydrothermal events have been dated yielding $^{40}$Ar–$^{39}$Ar ages of 1.8–1.7 Ga that can be interpreted as dating the brittle-ductile transition, in addition to 1107 ± 7–1034 ± 3 Ma and several Palaeozoic ages in the brittle realm (Sandström et al., 2009; Fig. 1; Fig. 2). In southern Finland, $^{40}$A–$^{39}$Ar geochronometry has been applied to the Porkkala–Mäntsälä fault (Heeremans and Wijbrans, 1999), which is a major polyphase shear and fault zone predating the adjacent c. 1645 Ma (Vaasjoki, 1977a) Obbnäs rapakivi granite. Fault generations crosscutting the rapakivi provided ages predominantly in the 1300–950 Ma range (Heeremans and Wijbrans, 1999). Viola et al. (2013) reported illite K–Ar ages (1006.2 ± 20.5 Ma and 885.8 ± 18.3 Ma) from < 0.1 µm fractions from a single but

* Corresponding author.
*E-mail address:* tuija.elminen@gtk.fi (T. Elminen).

https://doi.org/10.1016/j.precamres.2017.10.014
Received 13 February 2017; Received in revised form 9 October 2017; Accepted 14 October 2017

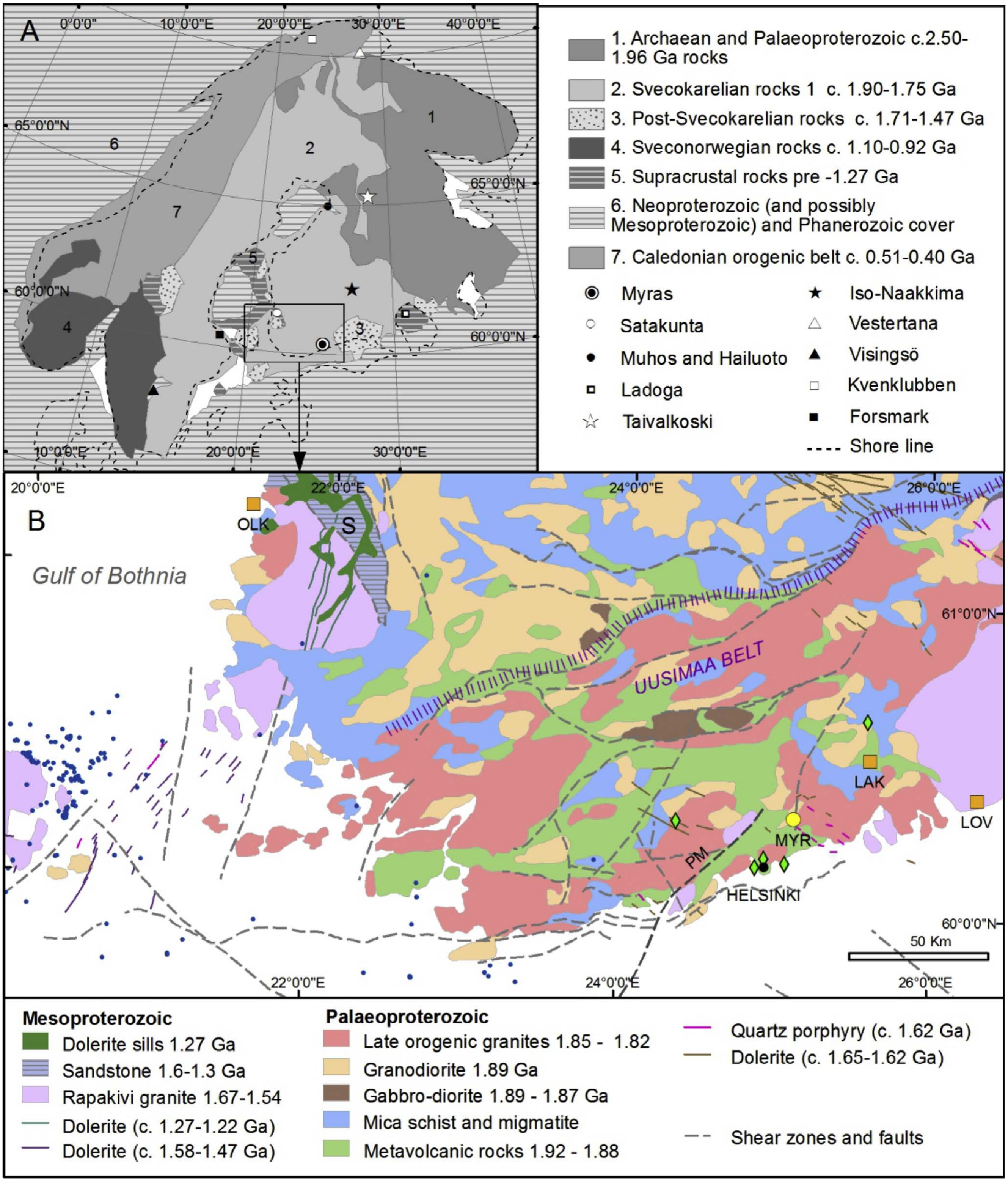


**Fig. 1.** (A) A schematic geological map of the Fennoscandian shield and locations of the Myras study site and sedimentary rock formations in Finland and Fennoscandia and other locations mentioned in the text. (B) A bedrock map of southwestern Finland. The yellow circle (MYR) indicates the Myras sampling point. Orange squares denote Olkiluoto (OLK), the uraninite dating point (LAK), and a fluorite vein (LOV). Green diamonds indicate palaeomagnetic measurements; (PM) Porkkala-Mäntsälä fault; small blue dots arenite dyke locations and (S) Satakunta Graben. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

reactivated gouge fault in a drill core from SW Finland. Palaeozoic faulting documented at 445 ± 9 Ma has been discussed by Torgersen et al. (2014) in northern Norway along the edge of a Palaeoproterozoic tectonic window in close proximity to the Caledonides. To summarise, the framework of brittle faulting within the Fennoscandian shield remains limited leaving the timescales and formation history of most of the brittle structures still obscure.

The Finnish Palaeoproterozoic bedrock is mostly veneered by unconsolidated deposits of Quaternary age, which are the results of glacial and glaciofluvial depositional processes. Only a few sedimentary rock