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Migmatization related to mafic underplating and intra- or back-arc spreading above a subduction boundary in a 2.0–1.8 Ga accretionary orogen, Sweden

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ABSTRACT

Absolute ages of migmatization and protolith formation, and constraints on the timing of ductile deformation in two major lithotectonic units in the south-western part of a 2.0–1.8 Ga orogenic belt in the Fennoscandian Shield, south-eastern Sweden, have been determined using U–Pb ion probe analysis of different generations of zircon in veined gneisses and leucocratic granite. Detrital and xenocrystic zircon in paragneiss and garnet-bearing leucogranite, respectively, in the Bergslagen lithotectonic unit show ages of 2.1–2.0 Ga and 1.9 Ga. Deposition of the sedimentary material occurred during or after a subduction-related magmatic event at 1.91–1.87 Ga. Two orthogneiss protoliths formed during this magmatic event around 1.88 Ga while most zircon in the leucosome in a third migmatitic orthogneiss was inherited from a 1.85 Ga igneous protolith. A polyphase tectonothermal evolution with anatexis under low-P metamorphic conditions around 1.86 Ga (M_1) and 1.84–1.81 Ga (M_2) is inferred for the migmatitic gneisses in the Bergslagen unit; garnet-bearing leucogranite crystallised around 1.84–1.83 Ga, close in time to major folding of the M_1 gneissic fabric. A previously unrecognised 1.86–1.85 Ga ductile deformational event under medium-grade metamorphic conditions has been identified in the adjacent lithotectonic unit to the south (Småland lithotectonic unit), close in time to the M_1 event in the Bergslagen unit to the north.

By constraining the timing of anatexis and comparing with information bearing on crustal thickness, excess mass at depth and the character and age of magmatic activity, it is inferred that anatexis in the Bergslagen lithotectonic unit is related to pulses of mafic underplating, during the early stages of two separate, subduction-related magmatic episodes after the 1.91–1.87 Ga magmatic event. It is suggested that each pulse was related to intra- or back-arc spreading above a subduction boundary, which had entered a retreating mode with separate, long periods (20–50 Ma) of extension or transtension. This study challenges the need to invoke crustal thickening related to plate collision at 1.9–1.8 Ga as a mechanism to explain high-grade metamorphism in the southern part of the 2.0–1.8 Ga orogen. Instead, a solely accretionary tectonic model involving an overriding plate along an active continental margin with significant extensional or transtensional crustal deformation is preferred.

1. Introduction

A large part of the Fennoscandian Shield in northern Europe (Koistinen et al., 2001) belongs to a major orogenic belt in which sedimentation, voluminous magmatic activity, pervasive ductile strain and metamorphism prevailed at different times in different places during the time period 2.0–1.8 Ga (Fig. 1; see, for example, Gaál and Gorbatschev, 1987; Stephens et al., 1997; Lahtinen et al., 2005, 2008; Daly et al., 2006). Current conceptual models for the tectonic evolution of this orogenic belt are dominated by a complex interaction between accretionary processes and continental collision (e.g. Nironen, 1997; Korsman et al., 1999; Korja and Heikkinen, 2005; Lahtinen et al., 2005, 2008; Kukkonen et al., 2008; Kukkonen and Lauri, 2009). Crustal thickening related to collision, orogenic collapse, delamination and a terminal phase with continent–continent collision have all been proposed in these models; resemblance to a Himalayan-type orogenic system is compelling.

A simpler model for the time frame 1.9–1.8 Ga in the south-western part of the orogen, which builds on earlier tectonic

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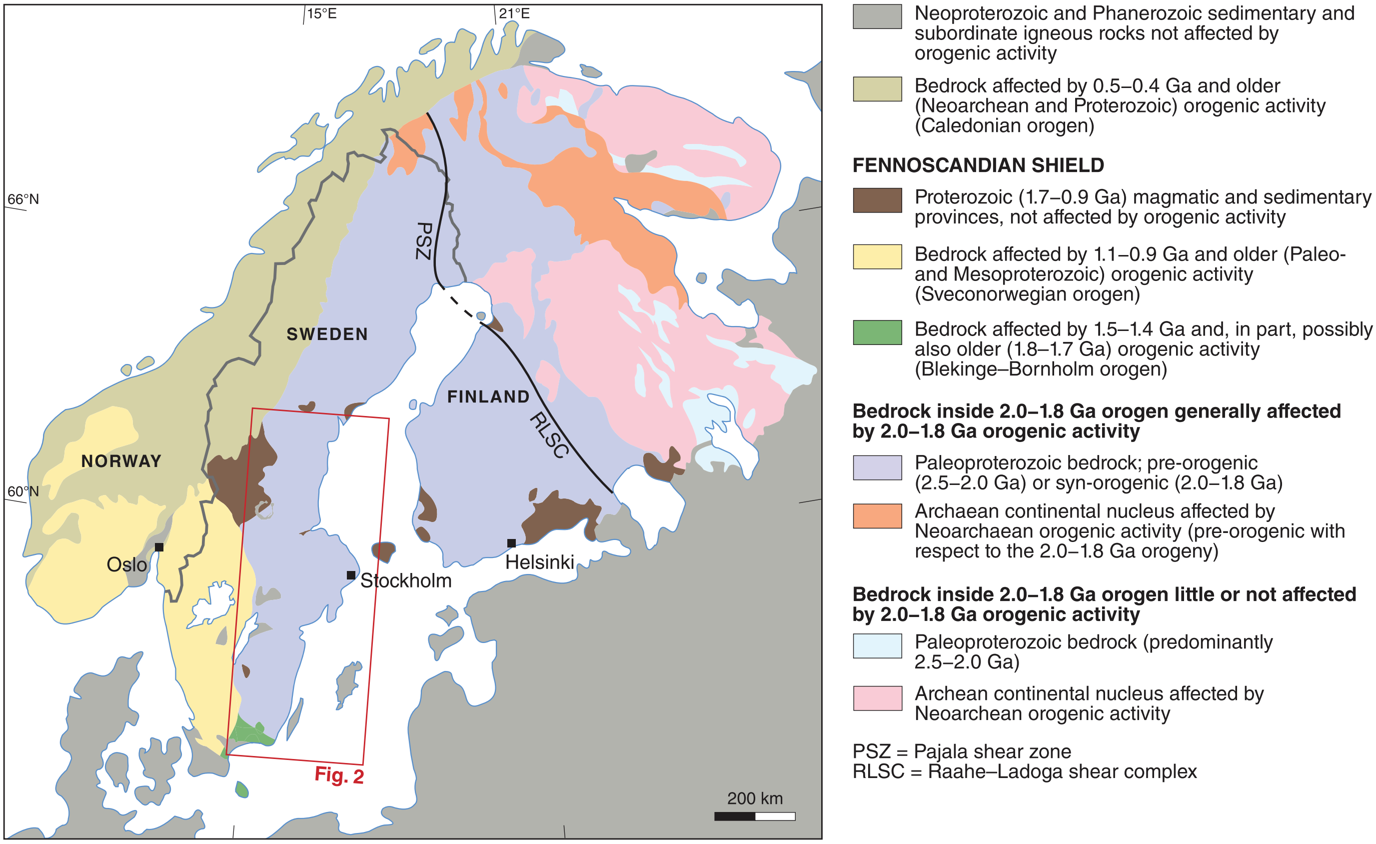

Fig. 1. Major lithotectonic units in the northern part of Europe. Map modified after Koistinen et al. (2001).

concepts for the 2.0–1.8 Ga orogenic belt (see, for example, Hietanen, 1975; Park, 1985), involves solely accretion along a single, active continental margin (Andersson et al., 2004; Hermansson et al., 2008a; Åhäll and Connelly, 2008; Stephens et al., 2009). This alternative model does not require the collision of exotic continental crustal segments and changes in subduction polarity at 1.9–1.8 Ga. Instead, it envisages a constant subduction polarity approximately to the north-east (using current geographic coordinates) beneath an active continental margin, progressive migration of the subduction system in an oceanward direction to the south-west with time in an extensional or transtensional tectonic regime, and tectonic switching (Collins, 2002) to shorter transpressional events at several time intervals.

A recent synthesis of the bedrock geology in the south-western part of the 2.0–1.8 Ga orogenic belt in Bergslagen, south-central Sweden (Fig. 2; Stephens et al., 2009), included a compilation of key metamorphic minerals and quantitative estimates of peak pressure–temperature (*P*–*T*) conditions during metamorphism. These data indicate metamorphism under low-pressure conditions, at depths close to or shallower than ~20 km, and at temperatures that varied considerably from low- to high-grade conditions, with the common occurrence of migmatite and locally granulite (Fig. 2A). An inspection of bedrock mapping data in this region, completed by the Geological Survey of Sweden (SGU), indicates that pervasive ductile strain had affected the bedrock prior to the peak of metamorphism (Stephens et al., 2009). Current data on the timing of metamorphism and migmatization in this part of Sweden, using U–Pb (zircon, monazite, titanite) geochronology, are limited and partly lack precision (Andersson, 1997, 2004; Persson et al., 2002; Andersson et al., 2006; see also overview in Stephens et al., 2009).

This study provides new data on the timing of migmatization, ductile deformation and protolith formation in the south-western part of the 2.0–1.8 Ga orogenic belt (Fig. 2). The study aims to integrate these new data with earlier geochronological work bearing on the timing of metamorphism, ductile deformation and magmatic activity, firstly, in order to shed some light on the possible mechanism behind the low-pressure anatexis in this area and, secondly, in order to evaluate the broader implications of all these data in the context of the alternative conceptual models for the tectonic evolution in the 2.0–1.8 Ga orogenic belt.

2. Geological framework

2.1. Context within the Fennoscandian Shield

Both the names Svecokarelian orogen and Svecofennian orogen have been used in the literature for the bedrock inside the volume affected to various degrees by the 2.0–1.8 Ga orogeny. Since there is no general agreement on the usage of a single name, we refer to this geological feature simply as the 2.0–1.8 Ga orogen or orogeny in spatial or process contexts, respectively.

East of the Pajala shear zone (Bergman et al., 2006a) and Raahe-Ladoga shear complex (Kärki et al., 1993), the 2.0–1.8 Ga orogen is dominated by Archaean (3.2–2.6 Ga) and Palaeoproterozoic (2.5–2.0 Ga) rocks, tectonically reworked to variable extent between 2.0 and 1.8 Ga, and subordinate 2.0–1.9 Ga syn-orogenic rocks (Fig. 1). By contrast, syn-orogenic 1.9–1.8 Ga rocks dominate to the west and south-west of these deformation belts (Fig. 1). After 1.8 Ga and prior to the break-up of Rodinia during the Neoproterozoic, igneous activity, deposition of siliciclastic sedimentary material and widespread brittle deformation (see, for example, Viola et al., 2009, 2013; Saintot et al., 2011), inside the 2.0–1.8 Ga orogenic belt, were related to younger tectonic events in far-field