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High-temperature deformation in the basal shear zone of an eclogite-bearing fold nappe, Sveconorwegian orogen, Sweden

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ABSTRACT

Ductile shear zones associated with emplacement of high-pressure nappes are key features to resolve exhumation mechanisms. The Eastern Segment of the Sveconorwegian orogen hosts an eclogite-bearing fold nappe, whose basal shear zone shows structures associated with emplacement of the eclogite-bearing nappe and decompression under high to intermediate pressure granulite and upper amphibolite facies conditions. Based on detailed structural mapping of a 4 km well-exposed section of the basal shear zone, we describe two major phases of deformation. An early deformation stage (D1) formed a penetrative gneissic foliation and tectonic layering, including isoclinal folds (F1). The sequence was subsequently affected by up to km-scale tight south-vergent folds (F2) with sheared out limbs. At the outcrop scale, asymmetric F2 folds are commonly S-vergent, but symmetric folds with different degrees of tightness are also present. Melt was present at all stages of deformation and the structural relations demonstrate mutual feedback between melt localization and fold formation. F2 folds have shallowly E-plunging fold axis parallel to a stretching lineation defined by high-grade mineral aggregates. Both constitute prominent structures of the basal shear zone. F2-folds are associated with an axial planar fabric (S2), defined by upper-amphibolite- and locally granulite-facies mineral assemblages. D2 shear structures are associated with top-to-the-east kinematic indicators throughout the section. The D1 episode was responsible for emplacement of the eclogite-nappe into its present structural position. The subsequently developed lineation-parallel folds are interpreted to form by general shear, where the structures reflect the regional E-directed flow of the entire eclogite-nappe.

1. Introduction

Largely eroded Precambrian orogens provide exceptional opportunities to understand the records and evidence of exhumation mechanisms that take place at high-temperature conditions in the deepest sections of the crust. In SW Sweden, eclogites have been tectonically emplaced during the Sveconorwegian orogeny, a collisional event that occurred at the end of the Mesoproterozoic and the beginning of the Neoproterozoic. These eclogites, which record evidences of deep burial and rapid exhumation during the last stages of the orogeny (990–970 Ma; e.g. Möller, 1998, 1999; Austin Hegardt et al., 2005; Möller et al., 2015), were exhumed as a partially molten low-viscosity nappe in the Eastern Segment of the Sveconorwegian orogen (Möller et al., 2015). The up to 4 km wide basal shear zone of this fold nappe is a strategic place to study the tectonic emplacement and deformation mechanisms during exhumation of the eclogite-bearing nappe.

In this paper we present new structural, microstructural, kinematic and petrographic data and describe the sequence of deformation events preserved in the basal shear zone of the eclogite nappe. We show the first systematic structural and kinematic study of a section across the basal shear zone and propose a mechanism for the origin of folding. The main exhumation phases, coined as D1 and D2, resulted in the formation of lineation-parallel folds and intense shearing, with an overall top-to-the-east sense of shear. We also demonstrate that the interplay between folding, shearing and melt played an important role during the exhumation process. Based on our data we propose a flow-perturbation model (e.g. Alsop and Holdsworth, 2004) for the exhumation of the eclogite-bearing units. This model implies that the lineation in the basal shear zone reflects the direction of the flow during the nappe's exhumation rather than the direct stress direction.

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2. Geological setting

The Sveconorwegian orogen consists of different crustal segments separated by roughly N-S trending shear zones: the Telemarkia, Bamble, Kongsberg and Idefjorden terranes in the west and the Eastern Segment in the east (Fig. 1). These terranes were tectonically juxtaposed during the Sveconorwegian orogeny at 1.1–0.9 Ga (Bingen et al., 2008). The Eastern Segment constitutes the reworked margin of Baltica, which experienced ductile deformation and partial melting during the late part of the Sveconorwegian orogeny, at ca. 0.99–0.92 Ga (Söderlund et al., 1999, 2002; Andersson et al., 2002; Möller et al., 2007). The Eastern Segment mainly consists of orthogneisses with protolith ages (1.74–1.66 Ga) and geochemistry similar to igneous rocks east of the Sveconorwegian Front (Transscandinavian Igneous Belt; Connelly et al., 1996; Söderlund et al., 1999, 2002; Petersson et al., 2013).

The Eastern Segment underwent metamorphism and migmatization during a pre-Sveconorwegian tectonometamorphic event, the Hallandian orogeny (1.47–1.38 Ga, Möller et al., 2007; Brander et al., 2012; Ulmius et al., this volume). Dykes and granitic plutons intruded during the Hallandian orogeny (Hubbard, 1975; Åhäll et al., 1997; Christoffel et al., 1999; Andersson et al., 1999; Brander et al., 2012; Ulmius et al., this volume). The youngest Hallandian intrusions (1.41–1.38 Ga) are important structural and metamorphic markers because they record the Sveconorwegian orogenic effects only.

The Eastern Segment is separated from the Idefjorden Terrane to the west by a major tectonic boundary: the several kilometer-wide west-dipping Mylonite Zone (Fig. 1). The Idefjorden and Eastern Segment have different protolith ages and different structural and metamorphic signatures (Andersson et al., 2002; Bingen et al., 2008). Structural investigations along the Mylonite Zone show complex multiphased evolution including top-to-the-east and top-to-the-west movements (Stephens et al., 1996; Berglund, 1997; Viola et al., 2011). Following the interpretation of Andréasson and Rodhe (1990), Viola et al. (2011) proposed the Eastern Segment to be an immature core complex exhumed in a general extensional regime. Eclogite occurences in the Eastern Segment (Möller, 1998, 1999; Johansson et al., 2001) are structurally bound within a 50 km recumbent fold nappe (Fig. 2a) and extrusion is suggested as the main mechanism for their emplacement (Möller et al., 2015). U–Pb SIMS dating of zircon in eclogite constrains the eclogite metamorphism at 990–980 Ma (Möller et al., 2015). The tectonostratigraphy is composed of distinctive units: (a) the eclogite-bearing unit in the core, with stromatic orthogneisses (b) a distinctive heterogeneously deformed 1.4 Ga augen gneiss, which is a tectonostratigraphic marker, outlining the megafold (colored in black in Fig. 2), and (c) an eclogite-free, orthogneisses unit that is enveloping the fold nappe (Möller et al., 2015; Fig. 2). (b) and (c) are hereinafter collectively referred to as enclosing orthogneisses.

The eclogite-bearing nappe has a basal shear zone, the southern part of what was previously coined as the Ullared Deformation Zone by Möller et al. (1997). The tectonostratigraphy has been traced from the coast eastwards along strike for ca. 50 km (Möller et al., 2015; Fig. 2). Deformation in the basal shear zone occurred at high to intermediate pressure granulite and upper amphibolite conditions, post-dating the eclogite facies metamorphism (Möller, 1998, 1999). Geochronology of syntectonic pegmatite suggests that this deformation occurred at ca. 970 Ma (Söderlund et al., 2002), contemporaneous with migmatization in other parts of the nappe (Möller et al., 2015). The tectonostratigraphy, including the eclogite nappe, has been folded into gentle antiforms and synforms trending roughly N-S (Fig. 2).

3. Section across the basal shear zone

In the following sections we describe the main lithological units present in the study area and the sequence of structures and fabrics observed along a ca. 6 km long profile through the basal shear zone and the underlying part of the enclosing orthogneisses (Figs. 2b and 3). Vertical N-S striking structural sections of the basal shear zone that are rarely accessible elsewhere are exposed along this profile. The cross-section in Fig. 3b was constructed perpendicular to the stretching lineation. Coordinates of key localities are given in Table 1.

3.1. Lithotectonic

Following the lithotectonic components in Möller et al. (2015) for the study area, mappable units from north to south are: (1) the eclogite nappe, inner part (2) eclogite nappe, basal shear zone, and (3) Eastern Segment orthogneiss (herein referred to as enclosing orthogneisses).

The precise contact between the eclogite nappe and the enclosing orthogneisses is not exposed in the studied section, but is located based on the presence of remnant eclogite assemblages in mafic boudins.

3.1.1. Eclogite nappe

The eclogite nappe is divided into a basal shear zone composed of heterogeneous mylonitic gneisses and an inner part dominated by stromatic migmatitic gneiss. Both units contain retroeclogite lenses, but kyanite-bearing varieties were so far been found only in the basal shear zone. The two main types of retroeclogite present in the study area are: (1) kyanite-bearing with local layers of kyanite-free, Fe-Ti-rich, quartz-bearing retroeclogites with higher amount of garnet and (2) a kyanite-free, quartz bearing eclogite. Both types of eclogite are dominated by dark red garnet and dull greenish gray clinopyroxene, and show a wide variation in grain size and degree

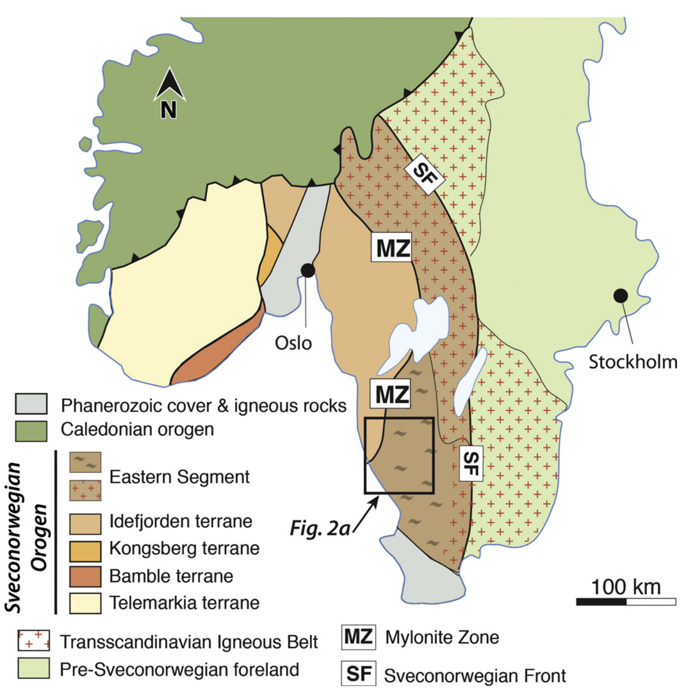

Fig. 1. Overview map of southern Scandinavia (Modified after Möller et al., 2007, Sveconorwegian orogen subdivisions after Bingen et al., 2008). Cross marks for the Transscandinavian Igneous Belt denote undeformed and non-penetratively deformed domains.