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High resolution reflection seismic imaging of the Ullared Deformation Zone, southern Sweden

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A B S T R A C T

The Ullared Deformation Zone (UDZ) is one of a few structures worldwide known to contain decompressed eclogite facies rocks of Precambrian age. Given the unique nature of the Ullared eclogites, a 15 km long reflection seismic profile was acquired across the UDZ in April 2007. The principal objective of the profile was to provide geometrical information on the deformation zone at depth. The profile was acquired along a crooked line which gave us the opportunity to extract strike and dip information of reflections from the data-set using non-standard seismic techniques, including a cross-dip correction. This cross-dip correction method proved to be very useful for constraining the geometry of the reflectors at depth. The most recent (from 1997) published geological interpretation of the UDZ area was based on aeromagnetic data and the UDZ was interpreted as a shear zone, or possibly a shear zone system. The seismic data and a detailed aeromagnetic analysis support the interpretation of the UDZ as a shear zone system. Based on differences in reflectivity and geometry, the UDZ can be separated into four different units. The north-easternmost unit is the only one where eclogites have been found so far. Structures of the eclogite bearing unit are interpreted to dip approximately 20–30° towards northeast at depth.

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1. Introduction

The Ullared Deformation Zone (UDZ) in southwestern Sweden (Fig. 1), is one of a few structures worldwide known to contain decompressed eclogite facies rocks of Precambrian age. Some other localities where Precambrian eclogites have been identified are, for example, the eclogite bearing suite of the Usagaran orogen in central Tanzania, with peak metamorphism dated to approximately 2.0 Ga (Collins et al., 2004), retrograded eclogites from the early Precambrian Hengshan Complex in the North China Craton (Zhao et al., 2000), mid-Proterozoic eclogites in the Lofoton area, Norway (Markl and Bucher, 1997) and Grenvillian age eclogites in northwest Scotland (Sanders et al., 1984) and in the eastern Grenville Province of western Labrador (Indares, 1993). Given the unique nature of the Ullared eclogites, a 15 km long reflection seismic profile was acquired across the UDZ in April 2007. Reflection seismic profiles over complex hard rock environments like the UDZ require that appropriate processing is applied and that special attention is paid to the interpretation of reflections. The profile was acquired along a crooked line (Fig. 2(a)) which gave us the opportunity to extract reflection strike and dip information from the data-set using non-standard seismic techniques further described later in this paper. The principal objective of the profile was to provide geometrical information on the deformation zone at depth. Understanding the geometry of the shear zone is the first important step towards understanding the tectonic setting in which the eclogites were brought to the surface. In this paper we first give an overview of the geological setting of the area and then present results from the seismic reflection data. The most recent outline of the UDZ (Möller et al., 1997) was based on aeromagnetic data where the UDZ was interpreted as a shear zone or possibly a shear zone system. The new reflection seismic data and a detailed magnetic anomaly interpretation have been used to update the former outline of the UDZ and also to highlight some areas of the UDZ that need further investigation.

2. Geological setting

The Sveconorwegian orogen in southwestern Sweden is 600 km long and up to 200 km wide. It continues westwards and northwards into the southern part of Norway and farther north it is buried beneath the Scandinavian Caledonides. The orogen can be divided into major litho-tectonic units (Fig. 1). The Eastern Segment is regarded as a parautochtonous unit directly linked to the Fennoscandian Foreland. It is dominated by orthogneisses and meta-mafic rocks. The orthogneisses have protolith ages of c. 1.73–1.66 Ga and show geochemical similarities to coeval rocks

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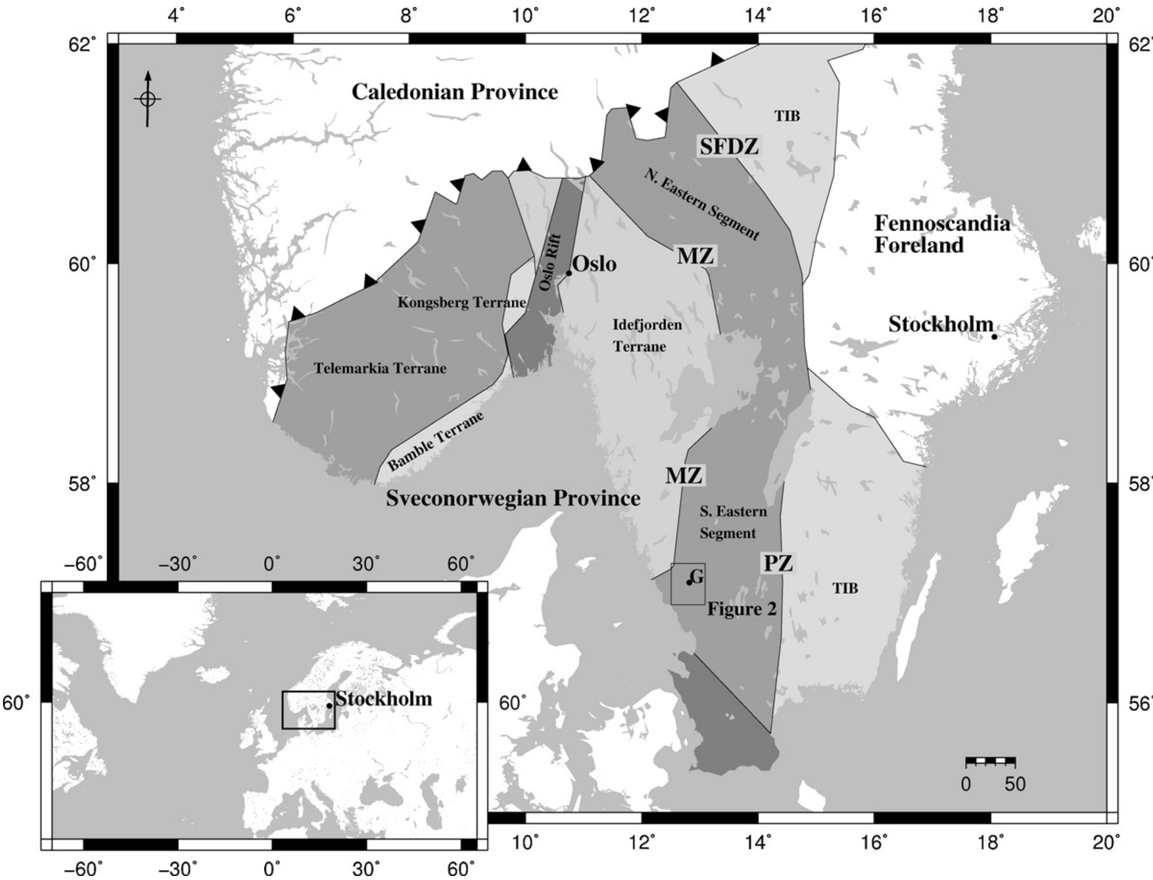

Fig. 1. Geological–tectonic map of southwest Sweden illustrating the location of the Eastern Segment in the Sveconorwegian orogen. The framed area marks the location of Fig. 2; G – Gällared; MZ – Mylonite Zone; SFDZ – Sveconorwegian Frontal Deformation Zone; PZ – Protogine Zone. Inset shows the location of the map in relation to Europe and the North Atlantic.

of the Transcandinavian Igneous Belt (TIB) to the east. A complex system of retrogressive deformation zones, the Sveconorwegian Frontal Deformation Zone or SFDZ (Wahlgren et al., 1994), forms the eastern boundary of the orogen and of the Eastern Segment in the north and in the south it is bounded by the subvertical Protogine Zone (PZ). To the west, the Eastern Segment is confined by the Mylonite Zone (MZ) that marks a major lithological, structural and metamorphic terrane boundary.

The UDZ is located in the southern part of the Eastern Segment (Fig. 1). The UDZ was recognized by Möller et al. (1997) and the outlined boundaries (Fig. 2(a)) were interpreted using aeromagnetic data. An internal discordance around a magnetic low anomaly was detected with differing foliation on the eastern and the western sides. The western side appears to cross-cut structures in the eastern side (Fig. 2(b)). Two hypothesis were presented to explain this observation. Either the UDZ is actually two different zones in which the western zone is the youngest. Alternatively, the discordance is caused by a large competent mafic body in the south which forms a tectonic lens that has influenced the deformation pattern, creating a false cross-cutting relationship.

The Eastern Segment of the Sveconorwegian domain consists of TIB rocks that have been underthrust, reworked and exhumed during the Sveconorwegian orogen (Bingen et al., 2008; Möller et al., 2007; Wahlgren et al., 1994). Bingen et al. (2008) described the Sveconorwegian development with a four phase model. In summary, prior to the Sveconorwegian orogen the Idefjorden terrain was accreted to the Fennoscandian shield (the Gothian orogeny 1660–1520 Ma). During the first Sveconorwegian stage, the Arendal phase, 1140–1080 Ma, the Telemarkia terrane was accreted to the Idefjorden terrane. A continent–continent collision produced an orogenic wedge consisting of the Bamble-Kongsberg terrane. The main Sveconorwegian phase, named the Agder phase, occurred between 1050 and 980 Ma. During this phase, Fennoscandia experienced continent–continent collision with an unknown continent, possibly Amazonia. Oblique eastward thrusting and crustal thickening occurred in the central part of the orogen. In the late stage of the Sveconorwegian orogen, the Falkenberg phase, 980–970 Ma, the crustal thickening propagated eastward, burying the southern Eastern Segment deep enough for eclogitization to occur. Based on dating of migmatization and the E–W fold pattern in the southern Eastern Segment, Möller et al. (2007) suggested a N–S shortening and E–W extension in the southern Eastern Segment in the Falkenberg phase that was coeval with eclogitization. The last stage of the orogenesis, called the Dalane phase (970–900 Ma) was dominated by relaxation and extension as the Sveconorwegian belt collapsed.

Sapphirine-bearing rocks have been found in eclogite relicts in the northern parts of the UDZ (Fig. 2(a)). Möller (1999) estimated that these rocks were subjected to peak pressures of at least 15 kbar, corresponding to depths in excess of 55 km. Metamorphism leading to eclogitization was dated to a maximum of 972 ± 14 Ma, (Johansson et al., 2001). Dating of cross-cutting pegmatite dykes at 956 ± 7 Ma (Andersson et al., 1999; Möller and Söderlund, 1997) set the minimum age limit for the eclogitization and high temperature decompressive deformation. A syndeformational pegmatite was dated at 961 ± 13 Ma (Söderlund et al., 2002). How the eclogites were exhumed is unclear, but the exhumation must have been reasonably fast in order for the mineral assemblage and texture, indicating eclogitization, to have been preserved. Based on the presence of a c. 960 Ma dyke swarm to the east, Johansson et al. (2001) suggested an extensional regime as a likely tectonic setting for the

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