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Localized occurrences of granulite: P–T modeling, U–Pb geochronology and distribution of early-Sveconorwegian high-grade metamorphism in Bamble, South Norway

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ABSTRACT

New localities of granulite in the Bamble lithotectonic domain of south Norway illustrate localized distribution of granulite facies rocks in an amphibolite facies gneiss terrain. U–Pb zircon SIMS data constrain the magmatic age of the protoliths to be both 1545 ± 7 to 1542 ± 5 Ma and 1149 ± 8 Ma. They provide a robust date of 1139 ± 11 Ma for metamorphic zircon, supporting available estimates for early-Sveconorwegian metamorphism in Bamble. P–T modeling using Grt + Opx ± Cpx + Pl + Bt + Qz-assemblages yields pressures up to 1.15 GPa and T > 850°C. Clinopyroxene-free granulite assemblages are preserved in low-strain lenses, while high-strain granulite shows crystallization of clinopyroxene. The replacement of orthopyroxene by amphibole illustrates hydration and reequilibration at amphibolite facies. The new findings in Bamble show that granulite-facies rocks occur unevenly distributed in high-grade metamorphic terrains and that relationship between granulite and amphibolite facies is complex and irregular. It suggests that factors as fluid availability, deformation and whole-rock composition are important for metamorphic evolution in addition to pressure and temperature gradients.

1. Introduction

Classical metamorphic models were developed more than 100 years ago where regional metamorphic transitions were established as controlled by changes in pressure and temperature. This led to the concept of the Barrovian zones (Barrow, 1912) which today is a well-accepted paradigm. Based on this concept, regional metamorphic isograds have been constructed in different orogens. Over the last decades, fluids and deformation have been defined as additional controlling factors for metamorphic transitions and distribution of metamorphic rocks (e.g. Jamtveit and Austrheim, 2010). The metamorphic landmark paper of Austrheim (1987) illustrated the importance of fluids as controlling metamorphic transitions to eclogite facies. Although complex metamorphic variations are well-known in many metamorphic terrains, in classic granulite terrain complex metamorphic variations have hitherto neither been fully documented nor understood.

The Bamble lithotectonic domain of south Norway (Fig. 1) is one of the classical transition zones from amphibolite-facies to granulite-facies regional metamorphism in a Proterozoic orogenic belt, where Opx-in, Cdr-in and Ms-out isograds define a granulite facies dome structure (e.g. Clough and Field, 1980; Nijland and Majier, 1993; Nijland et al., 2014; Touret, 1971a). Possibly the most seminal work performed in Bamble, is that the transition from amphibolite- to granulite-facies mineral assemblages parallels a change from water dominated fluid inclusions to high-density carbon dioxide dominated fluid inclusions (Touret, 1971b). The discovery highlighted the importance of fluid components as integral part of metamorphic systems (e.g. Putnis and Austrheim, 2010).

The isograds mapped in the Bamble transition zone, reflect an intermediate-pressure metamorphic gradient, typical for Proterozoic orogenic belts. Phase equilibria and thermobarometric estimates converge towards peak conditions around 0.6–0.8 GPa and 750–850 °C in the core of the granulite-facies domain around Arendal (Harlov, 2000; Knudsen, 1996; Lamb et al., 1986). Lamb et al. (1986) did not detect a significant increase in pressure–temperature conditions towards the core of the granulite-facies domain. Using a more extended sampling, Nijland and Maijer (1993), however, argued for an increase in conditions, and opine that the granulite-facies domain corresponds to a thermal dome. Nevertheless, occurrences of rocks with diagnostic granulite-facies assemblages (Nijland and Senior, 1991; Touret and Olsen, 1985) and metasomatic rocks (Austrheim et al., 2008; Engvik et al., 2011; 2014) are well known inside the amphibolite-facies domain, bringing complication to this apparently smooth prograde transition zone. Also several high-strain zones are mapped nearly parallel to the isograds (Starmer, 1991).

This work describes the localized occurrences of granulite-facies rocks on a regional scale. We report new occurrences of granulite-facies gneiss in the amphibolite-facies domain of Bamble north of Kragerø (Fig. 1) and document their petrology, P–T conditions and

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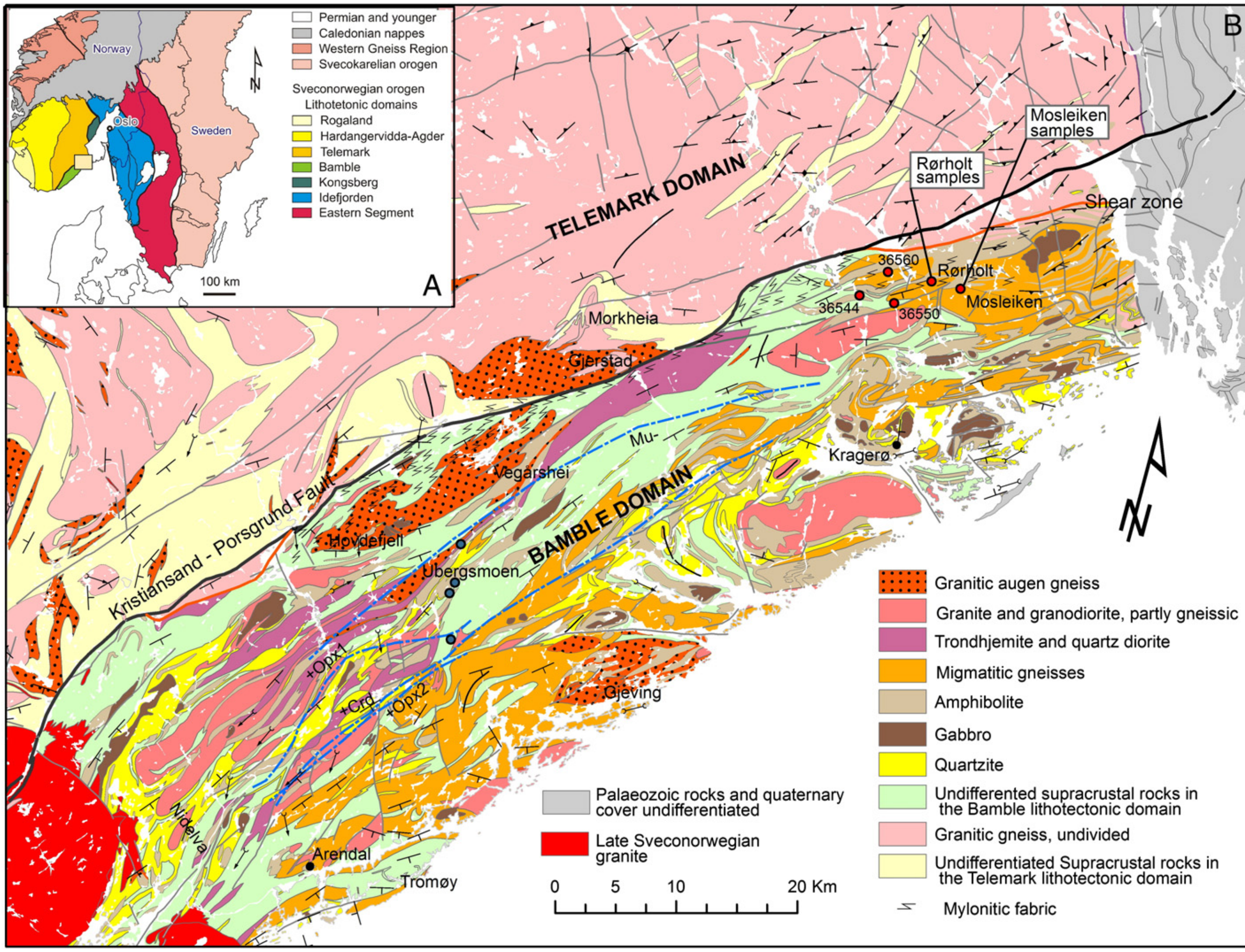

Fig. 1. A) Situation map illustrating the main lithotectonic domains of the Sveconorwegian orogenic belt of SW Scandinavia. Inserted square indicates area of Fig. 1B. B) Geological map (after Padget and Brekke, 1996) of the Bamble and Telemark lithotectonic domains, showing localization of the new occurrences of the Mosleiken and Rørholt granulites, including additional sampled granulites within the Kristiansand–Porsgrund Fault and Shear Zone. Opx-, Crd- and Ms-isograds after Touret (1971a) and Nijland et al. (2014). Blue dots indicate "granulite facies islands" after Nijland et al. (2014). Red dots are the new granulite occurrences north of Kragerø.

U–Pb geochronology. Local occurrences of granulite-facies rocks in the amphibolite-facies domain provide opportunities to recognize the high-grade metamorphism at a regional scale and to discuss its significance for tectonic and geological evolution. Importantly, these localized occurrences of granulite contribute to the discussion on the control factors of high-grade metamorphism, underscoring the importance of whole-rock composition, fluid composition, deformation, fluid availability and kinetic control on development and retrogression of metamorphic assemblages.

2. Geological setting

2.1. The Sveconorwegian orogenic belt

The Sveconorwegian orogenic belt in SW Scandinavia consists of late Palaeoproterozoic to Mesoproterozoic continental crust reworked during the Sveconorwegian orogeny (Bingen et al., 2008a; Bogdanova et al., 2008). The orogen is divided into several lithotectonic domains, variably called sectors, blocks, terranes or segments, separated by crustal scale shear zones. Seven lithotectonic domains are represented in Fig. 1A, from east to west, the Eastern Segment, Idefjorden, Kongsberg, Bamble, Telemark, Hardangervidda-Agder and Rogaland lithotectonic domains, each of them characterized by distinct characters. The main crust forming magmatic event in these domains, which reflects accretionary continental growth, is increasingly younger and juvenile towards the west (Bingen et al., 2005; Petterson et al., 2015). It decreases stepwise from ca. 1690 Ma in the Eastern Segment, to ca. 1500 Ma in the Telemark, Hardangervidda-Agder and Rogaland domains. The Palaeoproterozoic to Mesoproterozoic crust was subsequently the theater of a number of pulses of Mesoproterozoic magmatism between ca. 1400 and 1140 Ma and was reworked during the Sveconorwegian orogeny between ca. 1140 and 900 Ma (Bingen et al., 2008a, b; Möller et al., 2015). The Eastern Segment is geologically clearly distinct from the rest of the orogen. It is interpreted as a domain of clear Fennoscandia ancestry, contrasting with the allochthon character of the Idefjorden and other domains westwards (Bingen et al., 2008a, b; Möller et al., 2015; Petterson et al., 2015). The Sveconorwegian orogeny is classically interpreted as a collisional event, contributing to welding of Rodinia (Bogdanova et al., 2008). The Bamble and Telemark lithotectonic domains, making the focus of this study, are described succinctly hereafter.