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Research paper

The Bamble Sector, South Norway: A review

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ABSTRACT

The Proterozoic Bamble Sector, South Norway, is one of the world's classic amphibolite- to granulite-facies transition zones. It is characterized by a well-developed isograd sequence, with isolated 'granulite-facies islands' in the amphibolite-facies portion of the transition zone. The area is notable for the discovery of CO_2-dominated fluid inclusions in the granulite-facies rocks by Jacques Touret in the late 1960's, which triggered discussion of the role of carbonic fluids during granulite genesis. The aim of this review is to provide an overview of the current state of knowledge of the Bamble Sector, with an emphasis on the Arendal-Froland-Nelaug-Tvedestrand area and off shore islands (most prominantly Tromøy and Hisøy) where the transition zone is best developed. After a brief overview of the history of geological research and mining in the area, aspects of sedimentary, metamorphic and magmatic petrology of the Bamble Sector are discussed, including the role of fluids. Issues relevant to current geotectonic models for SW Scandinavia, directly related to the Bamble Sector, are discussed at the end of the review.

1. Introduction

The Bamble Sector is a classic Precambrian high-grade gneissic terrane in a 30 km wide strip along the coast of South Norway (Fig. 1), between the Permian Oslo Rift in the northeast and the city of Kristiansand in the southwest. The central part, including the Arendal region and off shore islands (notably Tromøy and Hisøy), forms a well-developed, continuous transition zone from amphibolite- to granulite-facies metamorphic grade, which has attracted both intense geological interest as well as (past) interest from mining and exploration. It was the first amphibolite- to granulite-facies transition zone in which CO_2-rich fluid inclusions were investigated and their importance in granulite genesis first recognized by Jacques Touret (1970, 1971a, 1972, 1974). CO_2-rich fluid inclusions have since been found in granulites worldwide (e.g. Touret and Huizenga, 2011, 2012; Touret and Nijland, 2012; and references therein). In the same set of studies, (Na, K)Cl brine inclusions are also reported, though the importance of (Na, K)Cl brines as 'the other' granulite-facies fluid was realized only decades later (e.g. Newton et al., 1998). Though apparently regular, the transition zone shows local variations, like 'granulite-facies islands' in the amphibolite-facies zone, which are controlled by fluid and precursor chemistry, local LILE-depletion. The transition zone developed in what was an already high-grade metamorphic terrane. The current paper provides a review of the sedimentary, magmatic and metamorphic petrology of this classic area.

2. Brief history of geological research and exploration

From the 16th century onwards, iron ore mining and smelting in the Bamble Sector became important pre-industrial activities, stimulated by the Danish crown (e.g. Kjerulf and Dahll, 1861, 1866; Vogt, 1908; Christophersen, 1974; Fløystad, 2007; Vevstad, 2008). Around 1800, the iron mines and works attracted early scientists such as the French metallurgist Gabriel Jars (1774) and the Germans Leopold von Buch (1813) and Alfred Hausmann (1812). In his

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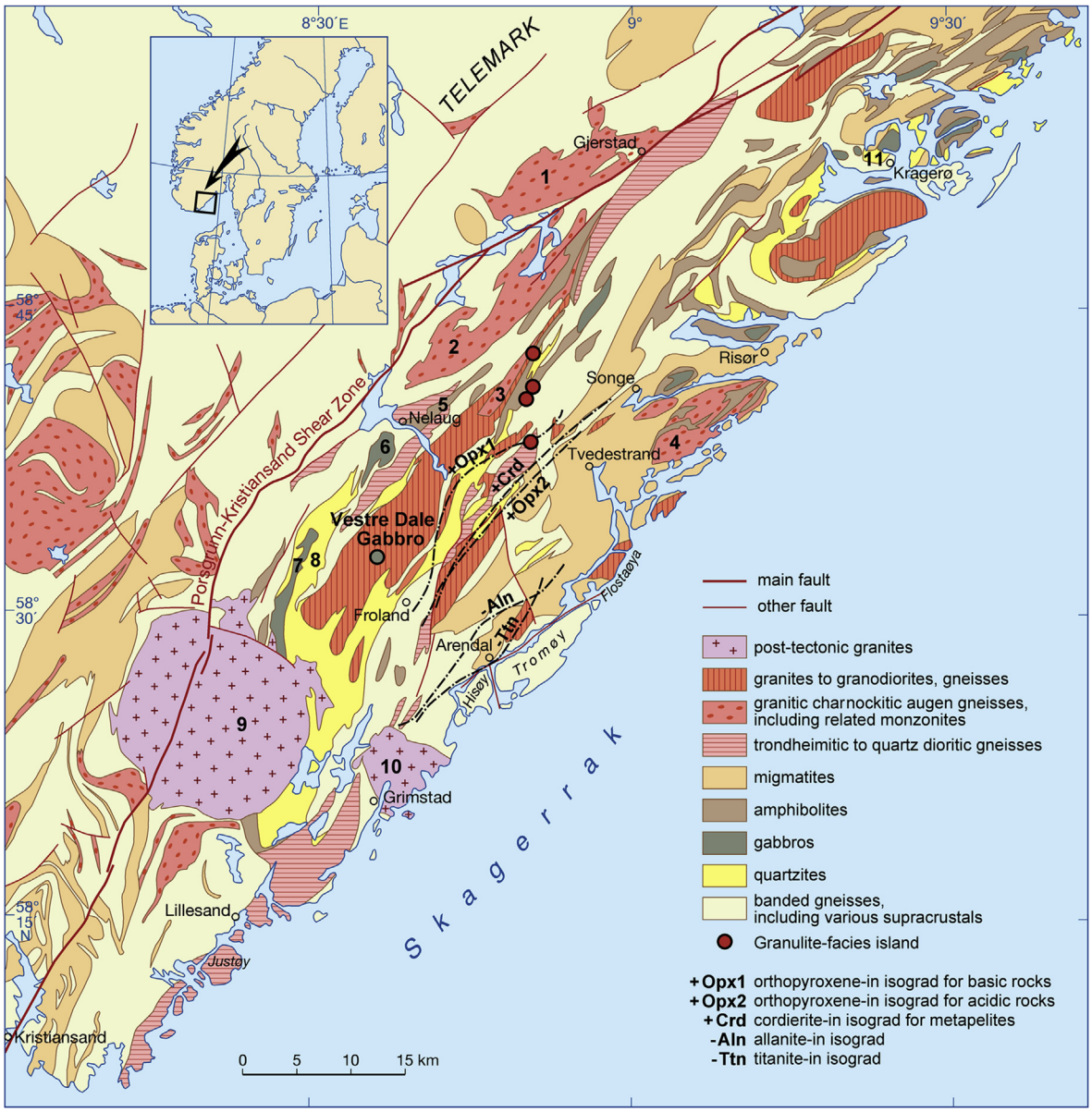

Figure 1. Geological sketch map of the central part of the Bamble Sector, South Norway, with isograds and major intrusions (Modified after Padget and Brecke, 1996; Nijland et al., 1998a). Isograds: +Opx1 – orthopyroxene-in in basic rocks, +Crd – cordierite-in, +Opx2 – orthopyroxene-in in felsic rocks, -All and -Ttn – allanite-out and titanite-out isograds (all lithologies). Lithological units: 1 – Gjerstad augen gneiss and Morkheia monzonite suite, 2 – Hovdefjell-Vegårshei augen gneiss, 3 – Ubergsmoen augen gneiss, 4 – Gjeving augen gneiss, 5 – Vimme amphibolite, 6 – Jomåsknutene gabbro, 7 – Blengsvatn gabbro, 8 – Nidelva quartzite complex, 9 – Herefoss granite, 10 – Grimstad granite, 11 – Coastal quartzite complex.

Journey through Scandinavia in the years 1806 and 1807, Hausmann (1812), remarked about the richness of the ores: '*Occurrences of small size, which would still have been very appreciated in Germany, are not mined in Norway, though these occur everywhere in the surroundings of Arendal.*' The local miners were well aware of the interest in mineral specimens: 'Not long after my arrival, and briefly after that I had told the reason for my journey, was I ran over by miners, who brought minerals from the nearby mines for sale. One would not expect such an industry in a city that far away from any mineral trade. In this extent, one does not find it in Clausthal and Freiberg' (Hausmann, 1812). Both Clausthal and Freiberg were famous German mining towns at that time. Iron mining, concentrated around Arendal and Kragerø, declined in the 2nd half of the 19th century, and was revived during both world wars in the 20th century.

Especially in the 19th century, nickel ore was mined from several mineralized metagabbros throughout the Bamble Sector (Vogt, 1893; A. Bugge, 1922; Jerpseth, 1979; Petersen, 1979; Boyd and Nixon, 1985; Brickwood, 1986). Base metals (Cu, Zn, Pb) were mined on a small scale and for shorter periods, the most important being the Ettedal (also called Espeland) Ag-Pb-Zn deposit (Naik, 1975; Naik et al., 1976; Tørdal, 1990; Petersen et al., 1995). Rutile was mined intermittently over the years, most notably from metasomatized gabbros (Force, 1991; Korneliussen and Furuhaug, 1993; Korneliussen, 1995). Though granulite-facies rocks in the Bamble Sector are depleted in gold (e.g. Cameron, 1989), there are several early reports of the occurrence of gold in the area (Pontoppidan, 1752; Daubrée, 1843), specifically on the island of Hisøy (Bugge, 1934; Johansen, 2007a,b). Amongst the non-metallic ores, apatite was most prominent. Around World War I, several small, short-lived