

Micro-scale element migration during eclogitisation in the Bergen arcs (Norway): A case study on the role of fluids and deformation

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Abstract

Understanding chemical element mobility during high-pressure metamorphism is paramount to the knowledge of the transformations occurring during the course of eclogite-facies metamorphism. In particular, the role of deformation and fluid circulation appear essential. In order to better decipher this role, we investigated two eclogite-facies samples from the Lindås Nappe in the Bergen arcs (Norwegian Caledonides), which are related to a fluid/deformation metamorphic event. This study, based on detailed microtextural investigations, coupled with major and trace element analyses, either in situ EMPA and LA-ICP-MS or by conventional ICP-MS nebulisation on mineral fractions, illustrates the complexity of chemical reactions accompanying the eclogite- and amphibolite-facies metamorphism. A single eclogite-facies mineral species two eclogite-facies (i.e. phengite and epidote) depicts various chemical features depending on its textural location at thin-section scale. The correlation with the mineralogical reaction occurring in each textural site demonstrates that the compositional variations are inherited from the precursor minerals. Thus, the composition of eclogite-facies minerals is locally controlled by the composition of few hundred-micron domains. On the contrary, alteration phases of the amphibolite facies (symplectite and calcic amphibole) display clear enrichment in LILE, Pb, Sr and LREE compared to their precursor minerals (omphacite and garnet). This supports that the transport of elements at hand-sample scale was enhanced during the retrogression and elements were efficiently delocalised from one textural site to another.

The contrasting behaviour of element mobility between peak eclogite-facies metamorphism and retrogression can be explained in terms of rate processes and fluid/deformation activity. During eclogitisation, deformation allows the formation of textural and mineralogical microdomains. Contemporaneously the fluid circulation favours the development of heterogeneities by transport of elements in excess towards areas protected from deformation where phengite-bearing quartz lenses crystallise. This, together with the very fast recrystallisation of eclogite-facies minerals, results in a heterogeneous redistribution of elements at sample scale and in a chemical disequilibrium between different microdomains of hundred-micron size. During retrogression in the amphibolite facies, coeval with long-term ductile deformation, the fluids act as an efficient vector to redistribute the elements from a given textural site to another and, thus, allow to reach, at hand-sample scale, a new chemical equilibrium between the different crystallising phases.

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1. Introduction

Advances in analytical techniques now allow rapid, accurate and precise in situ analyses of trace elements, which are powerful to link element behaviour to petrogenetical processes (e.g. Tribuzio et al., 1996; Bea and Montero, 1999; Rubatto and Hermann, 2003). However some geochemical analyses such as partition coefficient determination or geochronological investigations, still need a larger sampling scale (mineral fractions) because minerals of interest are not rich enough in target elements, and also because isotope radiometric analyses are not easily performed in situ at the present time (i.e. Rb/Sr and Sm/Nd datings). When performing routine mineral-fraction dating or mineral partition coefficient determinations, the validity of the results depends, in particular, on the achievement, at a sample scale, of an isotopic and chemical equilibrium between the different mineralogical phases. Several previous studies have outlined the difficulty to obtain meaningful isotopic data from mineral separates, which is often related to a hand-sample scale chemical disequilibrium (Mørk and Mearns, 1986; Thöni and Jagoutz, 1992, 1993; Cliff et al., 1998; Zheng et al., 2002). The lack of penetrative deformation and intensive fluid circulation are the main reasons commonly put forward to explain such an incomplete re-equilibration process. The importance of synmetamorphic deformation to achieve a complete redistribution of chemical elements at sample scale has been previously discussed by several authors (i.e. for in situ analyses, Messiga et al., 1995; Sassi et al., 2000; Zack et al., 2002). It has been shown that deformation acts as a catalyst for recrystallisation processes thus favouring element redistribution and that fluid circulation enhances element mobility, allowing a better homogenisation of the system (Walter and Wood, 1984; Brodie and Rutter, 1985; Austrheim, 1986; Rubie, 1986; Wayte et al., 1989; Austrheim, 1990; Rubie, 1990; Zhang and Liou, 1997; Straume and Austrheim, 1999; Wain et al., 2001; John and Schenk, 2003).

The present work is focused on the redistribution of chemical elements that took place in eclogites from the Bergen Arcs system (Norway). Previous studies have demonstrated that deformation and fluid circulation are the main factors responsible for the transformation of dry granulites in eclogites during the Caledonian orogeny (e.g. Austrheim, 1986). The objective is two-folds: (1) investigate elements behaviour at thin-section scale to estimate the influence of parameters such as deformation and fluid circulation on element redistribution in the course of HP metamorphism; but also, (2) to test the scale of homogeneity of a single mineral phase in a hand-

specimen sample in view to constrain the chemical characteristics of the mineral fractions used for other investigations such as radiometric dating. Thus, detailed in situ electron microprobe (EMP) major elements analyses and in situ trace elements analyses, by laser-ablation inductively coupled-plasma mass-spectrometry (LA-ICP-MS), were coupled to conventional-ICPMS trace element analyses of mineral fractions. Several mineralogical fractions (up to nine) of a single mineral phase have been separated as a function of grain-size, density and magnetic properties. These fractions are constituted by phengite, further used for Rb/Sr dating and by garnet, used for Sm/Nd geochronology. The different micro textural sites and related mineralogical reactions operating during the eclogite-facies metamorphic event and the subsequent retrogression in the amphibolite-facies have been determined. Precise and extensive analyses of chemical composition (major and trace elements) have been performed on inherited granulite-facies minerals, neoformed eclogite-facies minerals and secondary amphibolite-facies minerals. The scale of chemical element redistribution has been estimated for different textural sites appearing during the eclogite- and amphibolite-facies metamorphic transformations and the role of infiltrating fluid (as a vector for transport of elements at sample scale) has been evaluated. At last, the effects of a deformation synchronous to a metamorphic event have been investigated in relation to element chemical redistribution.

2. Geological setting

The Bergen Arcs System (BAS), in the south-western part of the Norwegian Caledonides, is characterised by a series of Caledonian nappes, thrust onto a Precambrian parautochthonous gneissic complex (Fig. 1). Samples studied in the present work come from one of these thrust sheets, the Lindås Nappe, and were collected on the Holsnøy Island.

The Lindås Nappe extends over an area of more than 1000 km² and mainly consists of a Proterozoic anorthositic complex affected by two distinct metamorphic/deformation events. A first penetrative Grenvillian (Sveconorwegian) metamorphic event took place in the granulite facies (0.8–1.1 GPa, 780–900 °C; Austrheim and Griffin, 1985; Kühn, 2002) at ca. 930 Ma (Bingen et al., 1998, 2001) and a fluid/deformation Caledonian metamorphic event occurred in the eclogite facies (1.8 to 2.1 GPa, ~ 700 °C; Jamtveit et al., 1990) at ca. 425 Ma (Bingen et al., 1998, 2001; Glodny et al., 2002; Kühn, 2002) followed by retrogression in the amphibolite facies (1 to 1.2 GPa, 650–690 °C; Boundy

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