Lithos 232 (2015) 162–173

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Residual water in hydrous minerals as a kinetic factor for omphacite destabilization into symplectite in the eclogites of Vårdalsneset (WGR, Norway)

Céline Martin *, Stéphanie Duchêne [1]

CRPG, Nancy-Université, CNRS, 15 rue Notre Dame des Pauvres, 54501 Vandoeuvre les Nancy, France

ARTICLE INFO

Article history:
Received 24 May 2014
Accepted 26 June 2015
Available online 17 July 2015

Keywords:
Symplectite
Eclogite dehydration
Western Gneiss Region
Metamorphic fluids
Metamorphic reaction kinetics

ABSTRACT

Symplectitic intergrowths of sodic plagioclase + diopside ± amphibole as replacement of omphacite are commonly found in eclogites. These symplectites are interpreted as the exhumation-related decompression of eclogite into the amphibolite facies. The role of aqueous fluid in symplectite development, which would act as a catalyst and favor open-system reaction, has been suggested but not yet clearly established. In the Vårdalsneset outcrop of the Western Gneiss Region (Norway), eclogites that were not amphibolitized either display a primary eclogitic dry paragenesis (garnet + omphacite + rutile ± quartz) or a paragenesis including phengite. In the last case, omphacite is partly transformed into symplectite. The two groups have been further distinguished from a combined petrological, geochemical, and thermochemical study. *Group I* samples have a fine-grained unaltered microstructure, with medium Al_2O_3 (14–16 wt.%), high Fe_2O_3 (13–16 wt.%) and TiO_2 (1.4–2.4 wt.%). *Group II* samples have a coarse-grained microstructure and are characterized by the presence of symplectites and phengite. They display higher Al_2O_3 (17.5–23 wt.%) and lower Fe_2O_3 (5.5–8 wt.%) and TIO_2 (0.2–0.5 wt.%) contents than *Group I*. The *P–T* estimates for samples from both *Groups I* and *II* lead to similar conditions for peak eclogite metamorphism: temperatures range from 590 to 720 °C and pressures from 15 to 25 kbar. Perple_X modeling indicates that for *Group I* eclogites, temperature range is similar to the temperature range of the water saturation curve, whereas for *Group II* eclogites, due to slightly different chemical composition, the water saturation curve is located at much higher temperatures (770–900 °C), so that OH^- remains in residual phengite at peak eclogite temperature. With no residual hydrous phase in the eclogite assemblage, and although some structural water may persist in nominally anhydrous minerals, *Group I* eclogites were preserved without change during exhumation. In contrast, *Group II* eclogites retain hydrous minerals, and this hydrous component is available as a kinetic factor for symplectite formation during exhumation. This suggests that symplectite development can be promoted by an internally derived hydrous component, signaled by the presence of a hydrous mineral, and, so, does not necessarily require an influx of external fluid.

1. Introduction

During subduction, aqueous fluids are released from the slab when it dehydrates during prograde metamorphism (e.g., Andersen et al., 1994; Engvik and Andersen, 2000; Philippot and Selverstone, 1991; Rubatto and Hermann, 2002; Scambelluri et al., 1997), and may be re-incorporated via re-hydration reactions during retrograde metamorphism (Austrheim, 1987; Austrheim, 1989; Glodny et al., 2008; Jamveit et al., 1990; Kuhn et al., 2002). The progressive release of aqueous fluid by the breakdown of hydrous mineral phases during the descent of the subducting oceanic slab is relatively well constrained (e.g., Kastner et al., 1991; McCulloch and Gamble, 1990; Scambelluri et al., 1997; Schmidt and Poli, 1998; Spandler et al., 2003). The budget of water in the case of a subducting continent is less studied, but isotopic studies of UHP rocks from Dabie–Sulu suggest that aqueous components are transported at depth in the form of hydrous minerals, in fluid inclusions trapped inside UHP minerals, or in nominally anhydrous minerals, NAM (Zheng et al., 2003). In that case, the fluids responsible for retrogression are internally-derived (Zheng et al., 2003). Some hydrous minerals, like lawsonite or phengite, are stable at great depth, and would preserve OH-component within the rocks down to ~70–90 km depth (Bebout et al., 2013; Castelli et al., 1998). Additionally, the persistence of some aqueous component in high-pressure metamorphic rocks is demonstrated by hydrous minerals and fluid inclusions in eclogite-forming minerals (Philippot and Selverstone, 1991; Scambelluri and Philippot, 2000) as well as veins in eclogite facies (e.g., John et al., 2008; Rubatto and Hermann, 2002).

* Corresponding author. Present address: Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024-5192, USA.
E-mail address: cmartin@amnh.org (C. Martin).
[1] Present address: GET, CNRS, UPS Toulouse 3 — IRD, 14 rue Edouard Belin, 31400 Toulouse, France.

http://dx.doi.org/10.1016/j.lithos.2015.06.021
0024-4937/

The symplectites are assumed to be the product of an early stage of decompression-related to retrogression (Joanny et al., 1991). They are due to the destabilization of the jadeite component of the omphacitic pyroxene and consist of calcic clinopyroxene and sodic plagioclase intergrowths (e.g., Eskola, 1921; Griffin and Raheim, 1973; Joanny et al., 1991; Lardeaux et al., 2001; O'Brien and Rötzler, 2003), sometimes with amphibole (Anderson and Moecher, 2007; Elvevold and Gilotti, 2000; Vallis and Scambelluri, 1996). The possible role of fluid in the development of symplectites is still a conundrum. Some studies conclude that decompression alone is responsible for the reaction (Elvevold and Gilotti, 2000; Lardeaux et al., 2001), whereas others suggest that aqueous fluid may have had a significant impact on the symplectitization process. Aqueous fluid may only have a kinetic role, by facilitating cation diffusion (Joanny et al., 1991), or, in the case of non-isochemical symplectites, an influx of fluid from surrounding host-rock could introduce some additional chemical elements (Heinrich, 1982; Yang, 2004). Vallis and Scambelluri (1996) observed fluid inclusions in precursor omphacite crystals and assumed that this fluid contributed to the formation of amphiboles in symplectites. Anderson and Moecher (2007) suggested that hydroxyl can be stored in the M2 vacancies of Ca-Eskola component in precursor omphacite and be released to crystallize amphibole within symplectites.

In the present paper, we investigate why several eclogitic samples from a single outcrop either display symplectites, implying omphacite breakdown, or remain unaltered, showing no destabilization of omphacite. The chosen outcrop is Vårdalsneset, in the high-pressure area of the Western Gneiss Region (WGR) of Norway. The unaltered eclogites are cut by calcite and quartz veinlets, whereas the symplectitized ones do not show any veins, veinlets, or shear-zones. We performed a detailed petrologic and whole-rock chemical study of six eclogite samples from Vårdalsneset and calculated peak *P* and *T*. A previous study showed that for metabasites, heating to the P–T conditions of the water saturation curve (i.e. the curve that separates the P–T conditions where water is an actual phase from the P–T conditions where water is only included within hydrous minerals) triggers complete dehydration (Martin et al., 2010). At *T* above the water saturation curve, water will be present as a free phase but it will likely have escaped from the exhumed rock (e.g., Thompson, 1983). The resulting phase assemblage is anhydrous (the abundance of fluid inclusions in Vårdalsneset samples being negligible). The water saturation curve of each sample was therefore modeled with Perple_X software. Thermodynamic modeling indicates that at a given pressure, the water saturation temperature of eclogites depends highly on protolith chemical composition, even though all the samples are metabasites. Thus, symplectitization occurred only for the samples that did not reach the water saturation curve, that is, they were not completely dehydrated. The little hydrous component remaining in minerals (mica, epidote) after peak eclogite-facies metamorphism enabled symplectitization, whereas, for those samples that had been dehydrated (i.e., reached or surpassed the water saturation curve) during prograde metamorphism, no hydrous component remained to produce symplectite.

2. Geological background

The Western Gneiss Region (WGR) is part of the Caledonian Orogen, which resulted from the collision between Baltica and Laurentia during the Silurian and early Devonian, ca 435–385 Ma ago (Roberts and Gee, 1985). The WGR mainly consists of Precambrian basement and Lower Paleozoic rocks called the Autochthon/Parautochthon Nappe. The westernmost part of the WGR includes metamorphosed sedimentary rocks, Precambrian crystalline metamorphic rocks, and gabbros. A major detachment called the Nordfjord–Sognford Detachment Zone (NSDZ) is located at the boundary between the WGR and Allochthon nappes (Bryhni and Sturt, 1985; Gorbatschev, 1985). Caledonian eclogites occur within the crystalline basement as lenses or pods of cm to km size (e.g. Engvik and Andersen, 2000; Engvik et al., 2001; Eskola, 1921; Foreman et al., 2005; Milnes et al., 1997; Walsh and Hacker, 2004). Eclogites in the southern part of the WGR have been affected by high-pressure (HP) metamorphism (e.g., in Sognefjord and Dalsfjord; Smith, 1984; Walsh and Hacker, 2004), in contrast to the ultrahigh-pressure (UHP) areas along the coast (e.g. Labrousse et al., 2004; Wain, 1997; Walsh and Hacker, 2004).

The Vårdalsneset outcrop, in the Dalsfjord area (Fig. 1a), is a typical area of the southern part of the WGR, where meter-sized mafic eclogite and amphibolite bodies are embedded within amphibolite-facies gneissic host-rocks derived from granodioritic or granitic protoliths (Engvik and Andersen, 2000; Engvik et al., 2001; Foreman et al., 2005). The Vårdalsneset eclogite body is exceptionally well preserved, although it is located in the footwall of the NSDZ (Fig. 1b). The outcrop is a ~400 m-long massive mafic body of fresh eclogite, locally retrogressed into amphibolite along shear-zones (Engvik and Andersen, 2000). This outcrop was studied on a structural basis, and a petrologic study with calculation of P–T conditions was performed. Engvik and Andersen (2000) distinguished two types of eclogite, tectonic and mylonitic, using structural arguments. Tectonic eclogite occurs as lenses or veins of coarse-grained eclogite consisting of garnet, omphacite, amphibole, mica, epidote, quartz, kyanite, rutile as well as numerous accessory phases. Mylonitic eclogite, which cuts across the preexisting tectonic eclogite, is fine-grained and mainly consists of omphacite and garnet. Metamorphic conditions were determined with empirical thermo-barometers and yielded $T = 677 \pm 21$ °C and $P = 16 \pm 2$ kbar for the tectonic eclogite and $T = 691 \pm 20$ °C, $P = 15 \pm 1.5$ kbar for the mylonitic eclogite (Engvik and Andersen, 2000). Amphibole inclusions in garnet from eclogitic samples point to a prograde amphibolite-facies stage whose temperature was estimated to be 490 ± 63 °C, on the basis of a garnet-hornblende geothermometer (Graham and Powell, 1984). A THERMOCALC calculation yielded $T = 615 \pm 22$ °C and $P = 22.7$ kbar for the eclogite facies (Labrousse et al., 2004).

3. Analytical techniques

Major- and trace-element analyses on pulverized whole-rocks were obtained by ICP–AES and quadrupole ICP–MS respectively (SARM — Service d'Analyse des Roches et des Minéraux, CRPG—CNRS). Major element analyses of eclogitic minerals were performed with a Cameca-SX100 electron microprobe (Service commun de microscopies électroniques et microanalyses X, UHP, Nancy) with an acceleration voltage of 15 kV, a beam current of 10 nA and a counting time of 20 s except for Na (10 s). Analytical standards were well-characterized natural minerals including diopside (Si, Mg, Ca), albite (Na), orthoclase (K, Al), rutile (Ti), garnet (Fe), rhodonite (Mn), and apatite (P).

4. Petrological description

Two different eclogitic lithologies could be distinguished in the Vårdalsneset outcrop on the basis of petrographic characteristics (Fig. 1b). *Group I* represents what Engvik and Andersen (2000) identified as mylonitic eclogite, defined as fine-grained eclogite dominated by garnet and omphacite, with amphibole, mica, rutile and quartz as accessory phases. Our samples consist of fine-grained dark eclogites, displaying an anhydrous phase assemblage (garnet, omphacite and rutile, ±quartz), and the samples are sometimes cut by quartz veins (up to a few cm in size) (Fig. 1c). *Group II* represents what Engvik and Andersen (2000) described as tectonic eclogite, defined as coarse-grained amphibole-, mica-, kyanite-bearing eclogite. Our samples consist of coarse-grained, light green massive eclogites, displaying millimetric garnets, omphacite, phengite, and epidote (Fig. 1d). No veins were observed in *Group II* samples from the outcrop.