



Low stress deformation of garnet by incongruent dissolution precipitation creep

Sara Wassmann*, Bernhard Stöckhert

Institut für Geologie, Mineralogie und Geophysik, Sonderforschungsbereich 526, Ruhr-Universität Bochum, D-44801 Bochum, Germany

ARTICLE INFO

Article history:

Received 9 January 2012

Received in revised form

9 August 2012

Accepted 3 September 2012

Available online 25 September 2012

Keywords:

Garnet

Dissolution

Creep

Styrolite

Low stress

Subduction

ABSTRACT

Microstructures indicating incongruent dissolution precipitation creep of garnet in eclogite-facies graphitic micaschist (Tauern window, Eastern Alps) are investigated. Garnet dissolution is observed where garnet poikiloblasts grown at eclogite facies metamorphism approached each other as a consequence of progressive deformation during exhumation, with estimated P-T-conditions between 570 °C, 1.7 GPa and 470 °C, 0.9 GPa. The poikiloblasts are separated by a dissolution seam and flanked by strain shadows filled with quartz, white mica, and chlorite; there is no evidence for crystal plastic deformation of garnet. Two cases are investigated: (A) stylolitic contact zone, (B) smooth contact zone. In both cases, internal fabrics of the poikiloblasts and concentric chemical zoning are truncated. Material previously forming inclusions in the garnet poikiloblasts is now passively enriched in a dissolution seam, the original microstructure of fine-grained mica–graphite aggregates remaining preserved. Though microstructures suggest that garnet dissolution was driven by local stress concentration, the level of differential stress remained too low for plastic deformation of the fine-grained white mica–graphite aggregates set free from the stress supporting garnet. Incongruent dissolution precipitation creep appears to be a particularly effective deformation mechanism at low stress in a subduction channel.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

The idea of “pressure solution” dates back to the pioneering study of Sorby (1863) who conducted experiments on the solubility of salt under pressure and proposed that solution by chemical action is the result of mechanical force. The term pressure solution became established, although the process may be driven by inhomogeneity in the stress field rather than by gradients in non-deviatoric pressure (Durney, 1972; Bjørkum, 1996; Lohkämper et al., 2003). Notwithstanding the ambiguity with respect to driving force, pressure solution is widely used to describe dissolution of minerals during rock deformation.

Evidence of pressure solution is obvious in many quartz- and carbonate bearing sediments and considered to be an important mechanism of compaction under diagenetic conditions (e.g. Durney, 1972; Elliott, 1973; Cox and Etheridge, 1983). Also for rocks deformed at deeper crustal level, at metamorphic conditions, evidence of deformation by dissolution and precipitation processes is widely recognized (e.g. Rutter, 1983; Stöckhert et al., 1999; Mauler et al., 2001; Wintsch and Yi, 2002; Auzende et al., 2006;

Menegon et al., 2008; Trepmann and Stöckhert, 2009; Wassmann et al., 2011; Wassmann and Stöckhert, 2012).

In rheological models, for a closed system of arbitrary size, the term dissolution precipitation creep (DPC) is preferred (e.g. Raj and Chyung, 1981; Evans and Kohlstedt, 1995; Bons and den Brok, 2000; Wintsch and Yi, 2002; Menegon et al., 2008). DPC comprises the entire chain of processes, i.e. dissolution of crystalline matter in a source region of locally enhanced stress, transport of dissolved matter in an aqueous fluid phase, and precipitation in sinks (Paterson, 1995). DPC has been treated as analogous to Coble creep (e.g. Poirier, 1985), but with transport through an interstitial fluid phase and feasible at low temperatures (Rutter, 1976, 1983; Mc Clay, 1977; Robin, 1978; Raj, 1982; Lehner and Bataille, 1984/1985; Knipe, 1989; Tada and Siever, 1989). Hence, flow laws for DPC compare to those established for Coble creep (Poirier, 1985), though the rate controlling step may be different (Evans and Kohlstedt, 1995; Paterson, 1995). For Coble creep, understood to occur in a single phase solid material at high temperature, the rate is controlled by diffusion along dry grain boundaries, which is reflected by high grain size sensitivity of strain rate ($\dot{\epsilon} \propto 1/d^3$, with d denoting grain size; Coble, 1963). For DPC, strain rate is expected to be controlled not only by grain size, but also affected by fine-scale structure of interfaces, transport properties of the fluid along stressed interfaces, porosity, fluid pathway geometry, and rate of precipitation at free interfaces (Paterson, 1995). Along grain or interface

* Corresponding author.

E-mail addresses: sara.wassmann@rub.de (S. Wassmann), bernhard.stoekchert@rub.de (B. Stöckhert).

boundaries, where dissolution takes place, fluids may be present either as a continuous film (Rutter, 1983; Hickman and Evans, 1991) or in form of an island-and-channel structure (Raj, 1982; Urai et al., 1986; Lehner, 1990, 1995; Spiers and Schutjens, 1990; Spiers et al., 2004; Van Noort and Spiers, 2009). In the latter case, interconnected channels with a free fluid phase surround isolated load bearing islands of crystalline material. This fine-scale structure along interfaces controls the transport properties, and thus possibly the rate controlling step. Experimental results obtained by Raj and Chyung (1981), De Meer and Spiers (1999), van Noort and Spiers (2009) and van Noort et al. (2008a, 2008b, 2011) do not support diffusion of matter as the rate limiting process, but instead favor processes at the interface, hence dissolution or precipitation. In case of interface control, grain size sensitivity of DPC is weaker than for Coble creep, strain rate becoming inversely proportional to grain size ($\dot{\epsilon} \propto 1/d$ instead of $\dot{\epsilon} \propto 1/d^3$ derived for transport controlled Coble creep; Evans and Kohlstedt, 1995; Paterson, 1995).

Laboratory experiments addressing DPC under geologically relevant conditions remain difficult, as the process cannot be significantly speeded up by increasing the temperature. The process is rather insensitive to temperature, reflected by low activation energy (Rutter, 1983; Dewers and Hajash, 1995). Moreover, in any experiment, elevated temperatures would not simply speed up the process, but would probably affect phase assemblage, properties of the interfaces, and microstructure. This effect is expected to be severe, precluding laboratory experiments with results that might be transferred to natural conditions. As such, analysis and interpretation of microstructures in rocks play a special role for the understanding of DPC, providing the base for the design of theoretical and experimental studies, but without becoming obsolete by the latter.

Most theoretical studies and laboratory experiments on DPC address the behavior of single phase solid material in presence of an aqueous solution (e.g. Urai et al., 1986; Hickman and Evans, 1991, 1995; Schutjens, 1991; Schutjens and Spiers, 1999; van Noort et al., 2007; Gratier et al., 2009), although rocks do generally not provide evidence for DPC in strictly monomineralic materials. Experimental results obtained by Raj and Chyung (1981), Gratier and Guiguet (1986), Hickman and Evans (1991, 1995), Bos and Spiers (2001), Renard et al. (2001), Spiers et al. (2004), Meyer et al. (2006), and van Noort et al. (2008b, 2011) indicate that dissolution can be strongly enhanced along interphase boundaries between different solids. This observation is considered in theoretical models (Dewers and Ortoleva, 1990; Wheeler, 1992; Kruzhanov and Stöckhert, 1998) and matches the microstructural record observed in natural examples, which suggest DPC to be effective in polyphase material (e.g. Groshong, 1988; Knipe, 1989; Tada and Siever, 1989; Schwarz and Stöckhert, 1996; Stöckhert, 2002; Trepmann and Stöckhert, 2009; Wassmann et al., 2011), but not so in rocks essentially composed of a single mineral. If so, neither transport in the interconnected pore fluid nor precipitation at free mineral–fluid interfaces should be the rate controlling step, but dissolution along the loaded interface or transport out of it. Efforts to observe dissolution along stressed grain or interphase boundaries in situ with high resolution techniques were undertaken by Van Noort et al. (2011).

An appealing explanation for the special role of interphase boundaries as effective sites of dissolution is provided by Greene et al. (2009). Their experiments show that the enhanced dissolution rate along interphase boundaries is correlated with differences in electrochemical potential. In their low pressure ($P = 0.2$ – 0.3 MPa), low temperature ($T = 25$ °C) experiments, no convergence was observed when single crystals of the same phase, i.e. quartz–quartz or mica–mica, were pressed together in an aqueous electrolyte (CaCl_2) solution, and neither so in dry

experiments. In contrast, convergence by dissolution of quartz took place along an interphase boundary with mica in an aqueous solution under otherwise identical conditions, precluding a purely mechanical effect. In quartz–mica experiments, when dissolution occurred, a voltage potential difference between the surfaces of the unlike mineral phases could be measured. This suggests that dissolution may be controlled by electrochemical processes at the interphase boundary. If so, the effect would be catalytic and inexhaustible. Dissolution would continue as long as an interface between both phases exists. Such a process would very well explain observations in natural rocks (e.g. Groshong, 1988; Knipe, 1989; Tada and Siever, 1989; Schwarz and Stöckhert, 1996; Stöckhert, 2002; Trepmann and Stöckhert, 2009; Wassmann et al., 2011). It would also comply with the experimental results of van Noort and Spiers (2008a,b) and van Noort et al. (2008a,b), indicating interface control. Moreover, if dissolution is controlled by electrostatic effects, high local stresses would not be prerequisite for the dissolution process and only need to be sufficient to drive convergence.

Here, we provide an example of DPC affecting garnet in a high pressure metamorphic micaschist sample taken from the Eclogite Zone of the Tauern Window, Eastern Alps. The regional context and kinematics of exhumation being discussed by Miller (1974), England and Holland (1979), Behrmann and Ratschbacher (1989), Ratschbacher et al. (1990), Zimmermann et al. (1994), Kurz et al. (1998a,b), and Glodny et al. (2005), the purpose of the present study is twofold. First, we take the observation of truncated microstructural features and compositional zoning in large poikiloblastic garnet, including stylolites (to our knowledge not described elsewhere), to support the feasibility of pressure solution in garnet. Pressure solution in garnet was previously proposed in studies by Bell and Rubenach (1983), Hara et al. (1984), Bell et al. (1986), Duebendorfer and Frost (1988), Álvarez-Valero et al. (2005), and Smit et al. (2011), for cases where garnet crystals were found to appear flattened without crystal plastic deformation or exhibit a truncated chemical zoning. Second, we explore the correlation between thickness of the stylolitic dissolution seam with the amount of dissolved garnet predicted from geometrical relations. Finally, we address possible concerns concerning the role of local stresses, driving force for dissolution, implications for transport, and the peculiar role of interphase boundaries.

2. Geological setting

The investigated garnet–micaschist sample was taken in the Eclogite Zone (Miller, 1974; Zimmermann et al., 1994; Kurz et al., 1998a,b, 2008; Frey et al., 1999; Hoeschek, 2001, 2010; Gleissner et al., 2007) of the Tauern Window, Eastern Alps (Fig. 1). There, the Penninic units derived from subducted ocean and trailing European passive continental margin are exposed, framed by the Austroalpine nappes derived from continental crust of the over-riding Apulian microplate (Oxburgh, 1968; Coward and Dietrich, 1989; Schmid et al., 2004). The classical subdivision of the Penninic units in the Tauern Window distinguishes the Zentralgneis (central gneiss) unit in the center of the Tauern Window, mainly composed of Hercynian granitoids, the lower Schieferhülle (schist envelope), mainly composed of up to medium grade metasedimentary cover of the European passive margin, and the upper Schieferhülle, which is entirely made up of greenschist facies metasedimentary and metabasic rocks including serpentinites derived from the subducted ocean, which separated Europe from Apulia from the Jurassic to the Cretaceous (Frisch, 1974, 1975; Tollmann, 1975; Frank et al., 1987; Kurz et al., 1996).

In the Tauern window, high pressure (HP) metamorphic rocks are confined to the Eclogite Zone, which is exposed in the central part of the Tauern Window (Fig. 1), sandwiched between the lower

Download English Version:

<https://daneshyari.com/en/article/6445048>

Download Persian Version:

<https://daneshyari.com/article/6445048>

[Daneshyari.com](https://daneshyari.com)