Lithos 118 (2010) 255–268

Contents lists available at ScienceDirect

Lithos

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

Fluid inclusions in quartz related to subsequent stages of foliation development during a single metamorphic cycle (Schneeberg Fault Zone, Eastern Alps, Austria)

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ARTICLE INFO

Article history:
Received 27 November 2009
Accepted 8 May 2010
Available online 20 June 2010

Keywords:
Eastern Alps
Schneeberg Fault Zone
Differential stress
Quartz rheology
Fluid inclusions

ABSTRACT

Macro- and micro-scale structures, fluid inclusions, quartz rheology and host mineral chemistry were used to establish the *P–T–d* evolutionary path of monometamorphic metapelites of the Schneeberg Fault Zone. Four selected quartz generations indicate formation conditions during stages of prograde and retrograde metamorphism. Earliest foliation development S1 is outlined by quartz foam microstructures that are armored within foliation-parallel garnet layers which reflect individual growth characteristics during the prograde and early retrograde stage. The prograde path is linked with garnet growth at low differential stress up to peak pressure conditions of ca. 10 kbar. Final garnet growth during increasing temperatures and WNW-directed shearing up to ≤600 °C predates exhumation along an isothermal decompressional path and increasing differential stress. Exhumation was accompanied by the formation of younger quartz generations and the formation of a second foliation S2 that was incorporated into intense folding. Minimum pressure condition for S2 is about 4.5 kbar resulting from the gradient of fluid inclusion density isochores estimated from S2-related pressure shadows in combination with the temperature range for dislocation creep in quartz aggregates between 500 and 600 °C. The dominance of carbonic fluid inclusions indicates decarbonation associated with H_2O leakage as a main process during Alpine monometamorphism in the metasedimentary host rocks. Aqueous fluid inclusions are arranged along late fluid planes and reflect a wide range in densities with variable salinities.

This study corroborates the successful approach of combining mineral growth, fluid inclusions and macro- to micro-scale deformation stages to constrain a prograde to retrograde growth history of metamorphic minerals like garnet and quartz even though these underwent polyphase deformation and upper amphibolite facies metamorphism. It supports previous arguments about low differential stress at high-pressure conditions and allows speculations about the location of the metasediments of the Schneeberg Fault Zone nearby the low strength plate interface during late stage of Cretaceous subduction and subsequent early exhumation.

1. Introduction

Macro- and micro-scale deformation stages combined with the textural varieties of fluid inclusions and their calculated densities provide important constraints on the history of rocks during pro- and retrograde metamorphism. The slope of fluid inclusion density isochores plotted in a *P–T* field, varies between steep and more shallow for aqueous and carbonic inclusions, respectively, and can therefore be used for geothermobarometry when combined with additional temperature or pressure constraints (e.g. Boullier et al., 1991; Vityk and Bodnar, 1995a; Selverstone et al., 1995; Boullier et al., 1997; Fu et al., 2001, 2003; Krenn et al., 2008). Fluid inclusion generations have to be clearly distinguished by their chronology of entrapment (e.g. Van den Kerkhof and Hein, 2001). Preservation of fluid inclusions within the host minerals is a function of mineral strength, differential stress and of the deviation of the exhumation path from the isochores, like changing pressures, temperatures or fluid concentrations. The survival of primary fluid inclusions during burial and/or uplift accompanied with polyphase deformation depends strongly on composition and size (e.g. Boullier et al. 1991; Vityk and Bodnar, 1995a,b; Crispini and Frezzotti, 1998). Experiments and studies on natural fluid inclusions have shown that under conditions of internal overpressure large inclusions decrepitate at lower effective pressure than smaller inclusions (e.g. Wanamaker et al., 1990; Hurai and Horn, 1992; Vityk and Bodnar, 1995a,b). The behaviour of fluid inclusions along a *P–T* path is best known for quartz, where decrepitation textures may give important information for the exhumation style (e.g. Leroy, 1979; Vityk and Bodnar, 1995b). In general, during regional metamorphism exhumation often took place along nearly isothermal decompression and earlier fluid inclusions tend to decrepitate and form characteristic decrepitation textures (e.g. Vityk and Bodnar, 1995b; Boullier, 1999). Additionally, plastic

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0024-4937/$ – see front matter
doi:10.1016/j.lithos.2010.05.004

deformation and strain-dependent internal overpressure or underpressure within fluid inclusions lead to nucleation of dislocations and planar defects in the host minerals that allow leakage and hence changes in density and composition (e.g. preferential loss of H_2O from H_2O–CO_2-rich fluid inclusions; Bakker and Jansen, 1991, 1994).

For tracing the early evolution along a pressure–temperature–deformation (*P*–*T*–*d*) path, fluid inclusions should be taken from host minerals which are certainly related to the earliest stages of mineral growth and deformation events. This would be best by using foam microstructures of quartz with almost plane grain boundaries, which indicate very low magnitudes of differential stress for the stages of maximum burial and earliest exhumation (Stöckhert et al., 1997). The foam structures of quartz can be preserved by overgrowth of high-strength minerals like garnets that act as a container for fluid inclusions.

For the continuing evolution of the rocks, quartz generations, which were not enclosed by high-strength minerals, undergo subsequent deformation imprints like dislocation creep at increasing differential stress. In those cases fluid inclusions were affected by reequilibration, leakage and decrepitation processes. The isochores of these modified inclusions, which adapted to new conditions, are helpful to reconstruct the style of the retrograde *P*–*T* path. In addition, the occurrence of fluid inclusion planes and their orientations, which are always parallel to the direction of maximum shortening, plays an important role to identify the regional stress field that affected the host mineral or host rocks during deformation and foliation development. Different types of fluid inclusion planes can be distinguished by their structural relations and related different increments during a changing stress field (e.g. Lespinasse and Pechêr, 1986; Lespinasse, 1999; Wawrzyniec and Selverstone, 2001; Krenn et al., 2008).

This paper deals with a study of different generations of deformed quartz aggregates from the Schneeberg Fault Zone (Fig. 1), a metasedimentary rock sequence that was affected by several shearing and folding stages during a single regional metamorphic cycle. All mineral growth stages as well as deformation and fluid precipitation stages are related to one event of subduction and subsequent exhumation. To establish a *P*–*T*–*d* path for these metasediments, the fluid inclusion types from the different quartz generations are linked with the host rock chemistry and distinct stages of foliation development.

2. Geological setting

The area west of the Tauern Window is part of the Austroalpine Nappes and comprises the Upper Austroalpine basement nappes in the sense of Schmid et al. (2004) (Fig. 1). The rocks of the Upper Austroalpine basement nappes underwent a polymetamorphic (pre-Variscan, Variscan, Permian and Alpine) imprint. Variscan and pre-Variscan events are best preserved in the Ötztal Complex (ÖC) (Bernhard et al., 1996; Tropper and Hoinkes, 1996; Hoinkes et al., 1997; Kaindl et al., 1999) (zone of Variscan cooling ages in Fig. 1) and Alpine overprint increases toward the SE to upper amphibolite grade with relics of Alpine eclogites (Hoinkes, 1981; Thöni, 1981; Purtscheller and Rammlmair, 1982; Hoinkes, 1986) (Fig. 1). The parautochthonous low- to medium grade deformed and metamorphosed Mesozoic cover of the Upper Austroalpine basement nappes overlies the ÖC and defines the Brenner Mesozoic (BM) with a stratigraphic record from Permo-Triassic up to the Norian Hauptdolomit. The Paleozoic Steinach nappe represents a part of the Drauzug-Gurktal nappe system that occurs mainly in areas east of the Tauern Window (Fig. 1). East-directed extension at the transition between the BM and its underlying ÖC resulted into high exhumation rates for the ÖC in a time and temperature range between 90 Ma at ca. 450 °C and 60 Ma at <100 °C, (Fügenschuh et al., 2000).

The Schneeberg Fault Zone (Schneeberg Zug after Schmidegg, 1933; Helbig and Schmidt, 1978; Schneeberg Complex after Hoinkes, 1986; Schneeberg Normal Fault after Sölva et al., 2005) is part of the Upper Austroalpine basement nappes and represents a metasedimentary sequence of unknown origin. It was deformed and metamorphosed during the Alpine orogeny in the Cretaceous and is characterized by km-scale synform structures located between the ÖC in the north and the Texel Complex (TC) in the south (Helbig and

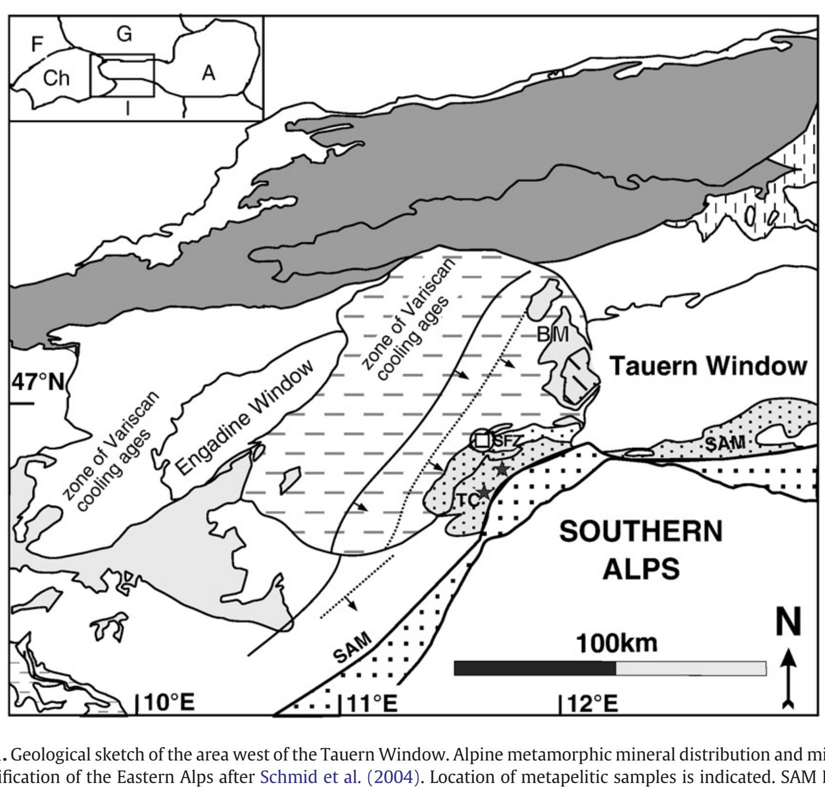

Fig. 1. Geological sketch of the area west of the Tauern Window. Alpine metamorphic mineral distribution and mineral cooling ages after Thöni (1981) and Frank et al. (1987). Nappe classification of the Eastern Alps after Schmid et al. (2004). Location of metapelitic samples is indicated. SAM Line (Southern Limit of Alpine Metamorphism) after Hoinkes et al. (1999).