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Tourmaline as a petrogenetic indicator in the Pfitsch Formation, Western Tauern Window, Eastern Alps

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ABSTRACT

Tourmaline is a common accessory mineral in the metasedimentary Pfitsch Formation located in the Pfitscher Joch (Passo de Vizze) area in the Tauern Window of the Eastern Alps. These post-Variscan metasedimentary units experienced peak metamorphic conditions of ~550 °C, 1.0 GPa during the Alpine orogeny. Tourmaline is most abundant in a ~25 m thick unit of feldspathic gneiss (~20–200 μg/g B), where it occurs as idiomorphic crystals typically 10 mm in length. The abundance and size of the tourmaline crystals increase near coarse-grained quartzofeldspathic segregations (~1200 μg/g B), reflecting the mobilization and concentration of B by metamorphic fluids. Near segregations, individual tourmaline crystals have up to three growth zones, recording pro- (~350–500 °C, 0.7–1.0 GPa) and retrograde (~400 °C, 0.2 GPa) growth as determined by combining textural information and sector-zoning thermometry. Retrograde tourmaline occurs as individual crystals as well as overgrowths on prograde tourmaline crystals, especially on the surface of extensional fractures formed by E–W extension during regional decompression.

Tourmaline in the Pfitsch Formation is dravitic with a variable Fe content that correlates with the Fe content of its respective host unit. Charge balance calculations suggest that a significant proportion of Fe in tourmaline is ferric, supporting the interpretation of a subaerial continental sedimentary protolith. Tourmaline near segregations has the highest inferred ferric iron content, which decreases across growth zones, potentially reflecting a reduction of the fluid during metamorphism. The Mg/(Mg + Fe) ratio increases with prograde tourmaline growth and decreases in retrograde overgrowths. In contrast, the Ca/(Ca + Na) ratio increases gradually from 0.05 to 0.20 with prograde growth and continues to increase up to 0.25 in the retrograde overgrowths, recording the maximum Ca/(Ca + Na) ratio of the fluid during Alpine metamorphism.

The metasediments of the Pfitsch Formation have very low and variable whole-rock $\delta^{11}B$ values (−14.1 to −33.6‰), with the highest values (−17.7 to −14.1‰) found in B-rich samples (165–1200 μg/g B) containing abundant tourmaline, and the lowest values (−24.2 to −33.6‰) in B-depleted samples (21–40 μg/g), which lack tourmaline. This observation supports preferential loss of ^{11}B from the rocks during prograde metamorphism. Zoned tourmaline crystals in the Pfitsch formation show successively decreasing B isotope ratios from −7.8 to −11.2‰ in their cores and −17.3 to −20.3‰ in their rims. As supported by a Rayleigh fractionation model, the B-isotope values of the host rocks and the tourmaline crystals are most easily explained by the internal redistribution of B from a B-rich precursor mineral (e.g. mica) to the tourmaline during Alpine metamorphism.

1. Introduction

Tourmaline, the most abundant and widespread borosilicate in the Earth's crust and a common accessory mineral in metamorphic rocks, particularly metasedimentary rocks, requires boron (B) to form. Average continental sediments have between 30 and 175 μg/g B (Ishikawa and Nakamura, 1993), which is principally hosted by phyllosilicates such as illite (100–2000 μg/g B) and muscovite (10–1340 μg/g B) (Henry and Dutrow, 1996). The growth of metamorphic tourmaline, which has ~30,000 μg/g B, necessitates either the concentration of host rock B (closed system behavior); the addition of B by infiltrating fluids (open system behavior); or a combination of both. Once formed, metamorphic tourmaline is mechanically and chemically

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resistant and has low intravolume diffusion, resulting in the common occurrence of compositionally distinct growth zones (e.g., Henry and Dutrow, 1996). Due to its stability at a wide range of pressures and temperatures, ranging from diagenetic to granulite facies, tourmaline can grow during both pro- and retrograde metamorphism (e.g., Marschall et al., 2009a). Moreover, variations in the composition of metamorphic tourmaline and its growth zones provide a record of the evolution of its growth environment in terms of temperature (e.g., Henry and Dutrow, 1996; van Hinsberg and Schumacher, 2007, 2011), fluid composition (e.g., Berryman et al., 2016; von Goerne et al., 2011), isotope composition (e.g., Marschall and Jiang, 2011; Marschall et al., 2009a, 2009b; Meyer et al., 2008), and in some cases also pressure (e.g., Berryman et al., 2015).

The Alpine metamorphic history of the Pfitsch Formation is well described (see below), but insight into the fluids present during metamorphism is lacking. In this study, tourmaline from the Pfitsch Formation is investigated as a probe of the host rock's pro- and retrograde fluid-rock interaction history. This is achieved by applying our current understanding of tourmaline-fluid element partitioning (Berryman et al., 2016; von Goerne et al., 2011), sector zoning thermometry (van Hinsberg and Schumacher, 2007), as well as its B isotope systematics in different metamorphic environments (e.g., Marschall and Jiang, 2011; Palmer and Swihart, 1996).

2. Regional geology and study area

The Tauern Window is a tectonic window in the Eastern Alps exposing part of the Subpenninic and Penninic units, which are otherwise covered by the overthrusted Austroalpine superunit (Fig. 1). The Subpenninic and Penninic units are paleogeographically interpreted to represent the pre-Alpine distal European margin and remnants of the Tethys Ocean floor, respectively. Within the Subpenninic units, exposed at the core of the Tauern Window, the stratigraphically lowermost tectonic unit consists of Variscan basement rocks (e.g., Schmid et al., 2013, and references therein), intruded by Late- and Post-Variscan, Permo-Carboniferous granitoids (e.g., Cesare et al., 2002; Schmid et al., 2004). In the Western Tauern Window, these units are traditionally referred to as the Zentralgneise and comprise the Ahorn, Tux, and Zillertal Nappes, stacked to form the Venediger Duplex (e.g., Frisch, 1980; Lammerer et al., 2008; Schmid et al., 2013). Overlying the Zentralgneise are the Post-Variscan cover units. At the contacts of the Zentralgneise Nappes, these cover units are folded into elongated basins (Veselá and Lammerer, 2008; Veselá et al., 2011), defining the nappe boundaries.

Veselá and Lammerer (2008) and Veselá et al. (2011) have described the stratigraphy and ages of the major basins of the Western Tauern Window. Their Carboniferous to Jurassic age (Veselá et al., 2011) indicates these units experienced only Alpine metamorphism (e.g., Schmid et al., 2013). The Venediger Duplex, including its Post-Variscan cover, experienced temperatures up to 500–550 °C (Hoschek, 1998; Oberhänsli et al., 2004; Schuster et al., 2004; Selverstone et al., 1984, and references therein) and pressures up to 1.0–1.1 GPa (Selverstone et al., 1984). Decompression was rapid and nearly isothermal (Selverstone et al., 1984) during orogen-parallel exhumation (e.g., Ratschbacher et al., 1991) and large-scale E–W extension (Frisch et al., 2000).

The samples investigated here were collected from within the Pfitsch-Mörchner Basin, near the Pfitscher Joch Haus in the Passo di Vizzi on the Austrian-Italian border. The basin forms a NE–SW-striking isoclinally folded syncline whose axis is parallel to the Greiner Shear Zone, which defines the contact of the Tux and the Zillertal Zentralgneis nappes (Fig. 1). Henry et al. (2002) described tourmaline from this area in sheared tourmalinite veins in a lazulite-kyanite quartzite of the Windtal Formation, which is estimated to be Early Triassic in age (Veselá and Lammerer, 2008). In these veins, tourmaline comprises three generations of growth with different compositions; the first generation is schorl-dravite and the second and third generations are schorl-foitite. Henry et al. (2002) interpreted the first generation as the primary vein tourmaline, sourcing its B from nearby evaporites. They suggest that the second generation grew from metamorphic fluids introduced early in the Alpine orogeny during activation of the Greiner

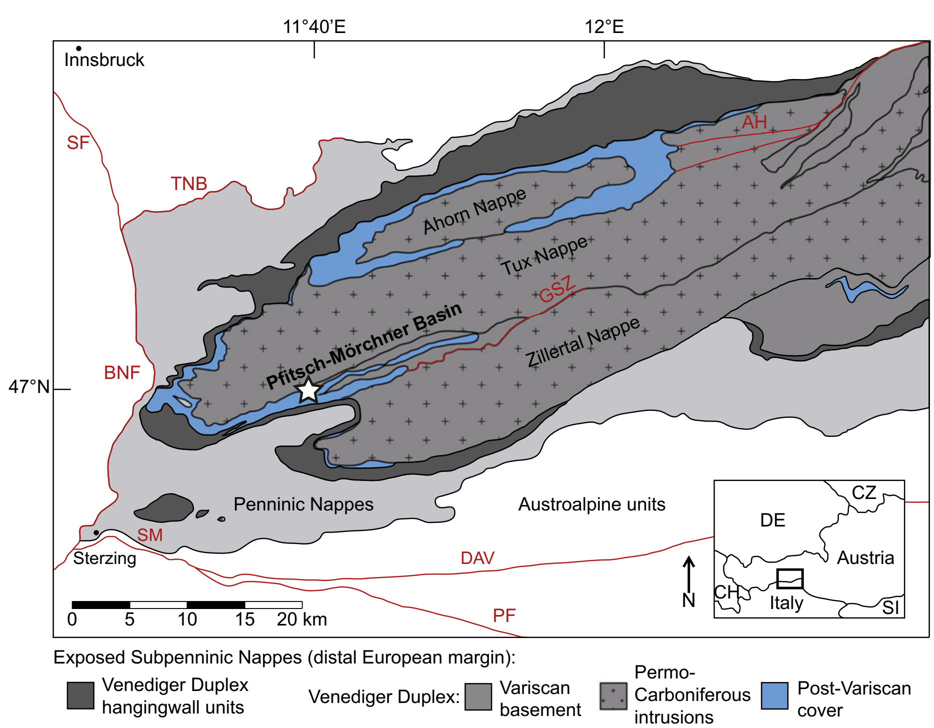

Fig. 1. Geological sketch map of the Western Tauern Window emphasizing the exposed units of the Subpenninic Nappes (modified after Schmid et al., 2013). The star indicates the position of the Pfitscher Joch Haus, the study area within the Pfitsch-Mörchner Basin. Alpine faults and shear zones are abbreviated as follows: AH Ahorn Fault; BNF Brenner Normal Fault; DAV Defereggen-Antholz Vals Fault; GSZ Greiner Shear Zone; PF Pustertal Fault; SM Sterzing-Mauls Fault; SF Silltal Fault; TNB Tauern Northern Boundary Fault.