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Chemical and stable isotopic characteristics of syn-tectonic tourmaline from the Western fold belt, Mount Isa inlier, Queensland, Australia

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ABSTRACT

Understanding hydrothermal fluid flow events related to orogenic events is important because they provide large-scale redistribution of metals which may become concentrated in ore deposits. In this study we determine the origin of tourmaline-bearing quartz veins and pegmatites in the Western fold belt of the Proterozoic Mount Isa inlier, a region which host numerous syn-orogenic Cu deposits. This paper uses tourmaline mineral chemistry and isotopic analyses (in-situ B and bulk O and H isotopes) to fingerprint the fluid reservoirs that contributed to the fluid budget during the Isan orogeny. All the tourmaline samples have schorl–dravite solid solution compositions. Quartz–tourmaline $\delta^{18}O$ (11.0–12.6 and 7.7–9.4‰ V-SMOW, respectively) pairs yield equilibrium formation temperatures of 305 to 575 °C with the higher temperatures related to pegmatitic tourmaline. Tourmaline δD values have a relatively narrow range from −68 to −56‰ V-SMOW. In most cases calculated $\delta^{18}O_{Fluid}$ and δD_{Fluid} values are compatible with primary magmatic water with a small component of metamorphic/^{18}O-enriched formation waters. However, there are large variations in tourmaline $\delta^{11}B$ values which range from +10.7 to −17.0‰, with the majority of values between −10 and −15‰. Variations in $\delta^{11}B_{Tur}$ in the pegmatites suggest that boron degassing generated relative ^{11}B depletion during crystallization. Similar $\delta^{11}B_{Tur}$ values in quartz–tourmaline veins spatially associated with the pegmatites, in cordierite- and sillimanite-bearing metamorphic rocks west of the Mount Isa fault, demonstrate a similar origin for B in this tourmaline. In contrast, quartz–tourmaline veins of similar timing hosted by greenschist grade metamorphic rocks east of the Mount Isa fault have much higher $\delta^{11}B_{Tur}$ values (+6.2 to +10.7‰) which reflect the involvement of a distinct B isotopic reservoir; mostly likely a near-surface derived evaporitic brine. Thus, the B isotopic data reveal important differences in fluid origin that are not reflected in the $\delta^{18}O$ values. Therefore, at least two isotopically distinct fluids, one sourced from fractionating anatectic pegmatites and the other from external basinal brines, circulated contemporaneously in separate areas during the Isan orogeny. There is no evidence, based on the tourmaline isotopic data, to suggest that these fluids mixed, which demonstrates that the hydrothermal plumbing system in the Western fold belt during the Isan orogeny was disconnected, probably due to differences in thermal structure/metamorphic grade across the Western fold belt during orogenesis.

1. Introduction

Interpreting the geochemical signatures of orogenic events is crucial to understanding the tectonic evolution of continent-building episodes. Many of these tectonic events correspond in space and time with the formation of important metallic ore deposits. Consequently understanding the development of old orogens also improves our ability to explore for metalliferous ores. The Mount Isa inlier of northern Australia is an example of a multiply deformed terrane that contains numerous ore deposits which formed during a series of orogenic events between ~1590 and 1500 Ma (Fig. 1; O'Dea et al., 1997; Betts et al., 2006). This period is collectively referred to as the Isan orogeny and it produced regional high temperature–low pressure metamorphism (including partial melting), pervasive deformation fabrics, and regionally extensive hydrothermal alteration assemblages (e.g., Connors and Lister, 1995; Huang and Rubenach, 1995; Mark et al., 1998; Giles and Nutman, 2002; Hand and Rubatto, 2002; Betts et al., 2006; Duncan et al., 2006, 2011). This paper discusses new chemical and isotopic data from six tourmaline-bearing samples to provide insights into the fluid reservoirs involved in metasomatic events during the Isan orogeny in the Western fold belt (WFB) of the inlier (Fig. 1). The aims of the study were to test

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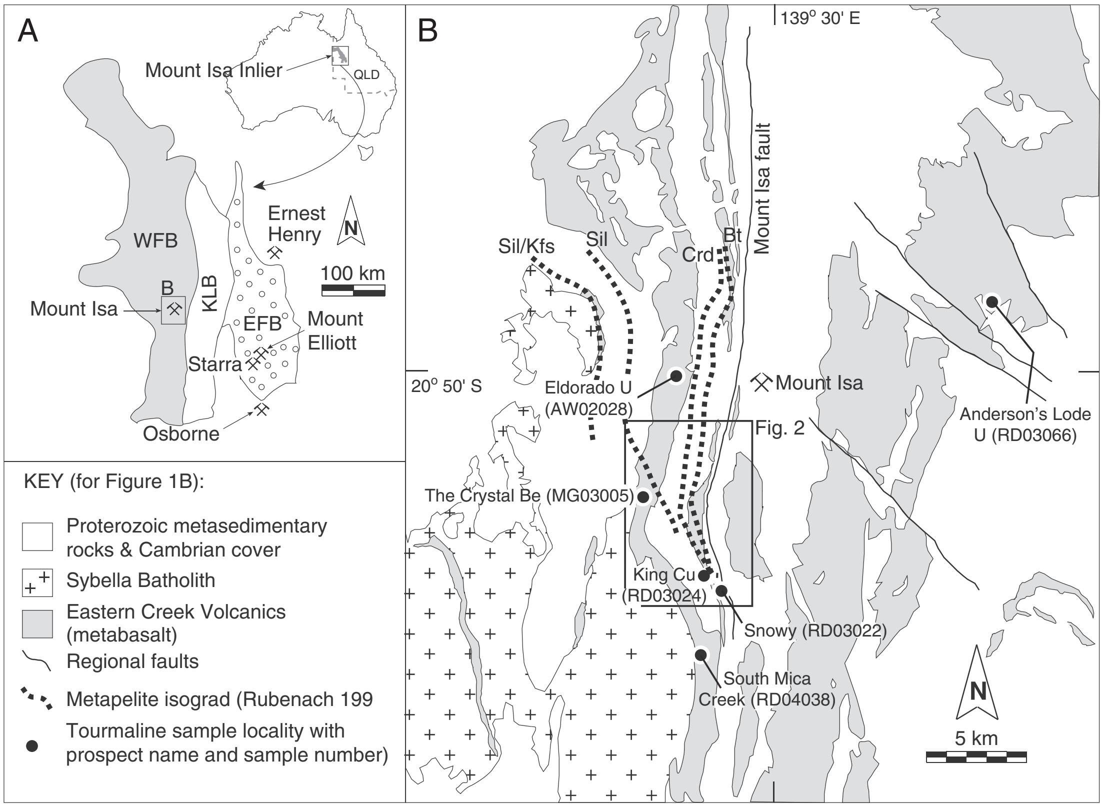

Fig. 1. (A) Location of the Mount Isa inlier, showing its tectonostratigraphic divisions and major ore deposits; WFB = Western fold belt, KLB = Kalkadoon–Leichhardt Belt, EFB = Eastern Fold belt. (B) Simplified geologic map of the WFB around Mount Isa, showing the location of tourmaline-bearing lithologies sampled in this study and metamorphic isograds (after Rubenach, 1992; Foster and Rubenach, 2006). Numbers are sample locations.
Mineral abbreviations are after Kretz (1983); Bt = biotite, Crd = cordierite, Kfs = K feldspar, Sil = sillimanite.

the sensitivity of B isotopes in tourmaline as a monitor and discriminator of fluid source, to compare this sensitivity with variability in O and H isotopes in tourmaline, and to investigate the relationship between tourmaline B isotopic composition and metamorphic grade. The WFB was selected as a study area because of tourmaline is relatively abundant in the area around Mount Isa, where is occurs in pegmatites and quartz veins (Heinrich et al., 1993; Duncan and Wilde, 2004), and previous studies have concentrated on syn-orogenic hydrothermal alteration in the Eastern fold belt (EFB; Fig. 1) of the inlier (e.g., Oliver, 1995; Rubenach and Lewthwaite, 2002; Mark et al., 2004).

Tourmaline is highly resistant to post-depositional modification (via metamorphism, hydrothermal alteration, and weathering), hence it tends to preserve primary geochemical signatures that allow fluid characteristics to be established (e.g., Henry and Dutrow, 1996; Slack, 1996; Dutrow et al., 1999; van Hinsberg et al., 2011) and is extremely useful in terranes, such as the Mount Isa inlier, that have undergone a protracted geologic history as it can preserve important information about the geochemical characteristics of each thermal event. Moreover, B is useful as an isotopic tracer because there is extensive B isotopic fractionation due to differences in boron coordination states in minerals, melts, and fluids (Palmer et al., 1992; Smith and Yardley, 1996; Marschall and Jiang, 2011). For example, ^{11}B is partitioned into trigonal complexes in fluids, whereas ^{10}B favors tetrahedral complexes in silicate melts (Pichavant, 1983; Palmer et al., 1992; Smith and Yardley, 1996) which may produce large B isotope fractionations with an ^{11}B enriched aqueous phase (Trumbull and Chaussidon, 1999). Incorporation of B into aluminosilicate phases, including tourmaline, is governed initially by adsorption of trigonal boron at the mineral surface (Palmer et al., 1987). The adsorption processes modifies the symmetry of the B species to a pseudo-tetrahedral in the adsorbed species, thus the mineral is relatively enriched in ^{10}B (Palmer and Swihart, 1996). Experimental work demonstrates that the B isotopic fractionation between an aqueous phase and tourmaline is inversely proportional to temperature (Palmer et al., 1992). Limited fractionation occurs between a melt and magmatic tourmaline due to the similar coordination of boron in tourmaline and peraluminous magmas (Smith and Yardley, 1996). The majority of tourmalines from granitic pegmatites have $\delta^{11}B_{Tur}$ values of between −12 and −5‰ (Swihart and Moore, 1989), which overlaps with the values for high-grade metapelite and quartzofeldspathic rocks (Palmer and Slack, 1989). Positive $\delta^{11}B_{Tur}$ occur in pegmatites where marine evaporites are the likely B source (Jiang and Palmer, 1998).

2. Regional geological framework

2.1. Stratigraphy

The mid- to late Proterozoic Mount Isa inlier comprises a number of poly-deformed belts that were tectonically active between 1900 and 1500 Ma (e.g., Blake and Stewart, 1988; O'Dea et al., 1997; Betts et al., 2006). The terrane is divided on the basis of tectono-stratigraphic characteristics into three north–south trending domains (Fig. 1). The WFB consists of variably deformed and metamorphosed sedimentary and volcanic rocks that were deposited in three superimposed intraplate extension-related basins between 1790 and 1595 Ma (Page, 1983; Page and Sweet, 1998). The oldest basin is dominated by sandstone and tholeiitic basalts (Eastern Creek Volcanics, ECV) interbedded with pelitic rocks. This package is collectively known as the Haslingden Group (Blake and Stewart, 1988). The youngest pre-Isan orogeny extension phase (between 1670 and 1655 Ma) allowed the accumulation of up to 2000 m of laminated dolomitic and carbonaceous siltstone and shale that comprise the Mount Isa Group (Page et al., 2000). The Urquhart Shale of the Mount Isa Group hosts the giant stratiform and stratabound Pb–Zn–Ag (150 Mt at 6% Pb and 7% Zn) and the breccia-