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# Origin and significance of tourmalinites and tourmaline-bearing rocks of Menderes Massif, western Anatolia, Turkey

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ABSTRACT

In the western central portion of Anatolia lies the Menderes Massif — a large metamorphic crystalline complex made of Neoproterozoic to Precambrian basement rocks overlain by Palaeozoic to early Tertiary metasedimentary rocks, and with a multistage metamorphic evolution developed from the late Neo-Proterozoic to Eocene. We have undertaken a study of the petrology, geochemistry and boron isotope composition of these tourmaline occurrences aiming to constrain the processes responsible for the enrichment of boron and other fluid mobile elements in the Menderes Massif. The dispersed tourmaline has chemical and boron isotope compositions typical of a continental crust setting, but while some of the tourmalinites display similar signatures, others have heavier boron isotope compositions (up to +7.5‰). We suggest that the tourmalinites with continental characteristics formed part of the original Pan African basement rocks, whereas those with heavier $\delta^{11}B$ signatures formed by later metamorphism during the Alpine orogeny, possibly through interaction with subduction-like fluids. This proposed process may also have been coincident with metasomatism of the lithospheric mantle beneath the massif, which is known to have experienced multistage metasomatism and enrichment history up to Neogene time.



## 1. Introduction

Tourmaline is a common accessory mineral in a variety of lithologies and mineral deposits; including, granitic rocks (Neiva, 1974), sedimentary and metamorphic rocks (Henry and Guidotti, 1985), tourmalinites (Ethier and Campbell, 1977), and stratabound and stratiform mineral deposits (Slack, 1996). Tourmaline can accommodate a wide variety of major and trace elements (e.g., Dutrow and Henry, 2011). Hence, the chemistry and isotopic composition of tourmaline has yielded valuable information concerning the origin of this mineral and its host rocks (Byerly and Palmer, 1991; Jiang et al., 1998; Palmer, 1991; Slack et al., 1989) and this study aims to examine the B isotopic variations of tourmaline-rich occurrences in the metamorphic rocks of the Menderes Massif, western Anatolia.

Within the Menderes Massif of western Anatolia, Turkey (Fig. 1), tourmaline-rich rocks are associated with augen gneiss, leucogranite and garnet-mica schist, as part of a complex geologic setting that underwent polyphase deformation and low- to high-grade regional metamorphism during the Pan-African to Alpine orogenic events (Candan et al., 2001, 2011; Dora et al., 2001; Mittwede et al., 1992; Oberhänsli et al., 1997; Régnier et al., 2003; Şengör et al., 1984; Whitney and Bozkurt, 2002). The genesis of these tourmaline-rich rocks within the Pan-African basement rocks of the Menderes massif is, however, controversial. On the basis of field and major element data previous studies have identified the tourmaline-rich rocks as having either a sedimentary (stratiform/stratabound tourmalinites) and/or magmatic origin (Bozkurt et al., 2006; Candan et al., 2011; Mittwede et al., 1992). Hence, we have undertaken a geological, mineralogical, and geochemical study (B isotopic compositions in addition to major and trace element data) of tourmaline-rich rocks from the Menderes Massif in order to assess whether fresh insights can be gained into the geological evolution of the region. Tourmaline is particularly useful in this context because it is a robust mineral that can retain a record of regional geologic processes (e.g., van Hinsberg et al., 2011) and an understanding of the geologic history of the Menderes Massif is also important to interpretations of the pre- and post-collisional geodynamic evolution of the wider western Anatolia region.

## 2. Geologic setting of the Menderes Massif

In western Anatolia, the Anatolides including the Menderes Massif, collided with the Sakarya continental block along the İzmir–Ankara Zone (Okay et al., 2001). The northern edge of the Anatolide–Tauride platform, the Tavşanlı Zone, was subducted beneath the ophiolitic mélange rocks of the İzmir–Ankara Zone and the Sakarya Zone at ~88 Ma

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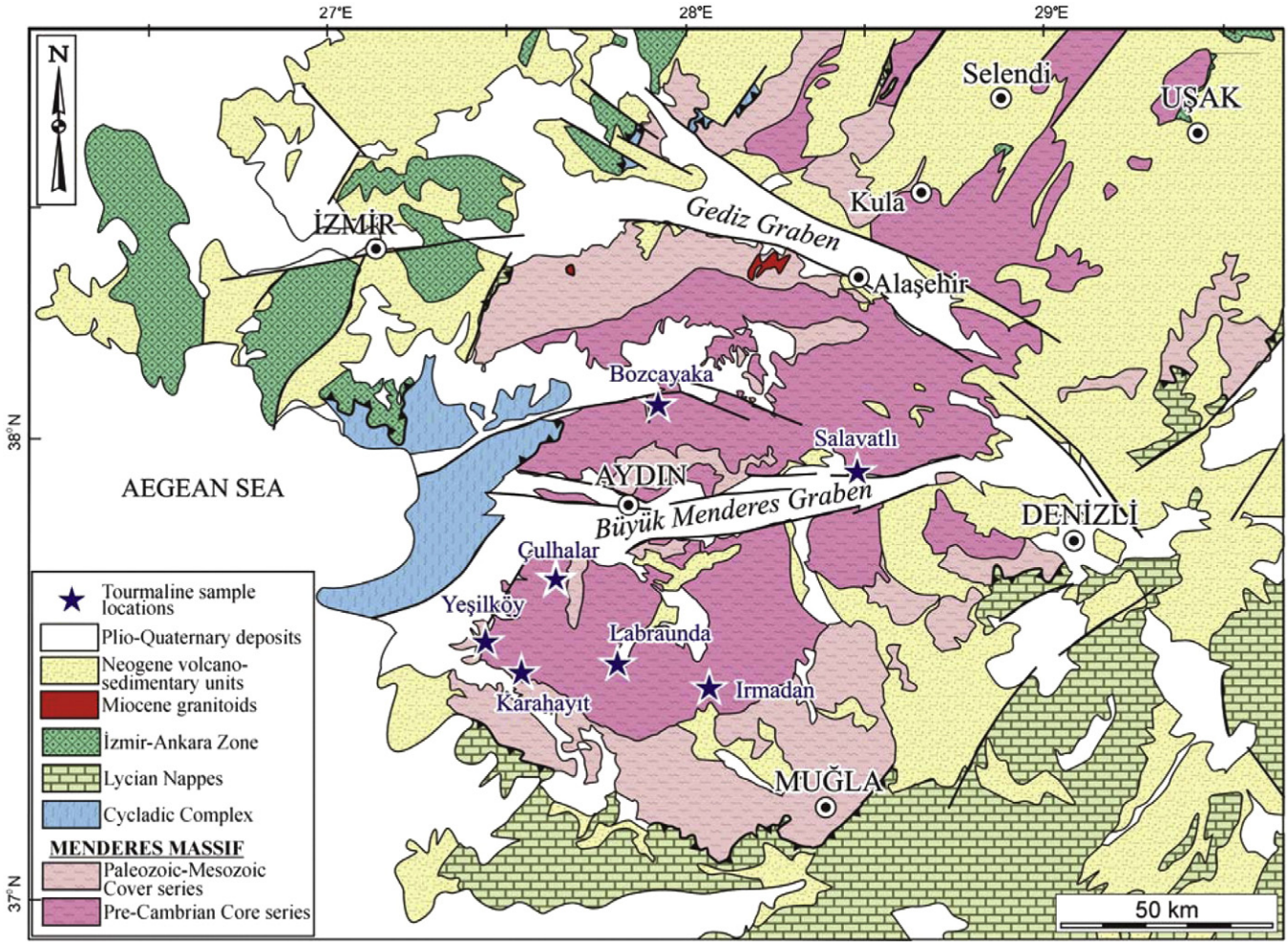


**Fig. 1.** General geological map of the central and southern part of the Menderes Massif, including tourmaline sample localities.

(Sherlock et al., 1999). This stage of continental collision resulted in crustal imbrication, accretion and thickening (Şengör and Yılmaz, 1981; Whitney et al., 2008).

The Menderes Massif constitutes a regional, NE–SW-trending, roughly elliptical metamorphic terrain of 30,000 km$^2$, which is made up of Pan-African basement (Precambrian core series) and overlying

**Table 1**
Classification and characteristics of Menderes Massif tourmaline samples.

| Type | Location | Sample numbers | Host rock | Mineral association* | Grain size | Habit & texture |
|---|---|---|---|---|---|---|
| I | Karahayıt | 71<br>74<br>75/C<br>75/D1<br>76<br>78<br>78/F | Tourmalinites | Qtz, Ms, Bt, Grt, Zrn, Ap | <0.1 mm | Granoblastic texture, anhedral to subhedral crystals |
| | Yeşilköy | 82/2<br>82/3 | | | | |
| | Madran | 58 | | | | |
| | Çine | 27<br>01-136/2<br>01-139 | | | | |
| II | Labraunda | 4<br>64<br>69<br>70 | Metasediment-hosted tourmalines | Qtz, Ms, Bt, Rt, Grt, Zrn | <800 μm | Anhedral to subhedral crystals |
| | Karahayıt | 72 | | | | |
| III | Irmadan | I-1<br>I-3 | Gneiss-hosted tourmalines | Qtz, Kfs, Ms, Ap, Rt, Zrn | <1 cm | Anhedral to subhedral crystals, eye-shaped nodules |
| | Bafa | BS-1 | | | | |
| | Yeşilköy | 83/A | | | | |

* Qtz = quartz, Ms = muscovite, Bt = biotite, Grt = garnet, Zrn = zircon, Ap = apatite, Rt = rutile, Kfs = K-feldspar.