

## Tourmaline from the Fakos porphyry-epithermal Cu-Mo-Au-Te prospect, Limnos island, Greece: Mineral-chemistry and genetic implications

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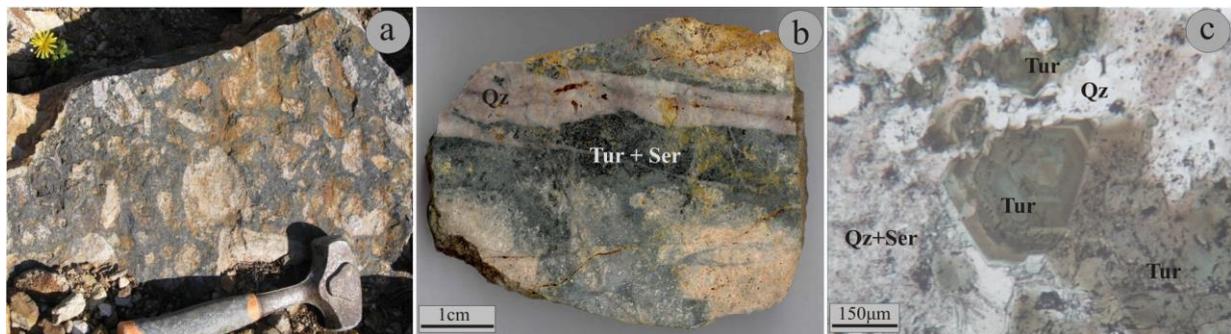
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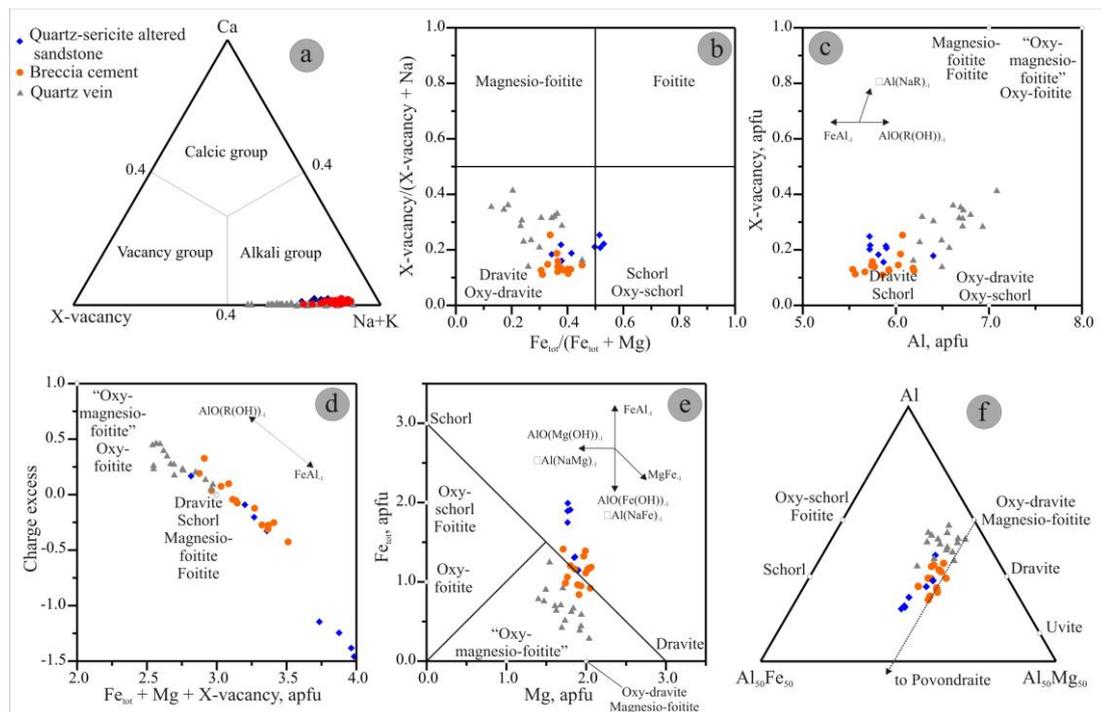
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The Fakos Cu-Mo-Au prospect, in Limnos island, NE Aegean Sea, comprises the first occurrence of porphyry-related tourmaline in Greece (Voudouris & Alfieris, 2005; Fornadel et al., 2012). The prospect is a telescoped porphyry-epithermal system hosted in lower Miocene alkaline to sub-alkaline igneous rocks and middle Eocene to lower Miocene sandstones. Tourmaline occurs within E-trending hydrothermal breccias (Fig. 1a) and quartz-tourmaline veins related to quartz+sericite+tourmaline alteration of the Fakos monzonite (Fig. 1b), as well as disseminations within sericite-altered sandstones. This study presents EPMA data on the Fakos tourmaline and attempts to record any chemical differentiations, which may reflect variations of the ore-forming fluids. Tourmaline occurs as isolated crystals (with size up to 0.5cm) or as radial aggregates. The crystals are optically zoned, usually with a darker core and nearly colorless rim (Fig. 1c). The lighter coloration is caused by a lower concentration of Fe. Due to the minor amount of Ca in all analyzed tourmalines (Fig. 2a; no higher than 0.02 apfu), the optimal plot to distinguish any different species is the binary  $Fe_{tot}/(Fe_{tot} + Mg)$  versus X-site vacancy/(Na + X-site vacancy) (Fig. 2b). This diagram does not distinguish among OH-, F-, and O-bearing species, however, F contents are either below detection, or very low in all analyzed grains, and therefore the W site is dominated by  $O^{2-}$  or OH. Consequently, the magnesio-foitite, dravite, schorl, and foitite fields could be considered as "oxy-magnesiofoitite", oxy-dravite, oxy-foitite, and oxy-schorl fields, respectively. This diagram shows that tourmaline from the sandstones falls into the dravite/oxy-dravite and schorl/oxy-schorl fields, whereas those from the breccia and the quartz veins are restricted to the dravite--oxy-dravite field only. However, the vein-related tourmaline is characterized by higher X-site vacancy/(Na + X-site vacancy) and lower  $Fe_{tot}/(Fe_{tot} + Mg)$  values than those in the other tourmalines studied here.



**Figure 1.** (a) Tourmaline breccia with fragments of phyllic-altered monzonite; (b) Hand specimen of quartz vein associated with tourmaline (Tur) and sericite (Ser) alteration halo, crosscutting phyllic-altered monzonite; (c) Microphotograph of zoned tourmaline (Tur) in association with (Qz) and sericite (Ser) (plane-polarized light; Tourmaline breccia).

In a plot of X-site vacancy versus Al diagram (Fig. 2c), the compositions of tourmaline from the sandstones and the breccia plot parallel to  $FeAl_{-1}$ , and  $AlO(FeOH)_{-1}$  vectors, whereas those from the quartz veins scatter between the two vectors  $AlO(R(OH))_{-1}$  and  $Al(NaR)_{-1}$ . In the (charge excess) versus  $(Fe + Mg + X \text{ vacancy})$  plot (Fig. 2d) it is obvious that the  $FeAl_{-1}$  vector is predominant for the tourmaline in the sandstones. In addition, this diagram shows two compositional groups in excess charge: below -1 and  $\sim -0.3$  to  $\sim -0.1$ . In the second group, most compositions have charge deficiency. Similarly most compositions of tourmaline from the breccia plot parallel to the  $FeAl_{-1}$  vector and have charge deficiency and plot close to the second compositional group of the tourmaline from the sandstones. However, tourmaline compositions from the quartz veins are parallel to the  $AlO(R(OH))_{-1}$  vector and have no charge deficiency. This testifies to negligible  $Fe^{3+}$  content in the tourmaline, although a Mössbauer study is required to test this hypothesis. The  $Fe_{tot}$  versus Mg diagram (Fig. 2e) and the ternary plot in terms of Fe-Al-Mg (Fig. 2f) show that tourmaline compositions from the sandstones and the breccia parallel the  $FeAl_{-1}$  vector and the oxy-dravite / povondraite (OP) trend, respectively. In contrast to the first- and second-types of tourmaline, the compositions of the quartz vein-related tourmaline parallel the  $FeMg_{-1}$  vector. Thus, they plot over the schorl-dravite join and are not parallel to the OP trend (Fig. 2f). The tourmaline compositions from the quartz veins are characterized by the  $AlO(R(OH))_{-1}$ ,  $Al(NaR)_{-1}$ , and  $FeMg_{-1}$  exchange vectors, probable negligible  $Fe^{3+}$  concentration, and are not parallel to the OP trend.



**Figure 2. Chemical compositions of analyzed tourmalines from the Fakos prospect in terms of: (a) Ca – (X-vacancy) – (Na+K); (b) X-vacancy/(X-vacancy +Na) vs Fetot/(Fetot+Mg); (c) X-vacancy vs Al; (d) Charge excess vs Fetot+Mg+X-vacancy; (e) Fetot vs Mg; (f) Al-Fe-Mg.**

Tourmaline from the Fakos area is Ca-poor that is attributed to Ca deficiency in the host rocks. Tourmaline from altered sandstone and breccia cement have similar major exchange vector substitution FeAl-1 corresponding to isomorphous substitution  $\text{Fe}^{3+} \leftrightarrow \text{Al}$  and parallel to the OP trend. Similarly, tourmaline with the same features have been described from other porphyry deposits (Baksheev et al., 2012; Lynch and Ortega, 1997; Yavuz et al., 1999). Difference in excess charge value between tourmalines from sandstone and breccia cement may be explained by more reducing conditions of tourmaline crystallization in the breccia cement. This more reducing environment may be caused by an increase in the  $\text{H}_2\text{S}$  fugacity, which resulted in sulfide deposition. In turn, the latter caused a decrease in the Fe content of the cement tourmaline, because Fe fractionated into sulfide minerals.

Tourmaline from alteration adjacent to quartz-tourmaline veins is different in terms of composition and isomorphous substitutions compared to the previous two types. For these tourmalines, the compositions follow the FeMg-1 vector, which is quite unusual in tourmaline from porphyry systems, but rather represents a major exchange observed in tourmalines from mesothermal gold deposits, greisen, mesothermal tin deposits, and base metal deposits. This is in accordance with field observations at Fakos where quartz-tourmaline veins are transitional from the porphyry to the epithermal environment. Future work will focus on the tourmaline chemistry from Limnos and will be used as a possible vector towards new mineralized (Au-rich) centers in the broader area, as has been suggested for other tourmaline-bearing, porphyry-style alteration assemblages elsewhere.

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