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Cr-bearing tourmaline associated with emerald deposits from Swat, NW Pakistan: Genesis and its exploration significance

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Abstract

Carbonate-talc altered ultramafic (and mafic) rocks of the obducted oceanic lithosphere along the Main Mantle Thrust in the Swat Valley host emerald deposits and are invaded by quartz veins and stockworks. Both the quartz veins and carbonate-talc altered rocks contain discrete grains and clusters of tourmaline crystals, which may be associated with emerald and/or chromian muscovite. Tourmalines from the Mingora and Gujar Kili emerald mines and the Spin Obo-Kuh area are Ni-bearing, Cr-rich dravites and "oxy-dravites" that exhibit substantial chemical variability with 2.0–2.5 atoms per formula unit (apfu) Mg, relatively low Al (4.8–5.8 apfu), high Cr (0.5–1.8 apfu), high Cr/(Cr+Al) ratios of 0.08–0.28, significant amounts of Ni (up to 0.11 apfu), and variable calculated W site O^{2-} (0.2–0.8 apfu). The mechanisms that appear to control the tourmaline chemistry at these localites are combinations of the dominant substitution Al = Cr with lesser amounts of the $Mg+OH^{1-} = (Al,Cr)+O^{2-}$ and $Al^{3+} = Fe^{3+}$ substitutions. Relative to the Mingora, Gujar Kili, and Spin Obo-Kuh areas, the Charbagh tourmalines are "oxy-dravites" that have comparable Mg contents (2.2–2.3 apfu) with variable calculated W site O^{2-} (0.6–0.9 apfu), but are more Fe-rich (0.5 apfu) and Al-rich (6.0–6.3 apfu) with low Cr (0.00–0.01 apfu) and Ni contents (0.01–0.02 apfu). The mechanism that appears to control the variable chemistry of the Charbagh tourmalines is primarily $Mg+OH^{1-} = Al+O^{2-}$. The chemical characteristics of tourmalines from the various localities relate most clearly to differences in host rock chemistry.

Tourmalines from the carbonate-talc altered ultramafic-mafic rocks and the invasive quartz veins have a common hydrothermal origin associated with emplacement and crystallization of younger granitoids. Furthermore, the occurrence of Swat emeralds in quartz-tourmaline (±chromian muscovite) veins suggests that the tourmaline is cogenetic with emerald formation. The quality and quantity of Swat emeralds depend on the: (1) host rock composition and (2) nature of the hydrothermal fluids. Large deposits of gem-quality emerald occur in carbonate-altered ultramafic rocks, which also contain Cr-rich dravites and "oxy-dravites." This suggests that the presence of high-Cr magnesian tourmalines, particularly in magnesite-talc altered ultramafic rocks, can represent a criterion for further emerald exploration in the lower Swat region of Pakistan and comparable ultramafic-hosted emerald-producing regions.

Keywords: Tourmaline, chemistry, genesis, emerald exploration, NW Pakistan