Geochemistry of biotite, muscovite and tourmaline from Early Palaeozoic granitoids of Kinnaur district, Higher Himachal Himalaya

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Felsic magmatism exposed between Rakcham and Akpa regions is represented by Rakcham and Akpa granitoids in Kinnaur district collectively referred to as the Early Palaeozoic granitoids (EPG). Kwatra et al. (1999) have assigned Rb-Sr isochron age of 453 ± 9 Ma with initial Sr isotopic ratio ($^{87}Sr/^{86}Sr$) of 0.737 ± 0.002 for the granitoids of Rakcham area and 477 ± 29 Ma with this ratio of 0.7206 ± 0.00235 for the granitoids of Akpa region, which suggest episodic nature of Early Palaeozoic felsic magmatism derived from crustal protoliths. The EPG intrudes the granite gneiss (GGn) of the Central Crystalline Zone in the southern part of Higher

FIGURE 1. Bivariate Al_2O_3 vs. FeO^t plot for biotite (o) hosted in EPG. Biotites from EPG mostly plot in the field of biotites crystallized into peraluminous (S-type) felsic magma. Fields are after Abdel-Rahman (1994)

FIGURE 2. Fe (tot)–Al–Mg ternary plot for tourmalines of EPG (□) and TLg (o). Fields 1- Li-rich granitoid pegmatites and aplites; 2- Li-poor granitoids and their associated pegmatites and aplites; 3- Fe^{3+} rich quartz-tourmaline rocks (hydrothermally altered granites); 4- metapelites and metapsammites coexisting with an Al-saturating phase; 5- metapelites and metapsammites not coexisting with an Al-saturating phase; 6- Fe^{3+} rich quartz-tourmaline rocks, calc-silicate rocks, and metapelites, 7- Low-Ca metaultramafics and Cr, V-rich metasediments and, 8- metacarbonates and meta-pyroxenites (after Henry and Guidotti 1985).

Himachal Himalaya. The EPG and GGn belong to the Vaikrita Group, and are intruded by tourmaline bearing leucogranite (TLg) of Haimanta Group. The EPG are medium-to coarse-grained, porphyritic and bear qtz+Kfs+plag+bt+ms+zr ± ap±tur assemblage. Tourmaline mostly occurs in TLg as veins, pods and lenses but has also been found hosted in the EPG.

Modal mineralogy of EPG corresponds to monzogranite and granodiorite and suggests their nature typically as two-mica (biotite>muscovite) leucomonzogranite (*s.s.*) formed by partial fusion of crustal components. Based on mineral assemblages, occurrence of metasedimentary enclaves (xenoliths of country rocks or deeper lithology or restite from source), associated skarn-type tungsten mineralization and geochemical characters (SiO_2= 69.26-74.43 wt%, TiO_2= 0.02-0.64 wt%, Al_2O_3=13.09-16.78 wt%, K_2O = 2.55-6.93 wt%, CaO = 0.51-3.17 wt%, K_2O/Na_2O = 0.83-2.73, molar A/CNK = 0.93-1.33, CIPW corundum 0.17 to 4.29 wt%, Av. Sr = 208 ppm), the EPG can be characterized as peraluminous (S-type) granitoids derived by anatexis of fusible major constituents of sedimentary protoliths (Chappell and White 1974). Electron-probed compositions of biotite, muscovite and tourmaline from EPG have been extensively studied to understand nature of the host magma type and physical conditions of mineral evolution.

Biotites from EPG are ferri-biotites, and have shown chemical affinity with biotites coexisting with muscovite and aluminosilicates. Biotite compositions largely depend upon the nature of host magmas (anorogenic alkaline, peraluminous including collisional S-type, or calc-alkaline subduction-related including metaluminous I-type; Abdel-Rahman 1994). In terms of MgO, Al_2O_3 and FeO^t contents, most biotites from EPG appear crystallized and equilibrated in the peraluminous (S-type) granite melts derived by melting of crustal source (**Figure 1**). Few biotites however show affinity with biotites of calc-alkaline nature, which may be secondary in nature due to slight change in composition of EPG melts or as a result of magma mixing/assimilation. Most EPG biotites tightly cluster on bivariate MgO-FeO plot but to a certain extent few biotites have shown Mg – Fe substitution. Although the Mg – Fe substitution is less significant in biotites of peraluminous rocks because the biotites in peraluminous melts are significantly depleted in Mg compared to those of calc-alkaline suites. Overall the EPG biotites exhibit pronounced 3(Mg, Fe) – 2Al substitution, which were mostly buffered at NNO. However, a few EPG biotites being enriched into oxyannite component, at and above HM buffer, appear secondary in nature because of subsolidus modification. The EPG biotites (Fe/Fe+Mg = 0.53-0.76) buffered at NNO were projected onto experimental biotite equilibria at 2070 bars (Wones and Eugster, 1965), which suggest their evolution under reducing condition ($fO_2 = 10^{-13.50}$– 10^{-16} bar) in a temperature range of 820 °C - 700 °C. The observed reducing trends of biotite evolution in EPG melts are consistent with the magnetic susceptibility (MS) values ($\chi = 0.016$ to 0.187 SI, N = 104) of EPG similar to ilmenite series granites, which most likely prevailed during melting (intrinsic to source region) and/ or subsequent fractional crystallization events.
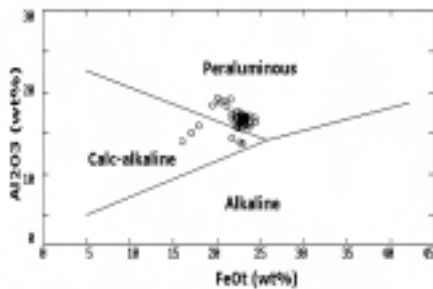
The EPG muscovites (Fe/Fe+Mg = 0.41-0.69) coexist with biotites, and are primary in nature containing mostly celadonitic and paragonitic components. They can be classified as Li-Al mica group representing lithian muscovite, lepidolite and zinnwaldite, which were evolved under differentiating peraluminous (S-type) EPG melts. It has been observed that some structural features of dioctahedral and trioctahedral micas from peraluminous granitoids could be related to the crystal forming conditions (Benincasa et al. 2003).

The EPG muscovites exhibit celadonite-like substitution involving octahedral site where Al^{3+} is mainly substituted by Fe and Mg^{2+} and minor amount of Ti^{4+}. Since Ti^{4+} content of EPG muscovite varies from 0.02-0.09 apfu, and therefore it is likely that both Fe and Mg^{2+} substitute for Al^{3+}. However ferro-celadonite substitution in EPG muscovite appear prevalent where the layer-charge neutrality is mainly accounted by exchange mechanism $^{[4]}Si\ ^{[4]}Al^{3+}_{-1}\ ^{[6]}Fe^{2+}\ ^{[6]}Al^{3+}_{-1}$. The observed substitution relations in EPG muscovite are common to most muscovites crystallized in peraluminous rocks observed elsewhere. The observed substitution relations in EPG muscovite are common to most muscovites crystallized in peraluminous rocks observed elsewhere.

Tourmaline compositions from EPG and TLg are indistinguishable, and mostly belong to alkali group based on occupancy of principal constituents at X-site. In terms of schorl (Fe-rich) – dravite (Mg-rich) and elbaite (Al+Li-rich) end-members, the tourmalines of EPG and TLg have shown affinity of their crystallization in Li-poor granitoids and associated pegmatites and aplites (**Figure 2**), being enriched into elbaite components. Equivocal tourmaline compositions of EPG and TLg point to a likely process that the tourmalines were impregnated locally into the remobilized EPG during TLg emplacement as a result of Himalayan orogenesis.

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