American Mineralogist, Volume 108, pages 1573–1596, 2023

Fluorine-rich mafic lower crust in the southern Rocky Mountains: The role of pre-enrichment in generating fluorine-rich silicic magmas and porphyry Mo deposits

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Abstract

Fluorine-rich granites and rhyolites occur throughout the southern Rocky Mountains, but the origin of F-enrichment has remained unclear. We test if F-enrichment could be inherited from ancient mafic lower crust by: (1) measuring amphibole compositions, including F and Cl contents, of lower crustal mafic granulite xenoliths from northern Colorado to determine if they are unusually enriched in halogens; (2) analyzing whole-rock elemental and Sr, Nd, and Pb isotopic compositions for upper crustal Cretaceous to Oligocene igneous rocks in Colorado to evaluate their sources; and (3) comparing batch melting models of mafic lower crustal source rocks to melt F and Cl abundances derived from biotite data from the F-rich silicic Never Summer batholith. This approach allows us to better determine if the mafic lower crust was pre-enriched in F, if it is concentrated enough to generate F-rich anatectic melts, and if geochemical data support an ancient lower crustal origin for the F-rich rocks in the southern Rocky Mountains.

Electron microprobe analyses of amphibole in lower crustal mafic granulite xenoliths show they contain 0.56–1.38 wt% F and 0.45–0.73 wt% Cl. Titanium in calcium amphibole thermometry indicates that the amphiboles equilibrated at high to ultrahigh temperature conditions (805 to 940 °C), and semiquantitative amphibole thermobarometry indicates the amphiboles equilibrated at 0.5 to 1.0 GPa prior to entrainment in magmas during the Devonian. Mass balance calculations, based on these new measurements, indicate parts of the mafic lower crust in Colorado are at least 3.5 times more enriched in F than average mafic lower crust. Intrusions coeval with the Laramide Orogeny (75 to 38 Ma) pre-date F-rich magmatism in Colorado and have Sr and Nd isotopic compositions consistent with mafic lower crust ± mantle sources, but many of these intrusions contain elevated Sr/Y ratios (>40) that suggest amphibole was a stable phase during magma generation. The F-rich igneous rocks from the Never Summer igneous complex and Colorado Mineral Belt also have Sr and Nd isotopic compositions that overlap with the lower crustal mafic granulite xenoliths, but they have lower Sr/Y, higher Nb and Y abundances, and distinctly less radiogenic $^{206}Pb/^{204}Pb_i$ compositions than preceding Laramide magmatism. Batch melt modeling indicates low-degree partial melts derived from rocks similar to the mafic lower crustal xenoliths we analyzed can yield silicic melts with >2000 ppm F, similar to estimated F melt concentrations for silicic melts that are interpreted to be parental to evolved leucogranites.

We suggest that F-rich silicic melts in the southern Rocky Mountains were sourced from garnet-free mafic lower crust, and that fluid-absent breakdown of amphibole in ultrahigh temperature metamorphic rocks was a key process in their generation. Based on the composition of high-F amphibole measured from lower crustal xenoliths, the temperature of amphibole breakdown and melt generation for these F-enriched source rocks is likely >100 °C higher than similar lower crust with low or average F abundances. As such, these source rocks only melted during periods of unusually high heat flow into the lower crust, such as during an influx of mantle-derived magmas related to rifting or the post-Laramide ignimbrite flare-up in the region. These data have direct implications for the genesis of porphyry Mo mineralization, because they indicate that pre-enrichment of F in the deep crust could be a necessary condition for later anatexis and generation of F-rich magmas.

Keywords: Fluorine, amphibole, Climax-type Mo deposits, topaz rhyolite, xenolith, southern Rocky Mountains, ultrahigh temperature metamorphism, granulite; Experimental Halogens in Honor of Jim Webster