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Fluorine-Rich Mafic Lower Crust in the Southern Rocky Mountains: The Role of Preenrichment in Generating Fluorine-Rich Silicic Magmas and Porphyry Mo Deposits

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Fluorine-rich ferroan leucogranites and rhyolites can be shown to be associated with porphyry Mo ("Climax-type") deposits and other critical mineral resources, but their origins and relationships to continental lithospheric source rocks remain unclear. It has been especially challenging to determine where and how they become enriched in F. We tested if F enrichment is inherited from deep crustal sources in the southern Rocky Mountains by directly measuring amphibole compositions of lower crustal mafic granulite xenoliths from the State Line District in northern Colorado and by analyzing whole-rock elemental abundances and Sr, Nd, and Pb isotope compositions for a suite of Cretaceous to Oligocene igneous rocks in Colorado to evaluate their sources. 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. Amphibole thermobarometry indicates equilibration at high-to ultrahigh-temperature metamorphic conditions (820°-940°C and 0.5-1.0 GPa) prior to entrainment in Devonian kimberlites. Mass balance calculations based on these values indicate that some parts of the mafic lower crust in Colorado are at least 3.5 times more enriched in F than average mafic lower crust. Batch melt modeling indicates low-degree partial melts derived from similar rocks with F-rich amphibole can yield silicic melts with >2,500 ppm F, similar to estimated F melt concentrations for fluorite-bearing leucogranites in the region.

Laramide-aged intrusions (75–38 Ma) predate F-rich magmatism in Colorado and have 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 isotopic compositions that overlap the lower crustal mafic granulite xenoliths, as well as lower Sr/Y (<40) and high Nb and Y abundances. We suggest that F-rich silicic melts in the southern Rocky Mountains were sourced from mafic lower crust and that fluid-absent breakdown of amphibole in rocks that experienced ultrahigh-temperature metamorphism was a key process in their generation. Experimental data indicate that F-rich amphiboles, such as those observed in the xenoliths, break down at higher T (>100°C greater) than typical lower-F counterparts. 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. Some rocks that predate the F-rich magmatism could also have been sourced from lower crust, but in this period lower crust melted under conditions in which amphibole was a stable phase or only low-F amphibole was available for breakdown, and therefore those rocks lack distinct F enrichment. These data have direct implications for the genesis of porphyry Mo mineralization, in particular in the Colorado Mineral Belt, because they indicate that F is inherited from crustal sources and that preenrichment of the crust could be a necessary condition for later anatexis and generation of F-rich magmas.