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Extreme channelization of fluid and the problem of element mobility during Barrovian metamorphism

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Abstract

Geochemical profiles across chemically altered zones (selvages) surrounding amphibolite facies quartz+kyanite veins were investigated to determine major, minor, and trace element mass transfer and volume strain due to channelized fluid flow. The three profiles are perpendicular to two veins cutting the Wepawaug Schist, Connecticut, U.S.A., which underwent Barrovian-style metamorphism during the Acadian orogeny. Selvages are highly aluminous with considerably more kyanite, staurolite, and garnet, and less quartz, plagioclase, and mica, than surrounding wallrocks. Kyanite crystals increase in size toward veins, and reach several centimeters in length within veins. Mass balance analysis indicates 50% silica loss and 34% volume loss from selvages, on average. Silica, transferred locally from selvages to veins, accounts for 40 to 80% of the vein silica; the remainder must have been precipitated from fluids that flowed through the veins during regional devolatilization. Fluid flow also transported elements into the rock mass, which were concentrated in the selvages. Gains of Fe, Mn, Y, and HREE were due to the growth of selvage garnet; Fe, Zn, and Li were sequestered into staurolite. Kyanite, staurolite, and garnet growth resulted in Al mass gains. Destruction of mica (particularly muscovite) and of plagioclase in the selvages resulted in losses of K, Na, Ba, Pb, Sn, and volatiles and losses of Na, Sr, and Eu, respectively. Thin Na and Sr enrichment zones associated with increased modal plagioclase are found along the margins between selvages and less altered wallrock and may represent either chemical self-organization produced during diffusive mass transfer and reaction, or are relics from a possible earlier period of Na enrichment in the selvages.

Simple, two-dimensional numerical modeling of flow in a fractured porous medium indicates that fluxes vary significantly over short distances (<1 m) adjacent to veins. Fluids, channelized into the high-permeability fracture conduits, carry the bulk of the fluid flow; mass transfer to and from selvages adjacent to the conduits occurred by some combination of diffusion and flow. In contrast, areas distal to the conduits are impoverished in fluid and undergo much more limited infiltration. As a consequence, different workers can come to vastly different conclusions about the magnitude of fluid fluxes and element transfer depending on the part of a fractured outcrop studied. This extreme spatial variability due to channelization can largely explain contrasting views that have arisen in the literature regarding the nature and intensity of non-volatile element mass transfer during Barrovian metamorphism. Determining "average" time-integrated fluid fluxes and levels of element transport across outcrops remains as important research challenges due to the spatial variability of flow.

Keywords: Fluid flow, metamorphism, Barrovian, veins, element mobility, modeling