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FLUIDS IN THE CRUST

Fluids in the crust during regional metamorphism: Forty years in the Waterville limestone

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Abstract

Research over the last four decades on carbonate rocks of the Waterville limestone, Maine, U.S.A., has contributed to the development of both concepts and methodologies for understanding fluid-rock interaction during regional metamorphism, including: (1) buffering of fluid composition by mineral reactions, (2) infiltration of carbonate rocks by aqueous fluids, (3) petrologic fluid-rock ratios, (4) infiltration-driven metamorphism, (5) one- and two-dimensional continuum models for coupled fluid flow and mineral reaction, (6) time-integrated fluid fluxes, and (7) channelized, horizontal fluid flow in the direction of increasing temperature within chemically isolated layers. Disagreement between the last concept and both hydrodynamic models for metamorphic fluid flow and empirical evidence for homogenization of fluid composition at a scale much larger than layer thickness motivated development of the latest models for coupled fluid flow and mineral reaction in the Waterville limestone. The new models consider a flow medium composed of layers that differ in the initial amounts and compositions of minerals, both horizontal flow in the direction of increasing temperature and vertical flow in the direction of decreasing pressure and temperature, significant but imperfect homogenization of fluid composition across layering by CO_2-H_2O interdiffusion, and infiltration by fluids that are spatially variable in composition on the kilometer scale with CO_2 content increasing with increasing grade of metamorphism. The new models reproduce measured progress of the biotite-forming reaction in the Waterville limestone over a range of spatial scales spanning six orders of magnitude, from differences in reaction progress of up to a factor of ~100 between adjacent centimeter-thick layers to the coexistence of mineral reactants and products over a distance of ~13 km parallel to the metamorphic field gradient. Results imply that the present spatial distributions of reaction progress represent a steady state achieved when rocks closely approached equilibrium with the infiltrating fluid during metamorphism. The new models resolve what for many years appeared to be fundamental discrepancies among petrologic data for regionally metamorphosed carbonate rocks, hydrodynamic models of regional metamorphism, and the length scales of mass transport of volatiles across layering by diffusion.

Keywords: Regional metamorphism; fluid-rock interaction; models for fluid flow; reaction progress; Waterville Formation, Maine; Invited Centennial article