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The Mythology of Metamorphic Fluid Expulsion

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Regional metamorphism occurs in an ambiguous rheological regime between the brittle upper crust and ductile sub-lithospheric mantle. This ambiguous position has allowed two schools of thought to develop concerning the nature of metamorphic fluid flow. The classical school holds that metamorphic rocks are inviscid and that any fluid generated by devolatilization is squeezed out of rocks as rapidly as it is produced. According to this school permeability is a dynamic property and fluid flow is upward. In contrast the modern school, selectively uses concepts from upper crustal hydrology that presume implicitly, if not explicitly, that rocks are rigid or, at most, brittle. For the modern school, the details of crustal permeability determine fluid flow and as these details are poorly known almost anything is possible.

Reality, to the extent that is reflected by field studies, offers some support to both schools. In particular, evidence of significant lateral and chanellized fluid flow are consistent with flow in rigid media, while evidence for short ($10^4 - 10^5$ y) grain-scale fluid rock interaction during much longer metamorphic events, suggests that reaction-generated grain-scale permeability is sealed rapidly by compaction; a phenomenon that is also essential to prevent extensive retrograde metamorphism. These observations provide a compelling argument for recognizing in conceptual models for metamorphic fluid flow that rocks are neither inviscid nor rigid, but have finite strength. The surprising result of this strength is that the steady state solutions for fluid flow in porous compacting media require that fluid expulsion is channeled into waves of fluid-filled porosity. The waves develop on a characteristic length scale known as the viscous compaction length, δ, that is also the length scale for lateral fluid flow. In this context, porosity refers to any hydraulically connected void space present on spatial scales $<< \delta$. Thus, porosity waves may be manifest in nature as domains of fluid-filled fractures. Because δ is proportional to rock viscosity and consequently decreases exponentially with increasing temperature, the flow regimes of the classical and modern schools are recovered at high and low temperatures.