



Changing fluid conditions during folding: Implications for deformation mechanisms

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Active deformation mechanisms within deforming rocks are lithology dependant and are controlled by pressure, temperature, and pore fluid chemistry (PTX). During development of macroscale folds, pore fluid PTX conditions do not remain static, but instead vary continually at all points within the deforming fold such that no two points within the fold will have the same deformation/fluid history. For example, one limb may have a different deformation/fluid history than the other limb or the hinge. Similarly, the PTX conditions at a particular point within a fold at initiation of folding will be different than those during folding, or after folding. Fluids may be compartmentalized or be relatively uniform throughout the fold. Detailed fluid inclusion and stable isotope studies in the central Appalachians and in the Sierra Madre Oriental, Mexico provide examples of dynamic fluid systems in developing folds.

The primary factor that controls fluid distribution within a fold is stratigraphy which, in turn, determines hydrologic structure, or the distribution of aquifers and seals. Some units, particularly clastic rocks, are aquifers, while shales and carbonate rocks tend to be seals, resulting in a stratigraphic compartmentalization. Interestingly, seals may be any thickness, and may separate fluid reservoirs of significantly different temperature and/or composition.

The fluid distribution within a fold is also controlled by the connectivity between fluid reservoirs. Poor connectivity results in highly stratified fluids that change little during the development of the fold, while dynamic changes in connectivity may allow influx and mixing of fluids and/or the expulsion of fluids. Factors that affect connectivity are 1) creation of fracture networks, 2) precipitation of vein minerals occluding permeability, 3) dissolution of vein minerals creating permeability, and 4) growth of phyllosilicates in solution structures. The preferential and progressive creation or loss of connectivity on one part of a fold as opposed to another may result in structural fluid compartmentalization that changes over time.

Pore fluid PTX conditions also change during folding. For example, pore fluid chemistry may change as a result of a variety of processes including mineral precipitation/dissolution, fluid mixing, water-rock interaction, and hydrocarbon catagenesis. Fluid temperature may increase linearly with depth, have significant steps across seals or be inverted due to passage of 'warm' fluids through an aquifer. Pore fluid temperature may change due to fluid flux from deeper (warmer)/shallower (cooler) reservoirs and/or meteoric influx, or syn-folding burial or exhumation. Pore fluid pressure conditions may range from hydrostatic to lithostatic and may fluctuate throughout folding. Pore fluid pressure may change due to changing fluid connectivity, syn-folding burial or exhumation, hydrocarbon catagenesis, or seismic pumping.

The presence of fluid in the rock during folding aids in 1) subcritical crack growth, 2) propagation of hydraulic fractures, 3) formation and enhancement of pressure solution structures, 4) hydrolytic weakening of minerals by assisting diffusion processes, and 4) the localization of deformation in high permeability zones.

Although the fluid history of a fold is often complex, it can be unraveled and understood through the combined use of fluid inclusion microthermometry and stable isotope studies of vein minerals. When studying the paleohydrologic evolution of a fold, a comprehensive sampling strategy must be developed. Where regional paleohydrologic systems are heterogeneous, data must be collected from veins in all stratigraphic or lithologic units. Similarly, vein samples must be taken from multiple positions across the fold and from all vein stages, and all paragenetic stages of minerals examined.

