Cementation in Mudrocks: Current Understanding

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Mud buried in the subsurface lithifies to form mudrock, but how? Today, in sandstones, quantitative theory of compaction and cementation is being applied to make predictions of porosity, permeability, and mechanical rock properties in the subsurface. Our current understanding of lithification in mudrocks is not so refined, but petrographic evidence shows that processes analogous to compaction and cementation in sandstones occur in mudrocks. Mudrocks also display some chemical (and possibly mechanical) processes, such as displacive precipitation, that are less commonly observed in sandstones.

Displacive precipitates are authigenic but are not cements in the classic sense of being phases that nucleate on grains and grow passively into primary intergranular pore space, but nonetheless these may represent a significant part of the rock's total authigenic volume and have an impact on the evolution of rock properties. The timing of cementation in mudrocks also contrasts with cement timing in sandstones, with volumetrically significant amounts of cement emplacement in many mudrocks taking place near the sediment/water interface. This early timing leads in some cases to authigenic material that is reworked to form intraclasts, creating a component of authigenic material within the grain volume that is rarely observed in sandstones. Finally, in sandstones precipitation within primary intragranular pores is not typically considered a significant component of the authigenic volume, but in many mudrocks with abundant biogenic debris, this element of cementation is important.

In mudrocks, calcite and Ca-phosphate are authigenic phases that can be demonstrated to form as fillings of intergranular pore space. Both of these peri-depositional precipitates can be subject to reworking. On the scale of an outcrop or core, calcite and Ca-phosphate cementation tend to be highly localized in the form of concretions or hardgrounds. Calcite and dolomite also form displacively within muddy sediments, in the form of isolated crystals with no apparent preferred nucleation sites, and in the form of highly substrate-specific nucleations. Like cements, displacive precipitates in mudrocks tend to have spatially limited distributions in core and outcrop.

Quartz cementation in mudrocks is very poorly understood, yet, is generally held to be a primary control on rock mechanical properties, as it is in sandstones. If the progress of quartz cementation in mudrocks follows the strong thermal-kinetic controls that are observed in sandstones this would generally limit quartz cementation to burial conditions (> 80°) under which compaction is quite pronounced. This late-burial timing may factor significantly into the technical challenge of observing quartz cement crystals within extremely small rock pores. So far, efforts to document quartz cement within rapidly deposited, thick mudrock sequences, for which the associated sandstones contain abundant quartz cement, have generally failed.

An alternative route to authigenic quartz formation, by recrystallization/replacement of opaline skeletal debris, is well-documented in many mudrocks across a range of temperatures generally lower than for quartz precipitated directly from pore fluids without a precursor phase. To date, petrographic observations using a variety of electron microbeam imaging methods have documented an abundance of authigenic quartz within mudrocks that contain such skeletal debris, very little of it being cement in the classic sense. Replacement of sponge spicules and radiolaria, quartz fracture-fillings, and cements within agglutinated skeletal fragments are all readily observed. Cement in the form of minute overgrowths on sand- and silt-size grains is also observed in such rocks. The technical challenge to observation in this case may relate to the fact that many of these overgrowths are nucleated on replaced grains which are themselves composed of authigenic quartz, making the petrographic discrimination of the cement component very difficult.