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The role of stress on chemical compaction of illite shale: An experimental study

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Physical properties of basin sediments are strongly affected by diagenesis. For the case of shale diagenesis, the mechanical processes that dominate in the upper 2-3 km of sedimentary columns have been simulated in the laboratory. In contrast, chemical processes that dominate in deeper basin domains are poorly constrained by laboratory studies. In addition, the effect of tectonic forces has received little attention in physical experiments.

We report on a series of compaction tests in which exposing the sample to well-controlled elevated temperature and pressure conditions relevant to deep basin-simulation activated chemical processes. We prepared our own synthetic samples by compacting illite shale powder into crystalline metapelite using a three-stage process, employing different stress fields to evaluate the effect of tectonic forces on compaction. In the first stage, dry powder (Maplewood Shale, New York, USA) was mechanically compacted in a hydraulic cold-press with a vertical load of 200 MPa. The second stage employed a hot isostatic press (HIP), set at 170 MPa confining pressure and 590 °C, to ensure powder lithification. In the final stage, further compaction was achieved by either repeating the HIP treatment or by performing confined deformation tests in a Paterson-type gas-medium apparatus. During the second HIP event, temperature and pressure were set at 490 °C and 172 MPa. Three different stress fields were applied in the Paterson apparatus: confined compression, confined torsion or isostatic stress. Deformation was enforced by applying a constant strain rate ranging from 7×10-6 to 7×10-4 s-1. Experiments were performed at 300 MPa confining pressure and a fixed temperature of 500 °C, 650 °C, 700 °C or 750 °C. These conditions were chosen based on a thermodynamic forward simulation of mineral stability fields.

Compaction is quantified by connected porosity, anisotropy of magnetic susceptibility and mica texture strength. The synthetic metapelites range from 1.0 to 17.1 % in porosity, reflecting variation in experimental conditions. SEM investigation identifies chemical compaction as an increasing amount of authigenic phengite and biotite, coupled with a decrease in detrital illite and related sub-micron clay-micropores as a function of porosity. Ultrafine (< 2 μm) quartz and biotite form with a shape-preferred orientation, which gives rise to foliation. This microstructure development is ascribed to fluid-assisted mass transfer, which is controlled by permeability anisotropy. The presence of micro-folds and kinks in both isostatically compacted samples, and samples that were compacted by axial compression, is explained by exhausted pore closure. Pore closure is the dominant strain accommodation mechanism in all compressed samples. Magnetic fabric and crystallographic texture show a linear evolution with compaction, regardless of the applied stress field. We observe that differential stress accelerates chemical compaction, without modifying the evolution of fabric and the measured properties, and state that laboratory strain rates did not change the mechanisms of compaction. We conclude that tectonic forces have no effect on the development of magnetic properties and texture in chemically compacting pelites when strain is accommodated primarily by pore closing.