



Fabric development during high temperature and pressure compaction of hot-pressed Rochester Shale

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The transformation of argillaceous sediments to metapelitic rocks involves both mechanical and chemical compaction. During initial burial (up to an effective pressure of 50 MPa but below 100 °C) mechanical processes dominate compaction in terms of porosity reduction and bulk density increase. At higher temperature and pressure, the remaining compaction (defined here as the final 15 % of porosity loss) is accomplished by a combination of chemical and deformational processes, whose relative contributions are poorly understood.

We present new experimental work on porous Rochester Shale powder under elevated temperatures (500, 650 and 700 °C) and pressures (300 MPa) which suggest that mica dehydration (between 650 and 700 °C) plays an important role in this final stage of compaction. The starting material was prepared by crushing and sieving (<150 μm) fragments of Silurian Rochester Shale from Western New York (USA), followed by uniaxial cold press (200 MPa) and hot isostatic press (160 MPa and 590 °C for 24 hr). The resulting aggregates have an effective porosity of 12.5 ± 1.2 % as determined by helium pycnometer analysis, which coincides with the degree of compaction solely by mechanical processes. The microstructure of this hot-pressed Rochester Shale powder is characterized by fine (3-15 μm) equant quartz grains (20-30 vol.%) embedded in a matrix of very fine (< 1 μm) illite and phengite flakes (60-75 vol.%) and oxides (2-4 vol.%). No foliation is visible, which is explained by the much larger grain size and equant shape of the shale powder in comparison with that of the individual phyllosilicates. For compaction experiments at 500 and 650 °C, very high differential stresses (> 600 MPa), independent of strain rate, are required to permanently compact cylindrical samples of hot-pressed Rochester Shale powder (starting porosity of 12.5 ± 1.2 %), a further 2-4 %. Whereas at higher temperatures (700 °C), above the mica dehydration reaction, hydrostatic deformation is capable of compacting the hot-pressed Rochester shale samples by more than 6 %. Uniaxial compression to compact samples to less than 3 % porosity is sensitive to strain rate. For a strain rate of 10⁻⁶ s⁻¹, 400 MPa differential stress is required.

A detailed study to investigate the permanent microstructural and textural consequences of this marked difference in compaction kinetics is in progress, using SEM imaging on both polished and broken surface samples, and X-ray texture goniometry in scanning and transmission mode. A map of finite volumetric strain versus porosity loss is used to categorize samples according to their deformation styles, confirmed by microstructural evidence. Ultimately, a link between deformation behavior and compaction kinetics is attempted.

After the hydrostatic / uniaxial compression tests, we note that in compacted samples with small differences between porosity loss and strain, deformation is primarily accommodated by void space collapse. Conversely, samples with relatively high strain and a low degree of compaction are observed to be prone to fractured quartz grains in addition to collapsed pore spaces. In all compacted samples a foliation developed, albeit irregularly and 'wavy' due to rigid quartz porphyroclasts. Importantly, continuity of the foliation within the whole sample is poor, implying the existence of large stress field heterogeneities within samples during compaction. With increasing temperature and time, we notice that foliation becomes more pronounced, suggesting recrystallization as a key contributor to the developing texture, rather than grain rotation. Based on microstructural observations, we conclude that chemical processes control compaction kinetics with increasing dominance with compaction temperature.