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Mineralogical and Microstructural Variations During Mudstone Diagenesis: Gulf of Mexico and North Sea

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Natural mudstone properties are important since they control how much petroleum can be trapped beneath a mudstone caprock deep in sedimentary basins and they control the isolating capacity of aquicludes in shallow aquifers. The project was planned as a pilot project to investigate the controls and scale-effects of mudstone rock properties. We selected two basins as natural laboratories that had contrasting thermal and burial histories: Miocene mudstones from the rapidly buried Gulf of Mexico and Cretaceous Shetland Group mudstones from the more slowly buried Northern North Sea. Mudstones from a wide range of depths from each basin were chosen to capture changes in properties during burial. These mudstone samples were examined with a wide range of techniques including core analysis, scanning and transmission electron microscopy, X-ray texture goniometry and X-ray diffraction.

It is well known that mudstones, typically rich in the clay mineral smectite at the time of deposition, become progressively dominated by the micaceous clay mineral illite during burial and heating, a form of incipient metamorphism. The samples from the Gulf of Mexico and North Sea conformed to this pattern. More unusual was the conclusion that the compaction experienced in the mudstones occurred over the same depth interval as the transformation of smectite into illite (Fig. 1). Microstructural studies at a range of scales revealed that mudstones, without identifiable fabric (isotropic microstructure) after minimal burial, developed a distinct fabric over the same depth interval that saw the evolution to low porosity and the change from smectite to illite. Image analysis of backscattered electron micrographs using ScionImage proved capable of quantifying the fabric change at a 10 μm scale. Transmission electron microscope analysis, tricky with such low strength samples, revealed that shallow-buried smectite-rich mudstones are dominated by high angle boundaries with attendant microporosity (on the nanometre-scale) while deeper buried illite-rich mudstones are dominated by low angle boundaries (subparallel crystals) with lower microporosity.

The study has revealed that porosity-loss and smectite-illite transformation in mudstones are likely to be interrelated and that they occur at the same time as the formation of well-developed fabrics. These simultaneous changes are unlikely to be coincidental. It is possible that the master variable is the time-temperature dependent mineralogy change that facilitates grain rearrangement and porosity-loss. This novel conclusion will be investigated further to help refine our understanding of the ultimate controls on mudstone rock properties. The long term goal is to be able to predict mudstone permeability for flow modelling at a range of scales in a range of basinal settings from aquifers to oil fields.

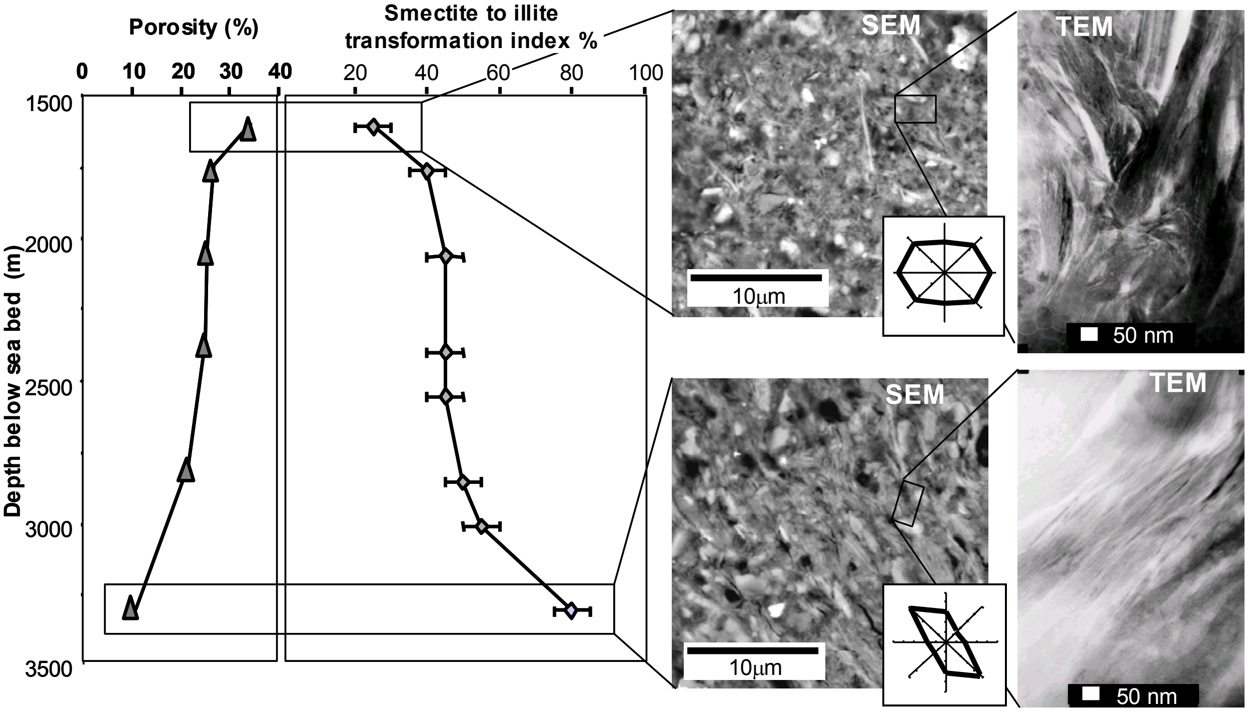

Figure 1 - Comparison of evolution of macroscopic and microstructural characteristics during burial of Shetland Group mudstones from the Northern North Sea basin. SEM images showed a change from a random arrangement of grains at shallow burial to a distinctly preferred orientation that occurred over the same depth interval as the change from smectite to illite (and compactional-loss of porosity). The inset figures give a quantitative measure of anisotropy from image analysis. TEM images revealed details of clay-grain packing with randomly aligned smectite crystals at shallow depths replaced by dominantly aligned illite crystals at great depths of burial.