

Spatial-temporal Boundaries of Shale Diagenesis Inferred from Magnetic Fabrics and Paleomagnetism

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ABSTRACT

The magnetic fabric and paleomagnetism of rocks can provide valuable clues to the mechanisms and timing of diagenetic processes operating in shales. Anisotropy of magnetic susceptibility (AMS) and paleomagnetic studies were performed on cores from the Barnett, Marcellus, Woodford and, Wolfcamp shales.

In general, compaction shapes the magnetic fabric of these shales with the long axis of grains oriented parallel to the bedding plane with oblate shapes. Interestingly, within certain lithofacies, punctuated degrees of magnetic anisotropy with relatively consistent bulk susceptibility values occur. These signatures are inconsistent with a linear compaction profile and could reflect episodes of compactional disequilibrium or diagenetic alteration. Sub-vertical fabrics with predominantly prolate shapes occur in horizons with elevated ferroan carbonate fractions, pervasive mineralized fracture networks and diagenetically altered facies.

Magnetic susceptibility values and high-field experiments suggest paramagnetic minerals (e.g. phyllosilicates, ferroan carbonates) control the AMS signals. Microstructural observations suggest the origin of sub-vertical fabrics in the Marcellus are caused by particulate flow and brecciation. The Woodford shale shows near vertical fabrics associated with pervasive mineralized fracture horizons. X-ray computed tomography (XRCT) confirm the origin of these fabrics are largely controlled by these microstructures. A high resolution AMS and hand-held X-ray fluorescence (HHXRF) dataset from cores in Wolfcamp Shale suggest strong compositional controls on AMS fabrics. High anisotropy fabrics generally contain elevated K and AI, suggesting these fabrics are controlled by clay minerals. A good correlation is observed between bulk susceptibility and Fe/S ratio indicating that sulfides do not significantly control the AMS fabric. Sub-vertical fabrics correspond to diagenetically altered facies showing widespread chertification and dolimitization. XRCT scans show pervasive barite filled fracture networks associated with sub vertical AMS signatures. These mineralized fractures are interpreted to have displaced the precursor fabrics.

Paleomagnetic studies reveal chemical remanent magnetizations (CRMs) in most of the shales studied. Barnett specimens from oriented cores were collected around northeast/northwest oriented vertical mineralized fractures for vein contact tests. The specimens around the fractures veins contain late Permian to Triassic CRMs in magnetite which are interpreted to date the timing of fluid migration in the veins. Virtinite reflectance and geochemical data from vein minerals suggest the CRMs in the Barnett could be related to fluids sourced from the Ouachita front. Marcellus specimens from an unoriented core contain a CRM in magnetite with shallow inclinations which corresponds to 285-305 Ma based on a comparison with the expected inclinations for the study location. Preliminary paleomagnetic data from the Wolfcamp indicate a

single low temperature component likely residing pyrrhotite. Steep inclinations suggest that this is a modern drilling induced magnetization (DIRM). The absence of an ancient magnetization could be related low burial temperatures (inferred from vitrinite reflectance) that inhibited precipitation of authigenic, remanence carrying minerals like magnetite. The paragenesis of the Woodford is also complex with extensive veining and brecciation as well as evidence for multiple fluid-flow events. Evidence for hydrothermal alteration includes unusual minerals such as magnesite and witherite. Samples taken from an unoriented Woodford core show evidence of a DIRM retained in low-stability magnetite as well as a CRM with both normal and reversed steep directions that is Cretaceous to Cenozoic in age. It is interpreted as forming from either hydrothermal fluid alteration or burial diagenesis. A third component found in both Woodford outcrop and core samples has a shallow-inclination that is Permian to Triassic in age, and is interpreted as a CRM held in magnetite resulting from burial diagenesis.

Integrated AMS and paleomagnetic studies have shown complex fabric genesis and magnetizations in all of the shales. This study demonstrates how these techniques can better constrain spatial-temporal boundaries of shale diagenesis and ultimately, gain a better understanding of reservoir quality and basin evolution.