Silt in Mudrocks as a Paleoenvironmental Indicator and Characteristic Fabric Element

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ABSTRACT

Mudrocks are characterized by nanometer-scale pores within a matrix comprising mud-sized (<20 m diameter) material, surrounded by the "framework" of silt-sized (2-63 O m diameter) grains that make up mudrocks whose characteristic fracture spacing is on the order of centimeters to meters. Despite the wide range of scales, silt grains may partly govern porosity distribution and even permeability, as they can distribute stresses around the pores. Moreover, some have argued that silt-sized grains may be used as proxies for paleoenvironmental conditions. Based on studies of deep-marine sediments, grain size in such fine-grained materials tends to follow a lognormal distribution that results from cohesion between grains as they are mobilized by bottom currents and then resettled from suspension. With each increment of sediment transport, the mean grain size decreases, resulting in a local predominance of sortable silt (10-63 O m) whose abundance reflects the hydrodynamic system at a given time. As these sediments are buried, particles rotate into a bedding-parallel fabric with compaction, initially closing, and then protecting porosity. Therefore, silt size, shape, and orientation is directly connected with both the geological nature of a mudrock formation, and the hydrogeology and geomechanics of the pore-grain system.

There is, however, little knowledge of the basic properties of silt grains in natural mudrocks because these formations are too indurated for analyses that require disaggregation, the commonly used technique to study sedimentary materials. This technical challenge is compounded by the non-unique depositional settings that can lead to a wide variety of mudrock sedimentary structures and compositions. Compositional diversity in particular is striking, encompassing silicate- and carbonate- dominated silt-clast assemblages of both biologic and abiologic origins, a range of organic materials, and an equally diverse clay-size detrital and authigenic "matrix". In an effort to overcome these obstacles, we conducted a quantitative scanning electron microscope petrographic study of polished thin sections.

Our method produced data on 16,225 grains in samples from three different formations reflecting a wide range of tectono-sedimentary environments, burial depths, and compositions. The formations/members included core-samples from the Bexar and Pine Island Members of the Pearsall Formation, the Barnett Shale, and outcrop samples from the Marcellus Formation. Though we know recovery depths only for the Pearsall Formation, the samples reflect a range of burial depths inferred from thermal maturities which increase, in general, from Pearsall to Barnett to Marcellus. Similarly, detrital compositions of the three formations are variable, with a range of total organic content (TOC), and variable amounts of carbonate in the Pearsall and Marcellus and predominantly silicate detritus in the Barnett.

We found that the samples are all moderately well-sorted (following the criteria of Folk, 1957) with silt contents ranging from 20 to 38%. All samples have a peak in a probability density function of diameter between 2.7 and 4.4 O m, exponentially tailing off > 100 m; area is also described by a similar lognormal probability density function. The variance in grain size distribution does vary between formations (as better

viewed in a phi-diagram), with Marcellus having the tightest distributions (± 3.3-3.7 O m), Barnett a modest range (±3.4-4.1 O m), and the Pearsall the widest (±4.4-2.7 O m).

We also considered the shape and orientation of grains. The preferred orientation of the grains' long axes is also relatively uniform across the sample suite. The grains have aspect ratios of 0.6 (±0.2, Ia), a well- known ratio for silt-sized detrital quartz grains, but we find this aspect ratio also holds for feldspar, calcite, and dolomite. The long axes of the grains are scattered in orientation within ±36° of the bedding-parallel compaction-induced foliation. Within that foliation the grains are dispersed, defining no lineation.

Though there are some differences in grain-size distribution between samples, and a contact-area study (not shown) suggests that there is some compaction with depth across the sample suite, we suggest that, overall, the silt grains have characteristic sizes, shapes, and orientations across these diverse depositional environments, grain compositions, and burial depths. We suggest that the characteristic grain size indicates that sediment reworking has brought the mean and maximum grain sizes to below that which is sensitive to successive episodes of sediment transport, leaving behind the sortable silt and coarser grain fractions in other deposits, however proximal or distal. The fact that we find all of our samples to have essentially the same silt microtexture regardless of paleo-burial depth, and even regardless of silt percent, suggests that the March-model behavior (rotation of grains with compaction) and silt-bridge development occurs in the top few hundred meters burial depth, if not much shallower, and subsequent porosity collapse is primarily via chemical diagenesis. Thus, depositional and burial processes bring grain size and orientation distributions to "steady-state" thereby creating underlying length scales and anisotropy that likely govern geological and geophysical measures of mudrock lithologic properties.