Identifying biogenic silica: Mudrock micro-fabric explored through charge contrast imaging

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**ABSTRACT**

Visual inspection (optical microscope point counting) and silica abundance show that laminated shale from the Late Cretaceous of Colombia contains high levels of detrital quartz silt and sand particles. Closer examination using the charge contrast imaging (CCI) technique, however, illustrates that much of the quartz is authigenic micro-quartz, and thus not exclusively of detrital origin. In addition, many “sand” grains that otherwise appear to represent simple detrital quartz particles are actually of biogenic origin, representing the tests of agglutinated foraminifera, formed from cemented silt-sized quartz particles. Finally, CCI shows that original detrital grains have undergone authigenic modification, with both syntaxial overgrowths and micro-quartz. Without recognition of these features, the relative proportion of detrital quartz (sand) would otherwise be greatly overestimated, with important implications for environmental interpretation. Furthermore, the recognition of biogenic structures, including agglutinated foraminifera, provides additional environmental information that otherwise could be easily overlooked.

**Keywords:** Shale, silt, quartz cementation

**INTRODUCTION**

Mudrocks represent approximately 65% of the stratigraphic record on continents (Ibbeken and Schleyer 1991) and are a significant proportion of marine sediments (Blatt 1970; Ibbeken and Schleyer 1991). They are economically significant, representing sources and seals for hydrocarbon resources (Al-Bazali et al. 2005; Olabode et al. 2012) as well as potential seals for carbon dioxide storage/carbon sequestration (Olabode et al. 2012) and can contain metal enrichments up to low grade ore levels (Anjum et al. 2012). Although superficially simple and supposedly homogenous, mudrocks are highly variable at the micro-scale in terms of composition and texture (see examples in Camp et al. 2013; Milliken 2014; Milliken et al. 2016) documenting the complex overlying/integrated effects of dynamic primary depositional conditions and post-depositional diagenetic alteration. Comprising a wide range of dominantly clay-size clay minerals (smectite, illite, kaolinite), they also feature varying contents of silt and sand particles (quartz, feldspars, and micas), organic matter (charcoal, kerogen, bitumen, phytoclasts), and siliceous and calcareous micro-skeletal materials (diatoms, radiolaria, foraminifera, etc.). Fabric can range from massive to fissile (mudstone vs. shale), and at the microscopic level, porosity/permeability, clay mineral composition and orientation can be drastically altered through diagenesis during burial, including the formation of authigenic phases such as calcite, quartz, pyrite, marcasite, and iron-oxides. Mudrocks therefore provide a significant repository of information regarding the depositional environment and subsequent diagenetic changes through time, with their study becoming an increasing focus of research (Bennett et al. 1991; Camp et al. 2013; Lazar et al. 2015).

The present study illustrates detailed results from charge contrast imaging (CCI) performed on a Cretaceous marine shale that has undergone substantial modification through massive authigenic quartz induration. The content of quartz “sand,” defined as quartz grains of 63 μm to 2 mm in diameter, in the shale had previously been estimated based on Si content from XRF, XRD of the >2 μm fraction, and optical microscope point counting of sand-sized grains in thin-section. Examination by scanning electron microscopy (SEM) illustrates that much of the original depositional information has been masked by pervasive silicification of the shale, a feature that is not obvious from examination of hand specimens, thin-sections or element abundance patterns, therefore leading to gross overestimation of the original sand fraction.

We tested a low-vacuum SEM technique of CCI to elucidate valuable information concerning the original depositional conditions of this shale. CCI has previously been shown to have applications on a range of other geological materials, where it has been utilized to illustrate crystal zoning, authigenic overgrowths, cement fabrics and healed fractures (Watt et al. 2000; Doehne and Carson 2001; Cuthbert and Buckman 2005; Buckman et al. 2016). The technique is comparable to cathodoluminescence within the SEM (Griffin 1997, 2000; Buckman et al. 2016), with contrast being controlled by differences in surface conductivity through subtle variations in composition and structural defects.

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