Sedimentary Geology 331 (2016) 162–169

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Experimental testing of the transport-durability of shale lithics and its implications for interpreting the rock record

Juergen Schieber *

Department of Geological Sciences, Indiana University, Bloomington, IN 47405, USA

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form 11 November 2015
Accepted 15 November 2015
Available online 19 November 2015

Editor: Dr. B. Jones

Keywords:
Shale
Mudstone
Shale lithic
Sediment transport
Shale fabric
Depositional history

ABSTRACT

Detailed petrographic studies of shales show that they consist of a wide range of components, including a wide spectrum of composite particles that were contributed to the precursor muds in the form of high-water-content suspended floccules, bedload floccules, rip-up intraclasts, pedogenic aggregates, and fully lithified shale clasts. Experimental studies show that shale clasts of sand to silt size (shale lithics) can survive hundreds to thousands of kilometers of bedload transport. Observations of modern river and shelf muds reveal the common presence of shale lithics in these sediments, and suggest that a significant portion of ancient shale formations could potentially consist of reworked shale lithics and not, as commonly assumed, of primary composite particles such as clay floccules and organo-minerallic aggregates. Identification of shale lithics in the rock record presents challenges, but careful petrographic examination (using SEM and ion-milled samples) and case studies will help to develop robust criteria for recognition.

The presented observations have manifold implications for the interpretation of many aspects of shales: mud transport and accumulation, sediment compaction and basin-fill modeling, and geochemical proxies. They emphasize the essential need for petrographic examination of shale samples before more advanced analyses are undertaken.

1. Introduction

The purpose of this study is to evaluate how far shale lithics might travel before they disintegrate, and what their potential contribution to fine-grained successions in the rock record might be. Muds are a very common sediment on the earth surface (Potter et al., 2005) and the precursors of fine grained clastic sedimentary rocks that are commonly known as shales or mudstones (I will use the widely used term shale for the remainder of this article). Shales constitute approximately 2/3's of the sedimentary rock record (Potter et al., 2005) and their constituents are derived from weathering and erosion of the landmasses and transported to the ocean basins by river systems that drain the continents. It is generally thought that the main source of mud constituents are soils where the underlying bedrock has been weathered to a mixture of resistant minerals (quartz, feldspar, etc.), clay minerals, and colloids (submicron size particles). Soil erosion delivers small mineral fragments (<62.5 μm), clay minerals, and colloids to rivers where, due to their small size, they travel in turbulent suspension until they are deposited in lakes and ocean basins (Potter et al., 2005).

Thus, when considering the origin of these rocks, the general assumption is that their constituents arrived at their site of deposition in finely dispersed form, and then were deposited through a combination of gravitational settling and flocculation (from river plumes), redistributed across basin floors by waves and currents (Schieber, 2011), and followed gravitational forces on slopes in the form of liquid muds and mudflows (Potter et al., 2005). Yet, whereas this is the common perception, recent studies of the rock record show instances where fine grained sedimentary successions appear to contain a significant amount of silt size particles that originated through the weathering and erosion of shale outcrops (Plint et al., 2012; Schieber and Bennett, 2013; Plint, 2014; Schieber, 2015). Pieces of other rocks that have been broken down to sand and silt size sedimentary particles have previously been described as "lithics" (Pettijohn, 1954; Williams et al., 1954; Dickinson, 1970), and the particles discussed in this paper are therefore referred to as shale lithics.

Internally, shale lithics are similarly fine-grained as the clays and silt grains (quartz, feldspar) they are deposited together with (Fig. 1). Thus, once a mud with shale lithics has been compacted, the lithics themselves could easily blend in with the clay rich rock matrix. It is therefore plausible to envision a rock that originated as a deposit dominated by sand-size shale lithics, yet would be classified as a shale when encountered in outcrop or drill core millions of years later. Whereas the original sand-size material was likely deposited by strong currents in bedload (like typical sands), the resulting deposit might be interpreted as a bioturbated shale and the overall environment considered of comparatively low energy. Also, unlike typical surface muds that have a high

* Fax: +1 812 855 7899.
E-mail address: jschiebe@indiana.edu.

http://dx.doi.org/10.1016/j.sedgeo.2015.11.006
0037-0738/

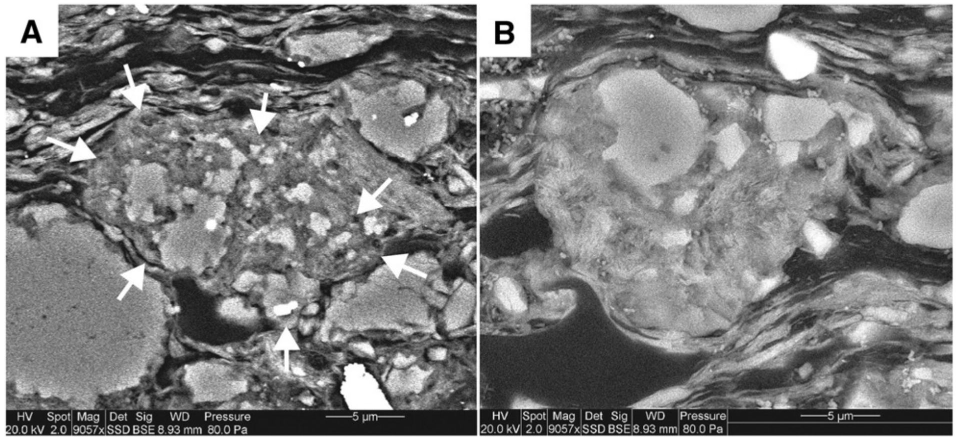

Fig. 1. SEM images (backscatter) of fine grained clasts (shale lithics) in Devonian black shales of the eastern US. (A) Shale clast (marked with arrows) with angular outline in the New Albany Shale of Indiana. Note differential compaction in the surrounding shale matrix. (B) Shale clast with rounded outline from the Chattanooga Shale of Tennessee. Note differential compaction of the surrounding shale matrix. In both cases (A + B) differential compaction indicates that the clasts were solid particles (firm, consolidated) at the time of deposition, and as such are bona fide shale lithics. Given their small size they cannot be detected with a petrographic microscope. A scanning electron microscope (SEM) is needed. In these examples the lithics contrast sufficiently with the matrix to be detectable, but in a matrix with less compositional contrast detection would be more difficult.

initial water content (e.g. Schimmelmann et al., 1990; Bennett et al., 1991) and undergo substantial compaction upon burial (Kominz et al., 2011), shales with abundant shale lithics (with lithics being already fully compacted) would experience much less compaction during burial. Not knowing about the shale lithic component could potentially upset estimates of reconstructed burial depth and lead to strata with “abnormal” thermal maturity that could be of considerable interest in hydrocarbon exploration. Shales with a substantial component of recycled shale lithics may also give erroneous results with regard to geochemical and mineralogical proxies for provenance, environmental parameters, and past climate. The purpose of this study is to evaluate how far shale lithics might travel before they disintegrate, and what their potential contribution to fine-grained successions in the rock record might be.

Shale lithics are composites of smaller mineral grains (clays, quartz, feldspar), and they are just one of a whole spectrum of composite grains that have a part in mud deposition. At the water-rich end of the spectrum are floccules, composite particles that consist of micron size clay minerals and other small particles and are held together by van der Waals forces. These floccules can range in size from a few ten to several hundred microns (Bennett et al., 1991; Schieber, 2011) and have water contents on the order of 85% or more. Organo-minerallic aggregates are common in marine pelagic environments (e.g. Fowler and Knauer, 1986), and depending on size also go by descriptors like “marine snow” (>0.5 mm) and phytodetritus (<0.5 mm). They consist of a mixture of mineral matter, bacteria, microorganisms, fecal pellets, and skeletal debris that is held together by bacterially secreted extracellular polysaccharides. Their water content is similar to that of floccules. Fecal pellets are produced by animals in the water column and within the sediment, can consist of a mixture of organic materials (shell fragments, tissue debris, etc.) and sediment grains (silt, clay etc.), and typically range in size from several ten to several hundred microns (Flügel, 2004). Their water content is lower than that of floccules (~70–75 %) but still rather high. Mud intraclasts, produced from erosion of surficial muds, are irregular shaped to rounded and their size ranges from silt grade (10's of microns) to several centimeters (Schieber et al., 2010). Depending on how deep erosive events remove the substrate, the water content of eroded mud intraclasts can be as high as 85%, although clasts with lower water contents are generally less likely to disaggregate in transport (Schieber et al., 2010). Pedogenic aggregates (Rust and Nanson, 1989; Wright and Marriott, 2007), and reworked alluvial mud crusts (Nanson et al., 1986) have still lower water contents, generally in the 30 to 40% range (Peverill et al., 1999), and are variably shaped particles that range from sub-mm to cm's in size. Composite grains of this origin occur in modern surface environments in association with soil forming processes and desiccation on floodplains (e.g. Nanson et al., 1986; Rust and Nanson, 1989; Wright and Marriott, 2007), and when transported these grains give rise to bedload transported mudstone intervals in fluvial successions (e.g. Wright and Marriott, 2007). These soil and floodplain derived composite grains are rather friable and flume studies suggest that they are not durable enough to survive long-distance transport (Smith, 1972; Maroulis and Nanson, 1996) beyond a few kilometers downstream distance. Shale lithics, solid pieces of fully consolidated rock, form the other (low water content) end of the spectrum. They are derived from weathering of shale outcrops, range in size from microns to mm's, and have low water contents (typically less than 5%).

Water content determines the degree of “flattening” that these particles experience as a consequence of compaction. Water-rich types (floccules, organo-minerallic aggregates, fecal pellets) are flattened to a high degree during compaction, may be squeezed and deformed between other grains, and in many instances can be difficult to differentiate from the shale matrix. The same is true for high water content intraclasts, unless the clasts differ significantly in texture and composition from the shale matrix. Even the relatively low water content soil aggregates are likely to suffer vertical shortening and deformation once buried. Shale lithics on the other hand, being solid rock already, are not likely to compact, although they may show deformation when squeezed between hard grains (quartz, feldspar, etc.) as shown below in Fig. 9. Once a lithic-rich sediment has again been turned into rock, it may not be readily apparent that it is a collection of shale lithics rather than for example a bioturbated shale.

It is the objective of this paper to show (A) that shale lithics should be a common component of fine grained sedimentary rocks; (B) to quantify their ability to be transported over large distances; and (C) to provide some initial criteria to identify them in the rock record. In addition to earlier mentioned criteria (fabric discordance), recognition may be facilitated when a mixture of shale lithics from multiple sources is deposited in the same bed and provides contrast, or if differential compaction around shale lithics points to their already compacted/lithified nature (Schieber and Bennett, 2013; Schieber, 2015).

2. Methods

Shales vary widely in composition and mechanical strength. In order to understand how far shale lithics can travel at a minimum before they