Marine and Petroleum Geology 71 (2016) 119–133

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Review article

Mud re-distribution in epicontinental basins – Exploring likely processes

Juergen Schieber

Department of Geological Sciences, Indiana University, USA

A R T I C L E I N F O

Article history:
Received 30 October 2015
Received in revised form
9 December 2015
Accepted 18 December 2015
Available online 21 December 2015

Keywords:
Shale
Deposition
Transport process
Epicontinental
Mud
Mudstone
Shallow marine

A B S T R A C T

Fine grained clastic sediments are very common in the interior deposits of ancient epicontinental seas. Not only do they make up the gross lithology in these basins, but they can also be traced for more than 1000 km offshore from basin margins. Given that epicontinental seas were overall shallow and in many parts most likely less than 100 m deep, basin floor slopes can safely be expected to be in the 0.01 to 0.001° range for much of depositional history. Known processes that bring muds to the basin margin and beyond are hypopycnal river plumes, hyperpycnal fluvial discharge events, storm-setup relaxation flows, and gravity-driven fluidized muds. With the exception of river plumes, all of these processes require the presence of sufficient slope for sustained movement. Due to that constraint, these processes combined might in the majority of situations have been able to move muddy sediments on the order of 100 km offshore. Whereas this is sufficient to distribute mud across marginal shelf seas, it becomes problematic in the case of much larger epicontinental seas. For example, those of Upper Devonian or Upper Cretaceous times extended in places for thousands of kilometers, and thus a process is needed that can move muddy sediments the rest of the way. Flume studies of the bedload transport of mud, combined with observations from the rock record, suggest that wind or tide induced bottom current circulation was most likely essential for moving muddy sediments from the periphery of epicontiental seas to their interiors. Remobilization of seafloor muds during frequently recurring lowering of sea level is likely to have aided in this process.

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E-mail address: jschiebe@indiana.edu.

http://dx.doi.org/10.1016/j.marpetgeo.2015.12.014

1. Introduction

Historically, a large portion of research in sedimentary geology and paleontology was conducted on sedimentary successions that were laid down in expansive epicontinental (or epeiric) seas (Shaw, 1964; Irwin, 1965; Hallam, 1975), and the processes that operated within them to circulate water and spread sediments are intricately linked to continued evolution of marine organisms and their preservation in the rock record. In addition, these successions constitute an archive of environmental change through time and are critical for understanding earth history. In order to best "read" this archive, understanding how it functions as a sedimentary "recording unit" is clearly desirable.

As defined by Johnson and Baldwin (1996), epicontinental seas are partially enclosed shallow seas within continental areas, and form large expanses when the oceans flood substantial portions of the continents. This happened multiple times over geologic history (e.g. Sloss, 1963), and the minimum to maximum sea level range most likely did not exceed 200 m at the extreme (e.g. Vail et al., 1977). Because there are no good modern analogs of epicontinental seas, much of what we currently know about them is a matter of reading the rock record and extracting process information from the sedimentary structures we observe. Going as far back as Hutton (1788), Hall (1859) and Grabau (1906), geologists had noted that epicontinental marine strata contained abundant evidence of shallow water conditions, such as wave ripples, mud cracks, and shallow water organisms. Because part of the aforementioned depth range (Vail et al., 1977) has to be expended to flood the continental margins (modern shelf seas, marginal seas, pericontinental seas) it stands to reason that the maximum water depth of epicontinental seas is likely only part of that range and probably only tens of meters over large areas (Shaw, 1964). Due to the fact that epicontinental strata are host to significant portions of the world's fossil fuel reserves (coal, natural gas, oil) these rocks have been extensively studied and there are rich data sets on stratigraphic patterns and lateral extent of sedimentary units. The economically driven needs for accurate stratigraphic correlation and the wealth of accumulated data led to geologically very well reasoned accounts of what the epicontinental seas of the past must have been like, notably those of M.L. Irwin (1965) and A.B. Shaw (1964). In his classic book "Time in Stratigraphy", discussing stratigraphic principles and correlation methods, Shaw (1964) compiled a highly useful conceptual view of the likely processes and boundary conditions that determine sedimentation patterns in epicontinental seas, and I shall refer to those repeatedly in the course of this exploration of mud transport across the expanses of ancient epicontinental seas.

Epicontinental seas differ from modern shelf seas by showing great lateral extent that at times must have been on the order of several 1000 km's (Shaw, 1964), and consequently they had comparatively small regional bottom slopes. Whereas modern shelf seas show average bottom slopes in the 0.02–0.1° range, ancient epicontinental seas probably had bottom slopes in the 0.001–0.005° range over large areas (Shaw, 1964; Johnson and Baldwin, 1996), although locally steeper slopes may have occurred. A condition for the formation of extensive epicontinental seas is that there is little topographic relief over large areas prior to sea level rise, because otherwise flooded river valleys and estuaries would result from marine transgression. Therefore, the resulting seabed should not only be shallow, but also rather flat. This is why large stable cratons of the Neoproterozoic and the Phanerozoic era, characterized by large expanses of nearly flat lowlands, were the places where extensive epicontinental sea deposits accumulated in the past (Shaw, 1964; Pratt and Holmden, 2008).

Shallow water deposition and almost negligible bathymetric relief led to accumulation of thin but laterally extensive blankets of sediments in epicontinental seas (Shaw, 1964), although the latter also contained areas of uplift or subsidence that are commonly referred to as domes and basins. Especially during orogenies, thrust loading led to formation of foreland basins (DeCelles and Giles, 1996) with much larger sediment thickness (high rates of subsidence and eventual sediment accumulation) that merged laterally into extensive thin sediment blankets that accumulated in more slowly subsiding portions of the continents. In North America, good examples

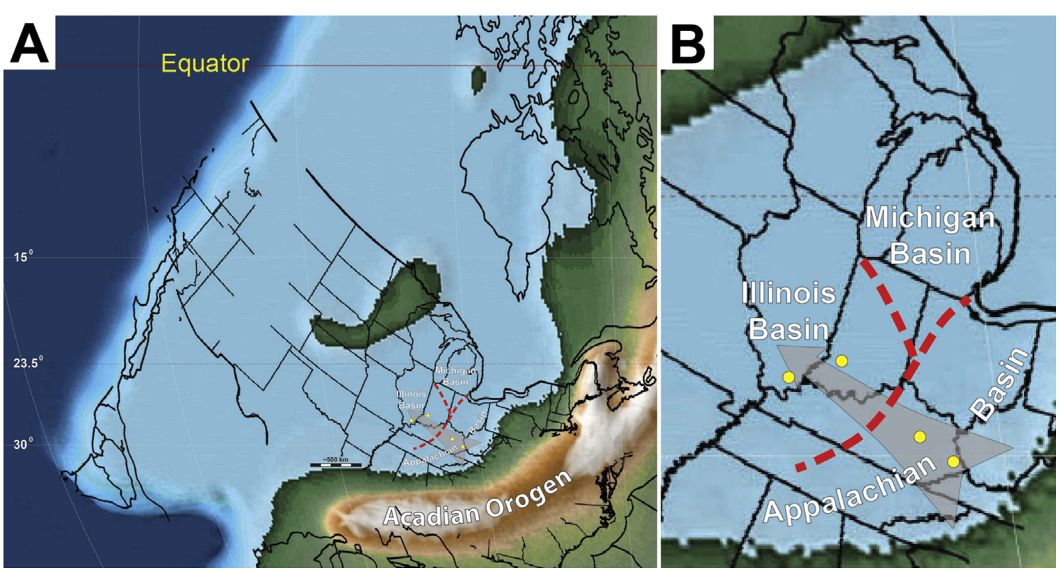

Fig. 1. (A) Paleogeography of North America in the Upper Devonian (Scotese, 2014), showing a wide expanse of shallow shelf (light blue) that extended for 1000's of kilometers. (B) Detail view from the eastern portion of this sea that shows positive elements (arches) as dashed red lines, and the general locations of the Appalachian Basin (foreland basin) and adjacent basins. All these basins contain expanded sections of Upper Devonian strata, with the Upper Devonian section in the Appalachian Basin approaching 2000 m thickness (Milici and Swezey, 2006). The yellow dots mark locations for Fig. 13, and the gray arrow stands for sediment dispersal from the Appalachian Basin, across the Cincinnati Arch, into the Illinois Basin. Scaling information from state outlines and scale bar (approximate). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)