ARTICLE IN PRESS
PALAEO-08355; No of Pages 18
Palaeogeography, Palaeoclimatology, Palaeoecology xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Palaeogeography, Palaeoclimatology, Palaeoecology
journal homepage: www.elsevier.com/locate/palaeo

Stratigraphy and depositional environments of the Mesaverde Group in the northern Bighorn Basin of Wyoming

Gordon Adams [a,*], Christopher R. Fielding [a], Francisca E. Oboh-Ikuenobe [b]

[a] University of Nebraska, Department of Earth and Atmospheric Sciences, Lincoln, NE 68588, USA
[b] Missouri University of Science and Technology, Department of Geosciences and Geological and Petroleum Engineering, Rolla, MO 65409, USA

ARTICLE INFO

Article history:
Received 27 July 2016
Received in revised form 1 July 2017
Accepted 6 July 2017
Available online xxxx

Keywords:
Sedimentology
Palynofacies
Multivariate statistical analysis
Paleoenvironmental interpretation
Integrated methodology

ABSTRACT

Using single stratigraphic methods in the geological analysis of incompletely or poorly exposed sedimentary successions can lead to non-unique interpretations and increased potential for error. In this study of the Mesaverde outcrops (Eagle Formation, the Claggett Tongue of the Cody Shale, and the Judith River Formation) in the northern Bighorn Basin of Wyoming, which has limited and variable quality exposures, an integrated method utilizing sedimentological, ichnological, and palynological data was used in order to overcome these limitations. Ten facies are identified within the exposures examined. These facies are arranged so as to depict a broadly distal to proximal gradient recording the progradation of fluvial-dominated deltas into a shallow marine environment. The utilization of a Zobaa Ternary Plot and Calgary and Brown factor analysis (CABFAC) for palynofacies analysis in the study allows for corroboration of the lithological interpretation, which has not been possible in previous studies of correlative outcrops. It also enables the identification of environmental trends not seen in the lithological analysis, thus allowing for a more robust stratigraphic analysis. The methods used in this study not only decrease the inherent error in paleoenvironmental analysis of poorly exposed areas and thereby decrease variability in paleoenvironmental interpretations, but also allow identification of changes that are not evident from a single method approach. The result of utilizing this approach in areas of limited or poor quality exposure is a more comprehensive and well-informed regional stratigraphic framework.

1. Introduction

Reliable environmental interpretation is vital in stratigraphic interpretation and hydrocarbon exploration. The quality, degree of resolution and reliability of the environmental interpretation is heavily dependent on the quality and extent of available data. In partially exposed or highly weathered surface sections there is a risk that key information may be obscured. In such situations, using a single method of analysis raises the risk of making incorrect or incomplete interpretations. By integrating lithofacies and palynological methods, including multivariate statistical analysis, the interpretational error is greatly reduced, resulting in less uncertainty in depositional environment interpretation and producing a more coherent regional stratigraphic framework. Integrated methodologies have been used previously to great effect with a quantitative focus on single linkage cluster analysis and principal components analysis (e.g., Oboh-Ikuenobe et al., 2005). By incorporating a Calgary and Brown factor analysis (CABFAC) (Klovan and Imbrie, 1971) and a Zobaa Ternary Plot (Zobaa et al., 2015) in this study, the correlation accuracy and reliability is increased, making it possible to detect underlying environmental factors not evident from lithologic or other quantitative analyses, even in areas of limited sporomorph diversity.

The Mesaverde Group in the Western Cordilleran Foreland Basin of North America is an economically important stratigraphic unit and has played a key role in the formulation of genetic stratigraphic models of the Cretaceous successions of the Rocky Mountain Region (Severn, 1961; Martinsen et al., 1995; Kieft et al., 2011). The numerous component formations are not only known to host coal, which has been extensively mined, but also large quantities of shallow biogenic gas which has become of interest in hydrocarbon exploration in recent years (Talbot, 1996; Condon, 2000; Johnson et al., 2005). The Mesaverde Group in the northern Bighorn Basin was selected for this study due the varying exposure quantity and quality, and the presence of a mix of sandstone and mudstone allowing for the extraction of palynofacies samples. While the Mesaverde Group as a whole has been intensively studied, only local studies have been undertaken in the outcrop belt within the Bighorn Basin. The aim of this study is to show that when palynological methods are integrated with classic sedimentological methods, interpretation is improved, resulting in enhanced identification of depositional environments in poorer quality exposures which would not be

* Corresponding author.
E-mail addresses: gordon.adams@huskers.unl.edu (G. Adams), ikuenobe@mst.edu (F.E. Oboh-Ikuenobe).

http://dx.doi.org/10.1016/j.palaeo.2017.07.005
0031-0182/

obvious through a single method. The result is a more complete depositional environmental and stratigraphic analysis illustrating the utility of integrating sedimentological and palynological data towards a more informed paleoenvironmental interpretation of the rock record.

2. Geological setting

The Bighorn Basin is a Laramide (Cenozoic) ponded basin surrounded by basement-cored mountain ranges and it preserves a thick Cretaceous succession (Lawton, 2008). The Cretaceous succession was formed in the broader, north-south-elongate, retroarc, Western Cordilleran Foreland Basin during the earlier Sevier Orogeny (Fig. 1) (Fitzsimmons and Johnson, 2000). The Mesaverde Group accumulated within the Cretaceous Western Interior Seaway during the Late Cretaceous (Campanian to Maastrichtian), approximately 83–76 Ma (Gill and Cobban, 1966). The timing of the Mesaverde Group accumulation is constrained by the presence of well-dated ammonite biozones and numerous dated ashfall deposits (Obradovich, 1993). The base of the Mesaverde falls within a biozone defined by *Scaphites hippocrepis* (82.7 Ma) and the top by *Baculites cuneatus* (73.91 Ma) (Gill and Cobban, 1973; Obradovich, 1993; Cobban et al., 2006) (Fig. 2). The stratigraphic history of the Mesaverde Group is characterized by Severn (1961), as two major progradational events during which deltaic systems prograded eastward into a shallow-marine basin. In contrast, Fitzsimmons and Johnson (2000) characterize it as four third order sequences bounded by four major basinward dislocations. The sands were derived from the erosion of the Sevier Orogenic Belt to the west of the basin (Fig. 1) (Jacka, 1965). The resulting succession within the study area is composed of the Eagle Formation, the Claggett Tongue of the Cody Shale, and the Judith River Formation (Fig. 2).

The Eagle Formation conformably overlies the Cody Shale and ranges in thickness from 20 m (Rice and Shurr, 1983) to 152 m (Condon, 2000). It consists of the basal Virgelle Sandstone and the upper Gebo Member (Fig. 2). The lithology of the Virgelle Sandstone is fine- to medium-grained sandstone coarsening upwards with well-defined bedding that changes from hummocky cross-stratified and parallel/flat-stratified at the base to trough cross-bedded near the top (Rice and Shurr, 1983; Condon, 2000). Thin shale and siltstone beds are also present throughout (Severn, 1961; Condon, 2000). The lithology of the Gebo Member comprises carbonaceous shales, claystones and thin lenticular sandstones (Severn, 1961; Swift et al., 2008). In addition, Fitzsimmons and Johnson (2000) and Swift et al. (2008) identified local, thicker sandstone beds. Depositional interpretations for the Eagle Formation vary greatly. Rice and Shurr (1983) interpreted the Virgelle Sandstone as having been deposited in a marine shoreface where sediment was transported by wave action. They also noted that the Gebo Member recorded a coastal interdeltaic setting along a sandy mainland shoreline, with no evidence of shoreward lagoonal deposits. Condon (2000) interpreted the Eagle Formation as comprising non-marine to marine shelf-sandstones, while Fitzsimmons and Johnson (2000) interpreted the formation as deltaic, with incised estuarine sandstones preserved within the Gebo Member. Working in the same localities as Fitzsimmons and Johnson (2000), Klug (1993) and Swift et al. (2008) interpreted the sandstones within the Gebo Member as barrier and ebb-tidal delta deposits, and the “incised estuaries” as “fat sandstones”, largely constructional, shore-parallel buildups of barrier and ebb-tidal delta sands (Swift et al., 2008). This has led to an active debate about the presence or absence of estuarine deposits in the Gebo Member (Swift et al., 2008). Finally, Severn (1961) described the Virgelle Sandstone as nearshore marine deposits and the Gebo Member as deposits of swamp, lagoonal and fluvial origin. The Eagle Formation is abruptly and unconformably overlain by the Claggett Tongue of the Cody Shale (Fig. 2) (Severn, 1961; Condon, 2000).

The Claggett Tongue of the Cody Shale ranges in thickness from 60 m (Severn, 1961) to 152 m (Condon, 2000). The lithology is described as predominantly dark gray to black shale and siltstone with bentonite beds near the base of the formation (Severn, 1961; Condon, 2000; Fitzsimmons and Johnson, 2000). The depositional environment of this lithology has been interpreted as offshore open shelf (Severn, 1961; Condon, 2000; Fitzsimmons and Johnson, 2000). Swift et al. (2008) had the same lithological description for the lower part of the Claggett but included a sand-rich upper member described as

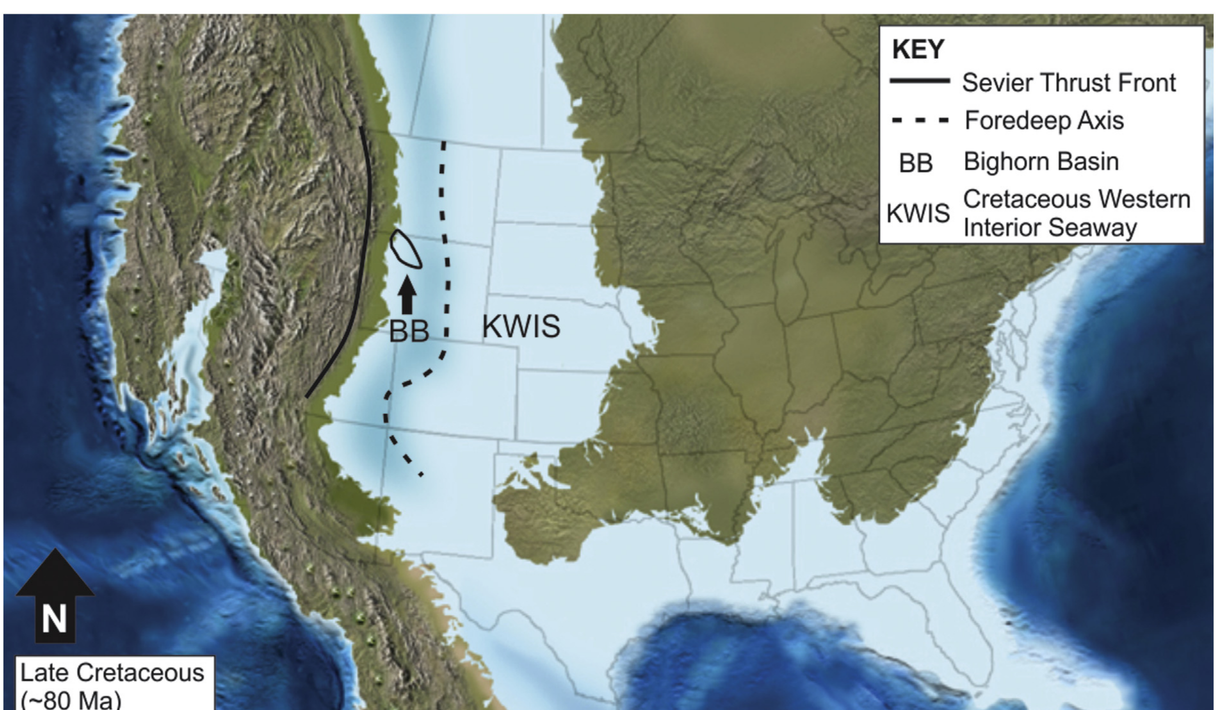

Fig. 1. Paleogeographic map of North America in the Late Cretaceous (~80 Ma) showing the Cordilleran Foreland Basin, Sevier fold thrust belt. Modified from Blakey (2011) and Finzel (2014).

Please cite this article as: Adams, G., et al., Stratigraphy and depositional environments of the Mesaverde Group in the northern Bighorn Basin of Wyoming, Palaeogeogr. Palaeoclimatol. Palaeoecol. (2017), http://dx.doi.org/10.1016/j.palaeo.2017.07.005