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Stratigraphic architecture of back-filled incised-valley systems: Pennsylvanian–Permian lower Cutler beds, Utah, USA

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ABSTRACT

The Pennsylvanian to Permian lower Cutler beds collectively form the lowermost stratigraphic unit of the Cutler Group in the Paradox Basin, southeast Utah. The lower Cutler beds represent a tripartite succession comprising lithofacies assemblages of aeolian, fluvial and shallow-marine origin, in near equal proportion. The succession results from a series of transgressive–regressive cycles, driven by repeated episodes of climatic variation and linked changes in relative sea-level. Relative sea-level changes created a number of incised-valleys, each forming through fluvial incision during lowered base-level. Aeolian dominance during periods of relative sea-level lowstand aids incised-valley identification as the erosive bounding surface juxtaposes incised-valley infill against stacked aeolian faces. Relative sea-level rises resulted in back-flooding of the incised-valleys and their infill via shallow-marine and estuarine processes. Back-flooded valleys generated marine embayments within which additional local accommodation was exploited. Back-filling is characterised by a distinctive suite of lithofacies arranged into a lowermost, basal fill of fluvial channel and floodplain architectural elements, passing upwards into barform elements with indicators of tidal influence, including inclined heterolithic strata and reactivation surfaces. The incised-valley fills are capped by laterally extensive and continuous marine limestone elements that record the drowning of the valleys and, ultimately, flooding and accumulation across surrounding interfluves (transgressive surface). Limestone elements are characterised by an open-marine fauna and represent the preserved expression of maximum transgression.

1. Introduction

Although many previous studies have examined the interactions between aeolian and fluvial depositional systems developed in semi-arid climates (e.g., Langford and Chan, 1988, 1989; Stanistreet and Stollhofen, 2002; Mountney and Jagger, 2004), relatively few have examined tripartite styles of interaction where aeolian, fluvial and shallow-marine processes all operated coevally in coastal settings (e.g., Simpson and Eriksson, 1993; Blakey et al., 1996). One system for which the regional stratigraphic record of such tripartite interactions is now relatively well documented is the Pennsylvanian to Permian lower Cutler beds of the Paradox (foreland) Basin, southeast Utah (Rankey, 1997), a coastal desert system whose development was influenced by high-frequency changes in climate from arid to sub-humid, and associated changes in relative sea-level driven by glacio-eustasy (Loope, 1985; Dickinson et al., 1994; Jordan and Mountney, 2010, 2012). In this location, highstands can be demonstrably linked to phases of increased climatic humidity, whereas lowstands equate to relatively more arid climatic phases (Jordan, 2006). Related styles of interaction are also identified in other formations of the Paradox Basin (Loope, 1985; Atchley and Loope, 1993; Dickinson et al., 1994; Goldhammer et al., 1994; Rankey, 1997; Jagger, 2003; Mountney and Jagger, 2004; Jordan, 2006; Mountney, 2006b; Jordan and Mountney, 2010, 2012), as well as from other Permian basins of North America (Heckel, 1980; Dickinson et al., 1994; Soreghan, 1994; Blakey, 2008).

Initial studies of the lower Cutler beds (Terrell, 1972; Mack, 1978; Loope et al., 1990; Jordan, 2006) determined the regional palaeogeographical setting and stratigraphic framework of the succession; being composed of 10–20 m-thick repeating cycles of sandstone and limestone (e.g., Terrell, 1972; Mack, 1978). The uppermost 10 to 12 cycles are accessible in tributary canyons of the Colorado River. Loope (1985) suggested that these cycles might have arisen as a result of Milankovitch-style orbital forcing and proposed a ~413 kyr duration for each. The relationship between continental and marine sediments establishes a model framework to account for stacked depositional cycles attributed to relative sea-level change (Rankey, 1997). Thin but laterally extensive and continuous marine limestone present within each cycle has been traced by Jordan and Mountney (2010, 2012) from locations indicative of relatively more off-shore and more

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landward settings. The limestones thin and eventually pinch-out defining the maximum transgression within each relative sea-level cycle; these units and other key stratal surfaces define the basis for a sequence stratigraphic framework (Jordan, 2006; Jordan and Mountney, 2010, 2012). Within this framework, 12 cycles record evidence for transgression, regression and sequence boundary generation in response to relative sea-level and associated climate changes (Jordan and Mountney, 2010, 2012); thus, the cycles define sequences sensu Van Wagoner et al. (1990).

During episodes of falling relative sea-level, the palaeo-shoreline shifted in excess of 80 km basinward allowing fluvial systems to extend across the low-gradient coastal plain to reach new lowstand shorelines and, in doing so, cut a series of incised-valleys. These were later back-filled during subsequent transgression associated with relative sea-level rise at commencement of the next sequence (Jordan and Mountney, 2010, 2012). Hitherto, there have been no published accounts of the detailed geometry of these incised-valleys or the sedimentary architecture and palaeoenvironmental significance of the infill for the lower Cutler beds.

This study documents the mechanisms responsible for generating and then infilling incised-valleys in the lower Cutler beds and establishes the timing of incision in relation to base-level fall and sedimentary style of back-filling during subsequent base-level rise. This study specifically: (i) documents the preserved sedimentological and architectural relationships between lithofacies assemblages of aeolian, fluvial and shallow-marine origin within and adjacent to the incised-valleys; (ii) demonstrates how interactions between coeval fluvial, shoreline and shallow-marine processes led to incised-valley formation and infill during one complete cycle of relative sea-level change; and (iii) discusses the climatic and eustatic conditions required to generate the preserved stratigraphic architectural relationships within the context of a sequence stratigraphic model.

2. Geological setting

2.1. The Paradox Basin

The Pennsylvanian to Permian lower Cutler beds represent the lowermost lithostratigraphic unit of the Cutler Group in the Paradox Basin, southeast Utah (Fig. 1). The Paradox Basin formed as a result of the growth of the ancestral Uncompahgre Uplift to the northeast, which initiated subsidence in the foreland due to lithospheric flexural loading (Condon, 1997; Barbeau, 2003; Fig. 2). The basin has an asymmetric oval morphology with a northwest-southeast-oriented long axis that is ~320 km in length and a perpendicular short axis that is ~150 km wide (Condon, 1997). The limit of the basin is generally defined by the maximum lateral extent of halite and potash salt deposits in the middle Pennsylvanian Paradox Formation of the Hermosa Group, which underlies the Cutler Group (Kunkel, 1958; Campbell, 1980; Blakey and Knepp, 1989; Nuccio and Condon, 1996; Condon, 1997; Barbeau, 2003). Throughout much of its evolution however, the Paradox Basin developed in an overfilled state and many of the formal stratigraphic units associated with the basin, including the lower Cutler beds, extend considerably beyond its defined boundaries (Blakey et al., 1996; Condon, 1997). Overfilling likely resulted from slower rates of accommodation space creation (Barbeau, 2003), which in turn promoted a basinward progradation of a large wedge of continental clastic detritus derived by the erosion of the ancestral Uncompahgre Uplift (Loope, 1984). Subsidence rates within the Paradox Basin during the deposition of the lower Cutler beds are considered relatively constant (Nuccio and Condon, 1996). Thus, any variations in the preserved sedimentary sequence can be attributed directly to variations in linked climatic and relative sea-level forcing.

The ancestral Uncompahgre Uplift served as the principal sediment source area during deposition of the lower Cutler beds. A series of fluvial systems drained into the Paradox Basin, with detritus delivered via alluvial fans and braided river systems that generally flowed south-westwards from the uplift (Nuccio and Condon, 1996; Condon, 1997; Jordan and Mountney, 2010). In the central part of the basin, distal to the fluvial-dominated foredeep region adjacent to the ancestral Uncompahgre Uplift, aeolian dune-field systems developed, with bedforms that migrated south-eastwards along the long-axis of the basin. The aeolian sediment was probably derived from pre-existing fluvial and coastal deposits in the north-western part of the basin (Condon, 1997; Blakey, 2009; Fig. 2). The aeolian dune field and its envisaged source system were bounded to the west and southwest by a shallow-marine seaway that transgressed and regressed over the coastal plain and inland across a low-relief alluvial plain. This had an impact upon the supply of sediment to the aeolian system and dictated its availability for aeolian transport, ultimately governing the timing of aeolian dune-field construction and deflation (cf., Kocurek, 1999; Kocurek and Lancaster, 1999; Mountney, 2012). The shallow-marine system was characterised by mixed siliciclastic and carbonate sedimentation in a gently-inclined ramp setting (Jordan, 2006; Jordan and Mountney, 2010). A varied marine faunal assemblage, including brachiopods, bivalves, crinoids and bryozoans, indicates open marine conditions (Terrell, 1972).

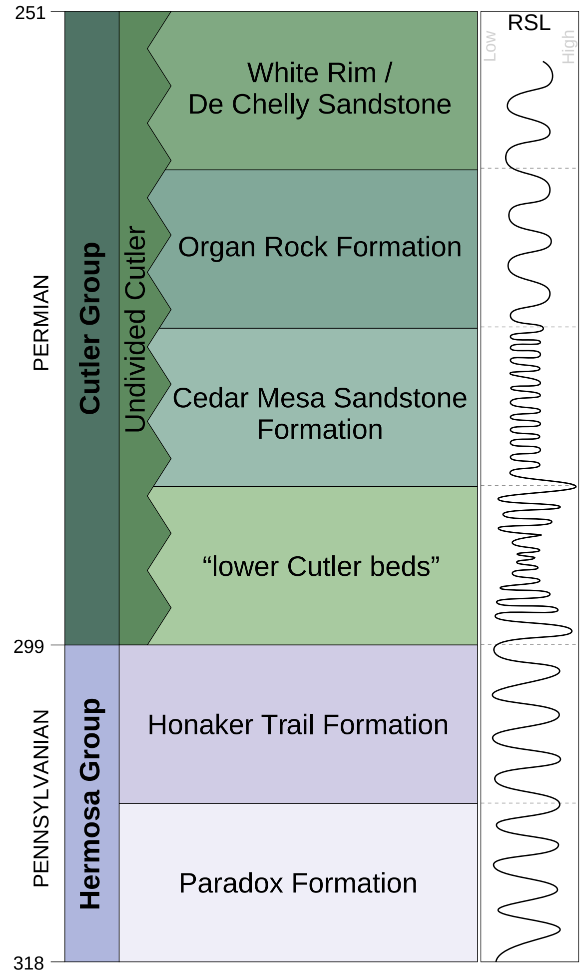

Fig. 1. Summary stratigraphical chart for the Paradox Basin region including a composite generalised relative sea-level (Loope, 1984; Grammer et al., 1996; Mountney and Jagger, 2004; Mountney, 2006b; Cain, 2009; Jordan and Mountney, 2012).

2.2. The lower Cutler beds

The "lower Cutler beds" is the informal name assigned to the lowermost strata of the Cutler Group that underlie the Cedar Mesa