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Climatic and paleogeographic significance of eolian sediment in the Middle Permian Dog Creek Shale (Midcontinent U.S.)

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ABSTRACT

Middle Permian fine-grained redbeds of Midcontinent North America are analogous to many Permian units globally. They archive an interesting time in Earth history, but the lack of fossils and the fine grain size have confounded attempts to refine the age and depositional setting, respectively. Here we focus on the Dog Creek Shale and correlatives of Oklahoma and Kansas (paleo-tropical western Pangaea), which are representative of many analogous Permian units across the region and globe, to assess the age, depositional environment, and provenance of siliciclastic material.

These mudstone-dominant units have long been interpreted to record marine deltaic or tidal flat deposition based primarily on the presence of evaporites and an inferred relationship with sandstone units southward. However, the uniform grain size, and occurrence of common paleosols, together with the lack of typical deltaic attributes such as hyper/hypo-pycnites, proximal deltaic channels, and large-scale upwardly coarsening trends, in addition to the problematic correlation, complicate this interpretation. Sheet-like tabular siliciclastic units thin northward from the Anadarko foredeep (Oklahoma) onto the Anadarko shelf (Kansas), and undergo lateral facies changes into marginal marine evaporites of the San Andres Formation in the Palo Duro Basin (Texas Panhandle). The fine and uniform grain size, massive bedding, and sheet-like geometry indicate that the siliciclastic units are eolian in origin, but at times were transported by wind and deposited and reworked in mudflats. Abundant Vertisols within the Dog Creek Shale indicate periods of wetting and drying in a low-relief setting. Major detrital zircon age populations reflect a dominantly east to southeasterly Appalachian–Ouachita source, with minor input from derivative sediment from the Ancestral Rocky Mountains to the west and northwest. These data indicate prevailing easterlies, and some westerly and southwesterly winds in western equatorial Pangaea, possibly representing north to south shifting of the Inter-Tropical Convergence Zone (ITCZ), likely associated with monsoonal circulation. The predominance of eolian-transported material and its capture in a series of mudflats and soils indicates that midcontinent North America (western equatorial Pangaea) formed a major sink for large volumes of atmospheric dust in middle Permian time, quite unlike the modern and recent tropics.

1. Introduction

Perhaps the most significant and relevant aspect of the Permian when compared to modern earth is that it archives the climate transition from global icehouse of the Carboniferous to predominantly greenhouse conditions by the Middle to Late Permian (e.g., Crowell, 1978; Frakes et al., 1992; Dickins, 1996; Isbell et al., 2003; Fielding et al., 2008). The supercontinent Pangaea was fully sutured by Early Permian and this large landmass forced fundamental changes in oceanic, climatic, tectonic, and biological components of the Earth System that are recorded globally. Aridification of continental interiors provided a favorable setting for eolian processes to dominate during the Middle to Late Permian and for surface waters and groundwaters to become extremely saline and acidic (Benison et al., 1998; Tabor and Montanez, 2004; Tabor and Montanez, 2005; M.J. Soreghan et al., 2008; Peyser and Poulsen, 2008). Although much work has focused on the recognition of arid-type facies such as eolian sandstone and evaporite deposits, fine-grained eolian components such as paleo-loess and dust have received much less attention despite the fact that they comprise the majority of the middle–late Permian rock record. This fine-grained component is increasingly recognized in Permian units and has great significance for interpretations of atmospheric dustiness in equatorial Pangaea.

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Permian evaporite and fine-grained siliciclastic "redbed" strata accumulated over a vast region of the Midcontinent U.S. (western equatorial Pangaea), ranging from Texas northward to Canada, and from Colorado eastward to Nebraska. The middle Permian Dog Creek Shale and the greater El Reno Group accumulated across the Hugoton embayment of Kansas, and the Anadarko Basin of Texas and Oklahoma in western equatorial Pangaea (Fig. 1C). The siliciclastic strata of the El Reno Group have long been interpreted to record marginal marine deltaic and/or tidal conditions primarily on the basis of intercalated evaporite and minor dolomite strata, and coeval sandstone in southern Oklahoma (Muir, 1933; Hills, 1942; Everett, 1962; Fay, 1964; Johnson, 1967). However, more recent research has documented the importance of lacustrine environments in producing evaporites that, until recently, were presumed of marine tidal origin (Lowenstein and Hardie, 1985; Benison et al., 2007). Strontium isotope data from the predominantly evaporite and minor carbonate strata of the San Andres Formation (El Reno Group equivalent) of the Palo Duro Basin (Texas panhandle; Fig. 1) suggest marine deposition, but low bromide values in the same rocks suggest nonmarine parent waters. In the Hugoton embayment of southwestern Kansas, there is clear geochemical evidence for continental deposition of middle Permian evaporites (Holdoway, 1978; Hovorka et al. 1993). Coeval strata in Kansas (Fig. 2; Nippewalla Group) have been interpreted to record acid saline lake ($pH < 1$), eolian, and paleosol environments in an arid continental setting (Holdoway, 1978; Benison et al., 1998; Benison and Goldstein, 2000, 2001). Previous paleoenvironmental interpretations of strata in equatorial Western Pangaea continue to emphasize a marine setting, although the extent of this marine realm has been clouded by discrepancies in interpretations, thus presenting the need for rigorous testing.

This study addresses depositional environments and provenance of Permian redbeds using sedimentology, geochemistry, and detrital zircon geochronology, focusing primarily on (volumetrically predominant) siliciclastic strata of the Dog Creek Shale of the U.S. southern Midcontinent. Previous work reveals an indeterminate provenance for the large volume of siliciclastic sediment deposited in the continental interiors of western equatorial Pangaea during the Permian.

In addition to expanding on the provenance, environment of deposition, and climate archived within the Dog Creek Shale, this study addresses chronostratigraphy of the El Reno Group between Kansas and Oklahoma by using magnetostratigraphy (Fig. 2).

2. Background

2.1. Tectonic setting

During the Late Paleozoic the greater study area was bordered by a series of orogenic belts in western equatorial Pangaea associated with the final assembly of the Pangaean supercontinent. The Ouachita–Marathon fold-thrust belt to the southeast was in the waning stages of uplift during the middle Permian, completing the long chain of orogenesis associated with the Appalachian orogenic belt to the east (Sutherland, 1988; Slingerland and Furlong, 1989). The Permo-Pennsylvanian Ancestral Rocky Mountains (ARM), generally located to the northwest, formed in the distal foreland of the Marathon–Ouachita orogeny (Fig. 1C; Kluth and Coney, 1981; Kluth, 1986; Dickinson and Lawton, 2003). However, recent studies suggest the major ARM uplifts were actively subsiding by Early Permian time as a product of relaxation of the compressional stresses associated with the Ouachita–Marathon orogen (Soreghan et al., 2012). Within the study site, subsidence of the Anadarko foreland basin continued into the Late Permian (Fig. 1C; Fay, 1964; Soreghan et al., 2012). The Wichita Uplift at the southern margin of the Anadarko Basin was buried and contributed no significant detritus to the basin by the middle Permian (Ham and Wilson, 1967; Johnson, 1971; Johnson, 1978; Gilbert; 1986; Soreghan et al., 2012). Deposition of the El Reno Group of Oklahoma, and correlatives in the U.S. Midcontinent, occurred in several basins (i.e., the Syracuse Basin, the Hugoton embayment of the Anadarko Basin, the Cimarron Basin, and the Sedgwick Basin), bound by small positive regions such as the Las Animas Arch, Nemaha Uplift, and Ozark Dome (Maughan, 1967; Mudge, 1967; Holdoway, 1978; Benison and Goldstein, 2001). Mudge (1967) and Cox (2009) suggested these bounding structures remained prominent throughout the Permian, although others consider these structures to have been buried by the Mid-Permian (Ham and Wilson, 1967; Johnson; 1967; Maclachlan, 1967).

2.2. Climate setting

The eventual demise of polar Gondwanan ice sheets by the middle Permian (end of the Guadalupian) generally marks the transition from the Permo-Carboniferous icehouse climate to the full greenhouse conditions that prevailed by the end of the Permian (Wanless and Shephard,

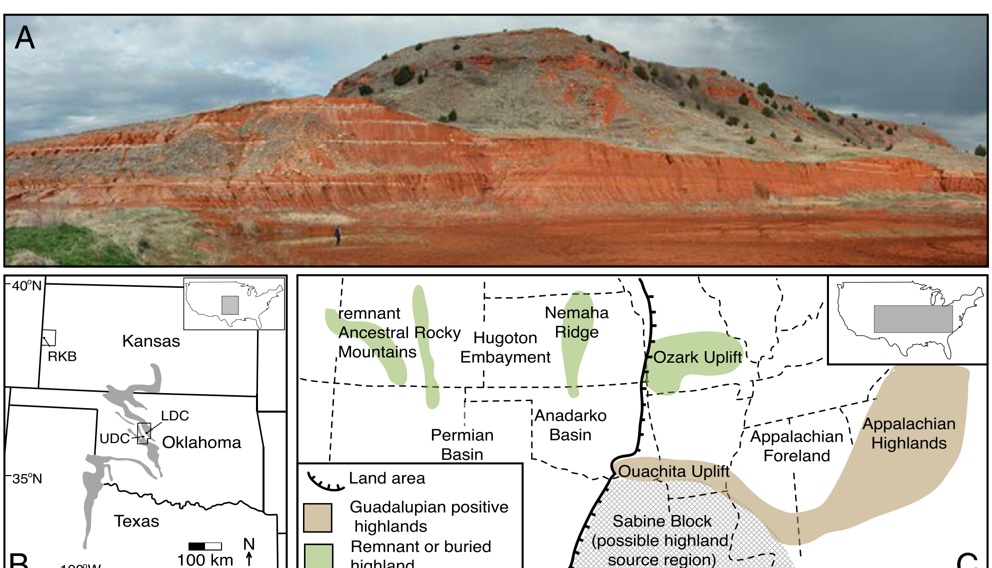

Fig. 1. (A) Outcrop showing the upper Dog Creek Shale, Blaine County, Oklahoma. (B) Areal extent of the El Reno Group of Oklahoma and correlatives in Kansas and Texas. RKB = Rebecca K. Bounds core (northern study site). LDC = lower Dog Creek Shale outcrop (southern study site). UDC = upper Dog Creek Shale outcrop (southern study site). (C) Guadalupian palaeogeography of the Midcontinent showing highlands and depocenters (Modified from Sweet et al., 2013). Approximate extent of land area from McKee et al. (1967). See text for more detail on the positive elements for this time interval.