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Paleoenvironmental and paleoecological implications of Permian (Guadalupian) radiolarian and geochemical variations in the Lamar Limestone, Delaware Basin, West Texas (USA)

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ABSTRACT

Geochemical proxies integrated with well-preserved radiolarian data from the Lamar Limestone and lower part of the Reef Trail Member of the Bell Canyon Formation provide insights into paleoceanographically and climatically driven controls on radiolarian distribution in the northern part of the Delaware Basin of west Texas, during late Guadalupian time. Data from a section of the Lamar Limestone (~8.9 m; ~500 kyr interval), indicate that major variations between sphaerellarian-dominated and *Follicucullus*-dominated faunas appear to be controlled by fluctuations in nutrient supply and salinity. Geochemical parameters of bulk carbonate carbon and oxygen isotopes ($\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$), organic carbon isotope ($\delta^{13}C_{org}$), and total organic carbon (TOC) were analyzed and show variations on two scales. On a fine-scale, sphaerellarian-dominated beds are associated with a relatively siltier lithology, higher TOC, and higher radiolarian richness but lower diversity, and are interpreted as the result of a rise in productivity stimulated from increased terrestrial input. The radiolarian variations and geochemical evidence imply that the Permian spongiose spumellarians are more opportunistic than *Follicucullus* (albaillellids) in response to eutrophication. On a broad-scale, $\delta^{18}O_{carb}$ variations in limestone samples are interpreted mainly as a proxy for paleosalinity in response to changes in basin circulation. Mg/Ca ratios from the carbonate fraction co-vary with $\delta^{18}O_{carb}$ and are used as an additional paleosalinity proxy in this basin. The limestone beds in the middle part of the section have lighter $\delta^{18}O_{carb}$ values compared to limestone beds above and below, and likely represent the interval when the Delaware Basin was less restricted and had relatively normal marine salinity. Impacts of diagenesis are mild but are likely the cause for systematically light $\delta^{18}O_{carb}$ values in silty limestone beds in the middle interval. The Mg/Ca ratios and $\delta^{18}O_{carb}$ values in the limestone samples both increase from the middle to the top of the section, implying a gradually enhanced evaporitic environment coupled with increased salinity towards the top section. Collectively, these data paint a picture of intermittent restriction in the Delaware Basin, prior to the change to a dominantly evaporative regime in the late Permian, and on a finer scale, show pronounced and frequent ecological fluctuations that appear to be driven by fluxes in terrestrial input and, to some extent, paleoproductivity.

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1. Introduction

Radiolarians are widely reported from Cambrian strata through modern oceans and are an important marine planktonic group with extensive applications to biostratigraphy and paleoenvironmental reconstruction. The investigations on radiolarians from modern oceans and Cenozoic sediments demonstrate that radiolarian abundance, composition, and distribution are constrained by both abiotic and biotic factors. Multiple controlling factors of radiolarian distribution and faunal composition have been widely discussed, such as depth (Casey et al., 1982; Itaki, 2003), food preference and food supply (Anderson et al., 1989a; Nimmergut and Abelmann, 2002; Abelmann and Nimmergut, 2005; Jacot des Combes et al., 2005), temperature and salinity (Anderson et al., 1989b; Hays and Morley, 2003; Tanaka and Takahashi, 2005), and other physicochemical or biological conditions (Casey et al., 1983; Itaki et al., 2004; Afanasieva et al., 2005).

However, paleoecological studies on radiolarians in pre-Cenozoic geologic records are often hampered by the complications in reconstructing environmental information from the ancient stratigraphic record. During the last decade, the knowledge of Mesozoic radiolarian ecology has been enriched with the application of integrated geochemical approaches (Erbacher et al., 1996; Bartolini et al., 1999; Hollis et al., 2003). On the other hand, research on Paleozoic radiolarian ecology lags greatly behind the Mesozoic and Cenozoic. Speculations as to the vertical distribution of Permian radiolarian assemblages have been discussed relative to stratigraphic information, and inferences were made from the observation of

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paleogeographical and lithological associations (e.g., Holdsworth, 1977; Casey et al., 1983; Afanasieva and Zamilatskaya, 1993; Kozur, 1993). Albaillellids have been hypothesized to be a deep water dwelling group in more open oceans relative to other Paleozoic radiolarians (Holdsworth, 1977), whereas spumellarians have been treated as shallow water dwellers (Kozur, 1993; He et al., 2005). However, there has been no corroborating data to test these ideas.

The Lamar Limestone in the Delaware Basin, west Texas, is an ideal unit in which to begin the exploration of late Paleozoic paleoecology because well-preserved radiolarians have been found in abundance. Radiolarians in the Lamar Limestone are well studied from a taxonomic standpoint (Ormiston and Babcock, 1979; Nazarov and Ormiston, 1985; Kozur, 1993; Noble and Jin, 2010), have reasonably good biostratigraphic control via fusulinid research (Skinner and Wilde, 1954), and importantly record a sharp compositional change from spumellarian-dominated to albaillellid-dominated assemblages in a 1.6 m interval sampled bed-by-bed (Zimmerman et al., 2000; Noble et al., 2011). The sharp compositional change in radiolarians appears to reflect an environmental change, as indicated by carbonate isotopes and organic biomarkers, and is not simply a function of turbidites transporting a shallower water spumellarian-rich fauna into the basin (Noble et al., 2011). From a geochemical standpoint, the Lamar Limestone appears to have undergone minimal diagenesis (e.g., Hays and Tieh, 1992; Scholle et al., 1992; Noble et al., 2011). Collectively, these attributes make the Lamar Limestone an ideal succession to explore the impacts of the environmental controls on Paleozoic radiolarians.

The aim of the current study is to quantify the radiolarian fluctuations in the Lamar Limestone, and use both sedimentological and geochemical proxies to seek the environmental factors driving the faunal shifts. The faunal fluctuations through the ca. 9 m study section are described by relative abundance, richness, and diversity of the radiolarian fossils, and the following geochemical parameters are used as paleoenvironmental proxies: $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ from carbonate, $\delta^{13}C_{org}$ from organic carbon, total organic carbon (TOC), and Mg/Ca ratio in the carbonate phase. The relationships between the radiolarian fauna and the geochemical data are analyzed by correlation and partial correlation analysis.

2. Geological setting

The Lamar Limestone Member is a wedge-shaped marine carbonate unit deposited in the Delaware Basin (Permian Basin) during the late Guadalupian (Middle Permian). It is exposed along a long belt (~110 km) of cuestas, which extend in a south to southeasterly trend across the basin (King, 1948). Unlike the older carbonate tongues in the Bell Canyon Formation that are largely restricted to the western margin of the basin (Hill, 1996), the Lamar Limestone spreads out from the basin margin and extends as a thin layer into the central basin. Near the basin margin, the Lamar Limestone is more than 90 m thick and merges with upper Capitan Formation toward the shelf margin, but only 2 m of Lamar Limestone is present in the basin center (Babcock, 1977). The great thickness change indicates high carbonate accumulation rates near the shelf margin and considerably lower accumulation rates in the basin.

The Lamar Limestone is the second youngest unit of the Bell Canyon Formation. It overlies the Ramsey Sandstone (Hill, 1996) and underlies the Reef Trail Member (Wilde et al., 1999; Lambert et al., 2002), which is covered by Upper Permian Castile evaporites. The different depositional environments in the Lamar Limestone and both lithological and biotic characteristics appear to be chiefly controlled by oxygenation conditions at the sediment-water interface (Babcock, 1977). The degree of oxygenation is interpreted to decrease from aerobic conditions along the immediate fore-reef, to dysaerobic and anaerobic basinward (Babcock, 1977). Correspondingly, the abundance and diversity of fossil groups in the Lamar Limestone generally decrease basinward (Babcock, 1977). Only a few kinds of organisms (mostly pelagic) persisted in the basin margin and central basin areas. Radiolarians are among those surviving groups. They are common in most of the basinal localities, but not found within 1.6 km of the shelf edge (Babcock, 1977).

Among the various Lamar fossils, conodonts and fusulinids are most useful for biostratigraphic control. In the upper part of Lamar Limestone, conodonts *Jinogondolella postserrata* and *J. shannoni* were found with the fusulinid *Reichelina lamarensis* (Bell et al., 2006), which is also abundant in several other outcrops of the upper Lamar Limestone (Skinner and Wilde, 1955). The concurrence of *J. postserrata and J. shannoni* indicates the age of the upper Lamar Limestone as late Capitanian based on a new conodont biostratigraphic scheme (Lambert et al., 2002; Lambert, 2006).

The study section (LR06; same locality as the "H" section in Babcock, 1977) is located at a roadcut on U.S. Highway 62/180 (Fig. 1), around 1.5 km northeast of the entrance road to the McKittrick Canyon, and about 7.2 km into the basin from the shelf edge (Brown, 2006). It was deposited near the basin margin (Babcock, 1977), where the fine-grained carbonates are not of pelagic origin, but instead are bioclastic, derived mainly from the shelf margin and foreslope and driven by debris flows, density turbidity currents, or other depositional mechanisms (Brown and Loucks, 1993). The lower 2.7 m of the section are thick-bedded (up to 20 cm) micrites with grainstone (debris) lenses, showing bioturbation by mottled fabric at the very bottom 0.8 m. The mottled beds appear equivalent to the "burrowed zone" in the upper Lamar Limestone (Babcock, 1977; Brown, 2006). The upper 6.2 m of the section are characterized by millimeter-scale lamination in interbedded gray purer limestones and brownish silty limestones, interpreted to be deposited through basinal suspension in anoxic conditions (Brown, 2006). According to the paleotopography and paleoslope reconstruction of the Capitan and Lamar Limestone (Babcock, 1977; Brown and Loucks, 1993), the carbonates from the LR06 Section should have been deposited on a relatively flat-surface.

In terms of time span, this ~9 m section possibly represents a time period less than 500 kyr based on its correlation to the upper part of Lamar Limestone (Babcock, 1977) and an estimated time span of less than 1 million years for the whole Lamar (Brown and Loucks, 1993). This estimation is generally consistent with the results of a sequence stratigraphy analysis of the lower Bell Canyon Formation (Tinker, 1998). A detailed study of the time frame and cyclic deposition of this section is covered in another paper in-progress.

Compared to equivalent basin-margin sections of Lamar Limestone, the study section contains much fewer benthic fossils (Babcock, 1977; Brown, 2006), and radiolarians are abundant, particularly in the upper two-thirds of the section. Over thirty species from four orders (i.e., Albaillellaria, Entactinaria, Spumellaria, and Latentifistularia) have been reported (Ormiston and Babcock, 1979; Nazarov and Ormiston, 1985; Kozur, 1993; Noble and Jin, 2010), including the biostratigraphically important albaillellid species *Follicucullus ventricosus* and *F. scholasticus*.

3. Material and methods

The whole 8.9 m section was sampled by collecting continuous pieces of the outcrop bed-by-bed from bottom to top. The top of each bed was defined along weathering breaks. Internally, most of the beds are laminated. Each bed was then cut for fresh surface in the lab and etched for a few minutes to better reveal textural and sedimentological features on the surface. In some cases beds were subdivided based on changes in lithology or grossly observable changes in fossil content. In other cases, the top of one bed was combined with the base of an overlying bed with the same lithology. A subset of nineteen samples was selected for petrographic examination to aid in identifying evidence of reworking, taxon-selective winnowing, and degree of diagenesis.

3.1. Radiolarian fauna

The samples were treated with 3–5% hydrochloric acid at room temperature for 2–3 days in order to remove carbonate components. The

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