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Paleoecology of pelmatozoan attachment structures from a hardground surface in the middle Silurian Massie Formation, southeastern Indiana

James R. Thomka [a,b,*], Carlton E. Brett [b]

[a] Department of Geosciences, University of Akron, Akron, OH 44325, USA
[b] Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA

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ABSTRACT

The contact between the basal limestone and overlying mudstone interval of the Massie Formation (Silurian: Wenlock, Sheinwoodian) represents a major flooding surface that is well exposed at the New Point Stone quarry at Napoleon, southeastern Indiana. At this locality, this surface is a locally microbiohermal hardground encrusted by numerous attachment structures of both crinoids and blastozoan echinoderms. The distribution of attachment structure morphologies is nonrandom with respect to variations in substrate properties and microtopographic relief. Discoidal structures and thecal attachments, predominantly representing diploporites, are concentrated on fine-grained, winnowed crests of the undulatory surface, reflecting the stability of this substratum. Complex root-like and runner-type structures, attributable to long-stemmed crinoids and rhombiferans, dominate the coarser, muddier, poorly sorted hardground troughs, reflecting the need for greater surface area in more unstable, rubbly areas. Microbioherms are densely encrusted by thickened radix systems belonging to long-stemmed pelmatozoans. The cause of thickening is unclear but may represent a pathologic response to some biotic interaction or investment by encrusting taxa in crustose holdfasts in order to prevent dislodgement. This study supports previous interpretations of pelmatozoan attachment paleoecology wherein solid, permanent discoids preferentially encrusted stable, homogenous substrata, whereas more complex structures were needed to occupy more heterogeneous and presumably less stable substrata. Thus, the hardground studied here highlights the strong influence of substrate variations in influencing paleoecological dynamics in topographically complex carbonate settings, possibly leading to locally increased alpha diversity and development of biofacies not typically encountered in certain normal marine environments.

1. Introduction

Pelmatozoan encrustation of carbonate firmgrounds and hardgrounds has been documented in deposits ranging from the Cambrian advent of such lithofacies (Brett et al., 1983; Sumrall et al., 1997; Zamora et al., 2010) to Recent carbonate environments (Messing et al., 1990; Bowden et al., 2011). Occurrences of in situ pelmatozoan attachment structures on hard substrata have provided a wealth of information on paleoecological relationships among stalked echinoderms because 1) synecologically significant spatial relationships are preserved, 2) autecological inferences can be made from styles of substrate affixation, and 3) relative abundance of individuals and taxa can be directly calculated. Further, because attachment structures are generally robust (Lewis, 1982; Brett et al., 1997; Thomka and Brett, 2014b), complete destruction by taphonomic processes is less likely than for other skeletal modules. In some cases, attachment structures permit low-level taxonomic identification where diagnostic, but considerably more delicate thecae, thecal plates, or arm-branching patterns are unavailable for study (Thomka and Brett, 2014a). Such material is particularly critical in settings where rapid post-mortem skeletal disarticulation, characteristic of most pelmatozoan echinoderms (Brett et al., 1997), complicates recognition of faunal composition, ecological structure, and evidence for paleoenvironmental parameters.

To date, most research has focused on hardground encrustation by Ordovician echinoderms (e.g., Palmer and Palmer, 1977; Brett and Liddell, 1978; Brett and Brookfield, 1984; Wilson et al., 1992; Guensberg, 1992, among many others), with few studies of Silurian hardgrounds (but see, e.g., Brett, 1984; McLaughlin et al., 2008a). This bias may reflect research indicating that the Ordovician rise of echinoderms as major components of the Paleozoic Evolutionary Fauna was substrate controlled (Guensberg and Sprinkle, 1992; Sprinkle and Guensberg, 1995; Dornbos, 2006; Zamora et al., 2010). Additionally, the elevated abundance of Ordovician hardgrounds was probably aided by lower bioturbation relative to Silurian marine environments (Brett, 1991). Secular oceanic-geochemical controls (Wilkinson et al., 1982; Walker and Diehl, 1985; Brett, 1988) further contributed to a greater number of hardgrounds developed during the Ordovician Period, particularly in Laurentia. Finally, late-diagenetic dolomitization of Silurian strata is widespread in eastern North America, obscuring

* Corresponding author at: Department of Geosciences, University of Akron, Akron, OH 44325, USA. Tel.: +1 630 935 2983.
E-mail address: jthomka@uakron.edu (J.R. Thomka).

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sedimentary fabrics and calcareous fossil content (e.g., Frest et al., 1977; McLaughlin et al., 2008b). As a result of these factors, pelmatozoan attachment structures on Silurian hardgrounds have not been reported frequently and, consequently, have not received much attention compared to other intervals.

The research presented here focuses on a diverse assemblage of pelmatozoan attachment structure morphotypes on a hardground surface within the middle Silurian Massie Formation in southeastern Indiana. The specific objectives of this study are: 1) to present the occurrence of the holdfast-encrusted horizon within the context of sequence stratigraphy; 2) to describe the physical characteristics and record the diversity of attachment structures on the hardground; 3) to document autecological data regarding morphological responses to immediate substrate properties; and 4) to document synecological data that enhance understanding of the relationships between Silurian pelmatozoans at the outcrop scale.

2. Stratigraphic setting and study site

Stratigraphic and paleontologic study of the late Llandovery and Wenlock Series of the west side of the Appalachian Foreland Basin, including the eastern Wabash Platform and Cincinnati Arch region, has long been hindered by three main problems. These are: 1) a narrow outcrop belt, 2) a preponderance of locally applied lithostratigraphic terms, and 3) widespread late-diagenetic dolomitization. The first problem is an inherent limitation, but has been mitigated in recent years by increased incorporation of subsurface data (e.g., McLaughlin et al., 2008b, 2012). The second problem has largely been rectified by revision of lithostratigraphic nomenclature, followed here, that allows a consistent terminology throughout the Cincinnati Arch region (Brett et al., 2012). The third problem is arguably the most problematic. The only reasonable approach to this issue is careful scrutiny of undolomitized sections, which are invaluable data sources on paleoecology and sedimentology but are largely restricted to scattered outcrops in parts of southeastern Indiana.

An undolomitized, fossiliferous section of the lower Sheinwoodian (earliest Wenlock) Massie Formation is well exposed at the New Point Stone quarry, situated ~1 km east of the town of Napoleon in Ripley County, southeastern Indiana (N39°12′31.39″, W85°18′53.74″; Fig. 1). This site, referred to as the Napoleon quarry, is renowned for the diverse, abundant, and well-preserved blastozoan echinoderm fauna recovered from the Lewisburg and Massie formations there (Paul, 1971; Frest et al., 1977, 2011; Thomka and Brett, 2014a,b). Indeed, this quarry is generally viewed as an unofficial type locality for the diploporite *Holocystites* Fauna (Frest et al., 2011; Thomka et al., 2012).

Most previous studies at the Napoleon quarry employed a lithostratigraphic terminology wherein most of the strata was included within the Osgood Formation (Foerste, 1897) or Osgood Member of the Salamonie Dolomite (Pinsak and Shaver, 1964), which is comprised of a lower shale, a middle carbonate, and an upper shale. Revisions to the stratigraphy of this region by Brett et al. (2012) resulted in establishment of three formation-scale units that correspond, with minor differences, to the three divisions of the former Osgood Formation; these are termed, in ascending order, the Osgood, Lewisburg, and Massie formations (Fig. 2). The main body of the Massie Formation is a thin, medium gray, readily eroded, calcareous mudstone representing a major highstand (Brett et al., 1990, 2012; McLaughlin et al., 2012). This distinctive lithology allows the Massie mudstone, previously known as the "upper Osgood shale" (Foerste, 1897; Pinsak and Shaver, 1964), to stand in sharp contrast to the light-colored, erosion-resistant carbonates that are more typical of the extensive shallow-water deposits that comprise the Wenlock Series throughout the Cincinnati Arch region (e.g., the Lewisburg and Laurel Formations; Figs. 2, 3A). This mudstone interval is underlain by a bed of pelmatozoan-brachiopod packstone–grainstone that is treated as the basal unit of the Massie Formation (Brett et al., 2012; the top of the "middle Osgood carbonate" sensu Pinsak and Shaver, 1964; Figs. 2, 3A).

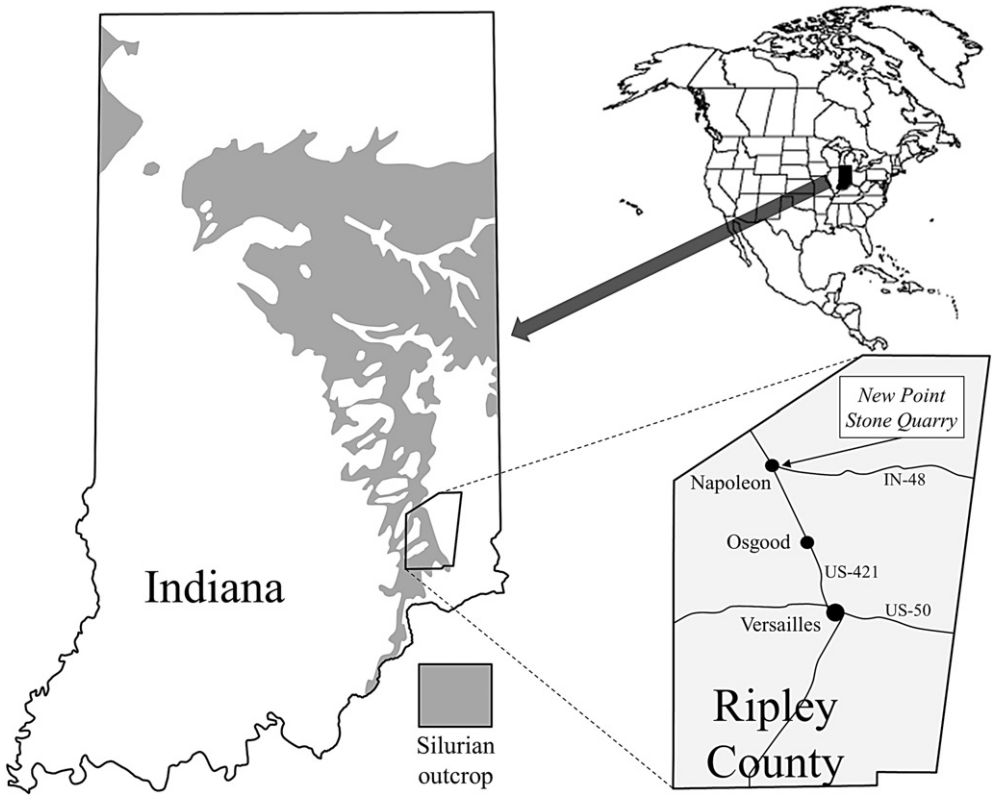

Fig. 1. Location of study site (New Point Stone quarry), ~1 km east of Napoleon, Indiana. Modified from Thomka and Brett (2014a).