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The holdfast of *Finitiporus boardmani* (Echinodermata: Diploporita) in the Silurian Massie Formation of the Cincinnati Arch region, USA

James R. Thomka[1] · Carlton E. Brett[2]

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Abstract A attachment structure, attributable to the sphaeronitid diploporitan *Finitiporus boardmani* Frest and Strimple, is documented herein from a hardground surface within the well-known middle Silurian (Wenlock) Massie Formation at the Napoleon quarry of southeastern Indiana, USA. This attachment structure is composed of multiple elongate plates lacking macroscopic pores, terminating in a slightly expanded disc. No portion of the theca is articulated to the specimen, though the morphology of the attachment structure is sufficiently distinctive to permit confident identification. The holdfast was dislodged from its attachment substrate but is present in the area immediately surrounding a bryozoan-micrite microbioherm, suggesting that *F. boardmani* occupied such elevated, hard environments. As the densely encrusted hardground containing this specimen has been partially destroyed since the initial report on pelmatozoan holdfasts, documentation of this occurrence is important for accurately recording of the total diversity and environmental distribution of echinoderms at an important locality.

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✉ James R. Thomka
jthomka@uakron.edu

[1] Department of Geosciences, University of Akron, Akron, OH 44325, USA

[2] Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA

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Introduction

The echinoderm fauna recovered from the lower Silurian (Wenlock: Sheinwoodian) Lewisburg and Massie formations (sensu Brett et al. 2012) at the Napoleon quarry of southeastern Indiana, east-central USA, is famous and well-studied owing to the unusually high abundance, diversity and quality of preservation (Frest et al. 1999). Much of the recent work on these echinoderms has focused on diploporitan 'cystoids,' including systematic treatment (Frest et al. 2011; Thomka and Brett 2014a; Sheffield and Sumrall 2015) and taphonomic evaluation (Thomka and Brett 2014b; Thomka et al. 2016a). However, studies of the entire echinoderm fauna are important for understanding whole-community palaeoecology. On this front, Thomka and Brett (2015a) documented the diversity and palaeoautecology of hardground-encrusting pelmatozoans occupying a densely encrusted surface within the Massie Formation.

The present short note represents an extension of the study of Thomka and Brett (2015a), in describing the attachment structure of an additional echinoderm taxon recognized after publication of the initial report. Documentation of this occurrence is particularly important because the hardground surface containing the diverse echinoderm fauna is no longer available for study in its entirety. Specifically, the objective of this study is to provide documentation of the attachment structure of the rare sphaeronitid diploporitan *Finitiporus boardmani* Frest and Strimple from the Napoleon quarry. This brings the total diversity of hardground-encrusting pelmatozoan echinoderm holdfast morphotypes at this site to thirteen.

Locality and stratigraphy

The study site is an active quarry operated by New Point Stone Company and located just east of the town of Napoleon in Ripley County, southeastern Indiana, USA (Fig. 1). A detailed overview of the stratigraphy of the Napoleon quarry and its palaeogeographic context is beyond the scope of this paper; the reader is directed to the more thorough treatments of this subject in Thomka and Brett (2014b, 2015a, b). The specimen described herein is present in the basal carbonate lithofacies of the Massie Formation (middle Silurian: Wenlock, Sheinwoodian), a relatively dense packstone to grainstone capped by a hardground surface that developed during transgression (Thomka and Brett 2014b, 2015a). The hardground is densely encrusted by a variety of crinoid, rhomibiferan and diploporitan attachment structures (Thomka and Brett 2015a) and serves as basal substrate for fistuliporoid bryozoan-micrite microbioherms (sensu Archer and Feldman 1986). The microbioherms themselves are also densely encrusted by a lower diversity fauna consisting of relatively long-stemmed echinoderms (Thomka and Brett 2015b).

The Massie Formation hardground surface, which was previously exposed at the northern end of the quarry (see Thomka and Brett 2014b, Fig. 1b), was largely destroyed by ongoing quarrying in 2015, and most of the rest of the surface was covered in rubble. Unfortunately, no additional bedding plane exposures of the hardground have been revealed over the past several years. Nevertheless, extensive photo-documentation of the hardground surface was conducted as part of the study of Thomka and Brett (2015a), resulting in discovery of the material described here.

Description and analysis of holdfast

A single specimen (Fig. 2) was photographed prior to destruction of the hardground surface. Based on comparison with published descriptions of echinoderms from the Napoleon quarry (Frest et al. 1999, 2011), it is apparent that this represents the holdfast of the sphaeronitid diploporitan *Finitiporus boardmani* (cf. Frest et al. 2011, pp. 67–68, text-Fig. 41, pl. 1.14–1.17). The holdfast was tightly embedded in the surrounding carbonate rock, preventing collection at the time the photograph was taken. Due to subsequent quarrying, the portion of the hardground surface was damaged, making photographs such as Fig. 2 the only remaining record of this fossil occurrence.

The proximal end of the attachment (labeled '*p*' Fig. 2) is detached from the theca along an irregular, somewhat jagged surface; it is unclear whether catastrophic breakage or decay-induced disarticulation followed by more gradual breakage was responsible for separation between the holdfast and theca. The distal end of the holdfast (labeled '*d*' in Fig. 2) is completely separated from the primary substrate, having become dislodged and reoriented prior to burial. Frest et al. (2011) noted that *F. boardmani* exclusively encrusted relatively large, flat surfaces such as

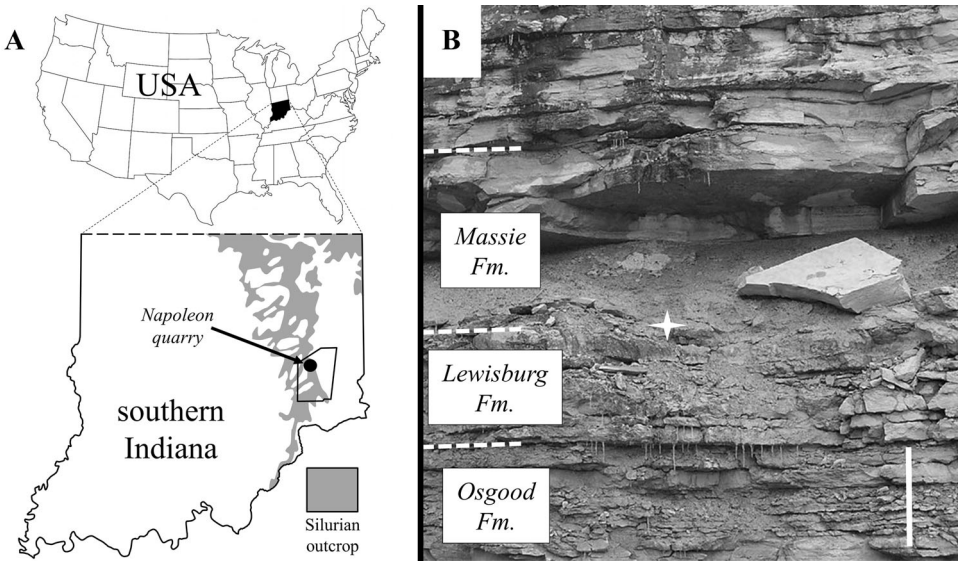

Fig. 1 Geographical and stratigraphical setting of the material described in this study. See Thomka and Brett (2014b, 2015a, b) for more detailed descriptions of palaeogeographic and sequence stratigraphic context. **a** Location of the Napoleon quarry in southeastern Indiana, USA. **b** Stratigraphy of units exposed at the study site, with the approximate position of the specimen marked by the *star*. Note that the *star* is immediately adjacent to a microbioherm in the basal Massie Formation. *Scale bar* 1 m. Figure slightly modified from Thomka et al. (2016b)

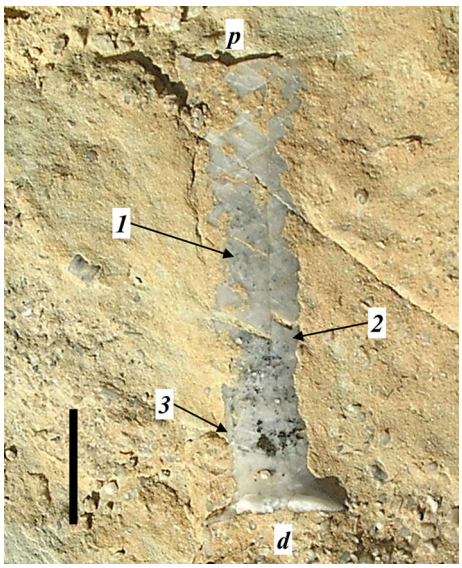

Fig. 2 Holdfast of *Finitiporus boardmani* from a hardground capping the lower carbonate of the Massie Formation, Napoleon quarry, Indiana, USA. The proximal end of the holdfast, where detachment from the theca occurred, is labeled '*p*'; the distal end of the holdfast, where attachment to the substrate occurred via an expanded cemented disc, is labeled '*d*'. Three elongate plates of the stem-like holdfast (labeled '*1*', '*2*', and '*3*') are visible; note that only the plate labeled '*1*' is exposed completely. *Scale bar* 10 mm

hardgrounds, microbioherms and cephalopods; however, the dimensions of the basal attachment area do not allow identification of the specific bioclast or lithoclast, if any, that was initially encrusted.

Slightly more than 40 mm in length, the holdfast is relatively wide at the proximal end, tapering slightly to a minimum at the base of the elongate, presumably hollow, stem-like attachment before expanding into a basal disc of approximate width to the proximal end of the holdfast (Fig. 2). Embedment in matrix prevents determination of the total number of plates comprising the structure. Frest et al. (2011) reported distal portions of thecae of *F. boardmani* that consisted of both six and seven plates, both of which are feasible given the width of exposed plates (Fig. 2). Portions of three elongate (~35 mm long) plates are exposed, with one plate completely exposed (labeled '1' in Fig. 2), approximately half of another plate visible (labeled '2' in Fig. 2) and only a small portion of the third plate visible (labeled '3' in Fig. 2). Sutures between adjacent holdfast plates are regular and straight with no evidence of ankylosis or crenulation. All plates are devoid of macroscopic pores, a state that is relatively rare among the diploporitan assemblage of the Massie Formation, but a distinctive characteristic of *F. boardmani* (Frest et al. 2011; Thomka and Brett 2014a). The basal attachment disc (labeled '*d*' in Fig. 2) is relatively solid, though it appears that one of the sutures between elongate plates of the stem-like area extends into the flared disc, so it may be composed of multiple plates, possibly six or seven corresponding to the plates of the rest of the distal theca.

Discussion

Thomka and Brett (2015a) described twelve distinct attachment structure morphologies on the Napoleon quarry hardground and documented the occurrence of each morphotype with respect to sub-environments across the undulating hardground surface. Four discoidal holdfasts are present on the elevated, well-sorted hardground crests; five radicular and dististelar attachment structures are present in hardground troughs partially filled with poorly sorted skeletal rubble; and three radicular attachment structures are present on fistuliporoid-micrite microbioherms (see Thomka and Brett 2015b). The *F. boardmani* holdfast was recovered from micrite- and pluricolumnal-rich sedimentary rocks immediately surrounding a microbioherm. Given that the holdfast is not directly attached to a discrete substratum (Fig. 2), it is likely that the specimen represents an allochthonous element dislodged from the microbioherm and transported to the adjacent low-lying area, along with the associated, relatively long pluricolumnals in the surrounding material. This interpretation is further supported by the restriction of *F. boardmani* thecal fragments to areas proximal to microbioherms (Frest et al. 2011).

Encrustation of microbioherms by *F. boardmani* on the Napoleon hardground is significant because other pelmatozoans occupying these buildups, namely the monobathrid camerate *Eucalyptocrinites* and the hemicosmitid rhombiferan *Caryocrinites* (Thomka and Brett 2015b), are characterized by relatively long columns terminating in dendritic, radicular attachment structures (Brett 1981, 1984). The previous absence of discoidal holdfasts and the overall low diversity of pelmatozoan encrusters on microbioherm exteriors at this locality was unexpected given the seemingly ideal substrate for diploporitan encrustation represented by microbioherms and the comparatively dense encrustation of similarly stable, hard substrata (hardground crests) by multiple forms of discoidal thecal attachment structures (Thomka and Brett 2015a).

This occurrence is significant not only because it represents an additional record of pelmatozoan echinoderm encrustation of a now-inaccessible, but palaeontologically valuable surface but also because it provides insight into the palaeobiology of a diploporitan taxon characterized by a relatively poor record owing to a delicately constructed theca (Frest et al. 2011). In addition, this find contributes to a clearer understanding of the palaeoecology of carbonate buildups in middle Palaeozoic level-bottom settings.

Conclusions

The holdfast of the sphaeronitid diploporitan echinoderm *Finitiporus boardmani* is present on a carbonate hardground in the lower Massie Formation (Silurian: Wenlock, Sheinwoodian) at the Napoleon quarry of southeastern Indiana, USA. This surface is densely encrusted by pelmatozoan echinoderms as documented by Thomka and Brett (2015a), but this particular holdfast morphology had not previously been recognized. This occurrence raises the documented diversity of attachment structures on this surface to thirteen.

The *F. boardmani* holdfast was preserved in sedimentary rocks immediately surrounding a microbioherm but is not directly attached to the substrate. Hence, it is likely that this taxon encrusted elevated microbioherms, but it is also possible that it occupied other areas of the hardground. Because the Napoleon quarry hardground has been partially destroyed subsequent to the publication of the initial report on encrusting echinoderms, noting a further attachment structure represents an important supplement to the record of pelmatozoan echinoderm diversity and distribution in the middle Silurian of the greater Cincinnati Arch region.

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