Field study of purported hardgrounds of the Cincinnatian (Ohio, USA)

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A number of samples conventionally believed to be indicators of hardgrounds are located in the Cincinnatian (Upper Ordovician) carbonates of the east-central USA. These consist of borings (especially *Trypanites*) in both fossil and limestone surfaces, as well as some encrusting bryozoans. The ostensible evidence for protracted sedimentation (hardgrounds) must be juxtaposed against a much more commonly occurring set of evidences pointing to rapid sedimentation. The latter include storm deposits, cross-bedded carbonates, large ripple marks and a large suite of orthocone nautiloids that are crowded into a single bed.

Hardgrounds are lithified regions of the sea floor. Their alleged ancient counterparts are inferred from the presence of trace fossils (borings) that can only be made on a hard substrate, and body fossils of specialized organisms believed to require a hard substrate to encrust. A set of slides depicting inferred hardgrounds is available online.[1] Not surprisingly, hardgrounds have long been presented as a challenge to Flood geology,[2] owing to the long time for modern hardgrounds to form. However, they also present difficulties for conventional uniformitarian geology.[3] Owing to the volume of information relevant to hardgrounds, this report is limited to our recent fieldwork itself. The reconciliation of apparent hardground phenomena with the Universal Deluge is to be presented subsequently.[4] Throughout the present work, standard uniformitarian terms related to paleoenvironments and deep time are employed without in any way implying our acceptance of them.

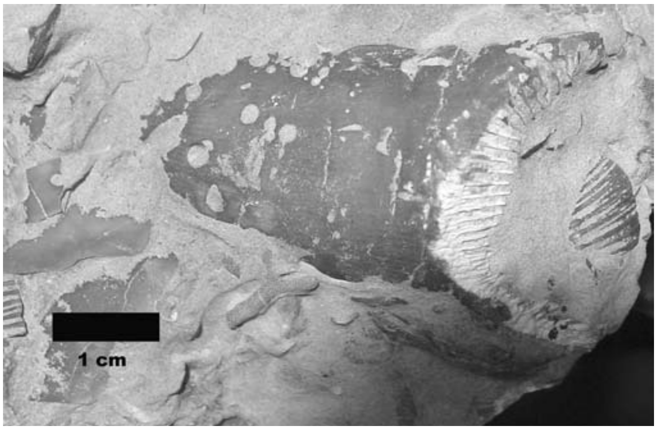

***Figure 1.** A detailed closeup of a bored coral* Grewingkia.

Geology of site

The Cincinnatian (Upper Ordovician: Caradocian to Ashgillian) strata of the east-central USA is especially known for its abundance of fossils. The online article by Holland provides excellent background information of the local geology.[5] The strata consist of a series of alternating shales and limestones. In terms of sequence stratigraphy, the Cincinnatian is divided into five limestone–shale marine transgressive-highstand cycles. The Ashgillian Liberty and Whitewater Formations at the Caesar's Creek Spillway (39°48'26"N, 84°03'27"W), south-west Ohio, the site of this field investigation, are assigned to the highstand part of the fourth depositional sequence.[6] The Spillway itself is located approximately 50 miles (80 km) NNE of the *Answers in Genesis* USA headquarters in Petersburg, Kentucky. Over a dozen hardground horizons are claimed to have been located at the Spillway itself by previous investigators,[7] as well as others throughout the Cincinnatian. To make matters even more ostensibly challenging for Flood geology, a 1.6-km-deep borehole just a few kilometres north of the Spillway intersects trilobite-bearing Cambrian strata,[8] implying the transpiration of a series of time-consuming events before even the first supposed hardground.

***Figure 2.** An* in situ *bored coral* Grewingkia*, partly obscured by powdered talus. It opens to the left, with relatively wide* Trypanites *boreholes. Penny for scale.*

Examination of site

Field guidebooks[9,10] descriptive of the site were studied. Compilations of photos of Cincinnatian fossils,[11–13] along with the PowerPoint program developed by Whitmore,[14] proved especially useful in the identification of fossils. Osgood's classic[15] was consulted for the identification of trace fossils. Owing to the fact that neither of us are specialists in any relevant fossil group, our identifications are necessarily tentative. Many different kinds of body and trace fossils were seen and collected, but only those relevant to hardgrounds are discussed in this report.

Six days of collaborative field work were carried out by the authors in 1999 and 2004. Thousands of square metres of talus and outcrop surfaces were examined. In

Figure 3. *A relatively large specimen of a bored coral* Grewingkia.

Figure 4. *An extensively bored specimen of the coral* Grewingkia *embedded in a brachiopod coquina. Penny for scale.*

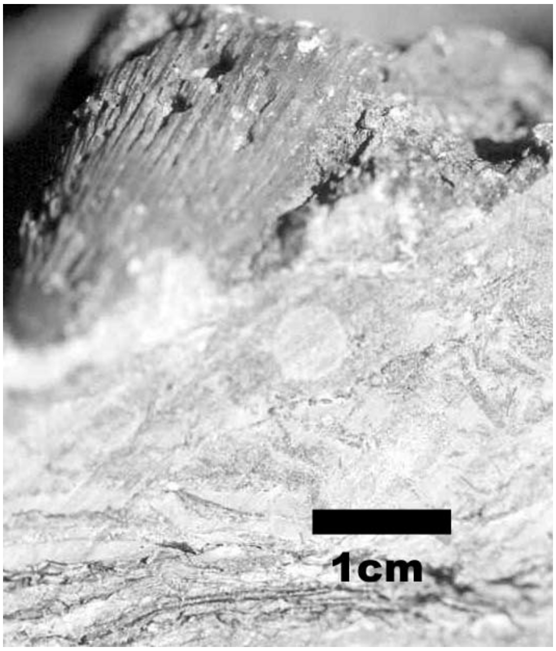

Figure 5. *Sectioned sample showing bedding, burrows, etc., within the strata in which is embedded a bored coral* Grewingkia.

addition, Dr Whitmore, who lives in the area, has done a considerable amount of fieldwork at this location, alone and with his college geology students, over the last 25 years. In the present fieldwork, Woodmorappe focused on the hardground-related evidence, while Whitmore concentrated on the ripple marks, cross-bedded lithologies and the nautiloid bed.[16]

Owing to the fact that the large Caesar Creek Spillway outcrop is almost entirely vertical with virtually no terraces, and *in situ* carbonate beds are usually obscured by the remnants of weathered shales, opportunities for seeing fossils and structures *in situ* are limited. For this reason, and in common with previous investigators, most of our time in the field was spent examining the thick layers of talus that occur at the foot of the outcrop.[17]

For scale in photos (figs. 1–24), the standard GSA (Geological Society of America) scale in cm was used, as were US coins (quarter—2.3 cm diameter and 1 mm thickness; dime—1.75 cm diameter; penny—1.9 cm diameter). Owing to the fact that the Spillway walls are constantly being eroded, no map exists of the Spillway itself, and none is provided in this report. However, GPS (Global Positioning Satellite) data is included for precise locality information as needed.

How ancient hardgrounds are recognized

In order to identify hardgrounds in the sedimentary record, one has to recognize body fossils and trace fossils of organisms that ostensibly required a hard seafloor substrate to colonize. In terms of specifics, the presumed recognition of hardgrounds in the sedimentary record can be summarized in the following quotation:

> ‘Although many hardgrounds show a characteristic mineral staining (most commonly by iron minerals) at or just below their surface, which can draw attention to the surface in outcrop, this is not always present (particularly in coarser-grained lithologies). In the absence of such staining it is the presence of the boring and encrusting fauna alone that testifies at the macroscopic level to the originally hard character of the surface … . Most hardgrounds go unrecognized in the field because the fossils associated with them are not usually noticed. We hope to increase the number of recorded hardgrounds by improving the abilities of geologists to distinguish the often esoteric fossils associated with them … . Since borings are the last faunal features to succumb to erosional scour, they are the most common criterion for recognizing ancient hardgrounds.’[18]

Many hardground-related features, such as mineral staining, can occur in non-hardgrounds.[19] It is for this and the other above-quoted reasons that we have emphasized borings in our search for hardgrounds. Apart from being much more conspicuous than encrusting fossils, these

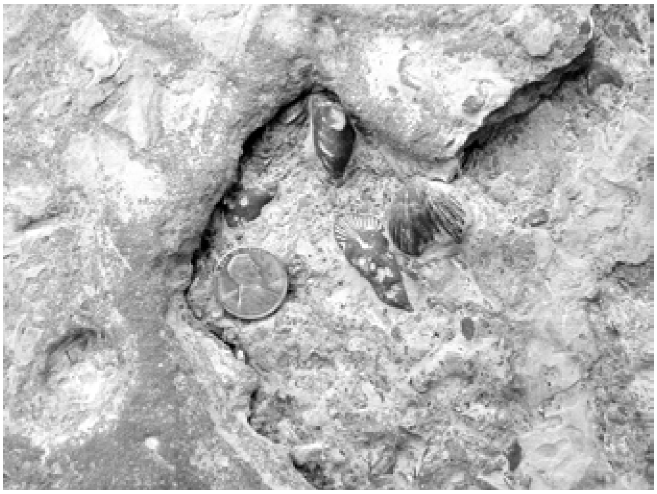

Figure 6. *Bored corals situated next to other benthic organisms that had escaped boring. Penny for scale.*

Figure 7. *Small slab containing bored coral* Grewingkia *(top left) and a bored brachiopod (far right bottom), in front and in focus. In the background can be seen a bored bryozoan-encrusted brachiopod (far left bottom, circled) and a bored bryozoan (middle left, circled). The superimposed white circles each have an inner diameter of 6 mm. Quarter for scale.*

hardground trace fossils are known to be much more numerous than individual encrusters. In fact, an areally-normalized census of Cincinnatian hardgrounds shows the borings to be several times more common than all hardground body fossils *combined.*[20] Furthermore, some lower Paleozoic hardground horizons lack encrusters entirely, and so are defined almost solely by the presence of borings.[21] Finally, if the Ordovician hardgrounds of southern Ontario, Canada, are any indicator, rarely, if ever, do hardgrounds *lack* borings.[22]

Of numerous taxa of mostly extinct organisms believed to have been obligatory hard-substrate encrusters, bryozoans are the most common in the Cincinnatian in general and in the Spillway in particular.[23] For this reason, along with the fact that other types of encrusting organisms tend to be minute and esoteric, we focused our attention on bryozoans.

Figure 8. *Closeup of the boreholes in the bryozoan-encrusted brachiopod and the bryozoan from figure 7. The minute borings are outlined by circles. Quarter for scale.*

Implications of hardground borings

The ichnotaxa of Paleozoic macroboring traces is acknowledged to be confused and subjective.[24] The 0.5–3.0 mm diameter boreholes prevalent in Lower Paleozoic fossils and hardgrounds have traditionally been assigned to the ichnogenus *Trypanites* (see illustrative photo online).[25] Bromley[26] has proposed a very broad definition of this ichnotaxon, one that encompasses most of the Phanerozoic and subsumes a considerable variety of unbranched, quasi-cylindrical cross-sectional shapes of the stated range of diameters. In contrast, Palmer *et al*.[27] suggest that Paleozoic *Trypanites* should properly be transferred to the ichnogenus *Palaeosabella*, as it differs from Mesozoic *Trypanites* in shape and length. Unfortunately, *Palaeosabella* itself has a history as a confused taxon.[28] To complicate matters further, another boring ichnogenus found in the Cincinnatian, *Sanctum*, has recently been described.[29] To avoid getting involved in taxonomic arguments, our usage of *Trypanites* in this report is in accordance with the broad definition advocated by Bromley.

While searching for borings in the carbonate lithologies, we were careful not to mistake vague depressions and soft-sediment burrows for borings. All three can be common on discontinuity surfaces, but the former is of inorganic origin, usually from hydrodynamic agencies and hydrochemical influences.[30] In contrast, borings are narrow, well-defined, and have very sharp edges (unless perhaps secondarily made indistinct by weathering).

But how is the investigator to distinguish between a boring and a burrow? Ekdale and Bromley[31] considered this question in some detail. Although the criteria for distinction between the two ichnofossils is not absolutely diagnostic, borings can generally be recognized as they cut through all pre-existing textures, fossils, bioclasts and grains in the rock. Unlike burrows, borings never stop at the foot of particular limestone constituents, nor steer around them. Moreover, a trace fossil cutting cleanly into a body fossil is almost

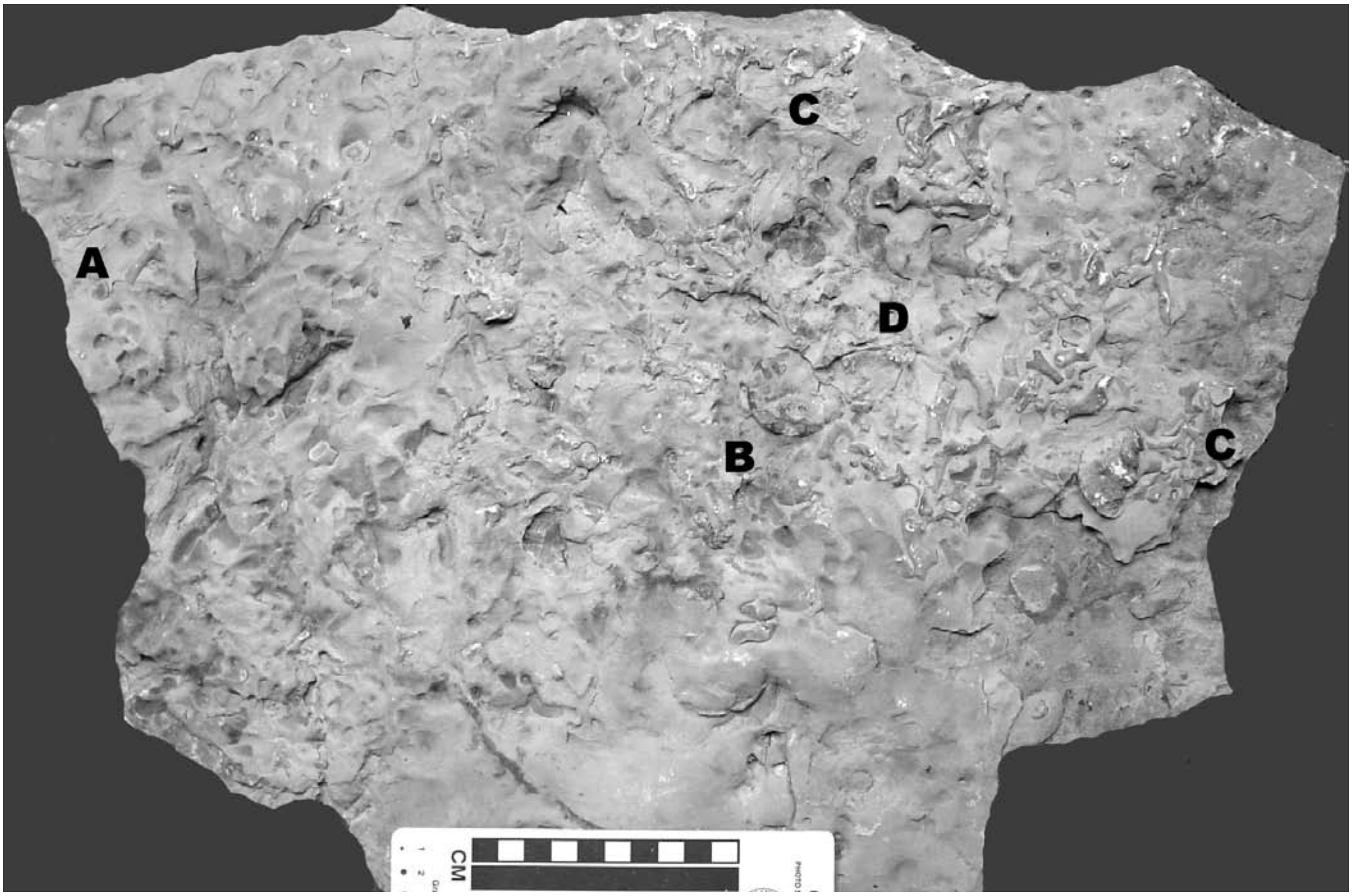

Figure 9. *Plan view of an inferred* in situ *marine benthic community (40 cm wide and 28 cm broad). Distinctive features include: Crinoid calyx directly above 'A', bryozoan-encrusted brachiopod directly to right of 'B', Corals directly above 'C's'. There is also a large area of ramose bryozoans in carbonate mud (D). Closeups of some of these features are shown in figures 10–12.*

certainly a boring. Ideally, the lithified state of the sediment at the time of boring (hence, by definition, a hardground) should in fact be verified by a microscopic examination of the borehole edge, with identification of carbonate grains that have been truncated during the boring action.[32] This has proven practical for the Ordovician hardgrounds in Iowa and Minnesota,[33] but not for those in south-west Wisconsin, owing to the fine grain and incipient dolomitization of the latter.[34] In view of the difficulties of examining carbonates (especially micstones—very fine-grained limestones) for grain truncations at Caesar Creek, reported by previous investigators,[35] we did not attempt any microscopic analyses of bored junctures. However, we had specialists verify our identifications of borings. Woodmorappe also sectioned some samples in order to verify the borings as such by their profiles.

Figure 10. *Coral in inferred growth position marked by penny (top left). The coral is at the top 'C' position in figure 9.*

Bored fossils—not necessarily hardgrounds

Corals occur much less frequently than brachiopods, the overwhelmingly dominant fossil of the Cincinnatian. However, by far the most abundant bored object found at the Caesar's Creek Spillway was the coral *Grewingkia*. In fact, approximately one third of all 20 fossil corals encountered by Woodmorappe contained borings.

Bored Late Ordovician *Grewingkia* corals have been found at numerous locations throughout North America,[36]

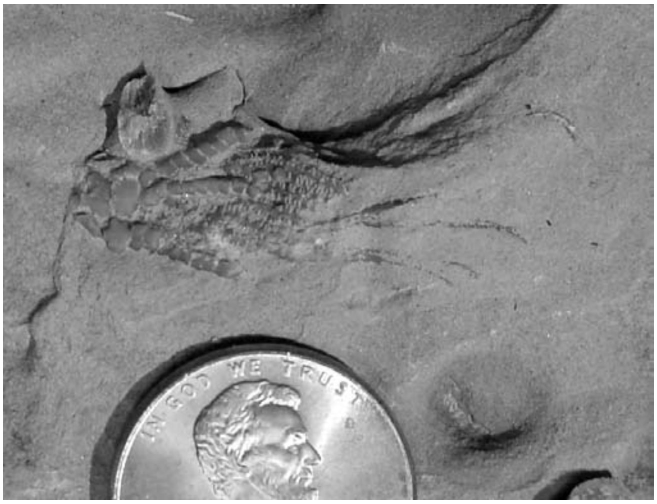

Figure 11. *Calyx of the crinoid* Cupulocrinus *in figure 9. Penny for scale.*

and figures 1–7, 10 and 17 illustrate just some of those we had observed. All of the corals pictured here come from large chunks of float, with the exception of the one shown in figure 2. The latter occurs in outcrop at the south-east margin of Clarksville Road and the Spillway outcrop. *Trypanites* openings within the corals of the Cincinnatian series tend to be less than 1 mm in diameter,[37] and this is especially evident in the minute size of the boring openings seen on the coral pictured in fig. 3. In a few instances (e.g. fig. 17), the coral is largely destroyed, perhaps by the boring action itself. Consistent with the reports of others,[38] the borings we saw usually occurred perpendicularly but sometimes obliquely to the surface of the coral (as especially seen in figure 5).[39] This tells us little about their exact origins, as the angle of borehole construction itself is not believed to vary consistently according to a predatory versus scavenging mode of origin.

Although brachiopods are manifoldly more common than corals, bored brachiopods are uncommon. We did find a few instances of bored brachiopods (figs. 7–8) and some examples of bored bryozoans (figs. 7–8). Of course, individual bored fossils, or groups of them, do not in themselves necessarily indicate hardgrounds. For one thing, organisms could have been bored on a hardground somewhere else before being transported to their present sites. Also, the presence of borings in fossils does not necessarily imply that the seafloor on which they rested had itself been lithified at the time of their boring. Finally, in most instances, it is not even possible to tell if the borings occurred while the coral was alive (hence a symbiotic or predatory action) or dead (hence a scavenging action). The

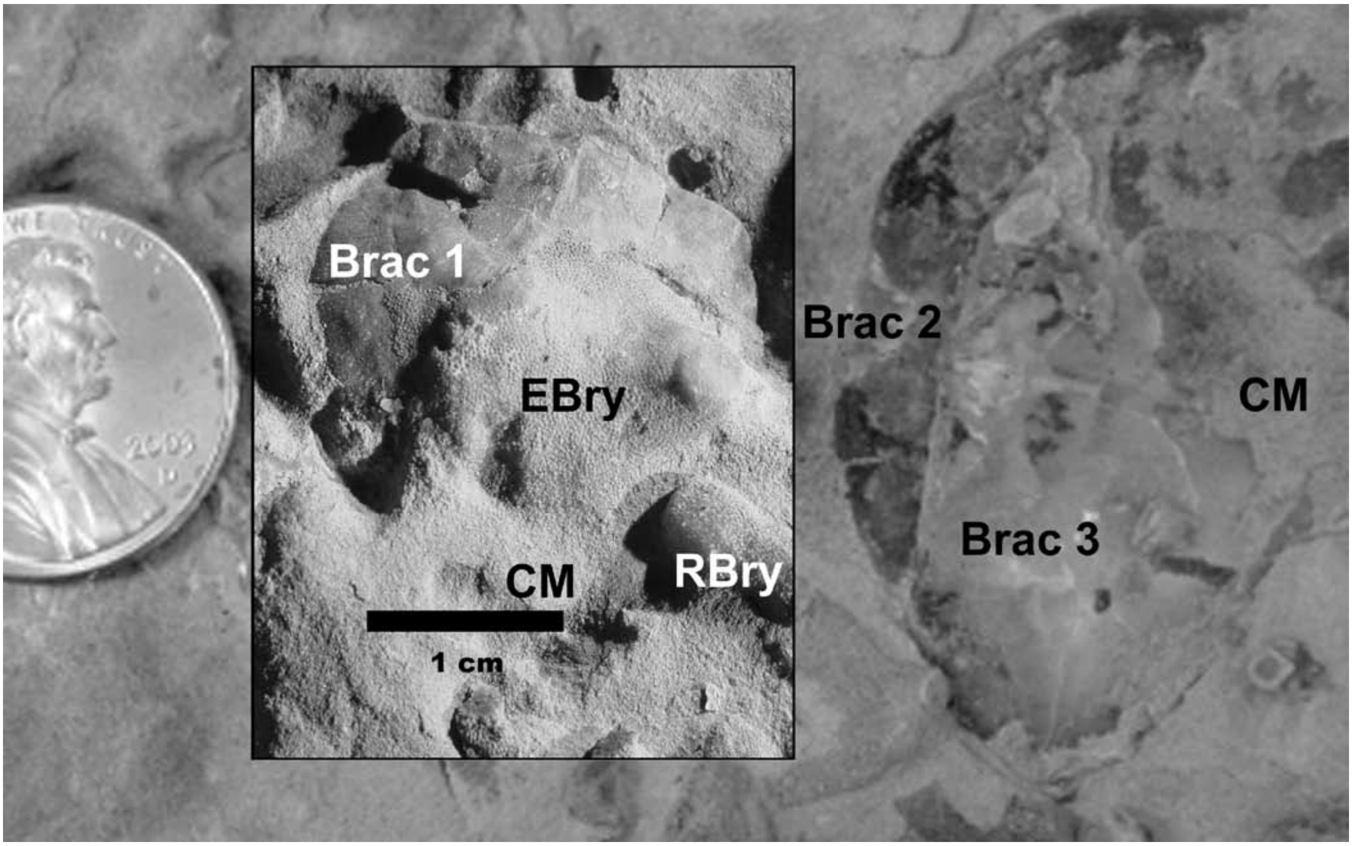

Figure 12. *Bryozoan partly encrusting a brachiopod (from figure 9), but not extending to the surrounding limestone surface. Brac 1, 2, 3—brachiopod nos. 1–3; CM—carbonate cement; EBry—Encrusting bryozoan; RBry—Ramose bryozoan. Penny for scale. The boxed-in area is shown at a higher resolution.*

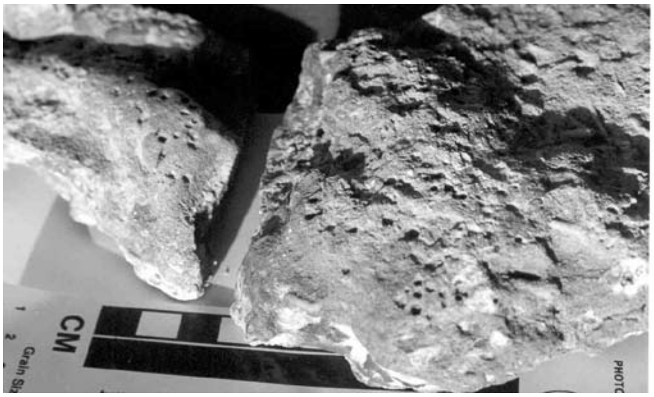

Figure 13. *Small hardground clasts (left clast shown sectioned in figure 14).*

presence of rare deep penetrations that had subsequently been partly healed establishes the fact that at least some of the borings were inflicted upon the corals while they were alive.[40]

Bored fossils can lead to conflicting interpretations of their origins. For instance, Wilson and Palmer[41] believe that layers of bored brachiopod shells found in Cincinnatian of the adjacent US state of Indiana are the remnants of seafloor crusts (a type of hardground) that subsequently underwent erosive breakup. By contrast, Kaplan and Baumiller[42] suggest that most of the borings in brachiopods were of a predatory nature. They further argue,[43] among other things, that the preferred sites for boring cannot be fully explained by hardground-borers' natural preference for elevated points on the seafloor, but instead most likely indicate predatory attacks on the brachiopods while they were still alive.

Patches of inferred ancient hardgrounds

As noted earlier, a bored carbonate surface, with or without accompanying bored fossils, constitutes unequivocal evidence of a hardground—according to conventional thinking. Bored carbonate surfaces were rarely seen. They were less common than bored brachiopods and very much less common than bored corals.

Woodmorappe located some clasts, the surfaces of which were riddled with *Trypanites* (figure 13) near the south-west intersection of the Spillway and Clarksville Road (N39˚28′43.5″, W84˚03′21.1″). This location is not far from that where Mitchell *et al.*[44] had found a hardground clast containing an encrusting graptolite. The maximum density of borings per 5 cm x 5 cm square, in the small clasts pictured in figure 13, amounted to about 25. This is roughly midway between the 8–47 range observed in the Ordovician hardgrounds in Ontario[45] and 4–38 for those in Iowa.[46] Woodmorappe also found a hardground surface (at N39˚28′43.2″, W84˚03′28.5″) containing both bored seafloor and bored *Grewingkia* next to each other (fig. 17). But do the hardground features seen in the

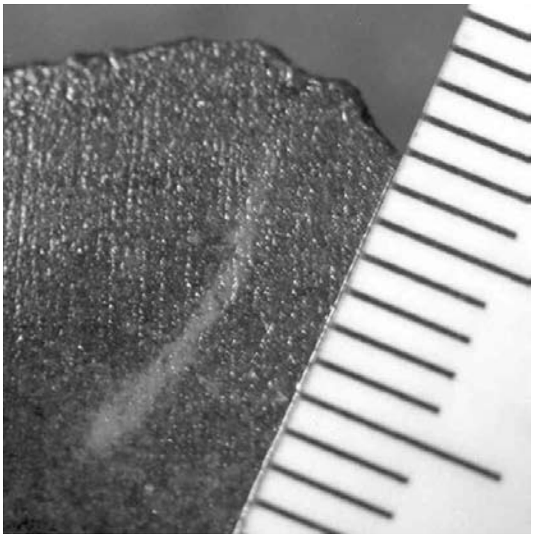

Figure 14. *Sectioned hardground specimen (from figure 13), displaying a classic J-shaped individual* Trypanites *boring in profile. (mm scale divisions.)*

Figure 15. *Woodmorappe sitting on a thick limestone ledge within the Liberty Formation, and pointing to a purple-tinted limestone slab that contains a definite hardground (figures 16–17).*

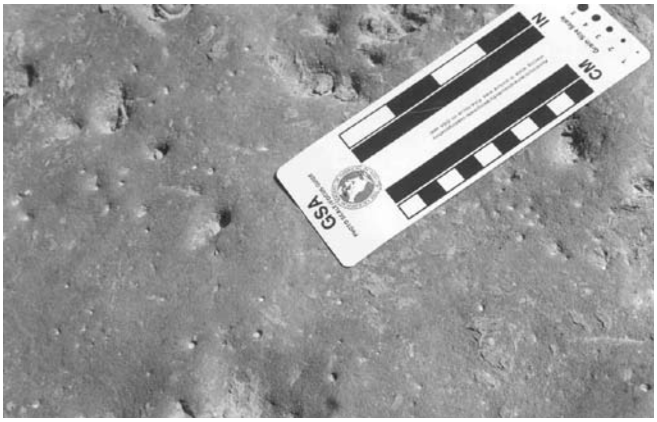

Figure 16. Closeup of purple-tinted limestone slab from figure 15. The boring* Trypanites *occurs as sharp awl-sized holes throughout this picture. The ostensibly lithified state of this surface (hence a hardground) is proved by* Trypanites *occurring in the limestone surface itself, as seen in this and the successive photo.*

***Figure 17.** Closeup of purple-tinted limestone slab from figure 15. Two highly-bored specimens of the coral* Grewingkia*.* Trypanites *occur in the limestone itself (at left).*

***Figure 18.** Hardground slab surface containing* Petroxestes *in plan view. Penny for scale.*

large broken-off slab (figs. 15–17) continue, or reappear, elsewhere on the coeval limestone surface? To answer this question, Woodmorappe attempted to trace the slab back into the outcropping limestone layers from which it may have broken off. However, this layer, and others near it, displayed only vague depressions and the trace fossil *Chondrites*, which we commonly encountered throughout the Spillway outcrops.

Whitmore found an interesting slab that contains hardground crusts embedded within a brachiopod coquina (fig. 21). Both uniformitarians and diluvialists can agree that these are allochthonous pieces of a hardground surface. The onetime hardground had experienced erosion and underwent fragmentation, with parts of it becoming incorporated into a current-winnowed coquinate deposit. Slot-shaped borings, *Petroxestes*, attributed to a bivalve,[47] were found by Whitmore at one location. They (figs. 18 and 19) closely resemble those pictured online.[48] In contrast to *Trypanites*, *Petroxestes*, based on our experience, are rare.

Sectioning of 'hardground' borings: evidence and interpretation

In the field, we were limited to seeing the borings in plan view. Woodmorappe sectioned some collected samples in order to examine the hardground borings in cross-section. In order to understand the nature of *Trypanites* borings in 3D, Woodmorappe used the sketches provided by Hecker[49] and Pemberton *et al.*[50,51] as a guide. A number of clast samples containing *Trypanites*, notably the ones shown in oblique view in figure 13, were then sectioned by Woodmorappe into cm-sized slabs.

Several borings could be seen in vertical section (e.g. fig. 14). Consistent with the earlier-discussed proposed redefinition of Paleozoic *Trypanites* as *Palaeosabella*,[23] the hardground cross-section (fig. 14) indicates a saccate (sac-shaped) boring with a 10:1 L/D ratio and an expansion of diameter with increasing depth. The angle of inflection[52] in the specimen is measured at 155°, which falls near the upper range of the 120°–160° customarily observed for *Trypanites.*[53] The cap of the boring is ellipsoidal, consistent with the 'Type B' hardground boring morphotype defined by Pemberton *et al.*[54] However, this assumes that the cut had sectioned the burrow end in full cross-section. A tangential slice of a rounded-end burrow ('Type A') would also appear ellipsoidal.

An *in situ* fossil community?

Our attention was piqued by a slab that has a diverse series of fossils situated together, some of which, according to conventional thinking, appear to be in life position. There are three *Grewingkia* corals on the slab, and these are situated at two locations shown in the overview (fig. 9).

Figure 19. *Preceding* Petroxestes*-bearing sample (figure 18) in oblique perspective.*

Figure 20. *Large slab with* Trypanites *that are filled with light-coloured limestone debris.*

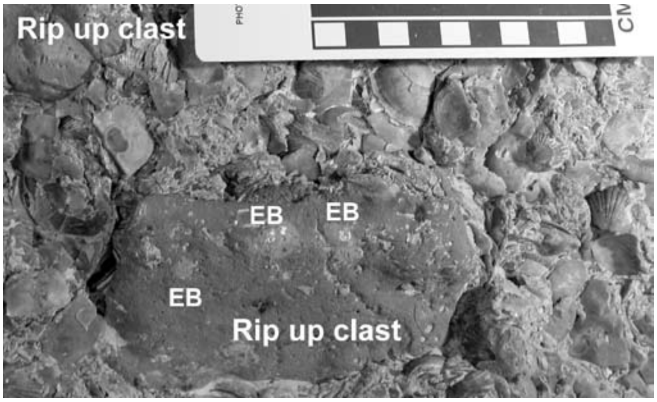

Figure 21. Trypanites*-containing hardground clasts embedded in a brachiopod coquina. EB—Encrusting bryozoan.*

One of these corals is shown closeup in figure 10. All three corals appear to be in life orientation, an example of which is sketched as figure 1 of Elias and Buttler.[55] There is a well-preserved crinoid calyx of *Cupulocrinus* (fig. 11) on the slab. Owing to the fact that crinoids disintegrate promptly after death, well-preserved remains are an indicator of rapid burial.[56] Well-preserved crinoid remains have previously been found at Caesar Creek itself,[57] but our find of the well-preserved calyx (fig. 11) is a fairly uncommon occurrence.

Does this assemblage of fossils represent a hardground? The slab (fig. 9) has no borings. What about hard-substrate encrusters? A bryozoan was found to encrust a brachiopod but, upon close examination, not the surrounding carbonate surface (fig. 12). This picture is visually reminiscent of a layer of moss encrusting a rock—whence the name bryozoan ('moss animal'). However, the absence of borings and the failure of the bryozoan to encrust the limestone surface itself prevent us from concluding that the surface had been lithified at the time of the encrusting. There are also some ramose bryozoans on this slab (not shown close up), but they are broken, suggestive of transport. For this reason, *in situ* growth cannot be assumed for these presumably hard-substrate encrusters, and so we cannot conclude that this fossil community (fig. 9) had been a hardground.

Some evidences of catastrophism in Cincinnatian strata

Brachiopod coquinas, as shown in figures 4, 7, 8 and 21 (albeit almost always without the borings), are monotonously common throughout the strata we examined. Most such concentrations of fossils in the Liberty Formation and the overlying Whitewater Formation are attributed to the actions of storms.[58] Any notion that the coquinas resulted from long-term accumulation of shells on an ancient seafloor is contradicted by the virtual absence of corrosion of the brachiopod shells. Placed in a broader context, coquinas consisting of fragmentary and/or complete body fossils are routinely attributed to the sediment-winnowing effects of storm-generated waves and currents.[59]

Several instances of cross-bedding were observed in rocks on this recent trip (fig. 23). There was also an extensive area of the Spillway floor that appears to exhibit large ripple marks (not shown). Ripple marks themselves can form in either quiet or rapidly moving water, and it is not apparent whether the large amplitude of the ripples that we have seen are necessarily indicative of a rapid flow of water.

Large concentrations of oriented fossils are a strong indicator of catastrophic deposition. Notable concentrations of current-sorted cephalopods were first brought to the attention of the scientific creationist community by

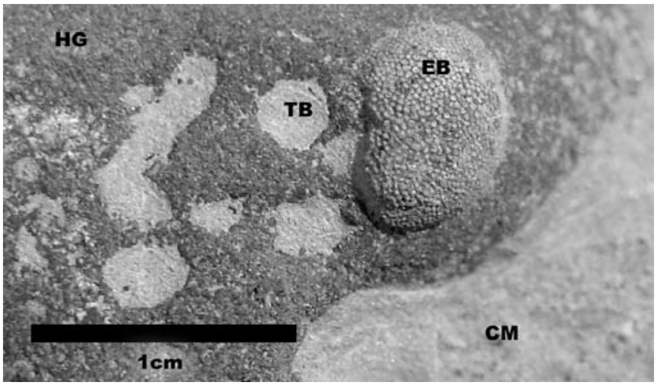

***Figure 22.** Closeup of preceding figure (21) showing a bryozoan encrusting the hardground surface. The mound-shaped bryozoan seems to be also partly encrusting a debris-filled* Trypanites *boring. EB—Encrusting bryozoan; TB—*Trypanites *burrow; HG—inferred hardground surface; CM—carbonate cement.*

***Figure 23.** A slab exhibiting cross-bedding. Penny for scale.*

Woodmorappe,[60] who cited such instances in the Caucasus Mountains and southern Germany. Subsequently, Austin[61] described a large concentration of oriented nautiloids in the Lower Carboniferous strata of the Grand Canyon. Some time ago, Whitmore had discovered a rich nautiloid bed outcropping in the floor of the Spillway (fig. 24). The bed is 8 metres long, 2 metres wide and, where its edges can be seen in the vertical direction, a few centimetres deep. As part of his ongoing study of this fascinating deposit, he measured the orientations of 67 individual nautiloids during this field trip. Directional statistics fell just short of justifying a preferred orientation for the nautiloids. However, their unusual concentration (about 4 individuals per square metre) is at least suggestive of catastrophic mass mortality.

Conclusions

Various previous researchers have noticed the rarity of borings even in fossils (which, as noted earlier, do not, in themselves, necessarily indicate a hardground). Decades ago, Bucher[62] commented on the rarity of bored specimens in the thousands of specimens he had observed from Cincinnatian strata in south-west Ohio. A more recent assessment[63] confirmed the rarity of bored Paleozoic shells, using the abundance of Cenozoic and extant shells for comparison.

We confirm this lack of boring from our observations. Moreover, one striking feature of this field experience is the extreme rarity of unambiguous hardground features—borings and encrusting bryozoans on rock surfaces. Out of thousands of square metres of carbonate surface examined, only a tiny fraction exhibit bored carbonate surfaces. There were numerous surfaces containing vague depressions but only a handful of instances, comprising perhaps tens of square centimetres, containing *Trypanites* or *Petroxestes*. While a very small fraction of fossils were found encrusted by bryozoans, limestone surfaces encrusted by bryozoans were even more infrequent.

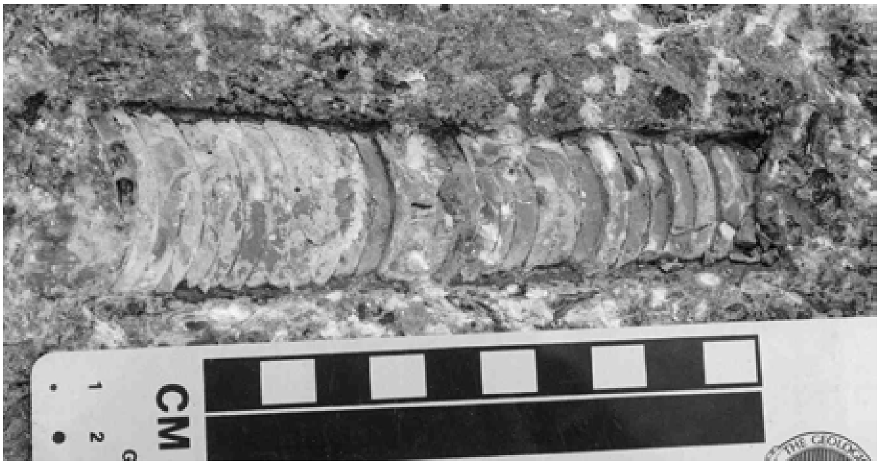

***Figure 24.** One of the 67 orthocone nautiloid conches found crowded into a small layer on the Spillway floor.*

Many carbonate layers contain well-preserved coquinas, pointing to rapid deposition. The intervening shales contain *Flexicalymene* trilobites preserved in a rolled-up state, indicating rapid sedimentation.[64] Since most of the Cincinnatian strata consist of rapidly deposited sediments, one can ask where the supposed millions of years of deposits are found. The standard uniformitarian answer is that most of the geologic time elapsed during mostly unseen periods of non-deposition and, in the present instance, during the formation of the hardgrounds. If the latter can be eliminated as a 'depository' of long periods of time, the entire Cincinnatian series can be understood as a catastrophic deposit. Apropos to this, the compatibility of hardgrounds and the Noachian Deluge is explored in an upcoming work.[4]

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