The stratigraphy and paleoecology of a hardground in the Grant Lake Limestone (Cincinnatian, Upper Ordovician) near Maysville, Kentucky

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INTRODUCTION

A laterally continuous carbonate hardground (Wilson and Palmer, 1992) exposed near Maysville, Kentucky, has bryozoan-encrusted surfaces that were extensively bored during the Late Ordovician. This hardground is unique because it hosts large bryozoan mounds both on top of the hardground and hanging underneath as part of a cave fauna. Bryozoan mounds can be up to 8 cm in height; borings penetrate the bryozoan mounds as well as the hardground. Detailed stratigraphic analysis of this hardground and bryozoan mounds yields paleoenvironmental conditions during formation.

LOCALITY

The Maysville Hardground is exposed for 111 metres on the east side and 10.7 metres on the west side of U.S. Highway 68, in northern Kentucky south of Maysville (Fig. 1). It crops out at road level about 0.2 km south of the junction of U.S. Highways 68 and 62. This hardground locality was believed to be destroyed between 1992 and 1998 due to road construction (Cuffey, 1998, locality KY-MS-0006), but recent visits to this location show that the hardground and encrusting bryozoan mounds are still exposed.

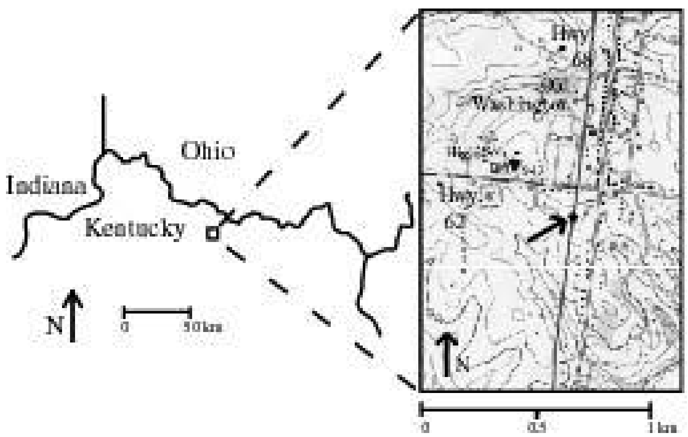


Figure 1. Location of Maysville Hardground (star). Mays Lick, Kentucky, 7.5-minute quadrangle.

FIELD METHODS

On the west side of the road, a 182-cm-thick stratigraphic column was measured, described, and divided into 14 units (Fig. 2). Samples from the resistant layers, hardground layer, and bryozoan mounds were collected for macroscopic and thin-section analysis. Only bryozoan mounds that encrusted the top of the hardground were collected because no samples of the bryozoan mounds that hung underneath are currently exposed; some samples of the underhanging bryozoan mounds were collected earlier by Mark Wilson. Claystone found directly below the hardground layer was collected for microscopic analysis.

LABORATORY METHODS

Thin sections and acetate peels. Twelve thin sections were made from samples of the stratigraphic column. Using a systematic grid, between 300 and 450 cement and faunal fragments were point counted in these thin sections to determine the composition of each layer (Table 1). Additional hardground and bryozoan-mound thin sections were made to interpret an event sequence among the hardground, encrusters, and borers. Acetate peels of the longitudinal, sagittal, and tangential sections of the bryozoans were made to determine the types of bryozoans that encrust and hang below the Maysville Hardground.

Statistics. Nearest-neighbor relationships of borings in samples of the Maysville Hardground were determined using the method of Clark and Evans (1954), as corrected by Sinclair (1985) for edge effects. This method compares the mean nearest-neighbor distances with nearest-neighbor distances expected from a random distribution of borings. Digital photographs of eight Maysville Hardground samples were used to trace the perimeter and borings. The tracings were scanned into *NIH Image* to calculate the area and perimeter of the samples and to measure the distance between nearest neighbors. Distance between two borings was measured from the center of one boring to the center of the closest boring.

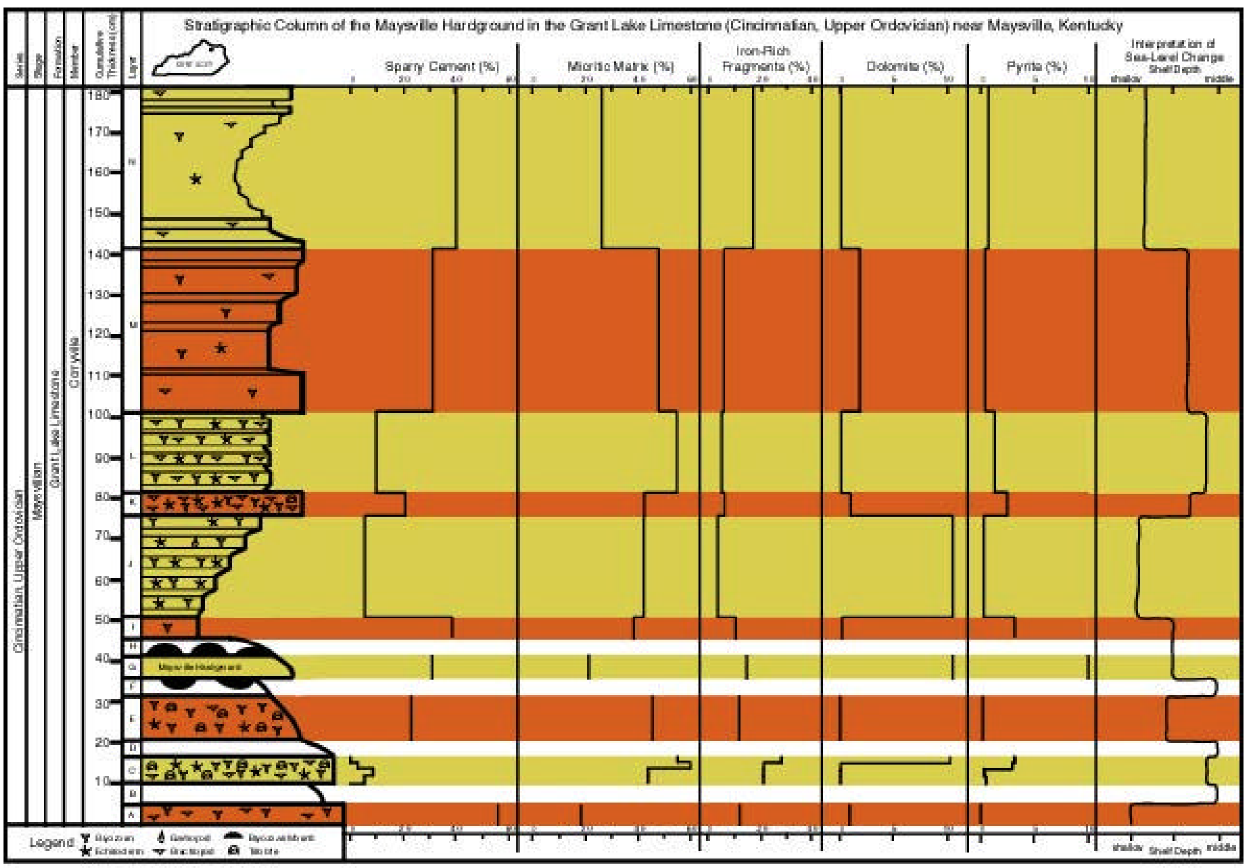


Figure 2. Stratigraphic column of the Maysville Hardground (Layer G) in the Grant Lake Limestone (Cincinnatian, Upper Ordovician) near Maysville, Kentucky. Symbols from Compton (1985) and Cuffey (1998). Accessory curves constructed from point-counting data. White bands represent claystone layers and gray bands represent carbonate layers.

MAYSVILLE HARDGROUND PALEOECOLOGY

Stratigraphy. The Maysville Hardground occurs in the Corryville Member within the upper part of the Grant Lake Limestone. The immediate stratigraphy of the Maysville Hardground consists of resistant layers of limestone intermixed with siliciclastic claystone. The claystones (layers B, D, F, H; see Fig. 2) may be derived from Appalachian erosion and possible volcanism. The claystone sample collected from directly below the hardground (layer F) did not contain any fossil fragments. The hardground and adjacent strata were formed in a shallow-shelf to middle-shelf marine environment. Table 1 shows the results of the amount of fossil fragments present from thin-section point counts. Figure 2 shows the stratigraphic column with accessory curves representing the percents from point-counting, and an interpretation of sea-level change throughout the stratigraphic column.

Hardgrounds have been reported to form under conditions of sea-level change (Wilson and Palmer, 1992). The Maysville Hardground formed after a slight change in paleoenvironment from middle-shelf depth to a shallower-shelf depth. Sea level then remained constant before the paleoenvironment shallowed even more. Sedimentary facies with a high percent of sparry cement probably represent high-energy environments, whereas high percents of micritic matrix represent low-energy paleoenvironments. Shell fragments can be used to determine local conditions; for example gastropods tend to be found in shallower waters and brachiopods tend to be found in deeper waters.

Layer	A	C1	C2	C3	C4	E	G	I	J	K	L	M	N
n	322	395	320	390	339	363	449	415	314	388	308	411	326
Bryozoans	4.04	7.34	6.56	1.28	0.00	7.16	0.22	0.24	18.15	4.64	12.34	4.38	0.92
Brachiopods	4.04	4.30	4.69	3.08	0.00	0.55	0.00	0.00	0.00	8.76	9.42	2.43	4.91
Echinoderms	0.00	7.85	5.94	2.05	0.29	2.20	0.22	0.00	8.28	5.41	4.22	1.46	0.92
Trilobites	0.00	3.54	3.75	0.77	0.00	5.51	0.00	0.00	0.00	1.03	0.00	0.00	0.00
Gastropods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00
Unidentified Shell Fragments	1.55	2.78	3.13	3.08	0.88	0.83	1.11	6.27	6.05	2.58	1.30	2.43	7.67

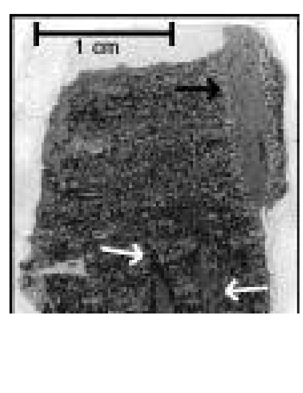
Table 1. Point-counting results (percents) for fossil fragments in carbonates. See Figure 2 for stratigraphic position of layers. (n= number of points counted)

Maysville Hardground. The appearance of a hardground in the rock record is marked by the presence of borers and encrusters. During hardground formation, cement precipitates and sediment accumulation is almost non-existent. The Maysville Hardground (layer G) varies laterally in thickness (0-5 cm) and is medium-gray, massive, and extremely well indurated. Shell fragments are rare, whereas pyrite, dolomite, and iron-rich fragments compose almost 40% of thin-section samples.

The high percent of iron may result from sulfate reduction before the formation of the hardground. The marine hardgrounds in the Lexington Limestone (late Middle Ordovician), similar to the Maysville Hardground, are marked by iron-staining due to the oxidation of pyrite that formed during deepening of a former shallow-water, high-energy setting (Pope and Read, 1997). The formation of the Maysville Hardground may have been relatively rapid because it formed in an area where large volumes of seawater flushed through the sediment pores (Wilson and Palmer, 1992) in a tropical, offshore carbonate platform.

Bryozoan mounds. Cuffey (1998) concluded that the bryozoan mounds were dominated by the trepostome bryozoan *Stigmatella personata*. Acetate peels of the encrusting and hanging bryozoan mounds match the description of *Stigmatella personata* by Fritz (1973). These bryozoan mounds are unique because they encrust and hang below the hardground and can be found up to 8 cm in height.

Paleoenvironmental event sequence. The relationships among the hardground, encrusters, and borers show borings penetrating into the bryozoan mounds as well as the Maysville Hardground. Borings penetrate the hardground from both directions and iron-staining occurs around the outer edge of some borings (Fig. 3). Borings also penetrate through the hardground and into the bryozoan and/or through



the bryozoan and into the hardground (Fig. 4). Multiple growth sequences of the bryozoans can be recognized by thin layers of sediment within a bryozoan mound (Fig. 5).

Figure 3. Vertical slice through the Maysville Hardground. Note that borings penetrate the hardground from above (black arrows) and below (white arrows).

Figure 4. Vertical slice of Maysville Hardground encrusted by a bryozoan mound; black arrow indicates stratigraphic up. Note boring (white arrow) that penetrates the hardground from below and continues into the bryozoan mound, where it terminates.

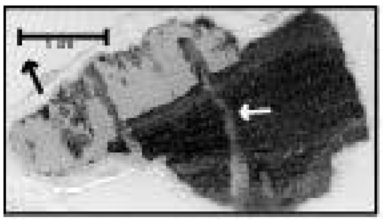
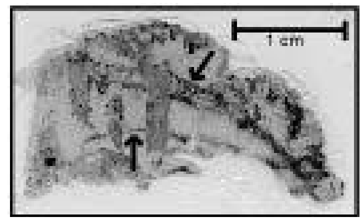


Figure 5. Multiple growth sequences in a bored bryozoan mound; each sequence is separated by a thin layer of carbonate sediment (black arrows).



Borings and nearest-neighbor relationships. Clark and Evans (1954) developed a statistical measure of nearest-neighbor relationships, which was corrected for edge effects by Sinclair (1985); here this method is applied to eight samples of the Maysville Hardground (Table 2). Clark and Evans (1954) defined R as equal to A/E (where A= the observed mean distance to the nearest neighbor, and E= the expected mean distance to the nearest neighbor); R values range from 0 to 2.1491. When A and E are identical, R is equal to 1 and a random distribution is confirmed. When A is less than E, R is less than 1 and this indicates aggregation or clustering. When A is greater than E, R is greater than 1 and this indicates spacing or dispersion.

In the eight Maysville Hardground samples, R ranges from 0.33 and 0.70 (Table 2), suggesting that the borings exhibit a relatively clustered distribution. Because the R values were less than 1, the boring organisms were probably not territorial or highly competitive. In addition, the R values did not reveal extreme conditions of clustering, so the organisms may not have been dependent upon a clustered population to survive. These organisms lived in a paleoenvironment where there probably was an abundant food supply; they may have lived together for reasons of reproduction, or perhaps certain areas of the hardground or bryozoans were more conducive to boring.

n	Area (mm^2)	Perimeter (mm)	A	E	R (A/E)
234	46,916	875	2.37 ± 0.26	7.28	0.33
281	49,772	905	3.99 ± 0.22	6.83	0.58
126	30,522	755	5.20 ± 0.40	8.11	0.64
279	49,915	901	4.39 ± 0.22	6.86	0.64
180	50,384	910	4.43 ± 0.36	8.64	0.51
343	41,389	814	2.11 ± 0.17	5.62	0.37
140	36,610	803	5.89 ± 0.39	8.40	0.70
555	47,679	877	2.19 ± 0.11	4.72	0.47

Table 2. Results of nearest-neighbor calculations. (n= number of distances measured, A= observed mean distance to nearest neighbor $\pm$ standard error, E= expected mean distance to nearest neighbor)

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