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Bioerosion of Lower Ordovician Hardgrounds in Southern Scandinavia and Western North America

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ABSTRACT

Trace fossils produced by macroboring invertebrates can be found in carbonate hardgrounds of early Ordovician age in southern Sweden, southern Norway and western Utah (U.S.A.). The bioeroded rocks are highly fossiliferous, thinly bedded, shallow-marine limestones. The macroborings in each of the three localities are vase-shaped cavities with diameters and lengths ranging from one to a few centimeters. At least some of the Swedish specimens apparently belong to the ichnogenus *Gastrochaenolites* LEYMERIE. These bioerosion trace fossils appear to be the oldest macroborings in carbonate hardgrounds, and they indicate that the macroboring niche was firmly established in shallow-marine carbonate shelf environments at least by Arenig time in the Ordovician Period.

Keywords: Bioerosion. Boring. Trace fossil. Hardground. Ordovician. Norway. Sweden. Utah.

RESUMEN

Se describen macroperforaciones producidas por invertebrados en "hardgrounds" carbonatados del Ordovícico inferior en el sur de Suecia, el sur de Noruega y el oeste de Utah (E.E.U.U.). Las rocas bioerosionadas son calizas marinas someras, bien estratificadas y muy fosilíferas. Las macroperforaciones tienen, en las tres localidades, forma de ampolla y diámetros y longitudes entre uno y unos pocos centímetros. Algunos de los especímenes suecos pueden ser asignados al icnogénero *Gastrochaenolites* LEYMERIE. Estas trazas de bioerosión parecen ser el registro más antiguo de macroperforaciones en "hardgrounds" carbonatados, e indican que el nicho de los macroperforadores estaba firmemente establecido en medios de plataforma carbonatada marina somera, al menos durante el Arenigiense en el período Ordovícico.

Palabras Clave: Bioerosión. Perforación. Pista fósil. Hardground. Ordovícico. Noruega. Suecia. Utah.

INTRODUCTION

Regionally extensive hardgrounds (cemented sea floor substrates) developed in platform carbonate sequences in many parts of the world during the early Paleozoic, as epicratonic seas alternately encroached and retreated across vast areas of the continents (Nielsen, 1992). Such regional hardgrounds are common in Lower Ordovician shallow-marine limestone and dolomite sequences throughout both Scandinavia and North America, and some of these hardground substrates exhibit intriguing evidence of bioerosion by macroboring invertebrate animals.

The Lower Ordovician rocks typically are highly fossiliferous, thinly bedded lime mudstones, bioclastic wackestones and bioclastic packstones. Complex ichnofabrics (*sensu* Bromley and Ekdale, 1986) indicate that the original sea floor ranged in character from softground (unconsolidated sediment) to firmground (stiff, compacted but uncemented sediment) to hardground (cemented sediment) from one place to another. Thus, burrowed and bored omission surfaces testify to a dynamic sedimentary environment in these early Ordovician seas. Although some small, simple borings have been reported in Lower Cambrian archeocyathid reefs (James et al., 1977; Kobluk et al., 1978), the oldest macroborings in carbonate hardgrounds are early Ordovician in age (Ekdale and Bromley, 1995, 1996, 2001; Benner and Ekdale, 1999).

This paper briefly discusses the bioerosion trace fossils in Lower Ordovician hardgrounds in Sweden and Utah, and it reports for the first time similar trace fossils in Lower Ordovician hardgrounds in Norway (Fig. 1).

LOWER ORDOVICIAN HARDGROUND BIOEROSION

Bioerosion of Swedish hardgrounds

In the late Arenig Bruddesta Formation on the Swedish island of Öland, located off the southeastern coast of Sweden in the Baltic Sea, there are numerous omission surfaces that indicate episodic deposition of fine-grained carbonate sediments (Janusson, 1961, 1973; Lindström, 1963). While most of these omission surfaces probably represent firmground substrates that were colonized by burrowing animals, a small number of these omission surfaces contain macroborings that indicate bioerosion of hardground substrates (Fig. 2). The macroborings are vertical, vase-shaped structures (up to 3 cm in diameter and 6 cm long) that occur in large numbers in the lower part

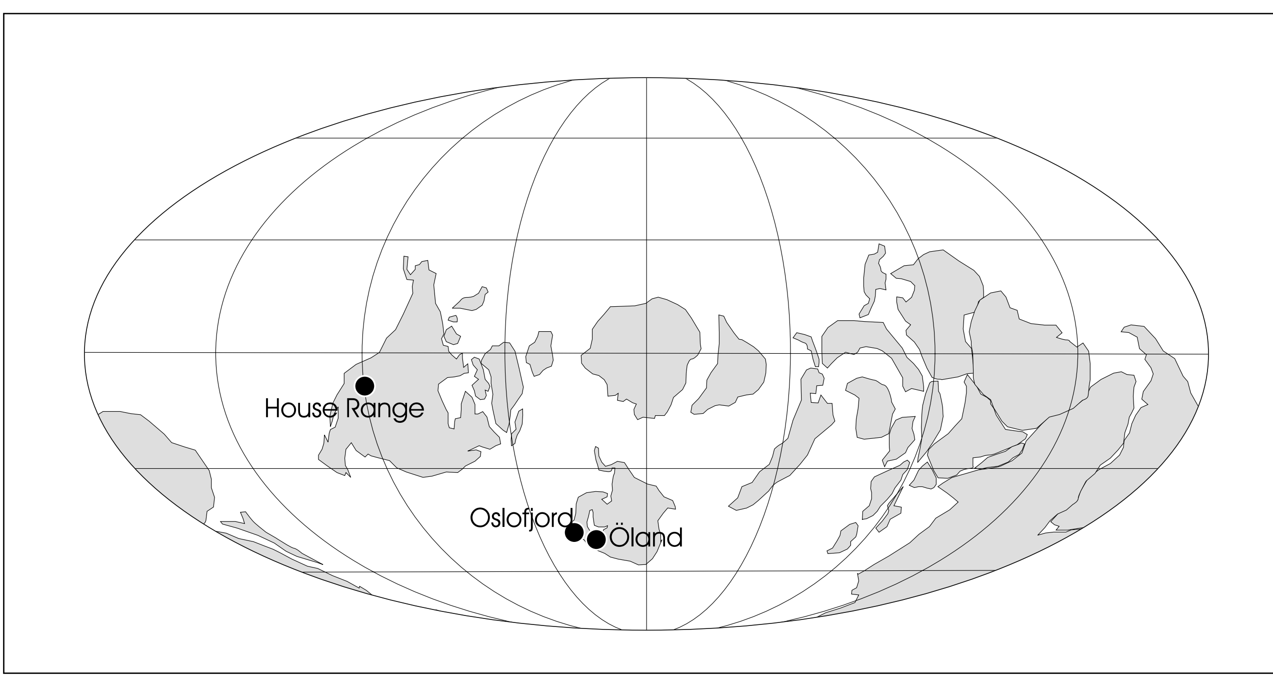

Figure 1. Location of the three bioerosion study sites discussed in this paper on a paleogeographic map depicting the distribution of continents during the Early Ordovician (map based on Scotese and McKerrow, 1990).

of the formation along a few brightly colored horizons, which reflect an extremely complex diagenetic history of numerous secondary mineralization events (Lindström, 1979).

These Swedish trace fossils appear to be the oldest examples of the ichnogenus *Gastrochaenolites* LEYMERIE, and they have been described as the new ichnospecies *G. oelandicus* (Ekdale and Bromley, 2001). The next oldest reported occurrences of *Gastrochaenolites* are early Pennsylvanian in age (Wilson and Palmer, 1998).

The Swedish *Gastrochaenolites* usually occur in large numbers along certain hardgrounds, and the apertures of the trace fossils coincide with omission surfaces, indicating that the trace fossils were excavated in the indurated sea floor. The margins of the borings are very sharp, and the fill sediment differs considerably from the surrounding host sediment.

These *Gastrochaenolites oelandicus* commonly contain small, post-omission burrows that reflect sediment reworking by tiny organisms that inhabited the lime mud that filled the cavity after it had been excavated by the borer. There is no obvious body fossil evidence of the producers of either the *G. oelandicus* or the post-omission burrows, so the biological affinities of the borers and burrowers in these hardgrounds are not known.

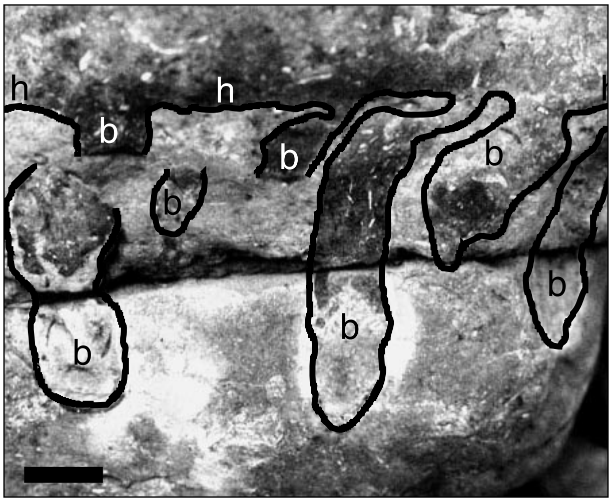

Figure 2. Macroborings (*Gastrochaenolites oelandicus*) in a Lower Arenig (Lower Ordovician) hardground in the Bruddesta Formation at Hagskog, Öland, Sweden. Vertical view in outcrop with the borings (b) and hardground (h) outlined in black in the photograph. Note that the borings appear to cut across more than one hardground. Scale bar equals 1 cm.

Bioerosion of Norwegian hardgrounds

The late Arenig Huk Formation outcrops in several places along the shores of Oslofjord near Oslo, Norway (Nielsen, 1995). This rock unit consists of fine-grained marine carbonates that contain numerous, repetitive omission surfaces, which commonly are highlighted by blackened, phosphatized crusts.

Many of these black crusts are penetrated by biogenic structures that might be macroborings (Fig. 3). While these trace fossils resemble the Ordovician *Gastrochaenolites oelandicus* in Sweden in several respects, including size, their ragged margins and irregular shapes make an ichnotaxonomic identification difficult. Nevertheless, it appears that a series of cemented and phosphatized omission surfaces were penetrated by a bioeroding endobenthos. In many cases, small shards of blackened, phosphatized limestone are incorporated in the sediment fill of the presumed borings, testifying to the fact that the phosphatized hardground was present before the trace fossils were produced.

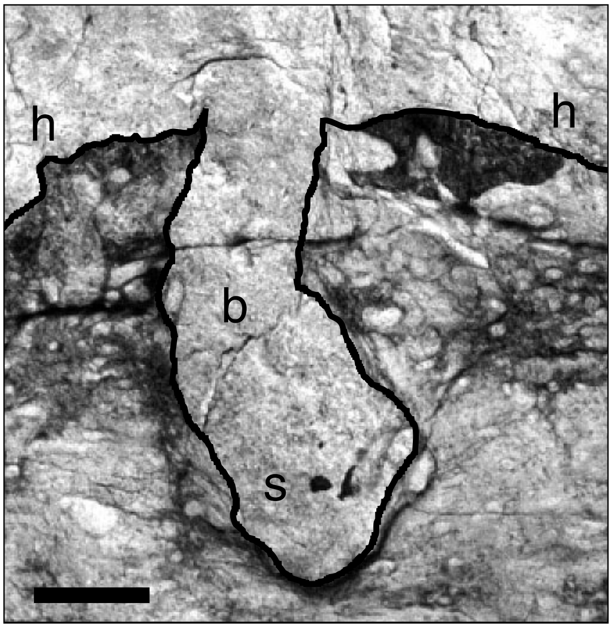

Figure 3. Macroboring in an Upper Arenig (Lower Ordovician) hardground in the Huk Formation at Hukodden, near Oslo, Norway. Vertical view in outcrop with the boring (b) and hardground (h) outlined in black in the photograph. Note that the boring cuts across a darkened (phosphatized) omission surface and incorporates some shards (s) of the dark-colored phosphatic crust in the fill sediment inside the boring. Scale bar equals 1 cm.

Bioerosion of Utah hardgrounds

In the Arenig Fillmore Formation in the House Range of western Utah, hardgrounds are common. They are recognized by their red-stained, partially silicified crust and an encrusting epifauna that included diverse echinoderms, brachiopods and sponges (Dattilo, 1993; Sprinkle and Guensburg, 1995).

Sparse borings, at least some of which closely resemble the Swedish *Gastrochaenolites oelandicus*, testify to a very successful bioeroding infauna (Benner and Ekdale, 1999). The borings occur in full relief, concave epirelief and hyporelief in the thin limestone beds (Fig. 4). These borings possess a circular to oval aperture (1 to 3 mm in diameter), which leads into a neck (up to 1 cm long), which in turn opens downward into an irregular, teardrop-shaped chamber (up to 1 cm in diameter) that terminates some 3 to 4 cm below the hardground surface.

These *Gastrochaenolites*-like borings were excavated in hardgrounds that developed on incipient sponge-algal patch mounds and pebble conglomerate. The largest specimens occur in the best-developed and thickest hardgrounds, while smaller borings occur mainly in incipient, thin hardgrounds. There is some evidence of a body fossil in a few of these borings, but the exact morphology and identity of these organisms is under current study.

PALEOECOLOGIC AND EVOLUTIONARY IMPLICATIONS

Trace fossil evidence from southern Scandinavia (Sweden and Norway) and western North America (Utah) indicates that the macroboring niche was firmly established in shallow-marine carbonate shelf environments at least by Arenig time in the Ordovician Period, and from that time bioerosion has persisted as a common, if not prominent, feature in submarine hardgrounds for the rest of geologic time.

The appearance of macroborings in the fossil record represents a milestone in the behavioral evolution of marine organisms. The ability to bore into an indurated omission surface created an important new niche during the expansive episode of faunal diversification in the early part of the Ordovician Period. Revolutionary experiments in ecological adaptation, including bioerosional innovations, contributed to the general biotic diversification at that time.

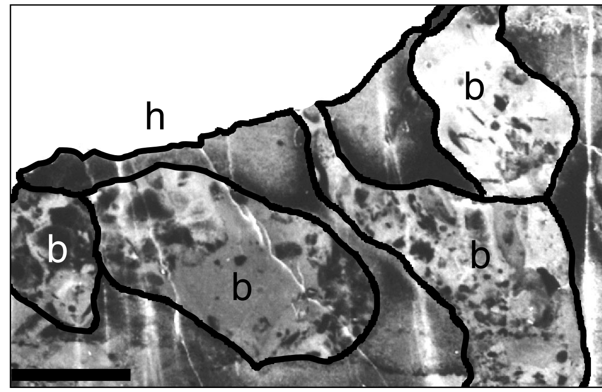

Figure 4. Macroborings in a Lower Arenig (Lower Ordovician) hardground in the Fillmore Formation at Skull Rock Pass, House Range, Millard County, Utah, U.S.A. Vertical view of a polished specimen of a large pebble that was eroded from the hardground surface with the borings (b) and hardground (h) outlined in black in the photograph. Note the sharp margins of the borings, and note also that some of the borings cut through the sediment fill of other borings. Scale bar equals 1 cm.

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