Early large borings in a hardground of Floian-Dapingian age (Early and Middle Ordovician) in northeastern Estonia (Baltica)

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Abstract: Large plug- or slightly amphora-shaped borings have been found in the hardground marking the boundary between Early and Middle Ordovician rocks in northeastern Estonia. These borings cut large bioclasts of the trilobite *Megistaspis* and cannot be assigned with certainty to any known ichnotaxon. They indicate that the diversity of early borings may have been greater than was recognized previously.

Key Words: Bioerosion; *Gastrochaenolites*; hardground; Early Ordovician; Baltica.

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Résumé : *Premières grandes traces de perforation découvertes dans un fond durci d'âge Floien-Dapingien (à la transition de l'Ordovicien inférieur-moyen) dans le NE de l'Estonie (Baltique).-* De grandes perforations cylindriques ou légèrement renflées, en forme d'amphore, ont été découvertes dans le fond durci qui sépare l'Ordovicien inférieur de l'Ordovicien moyen. Ces perforations recoupent de gros bioclastes dont des débris de trilobites (du genre *Megistaspis*). Elles ne peuvent être rattachées avec certitude à aucun ichnotaxon connu. Par conséquent la diversité des perforations primitives est certainement plus importante que ce qui était jusqu'à présent admis.

Mots-Clefs : Bioérosion ; *Gastrochaenolites* ; fond durci ; Ordovicien inférieur ; Baltique.

Introduction

Bioerosional trace fossils produced by macroborers are known since the Cambrian where they are represented by two genera *Trypanites* (KOBLUK *et alii*, 1978) and *Oichnus* (WILSON, 2007). Respectively, these borings are relatively small and simple tubes and small circular holes in shells. The earliest large borings (*Gastrochaenolites oelandicus* EKDALE & BROMLEY, 2001) are from the Lower Ordovician of Baltica (EKDALE & BROMLEY, 2001). Another Lower Ordovician *Gastrochaenolites* (identified as *Gastrochaenolites* isp.) is found in Utah (BENNER *et alii*, 2004). In addition to *Trypanites*, other possible large borings in hardgrounds are common in the Lower Ordovician of Baltica (DRONOV *et alii*, 1996, 2000; EKDALE & BROMLEY, 2001). The Ordovician was a time of great biodiversification (GOBE: SEPKOSKI & SHEEHAN, 1983; SEPKOSKI, 1995; MILLER, 2003; ZHANG *et alii*, 2010). Diversification of boring organisms, termed the Ordovician Bioerosion Revolution, was a function of this event. The number of ichnogenera increased from two (Cambrian) to at least eight (Ordovician, WILSON & PALMER, 2006).

Possible borings from the Lower to Middle Ordovician hardgrounds of Estonia have been known for a long time (ORVIKU, 1960, 1961; DRONOV *et alii*, 2000). However, the boring nature and taxonomic affinities of the organisms that produced these structures has been controversial. There are difficulties involved in discriminating true borings (formed through bioerosion) from lithified burrows, particularly if the latter have been scoured or otherwise eroded. In Estonia, probable large early borings (Billingen to Volkhov Stages) have been affiliated with *Amphorichnus* MÄNNIL, 1966, and *Conichnus* MÄNNIL, 1966 (DRONOV *et alii*, 2000), but these ichnotaxa are definitely burrows and not borings (WILSON pers. obs.). It has long been accepted that burrows and borings be given discrete ichnogenus and ichnospecies names, even if they are identical morphologically, because they represent dissimilar behaviors (HÄNTZSCHEL, 1975). Large borings from the hardgrounds of the Volkhov sequence of neighboring northwestern Russia have been identified recently as *Gastrochaenolites oelandicus*. However, these traces have considerable morphological variability: drop-like forms are

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definitely *G. oelandicus*), but there are also spherical varieties (probable *G. oelandicus*), and pencil-like or conical borings/burrows (MIKULÁŠ & DRONOV, 2005).

This ichnotaxonomic confusion indicates a possibility that not all earliest Ordovician East Baltic large conical trace fossils are true borings in hardgrounds, but that some may be burrows excavated into non-lithified sea floor. This paper attempts to:
1) evaluate these structures in northeastern Estonia as regards their origin as borings,
2) discuss the ichnosystematics of these trace fossils, and
3) review the evolution of bioerosion in the Lower Ordovician of Baltica.

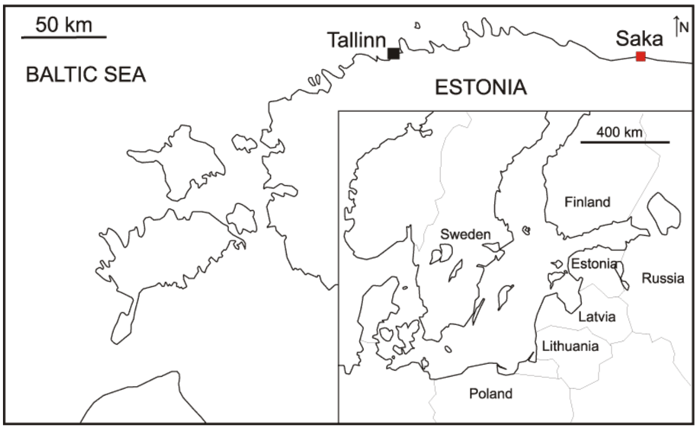

Figure 1: Location of the Saka outcrop in northeastern Estonia (red square).

Material and geological setting

The Saka section (northeastern Estonia) (Fig. 1) is part of the Baltic Klint which is one of the most extensive outcrops of Lower Palaeozoic rocks in the world (TINN, 2008). The section is 2 km west of the village of Saka. A trench about 20-30 m in width and depth was cut into the Klint to accomodate a sewage pipe from nearby Kohtla-Järve to the sea. Consequently, a section spanning the Lower Cambrian Tiskre Formation up to the Middle Ordovician Aseri Formation is exposed. The older part of the section is masked, but strata of the Volkhov Stage are well exposed.

Seven borings were studied from the Saka section. These occur in a supposed hardground at the boundary between the Hunneberg and Volkhov stages. The large plug-shaped borings were bored into the upper surface of the dolomitized glauconitic packstone of the Hunneberg Stage. The trace fossils were interpreted to be borings if they cut biomineralized trilobite bioclasts (*Megistaspis*) in the glauconitic packstone.

In 1961 ORVIKU described a variety of possible borings from the northern Estonian sections of the Baltic Klint. Possible borings range widely in morphology: from cone-shaped (northeastern Estonia) to vase and drop-shaped (northwestern Estonia).

Results

The hardground with large conical trace fossils is the boundary between the Lower and Middle Ordovician, and its age is either latest Early Ordovician (Floian) or earliest Middle Ordovician (Dapingian). Its surface and the interiors of the trace fossils are impregnated with iron-bearing minerals and are a rusty brown color. The trace fossils are filled with sediments richer in glauconite than the rock forming the hardground. One large trace completely cuts a *Megistaspis* pygidium in the upper third of its length (Fig. 2). The plug- or slightly amphora-shaped straight trace fossils have a circular cross-section. They are 10-18 mm in diameter and up to 30 mm deep. Their lower ends are sharp and slightly pointed (Fig. 2).

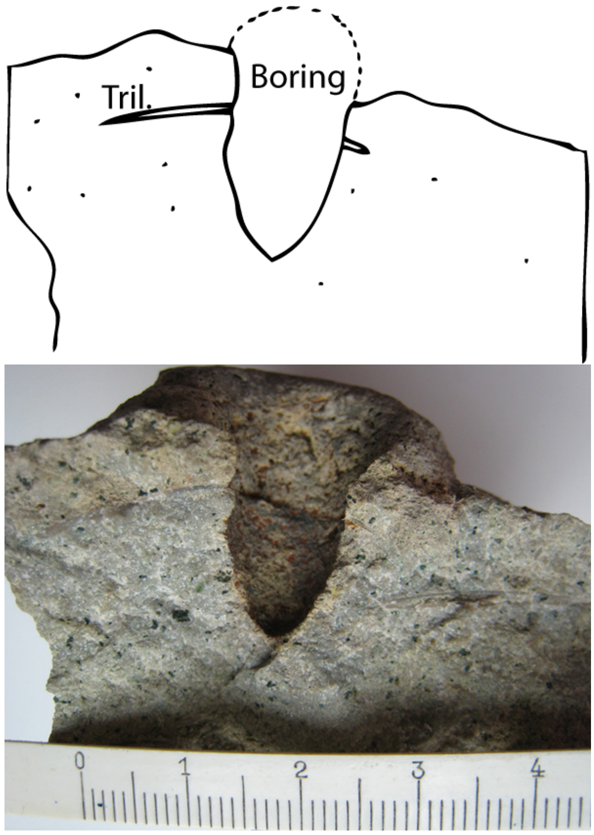

Figure 2: A plug-shaped vertical boring (filling sediment removed) cutting a trilobite pygidium (*Megistaspis*) in a hardground from Saka, at the upper surface of the Päite Member, marking the boundary between the Floian and Dapingian stages. The figured specimen is deposited in the Geological Museum, Museum of Natural History, University of Tartu (TUG): TUG 1405-1.

Discussion

That the large conical, slightly amphora-shaped traces in the Lower Ordovician glauconitic packstone are borings is supported by the observation that they sometimes cut large bioclasts (*Megistaspis* trilobites). The large *Megistaspis* skeletons are relatively massive. The traces were bored into a lithified sea-floor -

hardground. If the rock had not been lithified (a lime mud) prior to their excavation, the *Megistaspis* bioclasts would have been pushed aside by the digging organism and not cut through. We agree with Benner *et alii* (2004) that the cutting of a trilobite bioclast by *Gastrochaenolites* (Lower Ordovician) is direct evidence that this trace fossil is a true boring.

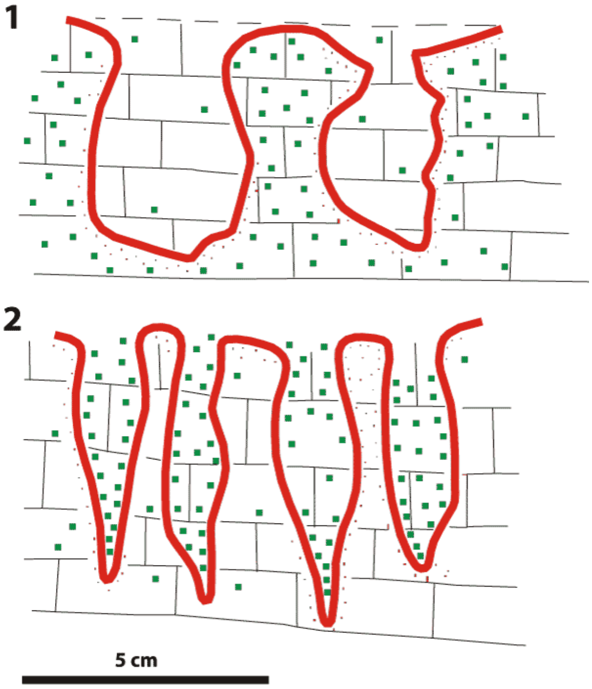

Figure 3: 1) Section of a possible hardground on the Väike-Pakri cliff with borings tentatively assigned to *Gastrochaenolites oelandicus*, cut into the upper surface of the Päite Member, the boundary between the Floian and Dapingian stages (after Orviku, 1961). 2) Section of a possible hardground with large plug-shaped probable borings, like those found in Saka: at the upper surface of the Päite Member, the boundary between the Floian and Dapingian stages (after Orviku, 1961). Hardground surface: brown; impregnation by glauconite: green.

Conical slightly amphora-shaped borings are difficult to assign to any known ichnogenus (Fig. 2). They are similar to *Gastrochaenolites oelandicus* in size and in the absence of parallel walls in the shaft. However, they lack a narrow aperture so are not club-shaped (Kelly & Bromley, 1984).Therefore they cannot be assigned to *Gastrochaenolites*. *Gastrochaenolites* isp. from the Lower Ordovician of Utah (Benner *et alii*, 2004) differs from the eastern Estonian borings in being more pouch-like rather than conical or amphora-shaped and does not have a slightly pointed lower end. The other vertical borings in Lower Ordovician strata are those of *Trypanites*, but this fossil has parallel shaft walls and is usually much smaller in diameter than the Utah trace fossil. Thus, the large borings described here could be a previously undescribed ichnotaxon, but further studies on the morphology and variability of the borings are necessary before formal description is feasible. Possible borings from a nearby section at Künnapõhja of the same age (Orviku, 1961) may be conspecific with those found in Saka (Fig. 3). On the other hand, large possible borings from the Väike-Pakri section (north-western Estonia) and of the same age are probably *Gastrochaenolites oelandicus* (Fig. 3).

Most examples of *Gastrochaenolites* are interpreted as domichnia of boring bivalves. Based on the absence of preserved body parts of the tracemaker in some Ordovician examples, it has been suggested that the borer might have been a shell-less, soft-bodied invertebrate of unknown affinity (Ekdale & Bromley, 2001). It is possible that the maker of the large borings in the Saka hardground was a soft-bodied animal, but different in morphology or behavior from the entity which made *G. oelandicus*. The biological affinities of the Saka large hardground borers are unclear, but similarity to plug-shaped burrows (Pemberton *et alii*, 1988) such as *Conichnus* (incl. *Amphorichnus*) may point to an affinity with actinarian sea anemones. Plug-shaped dominichnia are associated with anemones from the earliest Early Cambrian (Jensen, 2003). Thus, some of these burrowers may have been adapted to life in carbonate hardgrounds using chemical boring. Hardgrounds became very common in Ordovician calcite seas (Taylor & Wilson, 2003) and this development may correlate with the appearance of first large borers as a part of GOBE (Great Ordovician Biodiversification Event). The Saka borings suggest that the diversity of initial large borers and/or boring behaviors may have been greater than previously thought. Whether this was only a regional phenomenon in the Baltica or was part of a global change will be determined from future studies.

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