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SHORT COMMUNICATION

Sparsely encrusted hardground in the Darriwilian calcareous sandstone of Cape Pakri, NW Estonia (Baltica)

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Abstract. The occurrence of echinoderm and ptilodictyid bryozoan holdfasts on the surface of Darriwilian calcareous sandstone in northwestern Estonia indicates that it was lithified before encrustation. Pelmatozoans outnumber the bryozoans and cover a larger area of the hardground although both are very sparse. The hardground is very sparsely encrusted (0.37% of the total area studied) and lacks signs of bioerosion.

Key words: hardgrounds, encrustation, cementation, Middle Ordovician, Baltica.

INTRODUCTION

Hardgrounds form excellent attachment surfaces for encrusting and bioeroding organisms that otherwise must dwell on carbonate cobbles or the exoskeletons of various invertebrates. Carbonate hardgrounds are synsedimentarily cemented carbonate layers that have been exposed on the seafloor (Wilson et al. 1992). They were relatively common in calcite seas, such as those of the Ordovician, due to favourable conditions for early cementation of carbonate sediments in the seafloor (Wilson & Palmer 1992). Upper Ordovician hardground faunas were dominated by bryozoans and echinoderms, but cornulitid tubeworms and sphenothallids were also common (Wilson 1985; Taylor & Wilson 2003). The Ordovician hardground faunas of Baltica have been described both from Russia and Sweden (Vishnyakov & Hecker 1937; Rozhnov 2000; Blake & Rozhnov 2007; Eriksson et al. 2012). *Trypanites* borings have been reported from the Ordovician hardgrounds in Estonia (Orviku 1940, 1960; Einasto 1964; Põlma 1984; Saadre 1992, 1993). The earliest hardground faunas of Baltica include *Trypanites*, *Gastrochaenolites*? and *Balanoglossites* from the latest Early Ordovician (Vinn & Wilson 2010; Knaust & Dronov 2013). Ripple marks, associated with the hardground in the Vasalemma quarry, were described in detail by Hints & Miidel (2008). They also mentioned the occurrence of *Trypanites* borings and the edrioasteroid echinoderm *Cyathocystis*.

The aims of this paper are (1) to describe for the first time a hardground echinoderm–bryozoan community from the Darriwilian of Baltica and (2) to compare the hardground fauna from the Darriwilian of Estonia with other Ordovician examples.

GEOLOGICAL BACKGROUND AND LOCALITY

The area of modern Estonia (Fig. 1) was covered by a shallow epicontinental sea in the Ordovician. The Ordovician sequence of North Estonia is represented mostly by carbonate rocks except for the terrigenous Lower Ordovician part. Ordovician rocks, mainly limestones, are exposed in northern Estonia as a wide belt from the Narva River in the east to Hiiumaa Island in the west (Mõtus & Hints 2007). Drift of Baltica from the southern high latitudes to the tropical realm caused a drastic climatic change. The warming of the climate increased the sedimentation rate of carbonates. Deposits characteristic of arid and subtropical climate appeared in the Late Ordovician (Mõtus & Hints 2007; Dronov & Rozhnov 2008). In the Early and Middle Ordovician, when the Baltic Basin was situated in the temperate climate zone, these types of tropical deposits were completely lacking (Jaanusson 1973).

Pakri Cliff is situated on the western coast of the Pakri Peninsula in NW Estonia (Fig. 1). The hardground was studied at the northern border of the town of Paldiski. It is the second hardground from the top of the Pakri Formation and forms a surface within the formation (Fig. 1), which is detectable throughout the several kilometres long Pakri Cliff section. The Pakri Formation is about 1 m thick at Pakri Cliff and is composed of carbonate-cemented sandstone and sandy limestone. It represents the most onshore environment known from the carbonate part of the Ordovician of Estonia. The calcareous sandstones of the formation formed in a very shallow subtidal environment close to the ancient coastline (Põldsaar & Ainsaar 2014). These sandstones

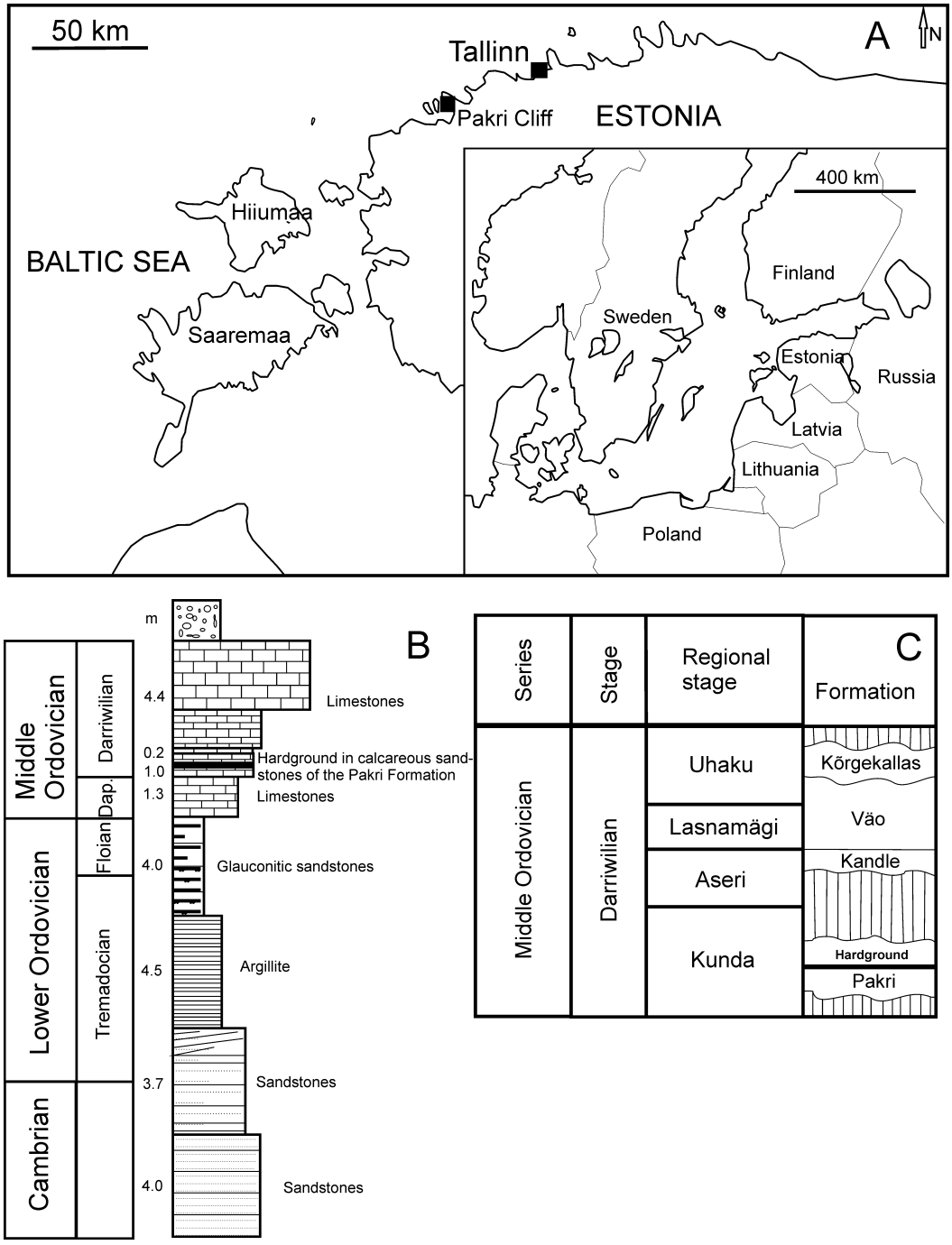

Fig. 1. A, location of Pakri Cliff in NW Estonia. **B**, Pakri Cliff with the studied hardground in the Pakri Formation (Darriwilian). Modified after Hints et al. (2008). **C**, the Middle Ordovician in Estonia. Location of the hardground within the Pakri Formation. Modified after Hints et al. (2008).

are rich in gastropods, cephalopods, brachiopods and trilobites. The calcareous sandstones of the Pakri Formation are overlain by limestones of the Kandle Formation, which have a thickness of about 0.10 m (Põldsaar & Ainsaar 2014).

MATERIAL AND METHODS

The encrusted hardground was discovered during extensive field work at Pakri Cliff in 2013. Several kilometres of coast below the cliff were carefully searched

for hardground surfaces exposed on boulders broken from the cliff. The total hardground surface available for the study measures 1260 cm^2. The hardground surface in the cliff is very hard to reach due to heavy cementation and falling rocks. The cliff is under natural protection and the removal of large parts of it to reach the hardground surface is not permitted. The hardground surface was cleaned with a brush and water and photographed in sunlight with a scale bar. Macroscopic encrusters were counted and identified. Signs of bioerosion and small encrusters were searched for using a 10× magnification lens. Only two echinoderms and a bryozoan holdfast were collected due to the hard rock matrix. They are deposited at the Natural History Museum (Geological Museum), University of Tartu (TUG), with specimen numbers TUG 1681-1, TUG 1681-2 and TUG 1681-3.

RESULTS

Five discoidal echinoderm holdfasts and a ptilodictyid bryozoan holdfast are cemented to the hardground surface within the Pakri Formation (Darriwilian) (Fig. 2). The hardground surface is darker in colour than rest of the rock matrix due to pyrite impregnation. It is not smooth and has a relatively low and irregularly shaped microrelief (Fig. 2). It lacks obvious signs of bioerosion and is sparsely encrusted. The encrusters cover only 4.65 cm^2 (0.37%) of the total hardground surface studied (1260 cm^2). Echinoderms cover 3.45 cm^2 and bryozoans 1.2 cm^2 of the hardground surface. Pelmatozoans outnumber bryozoans and cover a larger area of the hardground.

A single large discoidal holdfast is 26 mm wide and has a circular outline (Fig. 2A). It is strongly elevated (up to 3.0 mm) above the hardground surface. The holdfast has a relatively smooth surface. A few weakly developed short shallow radial furrows are found at the periphery of the holdfast in some places. The holdfast has a large shallow central depression (about 9 mm in diameter) that is surrounded by a slightly elevated narrow rim. The holdfast is assigned to echinoderms because of its circular outline, relatively smooth surface and shallow central depression (Wilson et al. 1992).

Five small discoidal holdfasts have a circular outline (Fig. 2B). They have a mostly unornamented surface with weakly developed irregular relief in some places. Their holdfasts are relatively flat, not much elevated above the surface of the hardground. One small discoidal holdfast shows a weakly developed central pit which is about 1/4 as wide as the holdfast. The holdfasts are assigned to echinoderms because of their circular outline, relatively smooth surface and lack of radial ornamentation (Wilson et al. 1992).

The single large semi-circular holdfast is 13.0 mm wide and covered with radial ridges that bifurcate and intercalate (Fig. 2B). About two ridges per 1 mm are found along the periphery. The surface of the holdfast is only slightly elevated above the hardground surface. The holdfast is assigned to ptilodictyid bryozoans because of its semi-circular outline and radial ornamentation composed of bifurcating and intercalating ridges (Wilson et al. 1992).

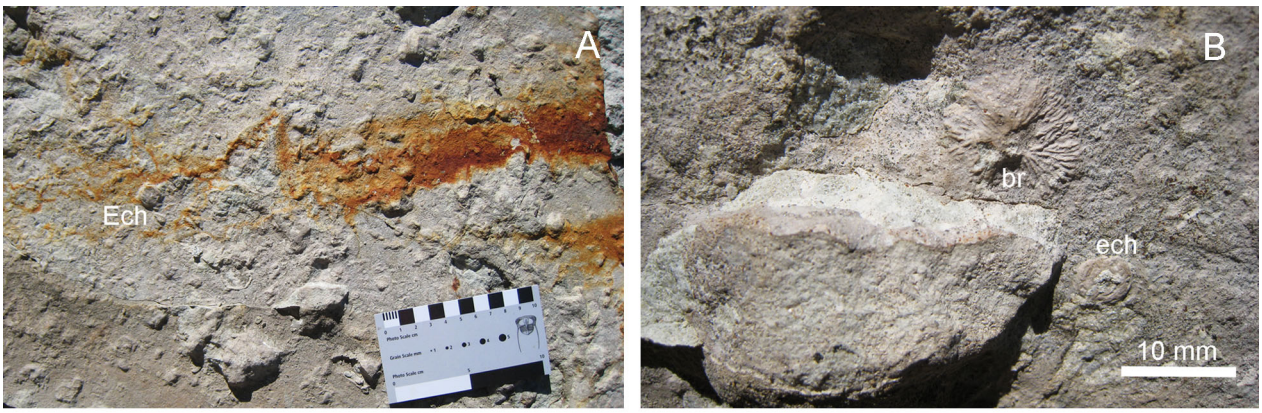

Fig. 2. A, hardground surface; Ech, large echinoderm holdfast, Pakri Formation, Darriwilian, Middle Ordovician, Pakri Cape, NW Estonia. TUG 1681-1. **B**, hardground surface; a ptilodictyid bryozoan holdfast (br) (TUG 1681-2) and small echinoderm holdfast (ech) (TUG 1681-3) cemented to the hardground from the Pakri Formation, Darriwilian, Middle Ordovician, NW Estonia.

DISCUSSION

Sedimentology

The occurrence of echinoderm and bryozoan holdfasts indicates that a surface of calcareous sandstone within the Pakri Formation was lithified before encrustation. The hardground seems to be slightly abraded and has few cryptic surfaces and broken off cobbles. The darker colour of the hardground surface is presumably caused by post-sedimentation mineralization by iron minerals, probably pyrite. The hardground formed in normal marine conditions in relatively shallow water as it was close to the supposed shoreline to the north (Jaanusson 1973).

Preservation

The Pakri Cliff holdfasts show signs of slight erosion. No echinoderm stem fragment was found attached to the holdfasts. This indicates that there was some hydrodynamic activity above the hardground surface.

Encrustation and diversity of the association

The Pakri hardground is very sparsely encrusted (Brett & Liddell 1978). The slightly older hardground fauna from the Middle Ordovician of Utah (Wilson et al. 1992) has similar diversity. The nearly equal areas of the Utah hardground were covered by bryozoans and echinoderm holdfasts (Wilson et al. 1992). The Pakri hardground bryozoans are among the earliest bryozoans known from the hardgrounds of Baltica or elsewhere (O. Vinn pers. obs.). Bryozoans are known from the Billingen and Hunneberg of Baltica (Koromyslova 2011). The lack of cornulitids in the Pakri association is most striking, but their earliest representatives in Baltica are known from the latest Darriwilian. Thus, the lack of cornulitids can be explained by their later appearance in the Ordovician of Baltica. Microconchids, which are characteristic of many Early Palaeozoic hard substrate faunas that appeared in the Late Ordovician (Zatoń & Vinn 2011), are similarly absent in the Pakri association. Bryozoans usually form an important part of Ordovician hard substrate faunas (Taylor & Wilson 2003) and they also occur in the Pakri fauna. The Pakri hardground environment may have been atypical for the Ordovician shallow sea carbonate hardgrounds. It presumably represents a very shallow subtidal environment (Põldsaar & Ainsaar 2014) with a lithified sand bottom (with carbonate cement), unlike most other Ordovician limestone hardgrounds. According to Orviku (1960), *Trypanites* borings occur in the Pakri Formation. It is surprising that the described hardground does not contain *Trypanites*.

SUMMARY

- A hardground in the calcareous sandstone of the Pakri Formation is encrusted by bryozoans and echinoderms. The association is dominated by echinoderms.
- The Pakri hardground differs from many other Ordovician hardgrounds of Baltica by the lack of bioerosion. It is possible that calcareous sandstone may have been an unfavourable substrate for boring organisms.

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Hõredalt asustatud muistne tsementeerunud kihipind Pakri poolsaare Ordoviitsiumist

Olev Vinn

Pakri pangal paljanduvast Kunda lademe lubi-liivakivist leiti kunagine tsementeerunud kihipind, mis oli hõredalt asustatud sinna külge kinnitunud sammalloomade ja okasnahksetega.