

A brachiopod boring on a belemnite from the Santonian Bavnodde Greensand Formation of Bornholm, Denmark

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We report the first record of a brachiopod boring from the Santonian Bavnodde Greensand Formation on the south coast of the island Bornholm in the Baltic Sea. The minute, but highly characteristic boring is referred to the ichnospecies *Podichnus centrifugalis* Bromley & Surlyk, 1973. It occurs on a small, belemnite guard tentatively identified as *Goniocamax lundgreni lundgreni* (Stolley). The boring is composed of a number of small pits each formed by etching of one of the brachiopod pedicle rootlets or filaments. The pits are arranged in a small highly characteristic circle and their size increase gradually away from the centre of the circle. The Bavnodde Greensand contains a rich fauna, including five brachiopod species. *Terebratula ciplensis* von Hanstein is interpreted as the most likely originator of the described specimen of *Podichnus centrifugalis*.

Keywords: *Podichnus centrifugalis*, Upper Cretaceous, pedicle trace, brachiopods, Bornholm, Denmark.

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Borings made by brachiopod pedicles were identified during the study of Recent brachiopods in the collection of the Natural History Museum of Denmark (Surlyk 1972, fig. 8). It was noted that the pedicle of the brachiopod *Terebratulina retusa* Linnaeus, 1758 was split into rootlets which were able to etch holes in carbonate shell fragments. Subsequently a search by Richard Bromley of shelly fossils from the British Upper Cretaceous chalk housed at the Natural History Museum of England resulted in the finding of borings which were attributed to brachiopod pedicles. These borings were described as a new ichnogenus *Podichnus* Bromley & Surlyk, 1973 with the type species *Podichnus centrifugalis* Bromley & Surlyk, 1973.

The aim of the study is to describe the first find on the island of Bornholm in the Baltic Sea of the brachiopod boring *Podichnus centrifugalis* Bromley & Surlyk, 1973 from the Santonian Bavnodde Greensand Formation and to interpret the possible originator of the boring. The specimen is stored in the collection of the Natural History Museum of Denmark (MGUH 35001 & 35002).

Geological setting and stratigraphy

The island of Bornholm in the Baltic Sea is part of a fault block mosaic situated in a N–S oriented dog leg on the NW–SE-trending fundamental tectonic lineament, the Sorgenfrei-Tornquist Zone (Fig. 1). The zone forms the northern border of the Danish Basin and continues SE-wards into Poland (e.g. Liboriusen et al. 1987; Mogensen & Korstgård 2003; Surlyk & Lykke-Andersen 2007). The south coast of Bornholm exposes Palaeozoic, Triassic, Jurassic and Cretaceous sediments in small fault blocks (Gry 1969a,b; Graversen 2009). The Upper Cretaceous succession in this area comprises the Cenomanian Arnager Greensand, the Coniacian Arnager Limestone and the Santonian Bavnodde Greensand at the top. These formations are separated by major unconformities and the faunas of the Bavnodde Greensand are described by Ravn (1921, 1946), Douglas & Rankin (1969), Solakius (1989), Kennedy & Christensen (1991), Tröger & Christensen (1991), Packer & Hart (1994), Christensen & Schulz (1997) and Nattestad & Milàn (2021).

The age of the Bavnodde Greensand has been much debated as the different fossil groups seem to indicate different ages. The belemnites were interpreted as indicating a late Coniacian – early Santonian age (Christensen & Schulz 1997), whereas the foraminifers indicate a Santonian age (Douglas & Rankin 1969; Solakius 1989; Packer 1991; Packer et al. 1989). The inoceramid bivalves likewise indicate a Santonian age Tröger & Christensen (1991). Ammonites are rather rare in the formation and indicate a Santonian age (Kennedy & Christensen (1991). The different ages given in the literature to some extent reflect that different levels of the formation are exposed in the low coastal cliff due to a north-ward dip and the irregular shape of the coastline seen in map view. Detailed reference to the different fossil sites are given in Christensen & Schulz (1997) but these are not at all easy to follow. Another locality map was presented by Brüschi (1984). Christensen & Schulz (1997) assign the lower part of the formation where the belemnite with the *Podichnus* boring was found to the upper Coniacian, but a definitive age cannot be

ascertained for the time being. Thus, a Santonian age is given conforming with the bulk of the literature.

Geological age of the belemnite

The studied specimen of *Podichnus centrifugalis* Bromley & Surlyk, 1973 was found on a belemnite from the Bavnodde Greensand close to a locality named Sengedynen, roughly in the middle part of the long stretch of exposure (Figs 1, 2). The locality map of Christensen and Schulz (1987, fig. 4) is not easy to compare with official topographic maps. Place names are few and poorly defined, reflecting the nature of the exposure of the formation, an about 4 km long, low coastal cliff with very few hall marks. The main fix points are Bavnodde and Horsemeye Odde, two promontories in the middle and eastern end of the cliff, respectively (Fig. 2). A commonly used unofficial place name is Forchhammers Odde a very minor feature which by most authors are placed as indicated in Fig. 2. According to the third

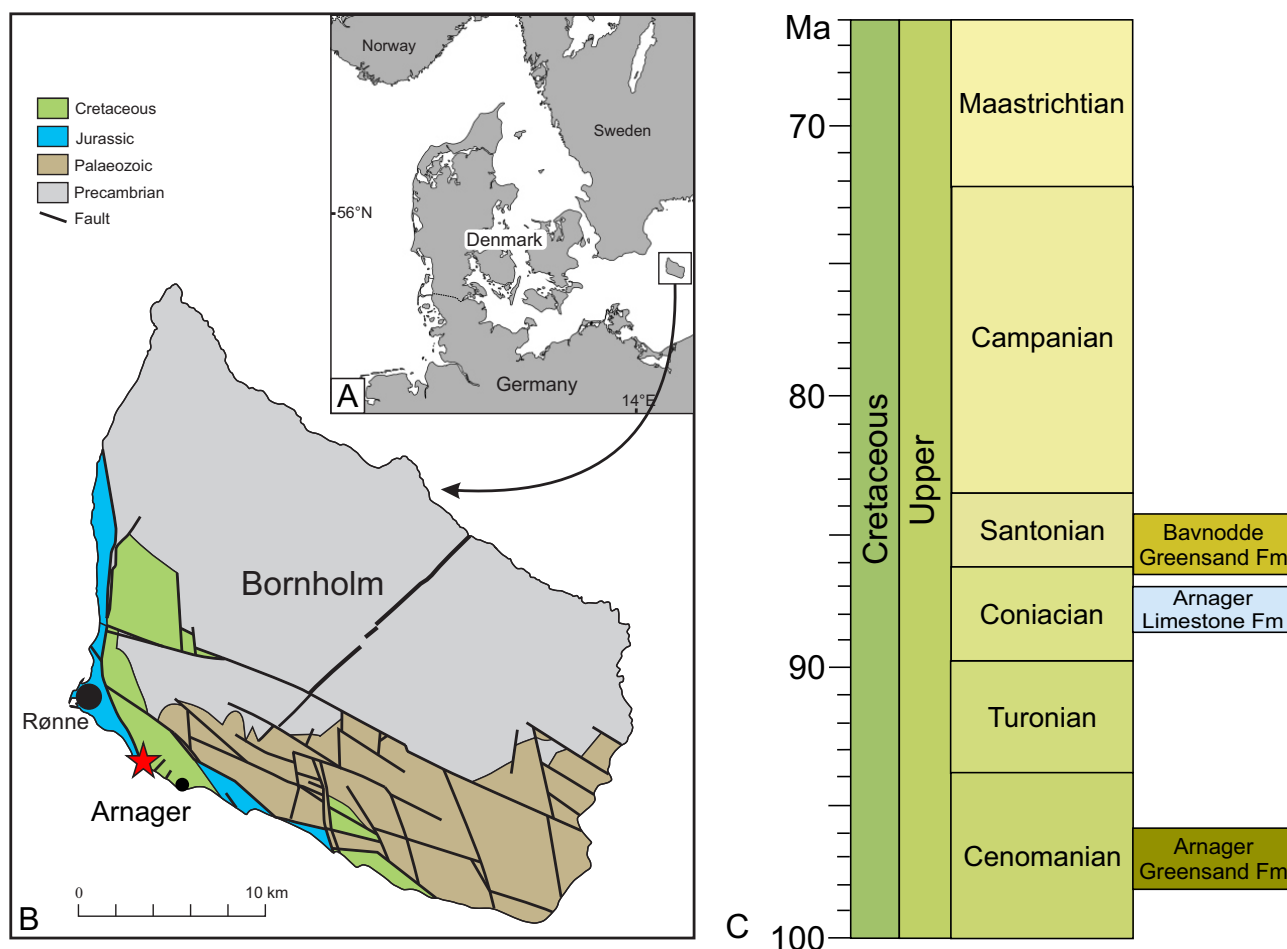


Fig. 1. A. Position of the island of Bornholm in the Baltic Sea south of Sweden. B. Simplified geological Map of Bornholm, showing the extent of the Cretaceous formations along the south coast of Bornholm. Modified after Graversen (2009). The Bavnodde Greensand Formation is exposed in the coastal cliffs between Rønne and Arnager. C. Upper Cretaceous stratigraphy of Bornholm.

author MFN, the finder of the belemnite, the location is in the stretch of the cliff termed F in Christensen & Schulz (1987, fig. 4). This stretch has yielded belemnites showing that it belongs to the oldest part of the formation close to the boundary with the underlying Arnager Limestone Formation and assigned to the upper Coniacian by Christensen & Schulz (1997) and to the Santonian on the basis of foraminifers (Packer 1991).

The belemnite

The brachiopod boring is situated on a belemnite which cannot be satisfactorily determined neither to genus or species as it is a small, juvenile specimen. The belemnite is 4 cm long and 5 mm wide (Fig. 3A). Splitting has been avoided in order not to risk destroying the *Podichnus* boring and the statistics used in species characterizations by Christensen & Schulz (1997) thus cannot be obtained. It tapers slightly towards the posterior end. The specimen is tentatively referred to *Goniocamax lundgreni lundgreni* (Stolley) which is common in the Coniacian – lower lower Santonian.

The brachiopod boring

Ichnogenus *Podichnus* Bromley & Surlyk, 1973

Type species *Podichnus centrifugalis* Bromley & Surlyk, 1973

The type species is found on the dorsal valve of the brachiopod *Carneithyris carnea* (Sowerby) found in the chalk of the Campanian *Belemnittella mucronata* zone, Mousehold, Norwich, England. It was interpreted as formed by the thick, unbranched pedicle like those of the Recent brachiopods *Hemithyris psittacea* and *Macandrevia cranium* (Bromley & Surlyk 1973, p. 364).

The brachiopod boring described here is not easy to see with the naked eye but all details can be studied with a hand lens, or better with a binocular microscope. The colour contrast between the white borehole pits and the brown colour of the belemnite gives, however, a clear picture of the boring (Fig. 3B). We have accordingly chosen not to clean the pits in order to keep their visibility. The brachiopod boring conforms well to the holotype of *Podichnus centrifugalis* Bromley & Surlyk, 1973 and is close to similar with other examples shown in Bromley & Surlyk (1973), notably their figure 6B where the *Podichnus* is situated on an upper Campanian belemnite from the chalk at Westlegate, Norwich, England.

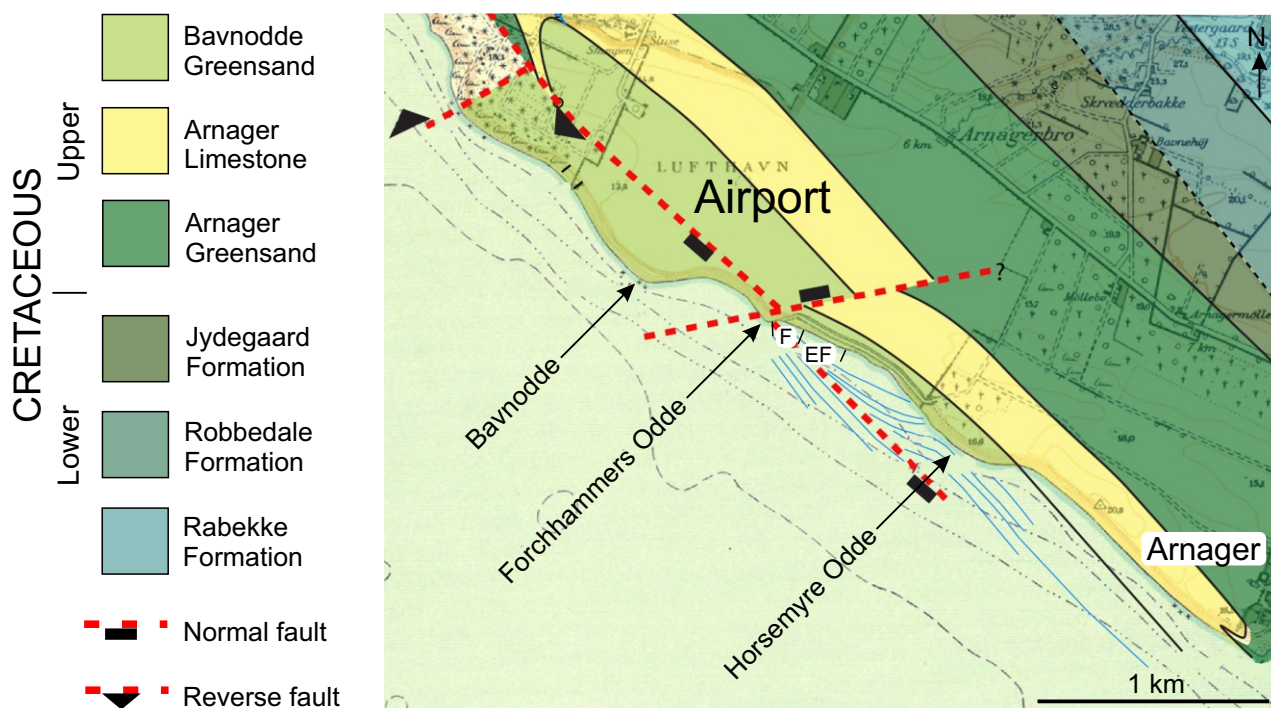


Fig. 2. Preliminary geological map by Arne Thorshøj Nielsen, showing a section of the south coast of Bornholm, covering the area with exposure of the Bavnodde Greensand Formation. The small exposures of the formation are indicated with the letter codes used by Christensen & Schulz (1997) and Brüsich (1984). The belemnite with the brachiopod boring *Podichnus centrifugalis* was found in the coastal cliff at section F, just east of Forchhammers Odde.

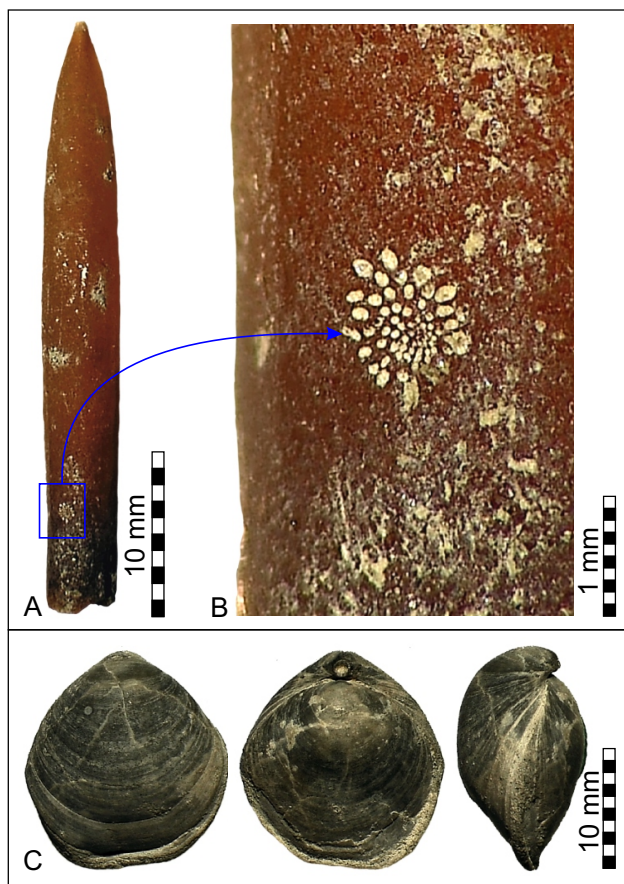


Fig. 3. A. The belemnite (MGUH 35001) with the trace of *Podichnus centrifugalis* Bromley & Surlyk, 1973. The belemnite is tentatively identified as *Goniocamax lundgreni lundgreni* (Stolley). B. detail of A showing the brachiopod boring *Podichnus centrifugalis* Bromley & Surlyk, 1973. Note the circular outline of the group of pits, which increase in diameter away from the centre of the circle. The individual pits are circular close to the centre and gradually become elongate ellipsoidal towards the margins of the circle. The pits were made by individual threads or filaments of the pedicle, the diameter of which was somewhat smaller than 1 mm. C. The figured brachiopod '*Terebratulina ciplensis*' is interpreted as the most likely culprit (MGUH 35002). It was found at the same locality as the belemnite with *Podichnus centrifugalis* shown in A and B.

The present specimen (Fig. 3B) referred to *Podichnus centrifugalis* from the Bavnodde Greensand is placed about 6 mm from the posterior end of the belemnite guard. It comprises about 58 small, shallow pits arranged in circle with a diameter of 1.1 mm. A few of the smallest pits are somewhat difficult to distinguish from non-biological marks on the surface of the belemnite. The size of the pits increases from 0.05 to 0.2 mm towards the margins of the circle, in a manner corresponding well to the name '*centrifugalis*'. The largest pits are elongate oval with a length axes pointing radially away from the centre of the circle. The smallest pits at the centre are circular to subcircular in outline.

Originator of the *Podichnus* boring

The originator of the described specimen of *Podichnus centrifugalis* cannot easily be interpreted. However, a number of brachiopods have been found in the Bavnodde Greensand but modern descriptions are lacking and both genus and species designations are outdated. They were described under the following names by Ravn (1921): *Lingula cretacea* Lundgren, *Rhynchonella* cf. *ala* Marklin, *Rhynchonella cordiformis* Posselt, *Terebratulina ciplensis* von Hanstein and *Terebratulina striata* Wahlenberg. Brüschi (1984) referred *T. ciplensis* of Ravn (1921) to the genus *Concinthyris* on the basis of external morphology.

The lingulid brachiopod can be excluded as an originator of the *Podichnus* due to its burrowing mode-of-life. *Rhynchonella* cf. *ala* is difficult to evaluate because Ravn (1921) only had one poorly preserved non-illustrated specimen at his disposal. '*Rhynchonella cordiformis*' is in external view very similar to *Homaletarhynchia limbata* (von Schlotheim) well known from the Maastrichtian chalk of northern Europe (Steinich 1965; Surlyk 2025). Like in this species the pedicle opening of '*R. cordiformis*' is very small and Brüschi (1984) describes the species as having a very thin shell with a strongly reduced foramen which in some shells is closed by secondary shell material. The species is accordingly interpreted as secondarily free-living possibly with a thin threadlike pedicle which could function as a sort of anchor. Only the juvenile specimens seem to have had a thin, threadlike functional pedicle. '*T. ciplensis*' has a suberect beak with a large permesothryrid foramen with a convex symphytium. It probably possessed a stout, functional pedicle although there is not necessarily a direct correlation between the diameter of the foramen and the thickness of the pedicle (Richardson 1997). *Terebratulina striata* occurs in a great variety of facies under a number of different species names such as *striatula* and *chrysalis*. It most likely possessed a rootlike pedicle as its recent relatives (Surlyk 1972). It would probably leave a much more irregular *Podichnus* trace than the one described here. It is rare in the formation and Brüschi (1984) does not indicate it as part of the main fauna, whereas '*Ter-*

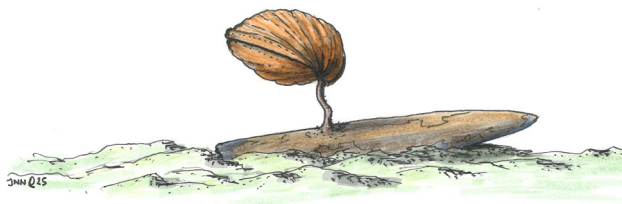


Fig. 4. Reconstruction of the belemnite with the brachiopod boring *Podichnus* and the most likely culprit '*Terebratulina ciplensis*' on the seafloor during deposition of the Bavnodde Greensand Formation. Drawing by Jakob Noe-Nygaard.

terebratula ciplyensis' is recorded with 66 specimens. A fine specimen of '*Terebratula ciplyensis*' was recently found at the same locality as the *Podichnus*-bearing belemnite described in the present study. It is thus interpreted as the most likely culprit of the boring (Fig. 3C, 4).

Summary

A fine specimen of the brachiopod boring *Podichnus centrifugalis* Bromley & Surlyk, 1973 is described. It was found on a belemnite from the Santonian Bavnodde Greensand Formation at Sengedynen in the low coastal cliff on the south coast of the island of Bornholm in the Baltic Sea. The belemnite is tentatively referred to *Goniocamax lundgreni lundgreni* (Stolley) from the lowest part of the Bavnodde Greensand. The originator of the trace cannot be determined directly, but the section has yielded five brachiopod species which all have to be considered as representing the potential originator of the trace. The small size of the belemnite substrate and of the trace itself is suggestive of a small originator, either a small species or a juvenile. Among the brachiopods described from the Bavnodde Greensand only one species, '*Terebratula ciplyensis*' (von Hanstein) seems to be a likely originator of the trace.

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