A cluster of the brachiopod *Magas chitoniformis* (von Schlotheim, 1813) represents settling of a single spatfall on a soft-bodied substrate, probably a sponge: instantaneous burial by a chalk ooze debris flow (Maastrichtian, Denmark)

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A well-defined monospecific cluster of the brachiopod *Magas chitoniformis* (von Schlotheim, 1813) was found in uppermost Maastrichtian chalk at Stevns Klint, Denmark. It comprises a sheet-like accumulation of 53 well-preserved adult specimens with an average length of 7.0 mm. The stratigraphical level is the 'Sponge Bed' named so by fossil collectors because of the wealth of imprints or skeletal elements of large sponges, commonly showing 3D-preservation. The unimodal size-frequency distribution of the brachiopod shells indicate that they represent a single successful spatfall most likely on a soft-bodied sponge. There are no signs of transport or winnowing of the chalk and the cluster is interpreted as formed by instantaneous burial of the sponge and its epifauna by a chalk ooze debris flow. The triggering mechanism was probably a major earthquake caused by movement on a nearby syndepositional fault. Another cluster dominated by *Magas chitoniformis* was found in the Nørre Flødal quarry in northern Jylland in an upper Maastrichtian chalk rich in imprints after sponges. A similar burial mechanism is envisaged based the position of the locality in the tectonically very active Sorgenfrei-Tornquist Zone. The clusters are excellent examples on brachiopod attachments to a soft-bodied organism, which has left no direct trace in the sediment.

Keywords: Terebratulida, Cretaceous, Stevns Klint, epifauna.

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Most brachiopods are attached to a substrate by means of a muscular pedicle. The pedicle can have many different functions and is much more than just a holdfast. Surlyk (1972) thus interpreted the pedicle of the Maastrichtian generalist species *Terebratulina chrysalis* (von Schlotheim, 1813) as root-like by analogy with the modern relative *Terebratulina retusa*. Richardson (1997) highlighted the great variability of brachiopod pedicles in terms of morphology and function. Fossil pedunculate brachiopods are only rarely found preserved in life position as the fleshy pedicle rapidly decays after death of the brachiopod. However, several specimens of the micromorphic brachiopods, *Aemula* n. sp. were found in life position on the test of an irregular echinoid (Surlyk 1974). *Aemula* n. sp. and its host lived on the quiet Maastrichtian chalk ooze at Hemmoor in northern Germany. This fortuitous preservation was probably caused by rapid burial of the echinoid by a predator whereby the minute specimens of *Aemula* were covered in chalk while still attached.

An almost identical find in the upper Maastrichtian of Belgium of several specimens of the closely related pedunculate *Aemula inusitata* Steinich, 1968 was reported as preserved in life position also in this case on the test of the echinoid *Echinocorys* (Jagt & Simon 2004). These two finds indicate that the mm-sized *Aemula* possessed a short pedicle and lived with the dorsal valve closely pressed against the substrate. Sudden burial of the substrate – in these cases an echinoid test – resulted in preservation in life position.

A number of examples have been described where an assemblage of mainly monospecific brachiopods was preserved in a cluster without any signs of concentration caused by currents or other means of transport. An assemblage of the rhynchonellid brachiopod *Owenirhynchia triangularis* (Wahlenberg, 1821) was interpreted as representing a result of a densely clustered attachment strategy (Asgaard & Bromley 1990). This interpretation was supported by the abundant occurrence of the boring *Podichnus* isp. on the shells. The boring was formed by the brachiopod pedicle being split into holdfast papillae, which could penetrate the carbonate shells (Bromley & Surlyk 1973). *O. triangularis* was an important member of the early Campanian rocky shore fauna at Ivö Klack, southern Sweden (Surlyk & Sørensen 2010; Schrøder *et al*. 2019).

A remarkable example of an immense, high-density monospecific Early Silurian assemblage of the brachiopod *Stricklandia lens lens* (Sowerby, 1839) was described and interpreted by Johnson & Baarli (2022) as resulting from an extensive spatfall settling on a barren shell pavement, covering a large area during a short interval of time. Clusters of Devonian, Carboniferous and modern discinid brachiopod shells were interpreted as original life assemblages by Mergl (2010). The living, modern clusters of *Discradisca lamellosa* (Broderip, 1833) and *Discinisca laevis* (Sowerby, 1822) comprised up to 25 individuals which were attached to each other with a short pedicle illustrated by some quite remarkable photographs (Mergl 2010, fig. 5). The clustering was interpreted as a protection against grazing. Fine examples of brachiopod clusters, notably *Lepidocyclus capax* (Conrad, 1842) and *Rhychotrema dentatum* (Hall, 1847) clearly preserved in life position were described from the Upper Ordovician of Indiana and Ohio by Richards (1972). Small clusters of densely packed brachiopods *Tetrarhynchia tetrahedra* (Sowerby, 1812) and *Lobothyris punctata* (Sowerby, 1812) were interpreted as genuine life assemblages by Hallam (1961). The clusters exhibited a wide size range and thus no evidence for current sorting and with only few signs of physica disturbance of the shells. Hallam (1961) suggested that at least three successive annual spatfalls were represented based on a size-frequency analysis.

The aim of this study is to describe and interpret a monospecific cluster of at least 53 specimens of the articulate brachiopod *Magas chitoniformis* (von Schlotheim, 1813) found in very fine-grained chalk in the uppermost Maastrichtian at Stevns Klint, Denmark.

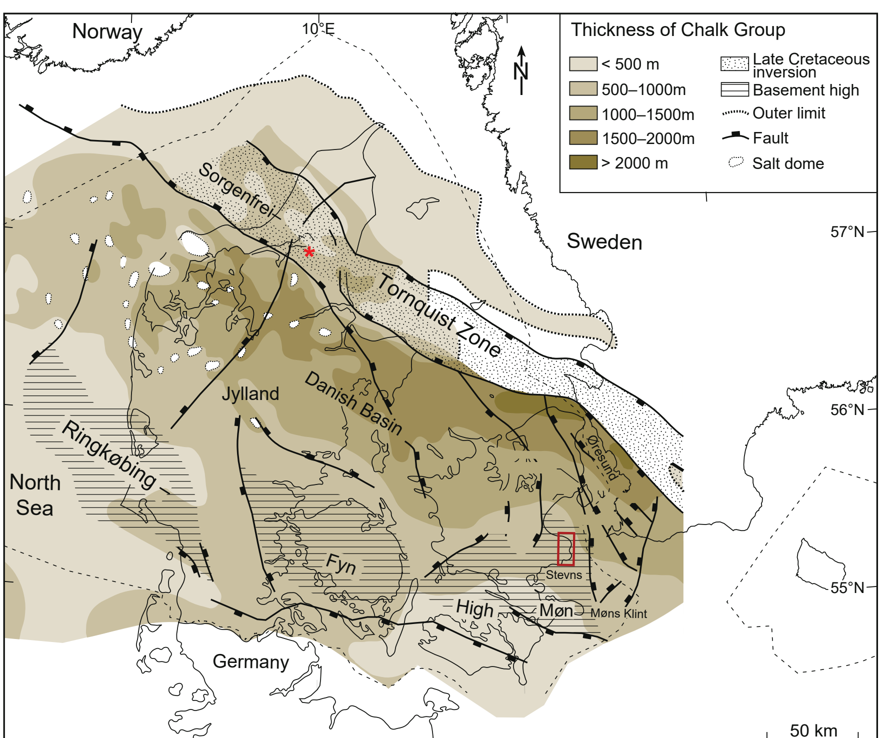

Fig. 1. Geological map, showing the outline of the Danish Basin and its southern and northern limits, the Ringkøbing-Fyn High and the Sorgenfrei-Tornquist Zone, respectively. Red rectangle marks the position of the coastal cliff, Stevns Klint. The position of the locality Nørre Flødal, northern Jylland is shown with an asterisk. Modified after Surlyk *et al*. (2013).

Geological setting and stratigraphy

The Upper Cretaceous Chalk Group of northern Europe is a major contourite complex formed at a time when the European craton was flooded by the relatively deep Chalk Sea. Reflection seismic data show that the chalk of the Danish Basin was deposited in a system of large valleys and ridges, moats and drifts sculptured by bottom currents (Lykke-Andersen & Surlyk 2004; Esmerode *et al*. 2007; Surlyk & Lykke-Andersen 2007).

The 14.5 km long coastal cliff, Stevns Klint in eastern Denmark shows excellent exposures of upper upper Maastrichtian chalk topped by an unbroken Cretaceous–Palaeogene boundary succession overlain by mounded bryozoan limestone (Surlyk *et al*. 2006). Stevns Klint was nominated a UNESCO World Heritage Site in 2014 based on an application written by Damholt and Surlyk (2012). The chalk was deposited close to the southern margin of the Danish Basin, which is limited to the south by the Ringkøbing-Fyn High (Fig. 1).

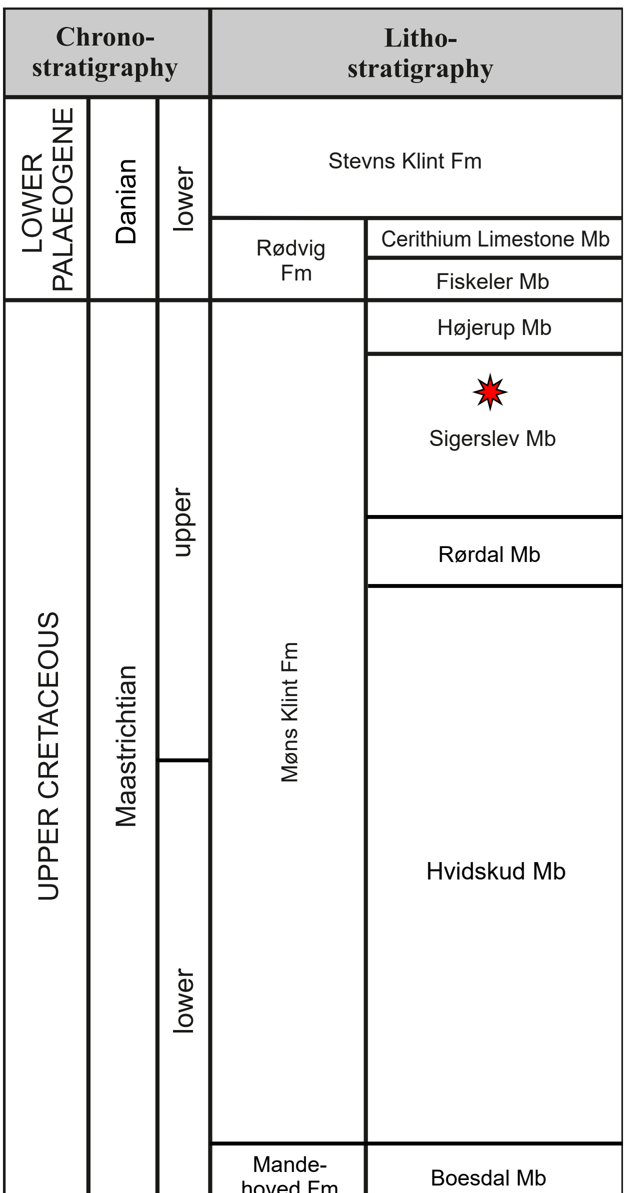

Fig. 2. Lithostratigraphic scheme covering the succession exposed at Stevns Klint. After Surlyk *et al.* (2013).

The brachiopod cluster forming the subject of this study was found in the Sigerslev quarry also known as Stevns Kridtbrud (Stevns chalk quarry), immediately adjacent to the cliff. The quarry exposes about 30 m of the Sigerslev and Højerup Members, Møns Klint Formation (Fig. 2). The lowest part of the Sigerslev Member was deposited in a complex of low mounds (Anderskouv *et al*. 2007). Mound growth was governed by currents flowing towards the WNW, the same direction as the interpreted Late Cretaceous current direction in the present Kattegat sea farther north in the Danish Basin (Surlyk & Lykke-Andersen 2007). Upwards, the mounded chalk give way to evenly bedded chalk, which is topped by a few metres of bryozoan-rich chalk of the Højerup Member. This is unit overlain by the K–Pg boundary clay, the lowermost Danian Fiskeler Member, passing gradationally upwards into the Cerithium Limestone Member (together forming the Rødvig Formation). The Cerithium Limestone is topped by an erosional hardground surface overlain by lower Danian bryozoan limestone of the lower Danian Korsnæb Member of the lower Danian Stevns Klint Formation (Fig. 2; Surlyk *et al*. 2006).

The *Magas chitoniformis* cluster from Stevns Klint

A cluster of the pedunculate brachiopod *Magas chitoniformis* (von Schlotheim, 1813; Fig. 4; Geomuseum Faxe, with registration number OESM-4620) was found by Peter Bennicke in the lower part of the Maastrichtian chalk of the Sigerslev Member exposed in the Sigerslev chalk quarry (Fig. 3). It was found in the so-called Sponge Bed, rich in large skeletons and imprints after sponges together with regular echinoids with all spines lying immediately adjacent to the tests (Figs 5, 6; Peter Bennicke and Sten L. Jakobsen, pers. comm. 2024). The bed has a high content of celestite, a mineral that has also been recorded in Maastrichtian chalk in the nearby fully cored Stevns-1 borehole. The celestite nodules were interpreted as formed by very early replacement of lithistid demosponges in localized reducing environmental conditions (Madsen & Stemmerik 2009). This took place during rapid burial of the sponges and the subsequent decomposition of the organic tissue by sulfide-oxidizing and sulfate-reducing bacteria forming local anoxic microenvironments. A similar interpretation is proposed for the Sponge Bed in the Sigerslev quarry both for the content of celestite and for the unusual 3D preservation of large sponges.

The well-defined *M. chitoniformis* cluster covers an area of about 14 x 11 cm set in a very pure chalk (Fig. 4). The chalk is structureless and non-bedded but the

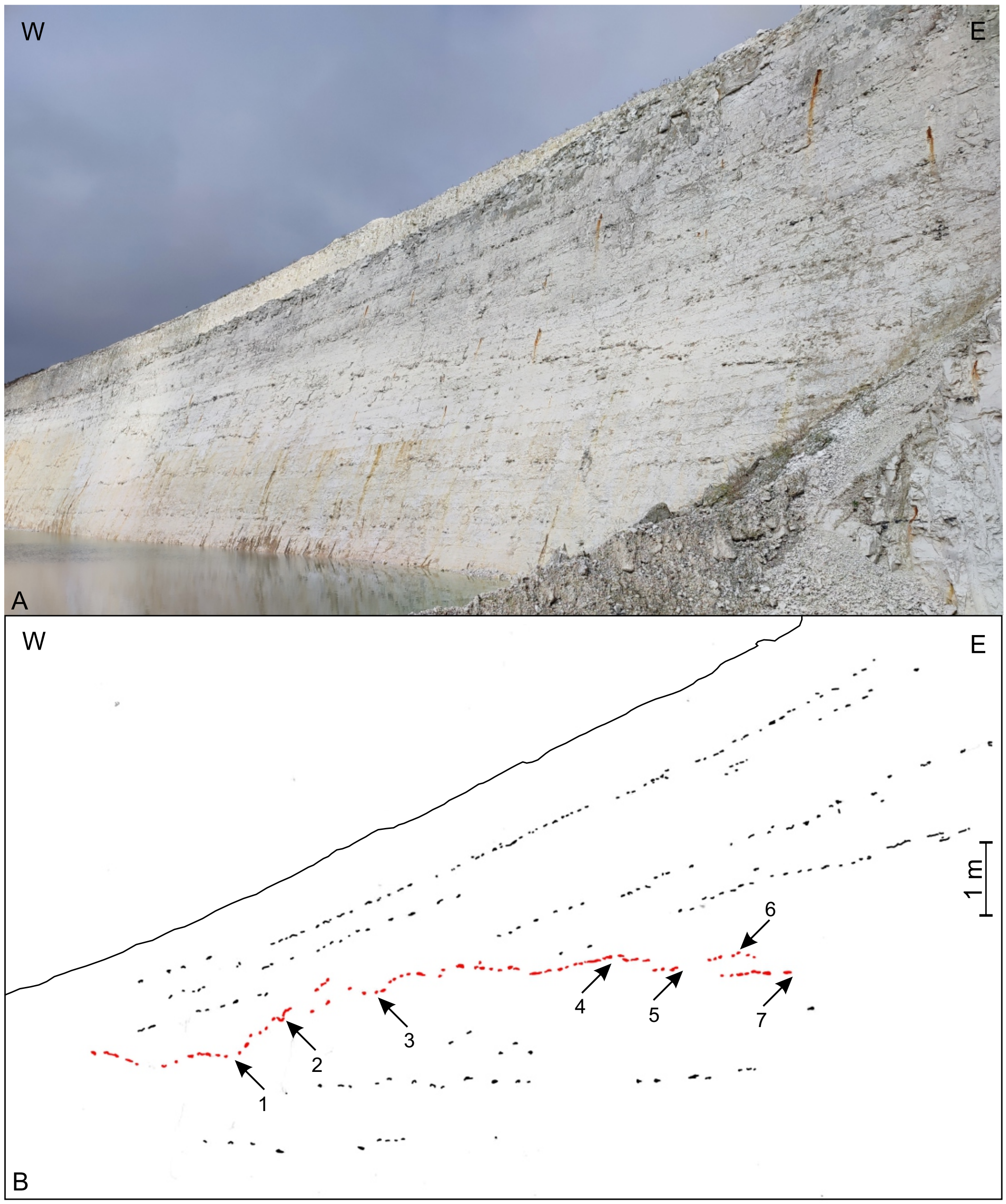

Fig. 3. A: Photograph of E–W wall in the Sigerslev quarry, Stevns Klint. The lower part of the section shows fossiliferous mound-bedded chalk, which upwards give way to horizontally-bedded, poorly fossiliferous chalk. The Sponge Bed is exposed in the adjacent N–S wall at the same level as the mounded chalk. The K–Pg boundary is situated immediately above the top of the exposed section. The mounded topography is outlined by layers of flint nodules. The mounds are mainly regular with evenly sloping flanks, but the eastern flank of the mound shown in the photograph is deformed and irregularly down stepping interpreting as reflecting redeposition of chalk and instant burial of the benthic fauna by debris flows. The western mound flank is strongly deformed with concave-up erosional surfaces interpreted as small slump scars. Photograph by Jesper Milàn. **B:** Drawing of photograph in A, highlighting the irregular, eastern mound flank interpreted as representing snouts of debris flows (flint nodules marked in red) (arrows 5, 6 and 7), and the possible slump scar at the western flank (arrows 1, 2, 3, 4).

Fig. 4. Cluster of the pedunculate brachiopod *Magas chitoniformis*. Housed at Geomuseum Faxe (OESM-4620). The 53 visible brachiopods are well preserved without any traces of wear or predation and belong to a single spatfall (Fig. 5). The few cracks are caused by later compaction of the very pure, soft chalk. Photograph by Sten L. Jakobsen.

thin slab contains only one layer of the brachiopod and is accordingly interpreted to parallel the original sediment-water interface. The cluster is monospecific and comprises at least 53 specimens. They are all well preserved without any signs of wear by transport or indications of predations such as gastropod borings, which are otherwise well known in brachiopods from the chalk (Surlyk 1972, 1973). The fragmentation, cracks and fissures seen in some of the shells are caused by late compaction of the surrounding chalk at contacts between more or less empty shells. These features and the lack of scatter of the specimens indicate rapid burial in the surrounding chalk.

The size-frequency distribution of the total assemblage (Fig. 7) is interesting and unusual for the brachiopod populations in the chalk which almost always have strongly right-skewed size-frequency distributions with a strong dominance of mm-sized juveniles (Surlyk, 1972). The size-frequency distribution of the cluster differs fundamentally from this pattern, not only in being unimodal with a *single* year class represented, but the specimens are all adults in contrast to virtually all assemblages known from the chalk (Fig. 7). Almost all specimens in the cluster fall in the 0.25–10.0 mm length class with an average length of 7.0 mm. The size-frequency distribution thus shows that the cluster represents a single spatfall. The larvae were successfully attached to a soft substrate of which there is no direct trace. This soft substrate was in all likelihood a sponge, reflected by the abundance of body fossils and imprints after sponges in the aptly named Sponge Bed. Other fossils from the Sponge Bed also show remarkable preservation, e.g. a slab containing abundant siliceous sponge fragments also contains a specimen of a regular echinoid, with all the delicate spines preserved immediately adjacent to the test (Fig. 5). It is referred to the species *Phymosoma ravni*, which is described in detail in Schlüter *et al*. (2012).

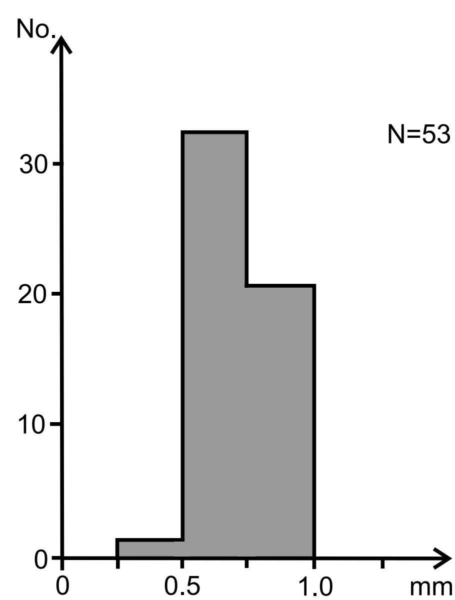

Fig. 5. Unimodal size-frequency distribution of the *Magas chitoniformis* specimens in the cluster shown in Figure 4, indicating that the cluster represent a single spatfall.

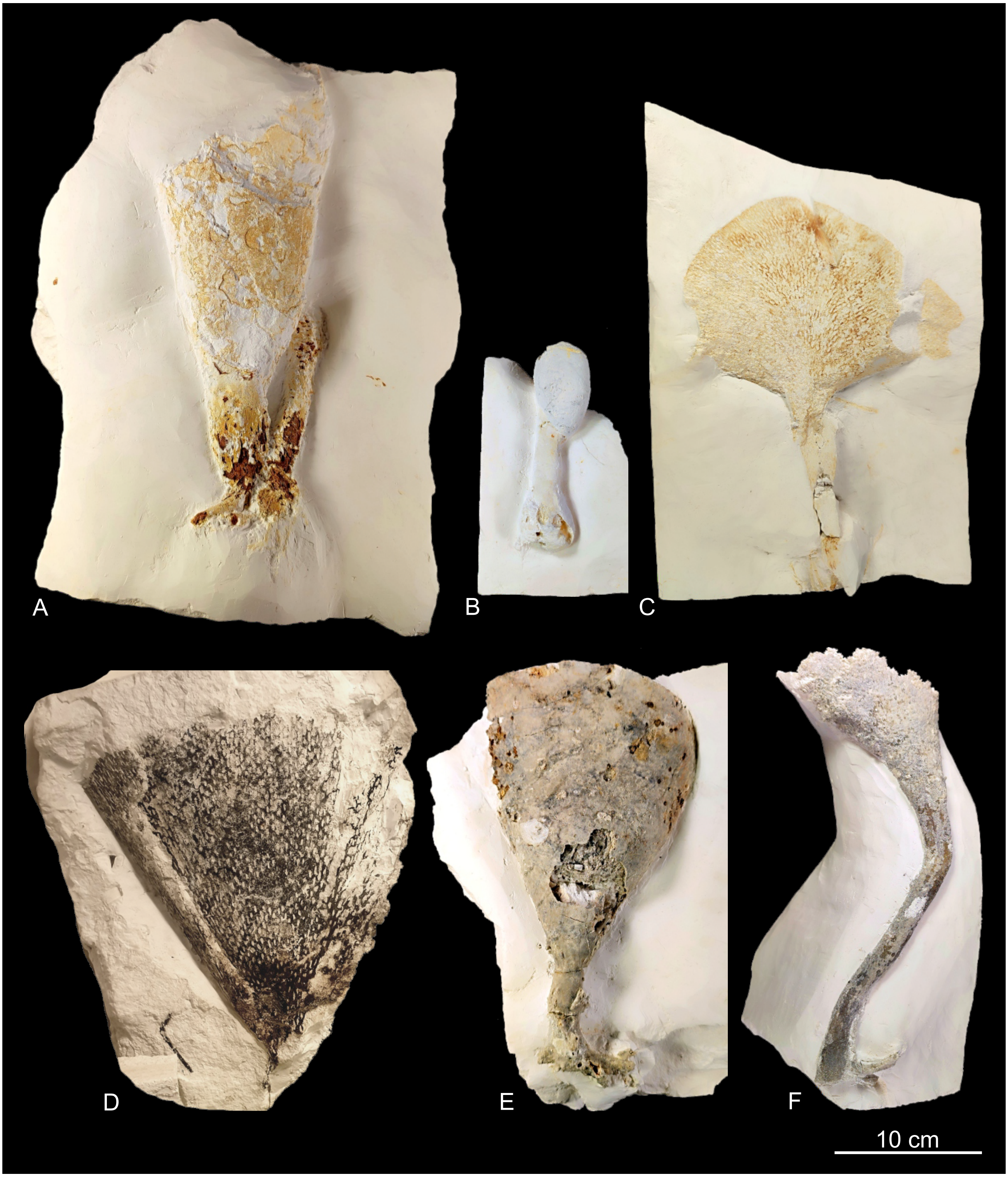

Fig. 6. Sponges preserved in 3D in the Sponge Bed. Sigerslev Member at Sigerslev quarry, Stevns Klint. **A–E:** Sponges very similar to *Ventriculites* (Hexactinellida, Lychniscosida), which is very common in the Upper Cretaceous. E: This sponge has the outer dense cortex layer preserved. A, B, **F:** These have pieces of a pyritified stalk preserved. **A:** This sponge has a possible *Ventriculites* attached to it. **B:** This stalk has a soft sponge with a short stalk attached to it, which may be similar to *Hyalonema* (Hexactinellida, Amphidiscophorida).

According to their outer shape and surface channels, the sponges are very similar to *Ventriculites* (Hexactinellida, Lychniscosida), a genus very common in the Upper Cretaceous (Figs 4A-E). One has the outer dense cortex layer preserved (Fig. 4E), some are pieces of a pyritified stalk (Figs 4A, B, F), one with a possible *Ventriculites* attached (Fig. 4A), another stalk has attached to it a soft sponge with a short stalk, that may be similar to *Hyalonema* (Hexactinellida, Amphidiscophorida). *Hyalonema* is an extant genus, which is occasionally found in the Upper Cretaceous (Mehl & Hauschke 1995; Dorte Janussen, pers. comm. 2024).

Attachment of brachiopods to sponges is a well-known phenomenon. Palaeozoic sclerobionts on sponges include bryozoans, brachiopods, acrothoracic barnacles, tabulate and rugose corals and other sponges, whereas Mesozoic sclerobionts comprise brachiopods, bivalves, serpulids, bryozoans and several other groups (e.g. Palmer & Fürsich 1981; Luci *et al*. 2023). The preferred and most commonly used substrate of modern terebratulid brachiopods from Antarctica and New Zealand are erect bryozoans, but sponges, rocks and echinoid spines have also been used as suitable substrates (Lee 1990; Barnes & Peck 1996).

A second example of a brachiopod cluster was found by the author back in the 1960s in a very pure lower upper Maastrichtian chalk at Nørre Flødal, northern Jylland, Denmark (marked with an asterisk in Fig. 1). The cluster was interpreted as follows: "The chalk contains abundant imprints after sponges and it

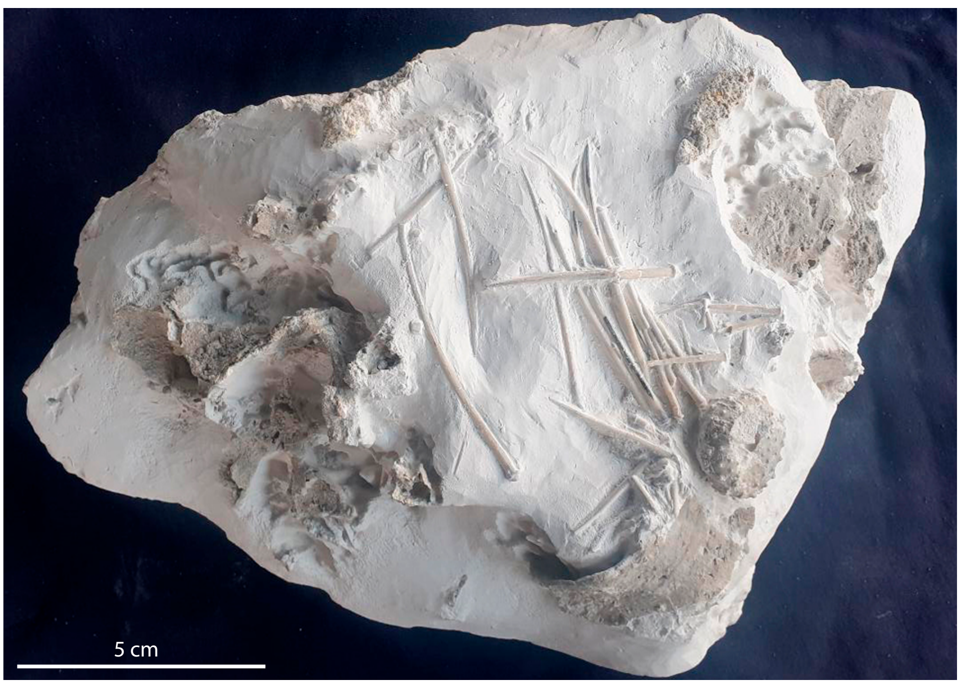

Fig. 7. Slab of pure chalk with abundant siliceous sponge fragments and a well-preserved specimen of the regular echinoid *Phymosoma ravni* with all its long, delicate spines preserved immediately adjacent to the test, indicating instantaneous burial probably by a chalk ooze debris flow. Sponge Bed, upper upper Maastrichtian, Sigerslev Member at Sigerslev quarry, Stevns Klint. Leg. Peter Bennicke. Photograph by Sten L. Jakobsen.

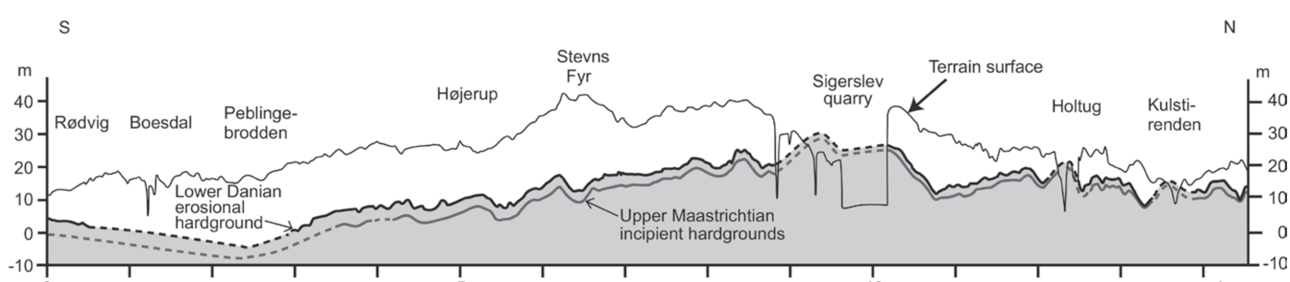

Fig. 8. Vertically exaggerated profile of Stevns Klint, showing the position of the Maastrichtian–Danian boundary which in this scale coincides with the 'lower Danian erosional hardground'. The position of the Sigerslev quarry is indicated and the *Magas chitoniformis* cluster was found where the boundary forms a small terrace below the letters 'arry' in 'quarry'. The instantaneous burial of the Sponge Bed and the *Magas chitoniformis* cluster is interpreted as caused by a debris flow on the slope of a small mound (Fig. 3) or by a debris flow sourced from the top of the large contourite ridge immediately to the south of the quarry at 9.4 km on the horizontal axis. The crest is about 30 m higher than the valley at 2.4 km, illustrating the remarkable sea-floor relief in the area formed by persistent WNW-flowing bottom currents in the latest Maastrichtian. From Lykke-Andersen & Surlyk (2004, fig. 13).

is considered most likely that the brachiopods were attached to a sponge and fell into a well-defined cluster by the death of the sponge. There are no indications of the brachiopods having been subjected to any significant transport" (Surlyk 1969, p. 283, Pl. 23, translated from Danish). This cluster is dominated by adult specimens of *Magas chitoniformis* but also contains a few specimens of *Gyrosoria gracilis* (von Schlotheim, 1813). Again, the notion of abundant imprints after soft sponges found together with a cluster of adult brachiopods is strongly suggestive of the substrate for the brachiopod spatfall being a soft-bodied sponge which was turned over and buried in the soft chalk, resulting in the death of both sponge and brachiopods.

Discussion

The examples presented here thus show that larger brachiopod species which normally require a large hard substrate could find appropriate substrates at times when the chalky sea floor was rich in soft sponges. The excellent preservation of the brachiopods in both samples apart from compaction fractures shows that the sponge and the attached fauna were instantaneously burrowed. The normal sedimentation rate is far too slow to account for rapid burial as it amounts to a few cm/ka. The large size of the extremely well-preserved sponges in the present examples supports the interpretation of instantaneous burial in soft chalk (Figs 4, 6, 7).

A causal agent overturning and burying the sponge could be by swimming animals, such as rays, which commonly seek their food in the upper sediment layers and are known to excavate bowl-shaped depressions, *Piscichnus waitemata* (e.g. Martinelli *et al*. 2001). But this interpretation does not fully explain the abundance of well-preserved sponge body fossils and imprints. Sediment gravity flows are the most likely agent responsible for the burial of the diverse fauna. Muddy turbidity currents or debris flows sourced from chalk ooze close to the sediment-water interface are close to impossible to identify directly in the monotonous chalk and would not leave any traces especially after subsequent bioturbation. A debris flow of chalk ooze from the uppermost, unlithified sea floor is thus considered the most likely cause for the instantaneous burial of the brachiopod assemblage and its soft-bodied substrate. A trigger mechanism could be strong earthquakes caused by syndepositional faulting. Syndepositional faults identified on reflection seismic data are common in the chalk offshore Stevns Klint (Esmerode *et al.* 2007; see also Erlström *et al.* 2018, fig. 1). The N–S-trending Stevns Fault is thus situated a few kilometres east of the locality. Major earthquakes caused by movements on the faults are thus suggested as a triggering mechanism for debris flows composed of chalk ooze which would result in burial and sudden death of much of the benthic fauna. The source area of such debris flow could be the slopes of the small mounds on the seafloor adjacent to the Sponge Bed. The slope angles of the mounds were 10–15° (Anderskouv *et al.* 2007). The mound topographies are normally regular and outlined by layers of flint nodules and flint layers. In contrast, the eastern flank of a nearby mound at the same level as the Sponge Bed shows step-wise terracing and a few over-steepened layers suggestive of slumping (Fig. 3). It is, however, remarkable and probably significant that the Sponge Bed is situated a short distance to the north of the crest of a major sea floor contourite ridge formed by WNW-flowing bottom currents (Fig. 8). The ridge had a relief of as much as 30 m above the deepest valley in the chalk exposed at Stevns Klint and 10–20 m above the surrounding sea floor (Lykke-Andersen & Surlyk 2004; Surlyk *et al.* 2006; Anderskouv *et al.* 2007). This ridge was an obvious potential source for generating large-volume debris flows composed of chalk ooze, which would travel a short distance of about 500 m down the northern slope to come to a rest on a slope terrace (Fig. 8; Surlyk *et al.* 2006, fig. 13). Such a debris flow comprising completely unconsolidated chalk ooze would not leave any trace in the form of sedimentary structures; the main evidence being the rich instantaneously buried fauna, comprising large 3D preserved sponges and a wealth of other unusually well-preserved faunal elements (Figs 4, 6, 7). So, both short-travelled debris flows down the flanks of the small mounds (Fig. 3) and debris flows from the crest of the large ridge (Fig. 8) are likely agents in the instantaneous burial of large, delicate fossils, such as sponges.

Conclusions

A monospecific cluster comprising at least 53 adult specimens of the brachiopod *Magas chitoniformis* is described from the uppermost Maastrichtian chalk at Stevns Klint, Denmark. The cluster was found at a level called the Sponge Bed by fossil collectors, due to the abundant occurrence of commonly large body fossils and imprints of sponges, some of which were soft bodied. The size-frequency distribution of the brachiopod assemblage is unimodal, comprising fully grown individuals with an average length of 7 mm. This population structure is fundamentally different from that seen in the other brachiopod species in the chalk, which are almost all strongly right-skewed with a dominance of juvenile individuals (Surlyk 1972).

The brachiopods are well preserved without any signs of transport or predation. They are interpreted as representing a single spatfall attached to a soft substrate, which was buried instantaneously by chalk ooze causing the death of the sponge and its epifauna. The causal mechanism for the burial is interpreted as a debris flow triggered by a strong earthquake and sourced either from immediately adjacent low chalk mounds or from the nearby crest of a major contourite sea-floor ridge. The earthquake was probably caused by movements on syn–depositional faults located offshore Stevns Klint. This is an excellent example of the substrate preference of a pedunculate brachiopod in a case where hard substrates of a suitable size were not available and adds to earlier interpretations of modes-of-life of the diverse brachiopod fauna of the Danish Maastrichtian.

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Contents

Fauna of the Sæterdal Formation (Cambrian Series 2, Stage 4) of North Greenland (Laurentia)

Peel, J.S. 2025. Fauna of the Sæterdal Formation (Cambrian Series 2, Stage 4) of North Greenland (Laurentia). Bulletin of the Geological Society of Denmark, Vol. 74, pp. 1–13. ISSN 2245-7070. https://doi.org/10.37570/bgsd-2025-74-01

Abstract: The fauna preserved in decalcified sandstones of the Sæterdal Formation (Cambrian Stage 4) of southern Peary Land, North Greenland (Laurentia) is dominated by the trilobites *Kootenia marcoui* and *Bonnia brennus*, which also occur in the equivalent dark carbonates and mudstones of the Henson Gletscher Formation to the west. They are associated with *Olenellus* and small ptychoparioid trilobites. Brachiopods compared to *Nisusia ancauchensis*, originally described from the Precordillera terrane in Argentina, show variation in shell morphology and the form of the pseudodeltidium. They occur together with *Kutorgina* cf. *cingulata*, which is conspicuous in the overlying Paralledal Formation, rare *Matutella* sp. and an indeterminate hyolithid.

Keywords: Trilobites, brachiopods, Cambrian Stage 4, North Greenland, Laurentia.

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A cluster of the brachiopod Magas chitoniformis (von Schlotheim, 1813) represents settling of a single spatfall on a soft-bodied substrate, probably a sponge: instantaneous burial by a chalk ooze debris flow (Maastrichtian, Denmark)

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Abstract: A well-defined monospecific cluster of the brachiopod Magas chitoniformis (von Schlotheim, 1813) was found in uppermost Maastrichtian chalk at Stevns Klint, Denmark. It comprises a sheet-like accumulation of 53 well-preserved adult specimens with an average length of 7.0 mm. The stratigraphical level is the 'Sponge Bed' named so by fossil collectors because of the wealth of imprints or skeletal elements of large sponges, commonly showing 3D-preservation. The unimodal size-frequency distribution of the brachiopod shells indicate that they represent a single successful spatfall most likely on a soft-bodied sponge. There are no signs of transport or winnowing of the chalk and the cluster is interpreted as formed by instantaneous burial of the sponge and its epifauna by a chalk ooze debris flow. The triggering mechanism was probably a major earthquake caused by movement on a nearby syndepositional fault. Another cluster dominated by Magas chitoniformis was found in the Nørre Flødal quarry in northern Jylland in an upper Maastrichtian chalk rich in imprints after sponges. A similar burial mechanism is envisaged based the position of the locality in the tectonically very active Sorgenfrei-Tornquist Zone. The clusters are excellent examples on brachiopod attachments to a soft-bodied organism, which has left no direct trace in the sediment.

Keywords: Terebratulida, Cretaceous, Stevns Klint, epifauna.

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