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FIRST RECORD OF A VERTEBRATE COPROLITE FROM THE UPPER CRETACEOUS (MAASTRICHTIAN) CHALK OF STEVNS KLINT, DENMARK

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Abstract— The first vertebrate coprolite from the Upper Maastrichtian chalk of Denmark is described. The coprolite is 31 mm long, with a maximum diameter of 11 mm. Computed Tomography scanning of the specimen shows / revealed the internal structure to be tightly coiled, suggesting that the coprolite originates from a small shark with an estimated total length not exceeding 1.2 meters. Coprolites are normally found in abundance in marine deposits worldwide, so the lack of recorded findings from the Danish chalk probably reflects a collecting bias; collectors have simply failed to recognize them.

INTRODUCTION

Coprolites are important paleobiological indicators that can provide important information about predator/prey interactions and the diet of extinct animals. Thus they aid in reconstructions of ancient ecosystems and are more and more frequently (being) included in palaeoecological analyses (e.g. Thulborn, 1991; Hunt et al. 1994; Northwood, 2005; Souto, 2008; Eriksson et al., 2011)

Vertebrate coprolites are known from the Silurian to the present (Hunt et al. 2012a). They are facies dependent ichnofossils and have been known from Upper Cretaceous chalks for almost two hundred years (e.g., Mantell, 1822; Buckland, 1835, 1836). Mantell (1822, pl. 9, figs. 3-11) first illustrated a number of specimens which he identified as probable conifer cones. Subsequently, Buckland (1835) recognized these fossils as coprolites and Hunt et al. (2012a) assigned them to *Iuloeidocoprus mantelli*. Also other spiral coprolites from Upper Cretaceous chalks in the USA and Germany have been identified as *I. mantelli* and *Liassocoprus* ichnosp. (Hunt et al., 2012a).

There has been extensive study of Cretaceous vertebrate coprolites. There is less work on Lower Cretaceous coprolites, but it includes records from North and South America, Africa, Australasia and Europe (e.g., Goldring et al., 2005; Souto and Schwanke, 2010; Hunt et al., 2012) and the earliest monograph on coprolites by Bertrand (1903).

There is a larger literature on Late Cretaceous coprolites. Nonmarine coprolites are widespread and have been studied in the USA (e.g., Chin, 2007), Canada (e.g., Chin et al., 1998), Mexico (e.g., Rodriquez de la Rosa et al., 1998), India (e.g., Prasad et al., 2005), Brazil (Souto, 2010). There are fewer reports of coprolites in marine strata of Late Cretaceous age but they occur in the Late Cretaceous of Europe (e.g., Eriksson et al., 2011) and North (e.g., Friedman, 2012) and South (e.g., Souto and Medeiros, 2012) America.

Mesozoic vertebrate coprolites from Denmark and other parts of Scandinavia are only known from a few localities; Two fragmentary coprolites were found in the Lower Cretaceous (Late Barriasian) of Bornholm, Denmark (Milàn et al., 2012a) and an extensive coprofauna with several different morphotypes has been described from the Upper Cretaceous (Campanian) of southern Sweden (Eriksson et al. 2011). From Cenozoic strata, the lowermost Paleocene (Danian) of Faxe quarry, eastern Denmark, coprolites attributed to sharks, bony fish, crocodylians and possible turtles have been reported (Milàn, 2010; Milàn et al., 2012b). The aim of this paper is to describe the first finding of a vertebrate coprolite from the Maastrichtian chalk of Sigerslev Quarry, Stevns Klint, Denmark and attempt to identify its producer.

GEOLOGICAL SETTING

The Upper Maastrictian (Upper Cretaceous) chalk of Denmark is famous for its extensive body fossil record of both vertebrates and invertebrates counting in excess of 450 species (see Damholt and Surlyk, 2012 for a complete fauna list), as well as abundant trace fossils (Bromley and Ekdale, 1984; Ekdale and Bromley, 1984). The chalk was deposited in an epeiric Boreal sea that covered most of Northwest Europe, and the distance to land areas from the Stevns Klint area was probably more than 200 km (Fig. 1). The chalk was traditionally considered as deposited as pelagic settling in a calm water column.

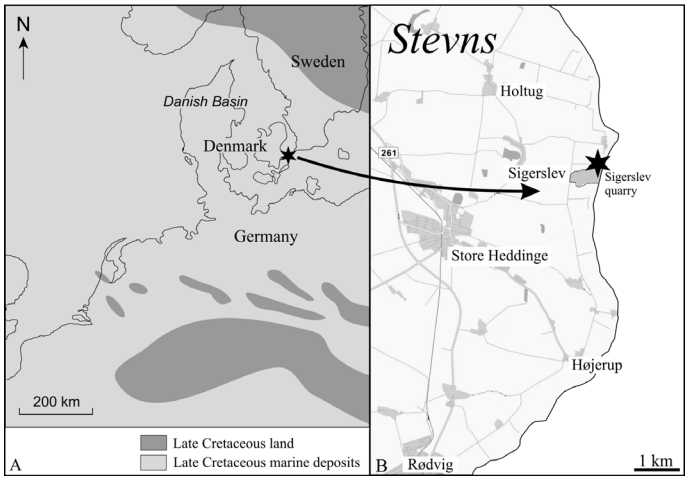

FIGURE 1. **A**, Map of NW Europe showing the distribution of Late Cretaceous land areas and marine sediments. Stevns Klint is marked by a star and is located at a peninsula in the south-eastern part of the Danish Basin. Modified from Ziegler (1990). **B,** Map of the Stevns peninsula. The coprolite (MGUH-30505) was found in the chalk quarry at Sigerslev, indicated by the star.

In the Stevns Klint area, however, evidence of gentle bottom currents resulted in formation of large and small scale mounds on the seafloor, below the photic zone (Surlyk et al., 2006). The Sigerslev quarry was situated on a ridge structure during the Maastrichtian. Periodically the mounded seafloor was colonized by abundant bryozoans and other benthic invertebrates as the result of increased bottom current activity and in particular nutrient supply (Anderskouv et al., 2007).

The stratigraphic succession exposed at Sigerslev quarry and vicinity is approximately 40 m thick (Fig. 2). The lower 30 m comprises mounded chalk rich in bryozoan fragments, overlain by evenly bedded benthos-poor chalk belonging to the upper Maastrichtian Sigerslev

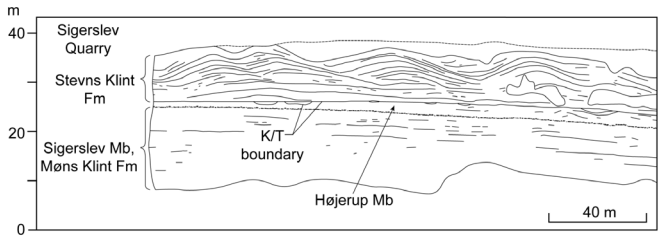

FIGURE 2. Geological profile of the Upper Maastrichtian–Lower Danian succession in the coastal section north of the Sigerslev quarry. Thin lines in the Sigerslev Member, Højerup Member and Stevns Klint Formation shows distribution of nodular flint bands. Modified from Surlyk et al. (2006).

Member of the Møns Klint Formation (Surlyk et al., 2006, 2013). The member is topped by a thick nodular flint band and two incipient hardgrounds that, in turn, are overlain by the few meters thick, mounded bryozoan-rich chalk of the uppermost Maastrichtian Højerup Member. The K/T boundary is exposed in the upper part of the quarry where the basal Fish Clay and Cerithium Limestone members of the Rødvig Formation occur in small depressions topped by an erosional hardground and overlain by Lower Danian bryozoan limestone mounds of the Stevns Klint Formation (Fig. 2).

MATERIALS AND METHODS

The small coprolite was found by amateur collector Thorbjørn Madsen in Maastrichtian Møns Klint Formation exposed in the chalk quarry of Sigerslev, at the Stevns Peninsula of Denmark (Fig. 1). The coprolite is the first to be discovered from the Maastrichtian of Denmark and based on that it is declared a so-called Danekræ (National Treasure) (DK-725), and is stored in the collection of the Natural History Museum of Denmark (MGUH – 30505)

In order to obtain better information about the internal architecture of the coprolite, it was CT-scanned according to the methods developed by Milàn et al. (2012b). The CT-scanning was performed at the Institute of Forensic Medicine, University of Copenhagen, Denmark, using a Siemens Somatom +4 MDCT scanner. A reconstruction kernel of 90 was used, as is normal for high density objects. Scanning parameters were set to 220kV and 120mAs, with a (X,Y) matrix of 0.5 x 0.5 mm and a reconstruction (Z) of 0.5 mm. With these settings the object is shown with isometric voxels and can be reconstructed with its true proportions.

DESCRIPTION

The specimen is dark grey and easily recognized against the white chalk in which it is partly embedded (Fig. 3A). It measures 31 mm in length and has a cylindrical circumference with a maximal diameter of 11 mm. A natural crack running perpendicular to the length axis, approximately in the middle of the specimen, reveals that the coprolite is composed of one single, tightly coiled layer with a thickness varying from 0.5 to 2.3 mm, thickest towards the middle/center of the specimen (Fig. 3B). CT scanning images, taken parallel to the length axis of the coprolite show the coiling to be spiraling towards one end of the coprolite (Fig. 4A), and CT images perpendicular to the length axis show the thickness of the layer to be almost constant throughout the length of the coprolite (Fig. 4B).

DISCUSSION

Identifying the producer of a coprolite can be a challenging task as feces from many unrelated animal groups can be very similar in appearance. Furthermore, large variation can occur within the morphology of feces from even the same group of animals, according to different diets, and mode of egesting (e.g. McAllister, 1985; Chin, 2002; Chame, 2003; Milàn, 2012).

The late Maastrichtian vertebrate fauna of Denmark comprises 31 species of chondrichthyans (Adolfssen and Ward, in press) and four species of actinopterygians (Bonde et al., 2008). Reptilians are represented by two genera of mosasaurs (Lindgren and Jagt, 2005), a crocodile of thoracosaurid affinity (Gravesen and Jakobsen, 2012) and one turtle (Karl and Lindow, 2009). The vast majority of the sharks living in the Danish basin during the Late Cretaceous were relatively small, less than 1.2 meters in length, with the exception of *Spehenodus*, *Notidanodon*, *Cretalamna*, *Squalicorax* and *Pseudocorax*, where adult specimens probably could reach a body length of more than two meters (Adolfssen and Ward, in press).

The specimen at hand, like the vast majority of coprolites derived from Upper Cretaceous chalks, has a spiral morphology. Spiral coprolites are produced by fish with valvular intestines (Williams, 1972; McAllister, 1985). The phylogenetic distribution of valvular intestines is not fully understood, but McAllister (1987) presented evidence that that some or all agnathans, placoderms, dipnoans, actinistians and chondrichthyans possess this structure. All these groups occurred frequently in the Paleozoic but by the Late Cretaceous only the chondrichthyans were common in marine environments, suggesting that one of the many Maastrichtian chondrichthyans produced the coprolite studied herein. Fecal pellets have been found preserved within the digestive tract of some Paleozoic sharks (e.g., Hunt et al.,

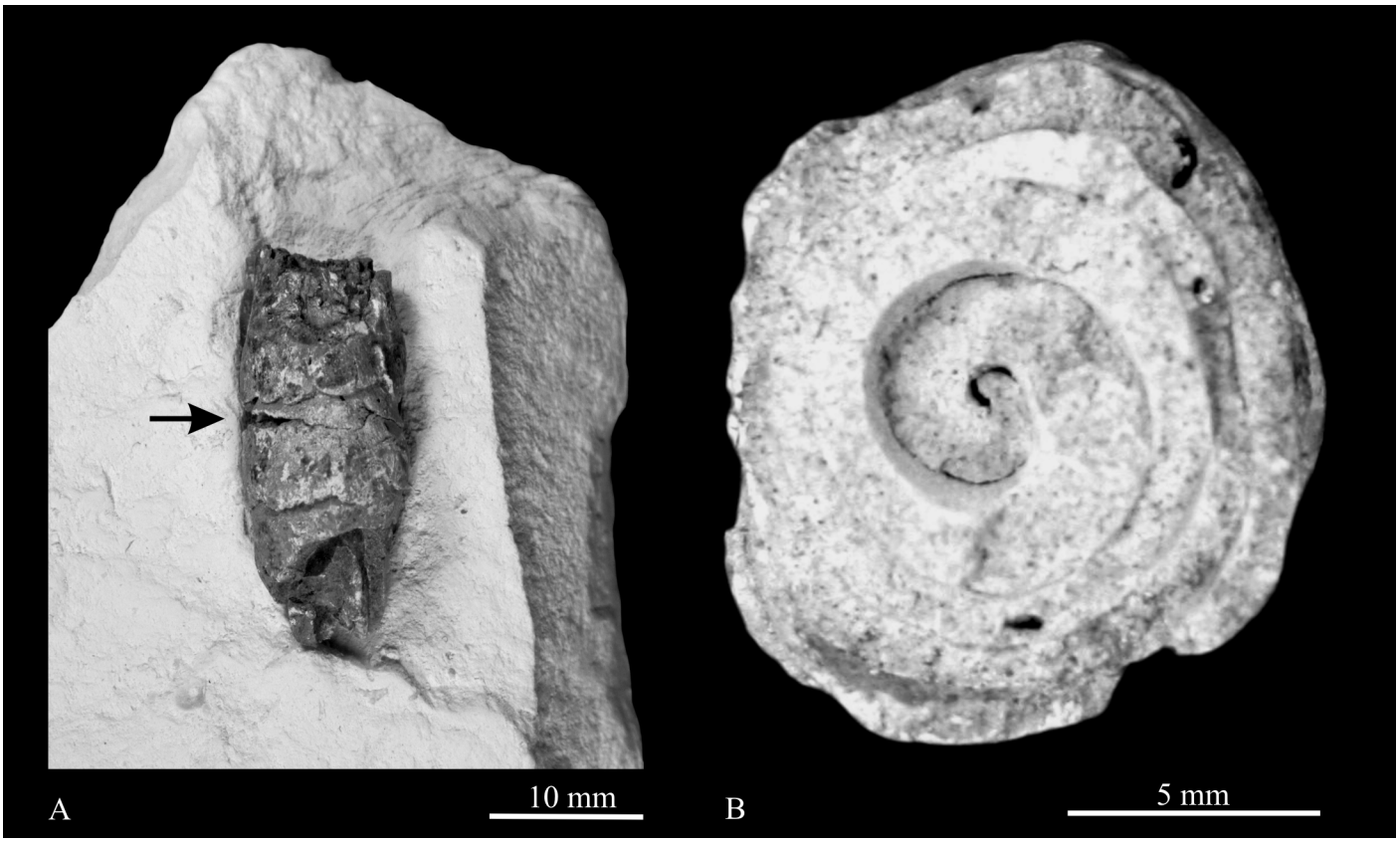

FIGURE 3. **A**, The coprolite (MGUH-30505) still partly embedded in matrix. The arrow indicates a natural break. **B**, Axial view of the section exposed by the natural break, showing the coiled internal morphology.

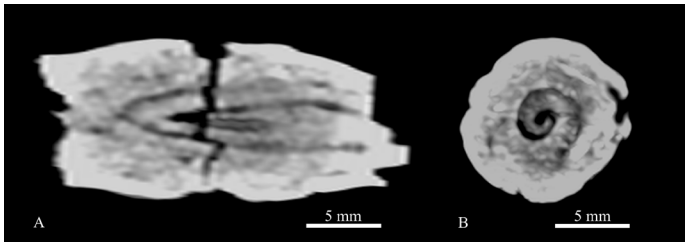

FIGURE 4. Computed Tomography images of the coprolite (MGUH-30505). **A**, Section parallel to the length axis of the coprolite showing the slightly coiled internal architecture of the specimen. **B**, Axial section through the specimen, showing the tight coiling of the layers, and which continues through the entire length of the specimen.

2012c) and suggesting that a 30 mm long coprolite was probably produced by a shark with a body length of less than 1.2 m. This is well in accordance with the abundance of smaller sharks represented in the Upper Maastrichtian of Denmark.

CONCLUSION

The first coprolite found in the Upper Maastrichtian chalk of Denmark is 31 mm in length and 11 mm in diameter with spiral morphology, suggesting that it has been produced by a small shark measuring approximately 1.2 meters in total body length. Coprolites are abundantly found in other marine deposits around the world, so the lack of finds from the Danish chalk possibly reflects a collecting bias. Local fossil collectors claim to have encountered similar objects in the chalk, but they simply never collected them as they did not recognize them as coprolites. Let this paper serve as a call for attention and to encourage the search for more coprolites in the Danish Chalk!

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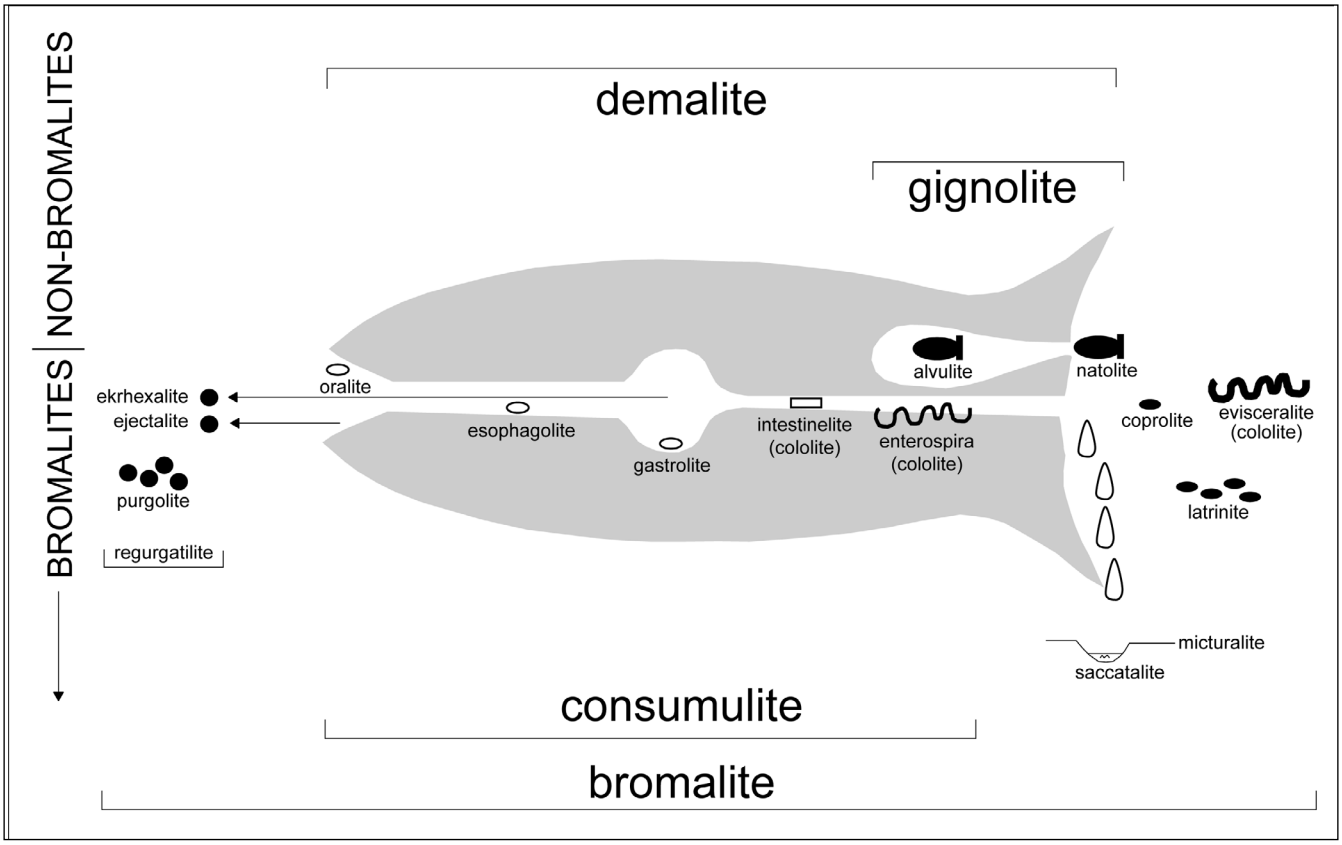
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