Crocodyle tracks and traces

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COPROLITES FROM THE DANIAN LIMESTONE (LOWER PALEOCENE) OF FAXE QUARRY, DENMARK

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Abstract—A collection of coprolites found in the Danian (Lower Paleocene) limestone of Faxe Quarry, Denmark, is described and attributed to the respective producers. Small, drop-like specimens with weak signs of spiral coiling are attributed to fish. Larger, heteropolar, spirally-coiled specimens are attributed to sharks, and large, cylindrical coprolites with longitudinal striations on the surface are identified as crocodile coprolites. Fish and sharks are known from abundant finds of otoliths and teeth in Faxe Quarry, and crocodiles are known from finds of single bones and teeth.

INTRODUCTION
Faxe Limestone Quarry, situated in the southeastern part of Zealand, Denmark (Fig. 1), is world famous for its Danian, well-preserved deep-water coral mounds and highly diverse invertebrate fauna (Bernecker and Weidlich, 1990, 2005; Willumsen, 1995; Sølyk and Håkansson, 1999; Graversen, 2001). Furthermore, the Faxe Quarry, together with the nearby sea-cliff, Stevns Klint, is the type locality for the Danian Stage (Desor, 1847).

Faxe is situated in the Danish-Polish trough, which is bounded to the south by the Ringkøbing-Fyn structural high and to the north by the Fennoscandian shield (Fig. 1) (Sølyk and Håkansson, 1999). In addition to the extensive invertebrate fauna (Graversen, 2001), vertebrates are represented by 13 species of marine fish (Schwarzhans, 2003), 15 species of sharks (Jan Schultz Adolfssen, pers. comm, 2009) and crocodiles (Bonde et al., 2008). Further evidence of vertebrates is found in the form of polished quartz pebbles interpreted as gastroliths (Noe-Nygaard, 1975). Here, I describe a number of coprolites from the collections of Geomuseum Faxe/Østsjællands Museum (10006-19, 10006-58 and 10006-59) and of the private collectors Alice and Henning Rasmussen, Faxe, and assign the coprolites to their respective producers.

COPROLITES
The coprolites were all collected in Faxe Quarry around 1998 when an extremely fossil-rich layer was temporarily exposed. A total of 49 coprolites were examined, but many were too fragmentary or eroded to be identified as more than just coprolites. However, 11 specimens ranging from 11 to 26 mm long are sufficiently well-preserved to be identified. Based on their external morphology, the coprolites are divided into three general morphotypes: One type consists of small, 11 to 14 mm long, spherical to drop-like coprolites, with small, pointed ends. The surface is smooth, and the coprolite appears to be composed of numerous thin layers. There are weak signs of spiral coiling at the pointed ends of the coprolites (Fig. 2).

A second group consists of heteropolar, spiral coprolites with an irregular surface. They are composed of several layers “wrapped” irregularly around each other, giving the coprolite the superficial appearance of a pine-cone. They measure 14 to 23 mm long and have a maximum diameter of 11 mm (Fig. 3). A broken specimen shows the internal coiling...
to consist of six mm-thin layers tightly wrapped around each other (Fig. 3D).

The last type is large coprolites, cylindrical in cross section, and with diameters of up to 24 mm (Fig. 4). The surface of the coprolites is smooth, with occasional longitudinal striations (Fig. 4D). All the examined specimens seem to be broken fragments of longer specimens, and the unbroken ends of the coprolites are rounded, as they have been terminated by constriction. Some of the broken surfaces show the coprolites to be composed of concavo-convex units (Fig. 4A). One specimen has preserved the partly dissolved remains of an indeterminate fish vertebra (Fig. 4E-F).

**DISCUSSION**

All the coprolites collected in Faxe Quarry are in excess of 5 mm in total length. This excludes most invertebrates as producers, as their fecal pellets normally are less than 5 mm long (Häntzschel et al., 1968). The vertebrate fauna from Faxe Quarry consists of 13 species of fish (Schwarzhans, 2003) and 15 species of sharks. Size-wise, the sharks ranged from 0.5 to 5 meter long (Jan Schultz Adolfssen, pers. comm. 2009). Crocodilian body remains from Faxe are known from two finds of bones, a basioccipital and a cervical vertebra, both stored in the collection of the Geological Museum of the Natural History Museum of Denmark (Bonde et al., 2008), and several loose teeth from the collection of Geomuseum Faxe/Ostsjællands Museum and private collectors. A complete skull and a partial upper jaw were described from the similar-aged Limhamn Quarry in Malmö, southern Sweden, as *Thoracosaurus scanicus* (Troedsson, 1923, 1924).

Spiral-shaped coprolites are generally attributed to fish having a spiral valve (Hunt et al., 1994; Summer, 1994; Northwood, 2005), and the heteropolar spiral coprolites are attributed to sharks, due to their more complex valves (McAllister, 1985). The large coprolites are all elongated and cylindrical to slightly flattened in cross-section. This is a shape commonly found in crocodylian coprolites of all ages, fossil and recent (Young, 1964; Sawyer, 1981; Thulborn, 1991; Souto, this volume; Milàn & Hedegaard, this volume), and it is a general shape for fossil (Chin, 2002) and modern animals having a diet similar to that of crocodilians (Chame, 2003; Stuart and Stuart, 1998). The presence of a recognizable fish vertebra in one of the specimens (Fig. 4E-F), suggest that it originated from another animal, as the digestion system of crocodiles tend to decalcify and dissolve bone tissue before it is excreted (Fischer, 1981). The concave endings of some of the coprolite specimens (Fig. 4A) are consistent with that of Cretaceous crocodile coprolites from Brazil (Souto, this volume), and what is observed in recent crocodile faeces (Milàn and Hedegaard, this volume). Coprolites with longitudinal striations on their surface have been described from Paleocene coprolites attributed to crocodiles and in recent crocodile fecal pellets (Young, 1964), as well as in Cretaceous specimens (Rodríguez-de la Rosa et al., 1998). Northwood (2005) discusses longitudinally striated coprolites and attributes them to archosauromorphs. Crocodiles are the only archosaurs known from the fossil record of the Danian limestone of Faxe Quarry, and are thus the most likely producers of the large coprolites.

**CONCLUSION**

Three different types of coprolites are described from the Danian limestone in Faxe Quarry. Small drop-like coprolites are attributed to indeterminate fish, and larger, spirally-coiled specimens are identified as shark coprolites. Large cylindrical coprolites, with longitudinal striations on the surface and a content of fish remains, are identified as crocodile coprolites. This is the first record of crocodilian coprolites from Denmark.
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