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A COPROLITE IN THE MDCT-SCANNER – INTERNAL ARCHITECTURE AND BONE CONTENTS REVEALED

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Abstract—A well-preserved coprolite from the lower Paleocene (Danian) limestone of Faxe Quarry, Denmark was investigated in a Multi-Detector Computed Tomography (MDCT) scanner. The oval/sub-cylindrical coprolite measures 34 mm in length and 16 mm in diameter, and at one end, a small vertebra, 3.8 mm long and approximately 2.7 mm in diameter, is partly exposed. The scanning data showed that the coprolite is composed of several concentric layers, approximately 2 mm thick. This reflects the original way the fecal mass was deposited in the intestines of the producer. Furthermore, the scanning showed that the embedded vertebra is complete and three-dimensionally preserved, and it was possible to identify the vertebra as deriving from a bony fish. In addition, numerous other, smaller, elongated bone fragments were revealed inside the coprolite. The high quality and resolution of the scanning images demonstrate that MDCT scanning is a useful, non-destructive technique to examine internal architecture and dietary remains of well-preserved, non-recrystallized coprolites.

INTRODUCTION

The examined coprolite was found in the lower Paleocene (Danian) limestone of Faxe Quarry, approximately 70 kilometers south of Copenhagen, Denmark (Fig. 1). The limestone of Faxe Quarry is famous for its well-preserved, deep water coral mounds and a highly diverse invertebrate fauna composed of over 500 species (Bernecker and Weidlich, 1990, 2005; Willumsen, 1995; Surlyk and Håkansson, 1999; Graversen, 2001, Lauridsen, in press). Vertebrates, however, are rare, but so far 13 species of bony fish (Schwarzhans, 2003), crocodylians (Bonde et al., 2008), marine turtles (Milàn et al., submitted) and approximately 15 species of sharks (Jan Schultz Adolfssen pers. comm, 2011), have been reported. In addition to body fossils, evidence of vertebrates is found in the form of polished quartz pebbles interpreted as gastroliths (Noe-Nygaard, 1975), and coprolites originating from fish, sharks and crocodylians, as described by Milàn (2010). A total of 49 coprolites from Faxe Quarry were collected in 1998, when an extremely fossil-rich bed was temporarily exposed. Among the specimens described, one coprolite exposed a partly embedded vertebra (Milàn, 2010).

Computed Tomography scanning has gained a strong position in paleontological research over the last few years as it allows examination of internal structures of fossils that would otherwise only be available

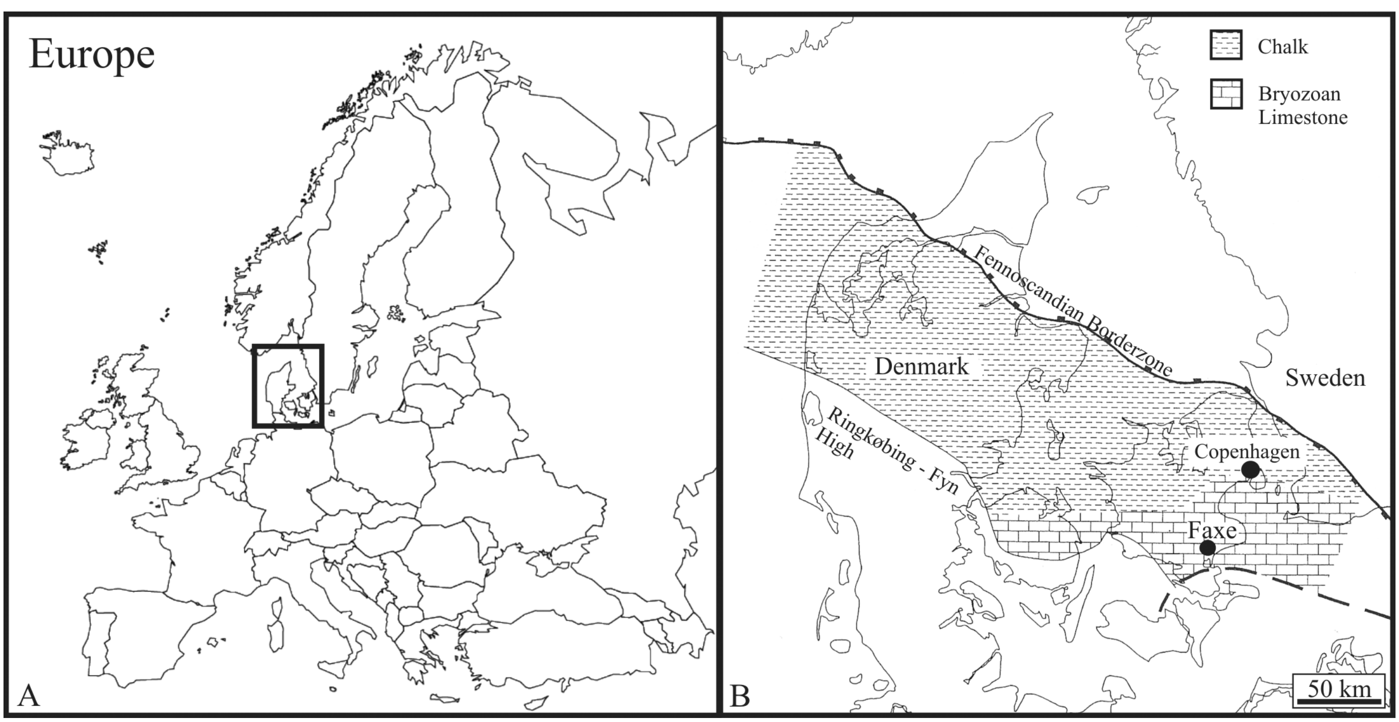

FIGURE 1. Faxe limestone quarry is located in the town of Faxe, approximately 70 kilometers south of Copenhagen in southeastern Denmark. It is a day quarry in a Middle Danian bryozoan and coral limestone. Location map modified from Schnetler et al. (2001).

through destructive methods. Furthermore, it facilitates elaborate three-dimensional anatomical reconstructions (e.g., Mueller-Töwe et al., 2008; Endo and Frey, 2008; Witmer and Ridgely, 2009; Evans et al., 2009; Farlow et al., 2010). In this study we explore the possibilities of using MDCT scan to examine the content and internal architecture of a well-preserved vertebrate coprolite from a Danian-aged bryozoan limestone.

MATERIAL AND METHODS

The specimen at hand was found in Faxe Quarry by local fossil collector Alice Rasmussen in 1998, alongside 48 other coprolites of different sizes and morphologies, attributed to fish, sharks and crocodylians (Milàn, 2010). The coprolite measures 34 mm in length, is cylindrical in cross section and has a maximum diameter of 16 mm. A small vertebra, 3.8 mm long and approximately 2.7 mm in diameter, is partly exposed in one end of the coprolite (Fig. 2). The coprolite is composed of a phosphatic limestone groundmass, with a yellowish appearance that distinguishes it from the white bryozoan limestone, and it does not appear to be recrystallized. The specimen was selected in order to scan it for additional bone fragments and/or other types of inclusions.

The scan 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, which is normally used for high density objects. Scanning parameters were set to 120kV 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 true proportions. Post processing and isolation of the bone contents was done with OsiriX by isolating the different density of the bone matters from the density of the coprolite groundmass.

RESULTS

Vertical, transverse sections through the coprolite show that the coprolite is composed of several concentric layers (Fig. 3A). Three individual layers, each approximately 2 mm thick, can be recognized in the sections (Fig. 3B). The layers cannot be followed all the way around the coprolite, but appear best defined on the left (as viewed in Fig. 3B) side of the coprolite, and coalesce toward the opposite side of the coprolite. In longitudinal section, the layering appears to run throughout the coprolite, and each successive outer layer wraps around the inner layer (Fig. 3C-D).

To achieve a three dimensional representation of the bone content of the coprolite, the density of the bone is isolated from that of the coprolite groundmass, making the vertebra and several smaller fragments with the same density, presumably also bone, visible (Fig. 4). The vertebra appears complete and three-dimensionally preserved, and when the images are cropped and rotated, so that only the part of the coprolite containing the vertebra is exposed, the complete morphology of the vertebra can be assessed (Fig. 5). The center is cylindrical in cross section, with the smallest diameter towards the middle. The articulation surfaces are deeply bi-concave, and there is no evidence of a neural arch or transverse processes.

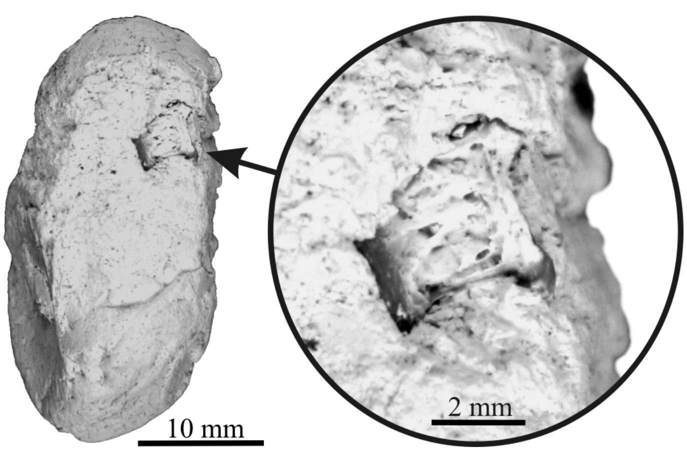

FIGURE 2. The coprolite used for the CT scanning is well-preserved, and non-recrystallized. An embedded vertebra is partly exposed in one end of the coprolite.

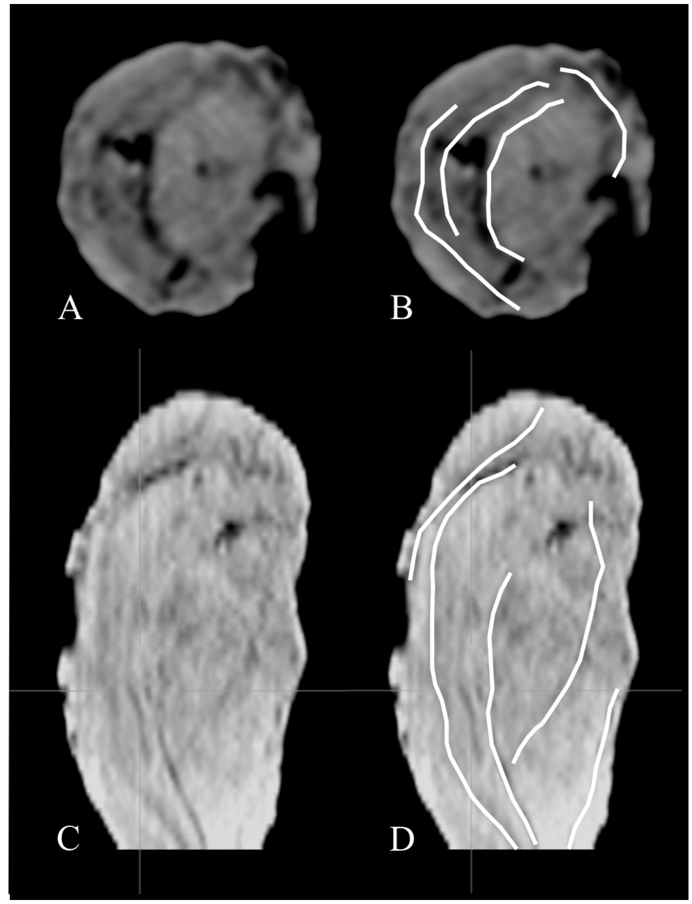

FIGURE 3. Longitudinal and transverse sections through the coprolite. **A**, Transverse section, a number of concentric layers can be recognized. **B**, Same view as A with concentric layers highlighted. **C**, Longitudinal section, the internal layers are seen to run from end to end, slightly wrapping around each other towards the terminations. **D**, Same view as C with the layering highlighted. The crosses in C and D are an artifact of the processing software.

DISCUSSION

The scanning data revealed that the coprolite is composed of concentric layers wrapping around each other (Fig. 3). For the layering to show up on the scanning images it requires differences in densities between the layers. Studies of cross-sections through fresh scat from extant crocodylians show the scat to be composed of several concentric layers of different densities, some almost clay-like and others less dense and with prey remains (Milàn, this volume). This layering is interpreted to represent the original way in which the fecal mass was deposited from the intestines of the producer. Farlow et al. (2010) used CT scanning to examine possible canid or turtle coprolites from the late Neogene Pipe Creek Sinkhole. The scanning images of these coprolites show the same internal zonation of denser and lighter layers.

The vertebra embedded within the coprolite is well-preserved and has deeply bi-concave articulation surfaces and lacks a fused neural arch (Fig. 4), a gross morphology typical of teleost fishes (Brinkman and Neuman, 2002). Very similar bone inclusions in coprolites are found in

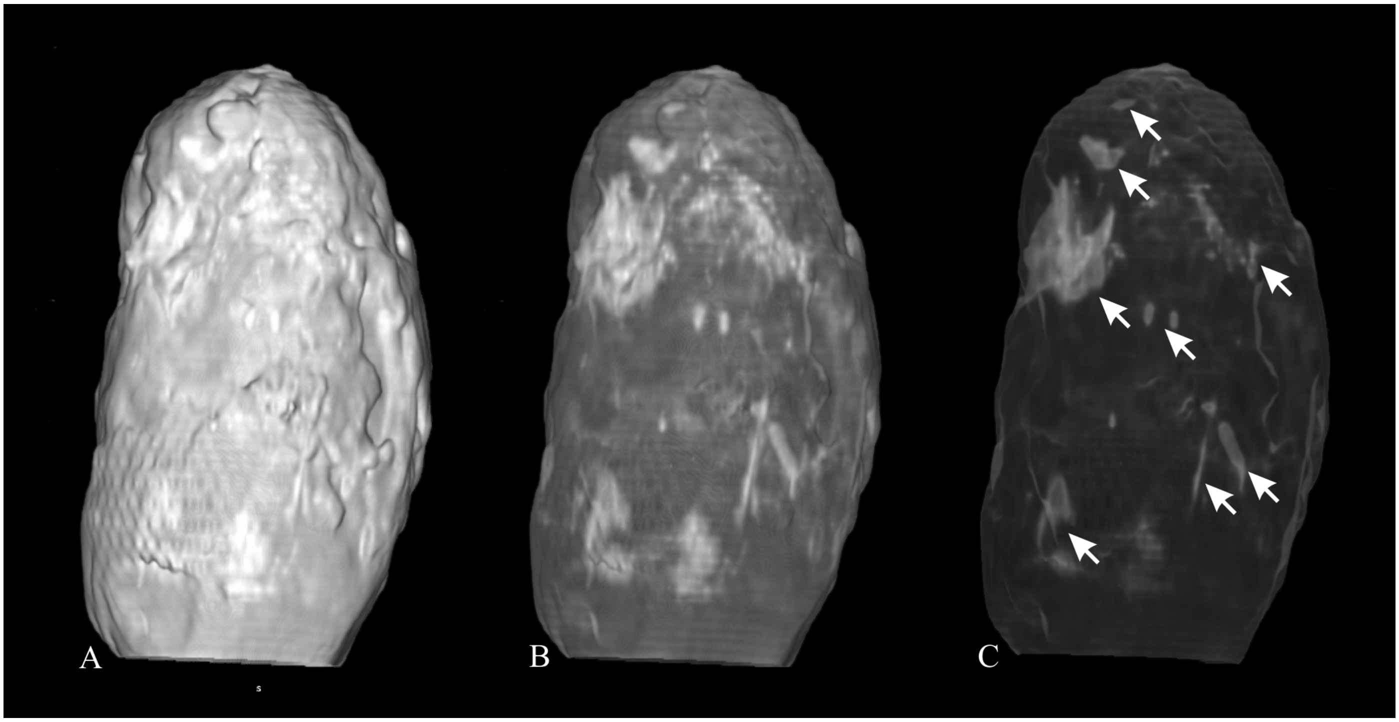

FIGURE 4. **A-C**, By isolating the density of the bone material from that of the coprolite groundmass, the vertebra and several smaller bones become visible inside the coprolite, as indicated by arrows in C.

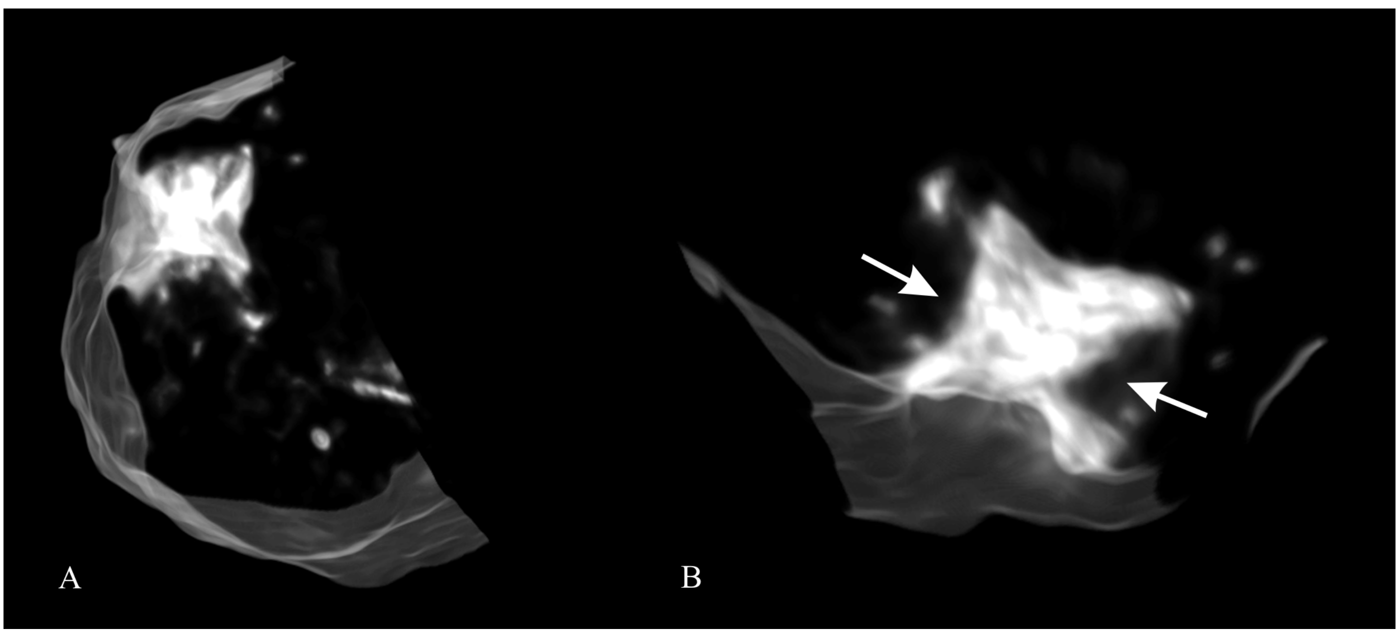

FIGURE 5. Cropped three-dimensional image of the coprolite showing the embedded vertebra from two different angles. **A**, Perfectly preserved in three-dimensions. **B**, Another view with the deeply bi-concave articulation surfaces of the vertebra highlighted with arrows.

Late Cretaceous coprolites from southern Sweden (Eriksson et al., in press). The vertebrate fauna known from Faxe Quarry and adjacent Middle Danian exposures in Denmark, and thus the possible producers of the coprolite comprise bony fish, sharks, crocodylians and turtles (Schwarzhans, 2003; Bonde et al., 2008; Milàn et al., 2011).

Coprolites from bony fish are generally spiral-shaped (Hunt et al., 1994; Sumner, 1994, Northwood, 2005), and sharks, with their more complex valves, produce heteropolar spiral coprolites (McAllister, 1985). Crocodylian coprolites and modern crocodylian feces are typically elongate and cylindrical to slightly flattened in cross-section, composed of fused concavo-convex units (Young, 1964; Sawyer, 1981; Thulborn, 1991; Souto, 2010; Milàn and Hedegaard, 2010; Milàn, this volume). Furthermore, this is a general shape for fossil (Chin, 2002) and modern animals that have a diet similar to crocodylians (Chame, 2003; Stuart and Stuart, 1998).

While the external morphology of the investigated coprolite, being cylindrical – slightly flattened, with convex endings – may suggest a crocodylian origin, however, the presence of a well-preserved fish vertebra, argues against that interpretation. Crocodylians have a very effective digestive system, with a concentration of hydrochloric acid that exceeds mammalian carnivores by a factor of 50 (Coulson et al., 1989). This completely decalcifies and dissolves all bone before it is evacuated (Fisher, 1981; Coulson et al., 1989; Trutnau and Sommerlad, 2006).

Examination of the digestive tract of the modern marine turtle *Caretta caretta* has shown that fish bones are not digested, but can survive throughout the digestive tract and be expelled in the feces (Plotkin et al., 1993). Moreover, gut contents of sea turtles from the Upper Cretaceous of Queensland, Australia, showed high concentrations of bivalve shells, only slightly corroded from gastric acid (Kear, 2006). Coprolites associated with these turtles have a gross morphology closely similar to that of the specimen analyzed here. Other coprolites attributed to turtles are depicted from the Upper Cretaceous of Brazil and they appear as cylindrical, tapering masses (Souto, 2008). Farlow et al. (2010), examined fresh scat from snapping turtles, *Chelydra serpentina*, and they have preserved abundant prey remains in the form of hair and bones. This scat was ropy, tubular or pelletoidal in shape with diameters of 1-2 cm; a morphology consistent with the examined specimen. The specimen examined here does not have the spiral shaped gross morphology typical of shark coprolites, however, the internal layering does suggest some degree of coiling (Fig. 3C-D). Therefore a shark or a large predatory and/or scavenging bony fish cannot be excluded as a potential producer. Until more specimens turn up, we cautiously suggest that the coprolite was evacuated by either a marine turtle or a shark.

CONCLUSION

The scanning images showed fine contrast between the bone and coprolite groundmass, enabling a perfect three-dimensional look into the coprolite and its inclusions. The images, moreover, revealed a coprolite architecture comprising several concentric layers, representing the original way the deposition from the intestine walls. The embedded vertebra could be identified as deriving from a bony fish based on the high resolution MDCT images. This demonstrates that MDCT scanning is a useful non-destructive technique to examine internal structures, such as the internal architecture and contents, of well-preserved, non-recrystallized coprolites.

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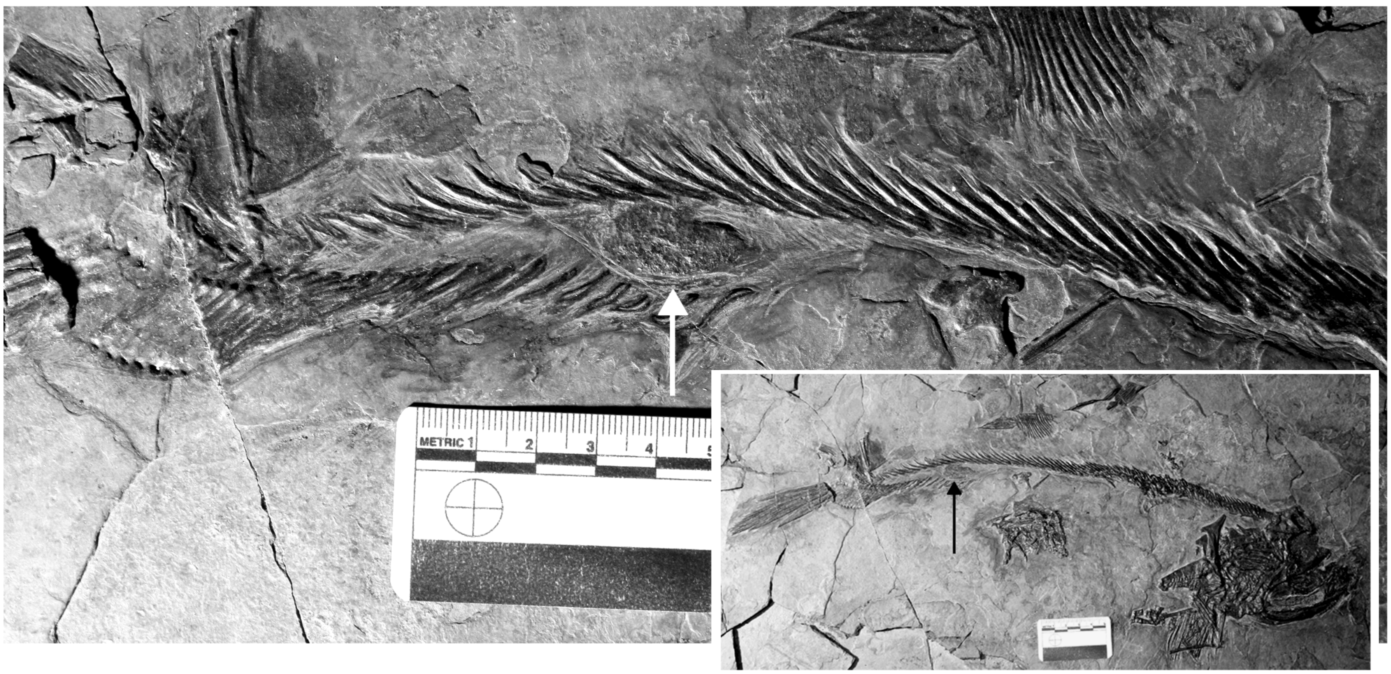

Cololite in a Pennsylvanian shark from New Mexico.