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Copololites from the lower Miocene Baripada beds of Orissa

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Copololites or fossilized faecal matter occur rarely and are considered to be good indicators of diet of ancient animals and depositional environments. We report here several coprolites from the Lower Miocene Baripada Beds in Mayurbhanj District, Orissa. Most of the coprolites that we collected are characterized by their teardrop, ovoid, cylindrical and spindle shapes. The sizes and shapes of these coprolites combined with fish teeth inclusion in some of them strongly point towards a crocodilian source.

Keywords: Coprolites, miocene, palaeoenvironment, taphonomy.

‘COPROLITE’ is the scientific term used for fossilized excrement, faeces or droppings of ancient animals. Coprolites also fall into the category of fossils, as they indicate the presence of particular animal(s) at a site and their study is an invaluable source of information on animal behaviour and site ecology. Though the fossilization of coprolites is rare, a detailed study of coprolites often provides useful information regarding palaeoenvironment of the area and the depositional environment in which certain organisms live, die and get buried. Knowledge of the faeces of the local fauna, their morphology, morphometric characters and parasites is essential to identify the coprolite source animal.

We report here several coprolites from Mukurmatia (21°54’40”N, 86°44’15”E), which is about 12 km northeast of Baripada town (Figure 1a). The coprolite-bearing bed at Mukurmatia is exposed along the river-cut section of Buruhalang river. Coprolite specimens were collected from the bluish shale which lies above the limestone bed. The precise geological age of the Baripada beds is highly debated. However, these sediments are broadly known for their assemblages of marine fossils such as foraminifers, shark and mollusks of Early Miocene (Aquitanian to Burdigalian) (D. K. Mehrotra, unpublished).

We collected more than 40 specimens (along with coprolite fragments) from Mukurmatia (Figure 1a). Scanning electron microscopic study of the samples was carried out using JEOL SEM JSM 6490 housed at the Geology

Figure 1. a. Locality map of Baripada. b. Stratigraphic section of Baripada beds at Mukurmatia.
Department, Panjab University, Chandigarh. Measurements of the specimen were made using a vernier caliper.

The litho and bio facies analysis of the coprolite-bearing locality, Mukurmatia, Baripada beds (Aquitanian to Burdigalan) indicates marine sediment accumulation of about 12 m thickness overlain by lateritic freshwater sediments of Quaternary age (Figure 1b). The shale is thinly laminated and yielded abundant shark teeth and foraminifers21-26,28-31 (D. K. Mehrotra, unpublished). The limestone bed is dominated by fossil oysters, whereas the greenish shale is characterized by the presence of foraminifers7-19,27-31.

Most of the coprolites were incomplete (Figure 2), therefore the exact length of the specimens is difficult to estimate in most cases. However, some specimens were found to be completely preserved (Figure 2). The specimens ranged in length from 10 to 40 mm and in diameter from 8 to 33 mm. Most of the coprolites fell under the diameter range 15-20 mm (Figure 3). The longest coprolite recovered was 40 mm in length. Certain coprolites were found with their lengths exceeding their maximum diameter. These types were mostly well-rounded at the centre. The lateral ends are usually categorized as either convex (rounded), pointed, dorsoventrally flattened, indented or having a cleavage scar.

All the coprolites collected from the Baripada beds were anisopolar and non-spiral. Baripada coprolites can be divided into four groups by analysing their definite shape, forms and sizes. These groups are briefly discussed as below.

**Group 1.** This type consists of an incomplete, teardrop-shaped (Figure 2a) coprolite in which the initial end is broadly rounded; however the terminal end is typically a clear nipple-like projection. Only one specimen of such type of coprolite was collected. It attains a maximum diameter of 2.1 cm. The external surface is smooth and whitish-grey in colour with rare scratches on it.

**Group 2. Type 1.** A total of six specimens of ovoid-shape to sub-cylindrical coprolites (Figure 2b) fall under this category. The diameter of these coprolites ranged between 2.8 and 3.3 cm. However the exact length of the specimens is unknown as they are incomplete. They possess gently tapering terminal end with straight longitudinal axis. Some specimens have a smooth surface whereas others have a rough surface. One of the specimens possess a rough blackish ferruginous concretionary coating on the surface with a circular constriction at the circumference of the coprolite representing an arrested stage in the breaking up of the faeces into segments (Figure 2b). The presence of a wrinkle at the smooth surface is due to muscular pressure exerted during its dropping through the rectum. A close examination of the polished section of this type of coprolite shows the presence of small holes inside the coprolite formed due to escaping of gas from the excrement (Figure 2i, m).

**Group 2. Type 2.** This variety consists of one kidney-shaped coprolite (Figure 3c). The surface of this coprolite is smooth with an abrupt bending in the middle forming a kidney shape. The terminal ends are little convex.

**Group 3. Type 1.** Four incomplete and three complete specimens of cylindrical-shaped coprolites are included under this category (Figure 2d-f). The coprolites are circular in cross-section, in which the longitudinal axis is straight. The length of the specimen usually exceeds the maximum breadth. The length of these coprolites varies from 2 to 5 cm with the maximum diameter of 3.2 cm. The terminal ends are bluntly rounded. The surface of some of the coprolites are smooth and some coprolites contain numerous holes and burrows. Circular opening in these coprolites represents the depression usually left by the escaping gas bubbles. One of the incomplete coprolites bears longitudinal striations and ribbing (Figure 2d) at its surface, which may have formed due to the puckering of the intestinal mucosa during peristalsis.

**Group 3. Type 2.** One complete spindle-shaped coprolite (Figure 2g) with a length of 3.2 cm and diameter of 1.5 cm falls in this category. This coprolite has gently curved longitudinal axis with a sharp trailing and tapering end. The surface is little eroded and it appears that the dung larvae had made craters into the dung.

**Group 3. Type 3.** One small incomplete sausage-shaped coprolite (Figure 2j) falls in this category. It has broadly rounded initial end. The longitudinal axis is curved; the external surface is smooth with a sub-circular outline. The maximum diameter of the specimen is 8 mm. This specimen differs from others in size, which might have been produced by a different source.

**Group 4.** Certain coprolites are found to be of irregular in nature. They do not possess regular shape and form (Figure 2h). Most such irregularly shaped coprolites are dorsoventrally flattened, the surface of which is characterized by significant burrows and cavities.

The well-preserved surface features of the coprolites suggest that the faeces were rapidly buried after they were excreted. Some of the coprolite specimens are found having sinuous unbranching traces. Some of the specimens have burrows filled up with clay sediments (Figure 2f, k, l).

The study of coprolites and identification of the source animal that produced them is a challenging task. Certain coprolite features, including size, shape, surface marks and inclusion can be used to assign the specific producers of the coprolites2,6,32-39. A detailed comparison of shape, size and structure in these coprolites with other crocodilian coprolites suggested that a majority of the coprolites from the Baripada beds are of crocodilian source. The study of crocodilian coprolites with definite shapes and forms that were used by Sawyer39 has been used as a reference for the identification of the source of producers. A typical crocodilian coprolite is characterized by its
Figure 2.  

a. Typical teardrop-shaped crocodilian coprolite having a smooth surface feature with a maximum diameter of 2.1 cm. 
b. Ovoid-shaped crocodilian coprolite having a circular constriction at the circumference, 3.3 cm dia.  
c. Kidney-shaped coprolite († crocodilian coprolite), 2.5 cm dia.  
d. Cylindrical crocodilian coprolite, the surface of which is marked with scratches, trail of invertebrates.  
e, f. Cylindrical-shaped crocodilian coprolites containing numerous cavities and burrows which are due to the action of coprophages, bacteria and fungi: 2.2–3.2 cm dia.  
g. Spindle-shaped (†) reptilian coprolite showing a longitudinal furrow, probably of crocodilian origin, with sharp tapering and trailing end, 2.5 cm dia.  
h. Irregular shaped dorsoventrally flattened coprolites, showing hole, burrows due to coprophages activities, ranging between 2.2 and 3.2 cm in length.  
i. Polished section of ovoid-shaped crocodilian coprolite showing the presence of gas vesicles inside, 2 cm dia.  
j. Small, sausage-shaped coprolite († reptilian) with a diameter of 8 mm.  
k, o. SEM images.  
l. Cylindrical-shaped crocodilian coprolite in which the burrow at the weathered surface is filled up with clay sediments.  
m. Cylindrical coprolite showing spherical cavities inside due to escaping of gas bubbles.  
n. Cylindrical-shaped crocodilian coprolite showing slightly weathered and eroded surface feature.  
o. Crocodilian coprolite showing inclusion of fish teeth († *Sparus cinctus* Agassiz) that cannot be digested inside the stomach.
teardrop, ovoid, cylindrical and kidney shapes\textsuperscript{40,41}. Spindle-shaped coprolites have been found to be typically of reptilian origin, most probably that of crocodilian source\textsuperscript{6}. A clearly nipple-like projection at the terminal end of the coprolite appeared to be often seen in the coprolites of crocodilian origin\textsuperscript{40,42}. Some of the crocodilian coprolites contained inclusion of fish teeth (Figure 2 o). There is hardly any evidence of other inclusions such as the vegetal remains, which could be due to the presence of gastrointestinal acid inside the stomach and intestine of crocodile\textsuperscript{43}. Moreover, lack of any macrofloral remains in these coprolites may also indicate a non-herbivore origin.

One of the specimens in our collection (Figure 2 j) is quite different from the other coprolites in size and shape. The sausage shape of this coprolite resembles that of reptilian coprolites\textsuperscript{6}, but at present it cannot be placed in any reptilian family with certainty.

The coprolites were found embedded in the bluish shale beds along with some bone fragments of turtles, diverse shark taxa such as \textit{Galaeocerdo cuvier}, \textit{Negaprion brevirostris}, \textit{Carcharodon carcharias}, \textit{Carcharodon megalodon}, \textit{Charcharias myliobatis} sp., \textit{Charcharias egertoni}, \textit{Aetobatis narinari}, \textit{Dentex} sp., \textit{Odontaspis ticuspidatus}, \textit{Negaprion brevirostris}\textsuperscript{22,23} (D. K. Mehrotra, unpublished) and mollusks (bivalves and gastropods) from these beds. These sharks and mollusks are known to be found in shallow marine environments\textsuperscript{17,18,22,23,25,27} (D. K. Mehrotra, unpublished).

The coprolites were found firmly cemented to the sediments. It appears that the faecal masses were deposited in a non-turbulent low energy condition as the underlying and overlying sediments show little evidence of disturbance\textsuperscript{6}. Flattening of some of the specimens due to the action of water with its weight may appear to be related to movement of water\textsuperscript{30,32}. Also, there is hardly any evidence of weathering and transportation seen on the coprolites, indicating an \textit{in situ} fossilization.

The coprolites were found as scattered aggregates rather than as one continuous layer in the bluish shale bed, where fossil shark teeth, molluscs, rays and teleost remains have also been found. The specimens which present a smooth surface (Figure 2 a, f) signify the mucous coating of the excrement\textsuperscript{6}. This coating prevents disintegration, dehydration and swelling up, making the specimens well-cemented to the sediments. The presence of spherical cavities inside some of the coprolites that might have been produced by the decomposition of gases (Figure 2 i, m) also suggests that these coprolites were excreted inside the water and hence the possibility of their being a terrestrial source is negated\textsuperscript{39}.

Therefore a close examination of the taphonomic processes, lack of vegetal impressions and other surface features of these coprolites in conjunction with associated fossil materials suggests deposition in a shallow marine environment where the energy levels were low. All the living species of crocodiles are restricted to tropical and subtropical areas in which the minimum temperature is not less than 15°C, though a few species have been found to live in warm temperate zones\textsuperscript{43}. As the majority of the collected coprolites from Mukurmatia are of crocodilian origin, it can be safely assumed that the Lower Miocene palaeoecology around this region was warm tropical to subtropical. This assumption is further supported by the diverse assemblage of sharks, turtles and oysters that prefer warm conditions\textsuperscript{23,27}.


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