LATE CRETACEOUS COPROLITES FROM WESTERN CANADA

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ABSTRACT. Abundant coprolites and possibly gut fills of holostean fishes are irregularly distributed throughout the kaolinitic clays and muds of the Whitemud Formation (late Cretaceous) of the Willows–Readlyn district, south-central Saskatchewan. The coprolites show a variety of internal and external structures including coiling, folding, and contraction marks of primary origin; secondary features, for example surface cracking, due to diagenetic replacement by siderite and pyrite, and subsequent alteration to iron oxides.

KAOLINITIC silts, muds, and clays, commonly light grey to white in colour, are characteristic of the nonmarine Whitemud Formation (late Cretaceous) in the type section of that unit, exposed near Eastend in the Cypress Hills region of south-western Saskatchewan (Kupsch 1956). The formation is well exposed further east in broad, deepened valleys, excavated below the general level of the northern Great Plains. This paper describes the first evidence of vertebrate life from this formation: abundant coprolites occurring in the Whitemud strata of south-central Saskatchewan as coiled and related forms of ironstone bodies.

The few specimens previously described as fossilized vertebrate excrements in the late Cretaceous strata of the northern Great Plains regions are of morphologically simple, for the most part broadly ellipsoidal forms, with the composition of apatite known from the Oldman Formation (Campanian) of southern Alberta (Waldman 1970; Waldman and Hopkins 1970).

The discovery of abundant coprolites, possibly tens of thousands of specimens of vertebrate origin in the Whitemud Formation (late Cretaceous) exposures of south-central Saskatchewan is important, in that these deposits have previously yielded only scarce molluscan remains and plant megafossils. The abundance of the coprolites, considered here, has effectively downgraded the economic potential of an otherwise valuable deposit of ceramic clay. The origin and mode of preservation of coprolites from the Whitemud sediments are discussed, with particular reference to external morphology and composition and the environment of deposition of the enclosing sediments.

COPROLITE LOCALITIES

Worcester (1950) describes the economic potential of the kaolin beds, but notes that their utilization is limited by an abundance of 'concretions' 'of odd shape, many as coils, . . . not uniformly distributed' in clay pits, located about midway between Willows and Readlyn in the southern half of Section 33, Township 7, Range 28, West of the Second Meridian. Worcester (1950) also noted the occurrence of ironstone concretions

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in the Medalta pit, 3 km north-east of Willows in the north-east quarter of Section 1, Township 8, Range 29, West of the Second Meridian.

These coprolite localities incorporate several abandoned kaolinite pits approximately 3 km north and east of Willows. Approximately 7 m of gently south-east-dipping Whitemud strata are exposed.

The coprolites are readily found, where they have weathered out of the poorly exposed strata. Talus and slope wash concentrations are often as dense as 200 specimens per square metre along a 200 m escarpment. Specimens were not visible in the Whitemud outcrops, adjacent to the immediate collecting area. Extensive slumping and weathering of the bluff face presented difficulties in ascertaining the spatial distribution of the coprolites within the sediments. They are randomly distributed, both horizontally and vertically in the Whitemud section at this locality.

TAXONOMIC DESCRIPTION

The coprolites from the Whitemud Formation are described on the basis of their gross morphology, external and internal, and by small-scale features such as surface ridge patterns and constrictions.

Gross morphology and size. Limonitic coprolites from the Whitemud Formation from the Willows localities are illustrated in Plate 43. An emphasis is placed on illustration of small-scale surface features, both organic and inorganic in origin.

The coprolites exhibit a limited number of morphologic forms. Relatively small (up to 6 cm long) spindle-shaped and segmented, elongate forms (Pl. 43, figs. 1, 2) account for up to 40% of the sample populations. Larger (1·5 to 22·0 cm long) forms, exhibiting spiral and helicoidal coils (Pl. 43, figs. 3–6), and consisting of irregularly contorted masses, resembling piles of lobate segments (Pl. 43, figs. 7–9) account for a further 40%. These morphologic forms may be obscured to varying degrees by irregular, knob-like encrustations of limonitic minerals, which may blanket the entire coprolite, reducing the sharpness of the form (Pl. 43, figs. 10–13). In other specimens, small-scale morphologic features of organic origin extend from within concretionary limonitic masses, as shown in Plate 43, fig. 14.

Constrictions. Both the spindle-shaped and coiled coprolites exhibit usually abrupt constrictions (Pl. 43, figs. 15, 16), which in each case represent a reduction in diameter of the coprolite to less than one-half of the average value, over a distance of a few millimetres along the direction of elongation. In other cases, the coprolites terminate with sharply pointed extremities (Pl. 43, figs. 17, 18).

Most coprolites obscured by concretionary processes retain at least one faint yet diagnostic feature, for example, the extrusive pinch-out of sphincter muscle contractions on the irregular and concretionary spheroid specimen (Pl. 43, fig. 5; arrow).

Perforations. Scarce, subcircular perforations, up to 1·5 mm in diameter and 1·0 cm or more deep, were observed on several coprolites belonging to the main morphological types.

Surface ridge patterns. Relatively smooth surfaces of coprolites from the Whitemud Formation frequently exhibit patterns of delicate ridges and striations (Pl. 43, figs. 19–24). These features are aligned parallel (Pl. 43, figs. 19, 20) or oblique (Pl. 43, fig. 21) to the long axes of straight, spindle-shaped and irregularly coiled forms, and are approximately transverse to the long axes of spirally and helicoidally coiled forms (Pl. 43, figs. 22, 23).

Polygonal patterns of cracks. Relatively smooth surfaces (Pl. 43, fig. 24) are infrequently seen and commonly Whitemud coprolites of all morphological types are transected by polygonal patterns of cracks. These impart a rough, broken, and frequently blocky appearance to the coprolites (Pl. 43, figs. 25–27).

Internal structure. Polished sections through coprolites from the Willows locality frequently reveal finely amorphous limonite, displaying considerable homogeneity in total absence of any internal layering. In a few cases, however, limonite forms a rind around an unreplaced sideritic core (Pl. 44, figs. 1, 2). Somewhat more complex internal structures characterize spirally coiled forms (Pl. 44, fig. 5) and limonitic bodies with extensive concretionary growth (Pl. 44, fig. 7).

Some of the limonitic bodies displaying extensive concretionary growth, with little or no surface evidence of an initial excremental origin, have a confused internal structure with no obviously coprolitic core.

The Whitemud coprolites in thin section are composed of amorphous limonite, frequently forming flattened, ovoidal bodies (Pl. 44, fig. 6).

Incorporated organic material. Isotropic, lath-like bodies which may be limonite-replaced plant fragments are fairly common within some coprolites (Pl. 44, fig. 4). Impressions after plant fragments, up to several centimetres in length, adhering to the outer surfaces of coprolites are common to all morphological types (Pl. 43, figs. 8, 10).

MINERALOGY

The original faecal material was totally replaced by siderite and pyrite, which were subsequently replaced by limonite, goethite, and lepidocrocite, partially to completely during the oxidizing environment of kaolinization of the feldspathic sand and diagenetic recrystallization of the kaolinitic detritus.

Three random samples, representative of major morphological categories, were selected for detailed mineralogical and geochemical examination:

A. Linear, rounded cross-section, irregularly ribbed, finely striated, terminal twist and constriction, with minor constrictions of one inch apart. Over-all length of 6·0 cm; maximum width of 2·5 cm.

B. Spirally coiled, with rounded cross-section, finely striated; surface blocky, because of polygonal fracture pattern. Over-all, coiled length of 7·5 cm; maximum width of 6·0 cm.

C. Irregular morphology, with coils largely obscured by concretionary growth; pustulate surface. Over-all length of 9·5 cm; maximum width of 7·5 cm.

The X-ray powder diffraction of the three samples indicates the coprolites to be composed of iron oxides and carbonate: goethite, lepidocrocite, and siderite. The presence of siderite was also confirmed by the exothermic reaction of the D.T.A. occurring between 350 °C and 500 °C, as well as the weight loss over the same range on the T.G.A. The major endothermic D.T.A. reactions between 200 °C and 350 °C are in agreement with the X-ray diffractometer identification of the various forms of goethite.

The degree of crystallinity of the siderite is believed to be inhibited, which is reflected by the subdued diffractogram peaks as well as by the T.G.A. and D.T.A. data. The thermal decomposition of the structure is between 350 °C and 500 °C, compared to end-member siderite decomposition of 580 °C. Total oxide analyses for three samples were carried out in a standard HF acid bath. Approximately one-half of the original material remained, and this residue was converted to a soluble chloride with hydrochloric acid. The balance in the mineral analyses were considered as oxides since X-ray diffractometer studies indicated the lack of any crystalline minerals, in addition

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EXPLANATION OF PLATE 43

All figures × 0·5.

Fig. 1. Spindle-shaped coprolite, transected by polygonal pattern of cracks.

Fig. 2. Segmented, elongate coprolite, showing pattern of fine surface ridges and striations. The partial twist is transitional from the untwisted linear form of fig. 1.

Fig. 3. Spirally coiled coprolite, displaying irregular cracks at surface. The full coil is transitional from the incomplete coiled form of fig. 2.

Figs. 4–6. Spiral and helicoidal forms: note the progressively diminishing diameter with each coil of the spiral forms (fig. 4) but the nearly consistent diameters of the helicoidal forms (figs. 5, 6).

Fig. 7. Piled, lobate coprolite with concretionary growth masking surface features.

Fig. 8. Piled, lobate coprolite. Arrow indicates surface occurrence of plant fragment.

Fig. 9. Irregularly folded coprolite with surface ridges and striations.

Fig. 10. Irregularly folded coprolite. Arrow indicates plant fragment.

Figs. 11, 12. Spirally coiled coprolites with gross morphology partly obscured and surface detail obliterated by concretionary growth.

Fig. 13. Irregular limonitic body of dominant concretionary origin. These bodies, however, may retain a single organic origin feature, such as a terminal neck (fig. 14).

Fig. 14. Coprolitic surface detail preserved amid concretionary mass (arrow).

Fig. 15. Spindle-shaped coprolite with prominent sphincter-pinched constriction.

Fig. 16. Spirally coiled coprolite with sphincter-pinched constriction and termination (arrow).

Fig. 17. Large, spindle-shaped coprolite with sphincter-pinched termination. Note rough surface.

Fig. 18. Irregularly folded coprolite with polygonal pattern of surface cracks and sphincter-pinched termination.

Fig. 19. Elongate coprolite with longitudinal striations.

Fig. 20. Irregularly folded coprolite with longitudinal striations.

Fig. 21. Spirally coiled coprolite with oblique striations.

Fig. 22. Spirally coiled coprolite with transverse striations.

Fig. 23. Irregularly folded coprolite with transverse striations.

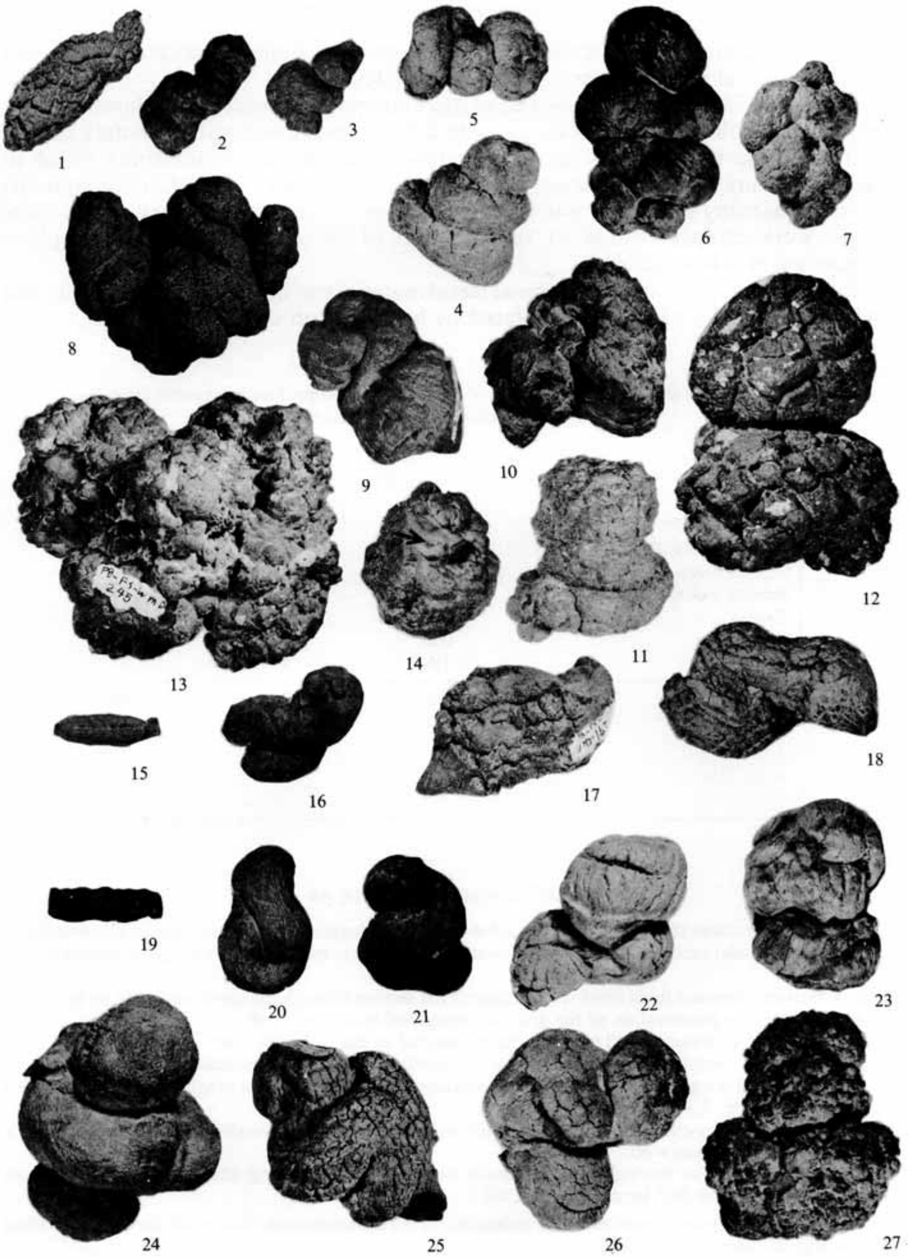
Fig. 24. Spirally coiled coprolite with smooth surface.

Fig. 25. Irregularly folded coprolite with surface broken by polygonal pattern of cracks.

Figs. 26, 27. Spirally coiled coprolites displaying polygonal patterns of surface cracks. The delicate muscle striations on the surface are obscured by the crack systems.

All figured specimens are deposited in the collections of the Saskatchewan Geological Survey, Subsurface Geological Laboratory, Regina.

PLATE 43



BROUGHTON, SIMPSON, and WHITAKER, fish coprolites to the observed iron oxides and carbonate. The oxide analyses of the three samples are expressed as calculated mineral percentages in Table 1.

Most coprolite specimens have two or more composite, concretionary layers of dark greyish-blue colour, in sharp contrast to the adjacent ochre yellow, light to dark brown, and hematitic red zones. X-ray examination of the major colour zones failed to distinguish any major mineralogical variation. Relict preservation of minor amounts of pyrite in many specimens was observed. The possibility that the dark greyish-blue zones were directly related to the presence of vivianite or another phosphate compound was discounted.

It is thus concluded that the original faecal material was likely replaced by pyrite and siderite, subsequently partially replaced by hydrous iron oxides after burial.

TABLE 1. Mineralogical compositions of representative coprolites calculated from wet chemical oxide analyses. For discussion see text.

		Specimen		
		A	B	C
	Composition	(Linear)	(Spiral)	(Concretionary)
Wt % of total sample	Goethite α $Fe_2O_3H_2O$	88·6	69·1	81·0
	Lepidocrocite γ $Fe_2O_3H_2O$	3·7	11·2	0·0
	Siderite $FeCO_3$	4·1	15·7	14·7
	Oxides	1·3	1·5	3·1
	Organics	0·2	0·1	0·1
	H_2O	1·6	1·7	0·9
	Total	99·5	99·3	99·8

EXPLANATION OF PLATE 44

Figs. 1, 2. Thin sections through irregularly coiled coprolites. Negative prints show rings of limonite (light) surrounding sideritic cores (dark) in sharp contact (fig. 1) and in gradational to irregular contact (fig. 2), × 2·3.

Fig. 3. Intricate, internal folds observed in longitudinal section through the spiral coprolite, of fig. 5 (this plate). Probably preservation of the gut and unexpelled excrement, × 40.

Fig. 4. Amorphous limonite and plant fragment internal to the coprolite, × 40.

Fig. 5. Polished longitudinal section through a spiral coprolite. The internal folds may represent preservation of the gut tissue and unexpelled excrement. Compare with the irregular texture of expelled excrement of fig. 7, × 0·5.

Fig. 6. Secondary amorphous limonite deposited as flattened ovoidal mosaics, a texture representative of expelled excrement, × 40.

Fig. 7. Polished section through irregular faecal mass with the obscuring effects of the concretionary and amorphous ovoidal limonite bodies, × 0·5.

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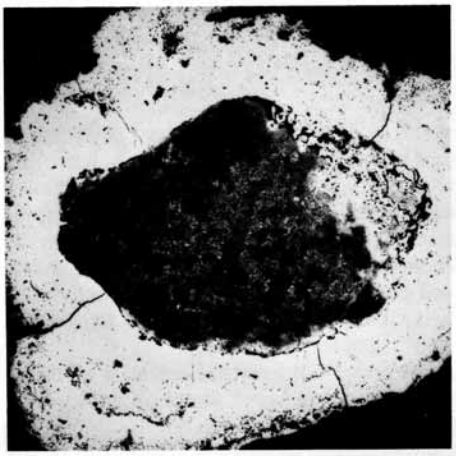
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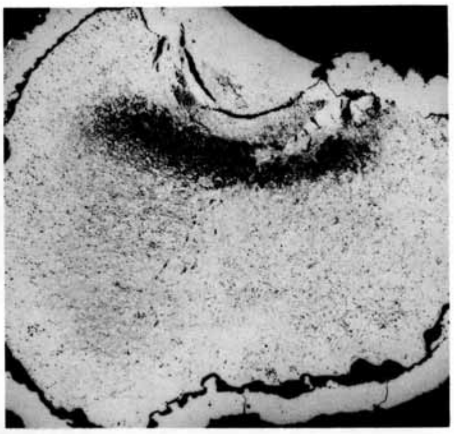
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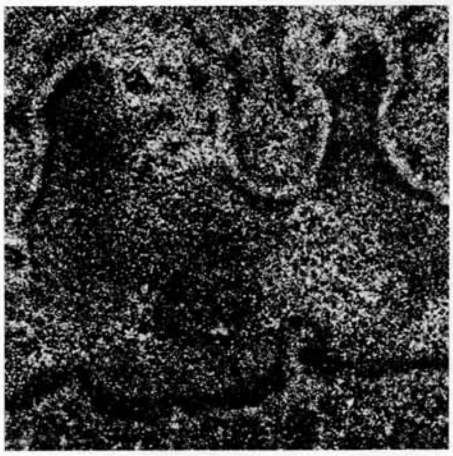
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DISCUSSION

Organic and inorganic origin of structural features

Amstutz (1958) was much impressed by the morphologies, displayed by Tertiary coprolites from Washington, to the extent that he wrote, '. . . the shapes do not leave any doubt as to their true animal excrement origin' and 'if it were not for the hardness, they could be taken for true excrements'. Much the same kind of sentiment might be expressed about the general gross external morphology of the limonitic bodies from the Whitemud Formation. However, the specimens exhibit transitions in the general morphology from excrements with preserved original surface details, although dung-like forms with varying degrees of obscuring limonitic encrustation to irregularly pustulate concretions, with little or no resemblance to cropolites.

The constrictions and striations that characterize the external surfaces of many specimens are undoubtedly of organic origin. These features are thought to have resulted from localized squeezing of the excrement, attendant upon contraction of the sphincter muscles during defaecation. The ridges and striations are thought to be the impressions of intestinal and sphincter muscles. The few irregular limonitic bodies, characterized by apparent dominance of concretionary growth may have originated as gastric residues or irregular faecal masses, similar to those described by Zangerl and Richardson (1963).

Perforations on the surface of some specimens may be gas-escape features, such as those described from coprolites by Jepsen (1963) and Zangerl, Woodland, Richardson, and Zachry (1969).

Hantzschel, El-Baz, and Amstutz (1968) have noted that the spiral form of some coprolites is regarded as a diagnostic feature of an excremental origin. Many specimens exhibit evidence of a spiral valve within the gut of the animal. The spiral coprolites frequently exhibit an intricate internal folding, similar to that figured by Williams (1972) and interpreted by him as representing mucosal folds of a shark's intestine. This suggests that at least some of the Whitemud coprolites are fossilized intestines and not expelled excrement. In a study of spiral coprolites from the Lower Permian Wymore Shale of Kansas, Williams (1972) concluded that the faecal masses are the fossilized intestines of pleuracanth sharks. Williams (1972) examined thin sections of the coprolites, which revealed structures analogous to mucosal folds of the intestine. Comparable features are rare in the Whitemud coprolites, but have been observed in a few cases (Pl. 44, fig. 3). Zangerl and Richardson (1963) adopted the view that the plasticity of faeces at the time of extrusion controls to a large extent the gross morphology of the resulting dung deposit. Thus, excrement extruded from the lower intestine into the rectum will roll into a coil at particular optimum plasticity, while deviations from that plasticity will produce irregular coiling or lack of spiral structure. This fact may account for the existence of uncoiled coprolites with similar 'primary' surface features to those of coiled ones also occurring in the Whitemud Formation. However, different coprolite morphologies, possessing essentially similar, small-scale, surface ridge patterns, may also represent droppings from different phases within a single episode of excretion, comparable to the fore, middle, and end droppings, distinguished by Kao (1962). The common occurrence of an outer sheath of embedded plant remains on coprolites of all types suggests that the majority was expelled on to a subaqueous depositional surface, strewn with plant debris. As noted above, the internal structure of some spirally and helicoidally coiled coprolites without a sheath of plant debris indicates that these may be the fossilized intestines of fishes.

It is likely that the density and depth of penetration of patterns of cracks on the surface of the coprolites are functions of the original composition and consistence of the faecal masses at the time of extrusion, as well as of physiological factors controlling the rate of extrusion. Many of the polygonal patterns of cracks, by analogy with similar fracture systems, developed around the sideritic concretions, described by Franks (1969), are a consequence of a synaeresis. Indeed, Conybeare and Crook (1968, pl. 47A, p. 177) figure a clay-siderite coprolite showing synaeresis cracks. Zangerl and Richardson (1963) suggest that larger cracks may have served as degassing channels during anaerobic decomposition of the faecal masses, because of accumulations of sulphides where the cracks make contact with the shales surrounding the coprolites. An association of pyrite crystals with some of the larger surface cracks on Whitemud coprolites indicates that this argument might be equally valid in the specimens considered here.

Possible systemic affinity. The meagre fossil record of the Whitemud Formation in southern Saskatchewan and, in particular, the lack of any finds of vertebrate body fossils precludes interpretations without uncertainty.

The spirally and helicoidally coiled appearance of many Whitemud coprolites, and the large sizes frequently encountered, suggest the possibility of activity of fishes among the larger elasmobranchs. The gut of the elasmobranchs is characterized by a short intestine, the surface of which is greatly increased by the presence of a spiral ridge or valve and also a strong pyloric sphincter marks the junction between stomach and intestine (Young 1962). Presence of a spiral, intestinal value in the animal of origin is essential in the production of coiled coprolites, regardless of whether extruded faeces (Zangerl and Richardson 1963) or unexpelled excrement (Williams 1972) is under consideration. Large size of coprolites has been a significant factor in arguments, to the effect that sharks were the animals of origin for such coprolites (Zangerl and Richardson 1963). This interpretation was favoured in a preliminary discussion of the Whitemud specimens by Broughton, Simpson, and Whitaker 1974).

A. Jerzmanska of the University of Wrocaw, Poland, pointed out (pers. comm. 1976) that such a narrow interpretation of possible animals of origin is perhaps ill-advised, since several other major groups of fishes possess spiral valves and representatives of some of these groups have been recorded from the Cretaceous rocks of the northern Great Plains of North America. Actinopterygian fishes of the Superorder Chondrostei, possessing spiral intestinal valves, included *Polypterus* (the bichir) and *Acipenser* (the sturgeon), while the Superorder Holostei includes *Lepisosteus* (the garpike) and *Amia* (the bowfin), which have somewhat reduced spiral valves (Young 1962). Furthermore, the sarcopterygh Order Dipnoi (lung-fishes) have spiral valves and do not excrete spirally coiled faecal masses (Williams 1972).

Of these several possibilities, sturgeons and bowfins constitute the most likely animals of origin for the Whitemud coprolites. MacAlpin (1947) recorded the occurrence of *Paleopsephurus wilsoni*, a polyodontid fish (sturgeon), in the upper Cretaceous sediments of Montana, while the presence of *A. frugosa*, also in the Montana Cretaceous, was noted by Boreske (1974).

The possibility that sturgeons produced the Whitemud coprolites is attractive for several reasons, most of which relate to the physiology and mode of life of these fishes, as described by Young (1962). The skull and skeleton are almost entirely cartilaginous and lack teeth development; the dermal skeleton is much reduced. These skeletal features might account for the apparent absence of body fossils of fishes in the Whitemud sequence, although the remarks of Romer (*in* Hantzschel *et al.* 1968) on coprolite and bone occurrences in the Texas Permian succession may be of significance. He noted that coprolites, mostly, if not all, of shark origin, are common in the Permian redbeds, but the bones tend to be relatively scarce and concentrated in pockets. Furthermore, sturgeons live in the sea, but migrate up rivers for breeding and to feed upon invertebrates collected from bottom muds, stirred up by the fishes' snout. This diet might account for the absence of skeletal material in the coprolites; if the latter had been produced by sharks, abundant bones, teeth, and scales would be expected to be incorporated in the faecal masses. Finally, sturgeons attain large dimensions, weighing up to 1000 kg.

CONCLUSIONS

Ironstone bodies, previously interpreted as inorganic concretions, are irregularly distributed throughout the kaolinitic clays, silts, and muds of the nonmarine Whitemud Formation (late Cretaceous) between Willows and Readlyn in south-central Saskatchewan. Gross morphology, surface features, and scarce internal structures indicate that reinterpretation of these bodies as coprolites is warranted. The abundance of the coprolites is such as to downgrade the economic potential of a section of otherwise valuable, ceramic clays.

There is no obvious reason for the concentration of coprolites at this site. It is the opinion of the authors that they form an *in situ* deposit and not a mechanical concentration. The preservation is remarkably good, and the coprolites lack any obvious signs of abrasion, due to transportation by currents. However, some selective erosion of bottom muds by currents, with attendant, minor, vertical displacement of the coprolites remains a possibility.

The coprolites have been preserved as a result of total replacement of the original faecal material by siderite and pyrite, which was subsequently replaced by limonite (goethite and lepidocrocite). A limited number of morphological types was recorded and certain external surface features are common to most of these: (1) sphincter-pinched constrictions and terminal necks; (2) polygonal patterns of cracks, probably of synaeresis origin; (3) patterns of fine ridges and striations, which appear to be intestinal and sphincter-muscle impressions; and (4) perforations of gas-escape origin. These surface features are masked to varying degrees by concretionary growth of limonite around the faecal masses.

The animals of origin of the coprolites were probably sturgeons or bowfins, which are known from the Cretaceous strata of Montana. The Whitemud Formation was deposited in near coastal alluvial floodplain palaeoenvironment.

Evidence of expulsion of the faecal masses from the animals of origin is provided by the fragmental plants adhered to the surface of the excrement upon deposition on to the substrate. Some of the spirally and helicoidally coiled faecal masses may be the fossilized intestines of fishes.

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