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A STRUVITE FAECOLITH IN THE LEATHERBACK TURTLE *DERMOCHELYS CORIACEA* VANDELLI: A MEANS OF PAGKAGING GARBAGE?

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ABSTRACT

A large stone-like object was collected from the rectum of a leatherback turtle beached at Midway Atoll, Hawaiian Islands. It consisted of biomineralized faecal material, the mineral being struvite ($NH_4MgPO_4.6H_2O$). Much material of anthropogenic origin (plastics in sheet and linear form, plus other packaging materials and monofilament nylon) was incorporated into the faecolith structure. It is hypothesized that the formation of struvite stems from the interaction of the leatherback's osmotic physiology with the metabolism of faecal bacteria. While the formation of the faecolith may be pathological, it could alternatively be an adaptive response to package garbage (whether natural or man-made).

INTRODUCTION

Beached adult specimens of the leatherback turtle *Dermochelys coriacea* Vandelli have almost invariably been drowned in nets, injured/killed by shark attack or in collision with boats. They may therefore be presumed to have been healthy beforehand. Necropsy sometimes reveals hard, round objects in the gut, particularly the hind gut. For example, the large male leatherback beached at Harlech in North Wales, UK (Eckert & Luginbuhl, 1988) had a hard, clay-like ball at the junction between the small and large intestines, while the rectum of a turtle beached at Midway Atoll in the northwestern Hawaiian Islands contained a hard, smooth, ovoid ball (the subject of this article). The aim of this investigation was to analyze the nature of this object, and perhaps elucidate the reasons for the occurrence of such faecoliths.

MATERIALS AND METHODS

A large (13 cm in diameter), smooth, stone-like object was collected (on 1.4.91) from the rectum (at the junction with the cloaca, but displaced to one side of the gut in an outpouching of the rectum) of a freshly-stranded specimen of *Dermochelys coriacea* at Midway Atoll at the northwestern end of the Hawaiian archipelago (28° 13' N, 177° 21' W) (see Fig. 1) . Leatherbacks are known to forage in the pelagic habitat to the north of Midway Atoll where they are not uncommonly entangled in Japanese, Taiwanese and Korean driftnets (Balazs, 1982). However, this was the first leatherback ever known to strand at Midway. The turtle had clearly been the victim of a shark attack as it had been decapitated very recently and lost all four flippers. Fresh blood was still flowing from its wounds and several sharks were swimming in shallow water immediately off the beach where the turtle stranded. On dissection (which revealed perfectly fresh tissues) the object was found immediately, so cannot have been an artifact of post-mortem deterioration.

The object was divided into two portions, one being sent to the UK for detailed analysis, while the other was used only for gross investigation. The faecolith portion sent to Britain was held for a few days in a water-saturated atmosphere. This caused the structure to soften. It was broken up and studied beneath a binocular microscope. During these observations, numerous small, hard, transparent crystals were seen embedded in the brown material of the softened faecolith structure. The crystals were dense and insoluble in water; they were separated from the rest of the material by washing and stirring. Crystals were prepared for X-ray probe microanalysis by freeze drying and attachment to an aluminium stub with double-sided adhesive tape. Crystals were studied in a scanning electron microscope (SEM) fitted with an energy dispersive X-ray microanalyser. A total of 10 faecolith crystals were investigated.

Once the elemental composition had been established, further crystals were investigated by X-ray diffraction. 20-30 of the larger and cleaner crystals were hand-picked under a binocular microscope and ground in an agate pestle and mortar under deionized water. The resultant slurry was spotted onto a glass slide and allowed to dry at room temperature. During drying the slurry was mixed using a scalpel blade in an attempt to minimize any preferred orientation. A diffractometer trace was obtained from this slide using $CuK\alpha2$ radiation in a Philips diffractometer.

RESULTS

GENERAL DESCRIPTION OF FAECOLITH

At the macroscopic level it was found that the smooth, rounded faecolith contained much material of anthropogenic origin (see Table 1). The rest of the faecolith appeared to be of an amorphous brown nature, with a strong faecal odour.

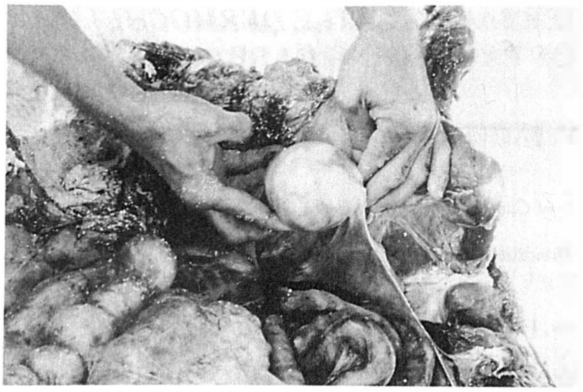

Fig. 1. Photograph of stranded leatherback, showing faecolith in situ.

At the microscopic level it could be seen that the brown material was made up of lamellae of soft material, which presumably consisted mainly of faecal bacteria (large numbers of bacteria were visible in early 'dirty' SEM preparations of the faecolith crystals). Between each of the lamellae were huge numbers of crystals (ca. 0.2-0.3 mm length, flattened and coffin-shaped). The crystals were transparent, colourless, hard, brittle and apparently insoluble in water.

FAECOLITH CRYSTAL COMPOSITION

First, it was noticed that the crystals prepared for X-ray microanalysis by freeze-drying appeared white and chalky rather than transparent; this indicated that the original crystals contained water of crystallization. All ten faecolith crystals subjected to X-ray microanalysis showed very similar patterns to that shown in Fig. 2. There are three obvious peaks. The Al comes from the stub on which the crystal is mounted; the Mg and P are the major elements of the crystal itself. Particularly surprising is the low amount of Ca; the faecolith was clearly not calcified.

X-ray microanalysis is largely qualitative, and calculation of peak areas yields only semi-quantitative information (see Morgan, 1985 for discussion). However, calculation yielded the following mean compositions (SD in parentheses): Na 1.6 (0.5)%, Mg 32.2 (1.9)%, Si 0.9 (0.3)%, P 67.1 (2.3)%, Cl 0.7 (0.8)%, K 0.3 (0.5)%, Ca 2.2 (1.5)%. From these values it may be seen that virtually all of the identified elemental material present in the crystals consists of Mg and P, with some crystal surfaces (particularly clean ones with no contaminating material visible on the surface) approaching levels of 100%. The technique is not capable of detecting the presence of elements with an atomic number below 11 (e.g. C, H, I or O), so although the X-ray microanalysis results, combined with the observation of crystalline rather than amorphous structure, strongly suggest that the crystals are almost pure magnesium phosphate, the technique cannot discriminate between different types of phosphates (e.g. between various orthophosphates, some of which contain H, and pyrophosphate), and cannot eliminate the possibility of the presence of ammonium in the crystals (as in struvite, $NH_4MgPO_4.6H_20$).

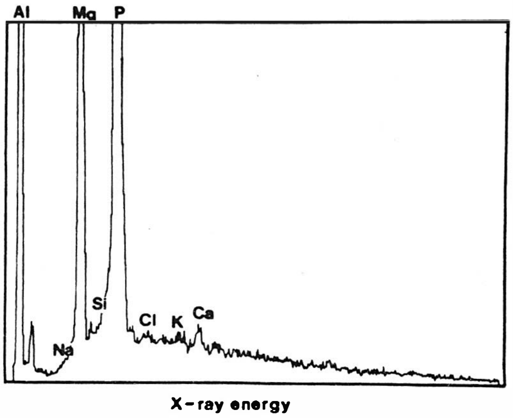

Fig. 2. Trace derived from X-ray dispersive microanalysis of faecolith crystals. Al is from the stub on which the crystal was mounted.

1. 300 mm length of tangled, blue polypropylene twine (5 mm thick).
2. 4 strands (120 mm, 105 mm, 120 mm, 130 mm) of old, unravelled polypropylene tarpaulin fabric, all 1 mm wide.
3. 160 mm length of monofilament nylon fishing line (approx. 8 lb breaking strain).
4. 4 pieces of green, hard, flat plastic (9x13 mm, 10x7 mm, 6x5 mm, 6x5 mm).
5. Piece of flat, white hard plastic (9x5 mm; 2 mm thick).
6. Piece of flat, yellow-orange hard plastic (5x5 mm).
7. 3 small strands of plastic (20 mm, 20 mm and 30 mm in length).
8. 6 small pieces (approx. 4 mm diameter) of expanded polystyrene foam.
9. Piece of unknown hard substance (6x5 mm).
10. Numerous polystyrene beads (< 1 mm diameter).
11. 3 pieces (each approx. 20 mm diameter) abraded material from polythene bags

TABLE 1. Material of anthropogenic origin incorporated in faecolith

The magnesium phosphates are all insoluble or only very slightly soluble in water, so degree of solubility cannot separate the forms, but the X-ray diffraction pattern gave a near-perfect match for struvite (JCPDS pattern number 15-762). The morphology of crystals is very similar to that recorded by LeGeros & LeGeros (1984) from struvites synthesized in gel systems. A good general description of struvite (also known as guanite) may be found in Palache *et al.* (1951).

DISCUSSION

Faecoliths are present in some stranded leatherbacks, but certainly not all; Den Hartog & Van Nierop (1984) did not report any in the six *Dermochelys* they studied. At present it is difficult to decide whether their presence indicates a pathological condition, or is a normal feature of turtle biology. Except for the injuries caused by the shark attack, the Midway turtle showed no obvious signs of disease and there was no compaction of plastic in the gut. The adaptive formation of hard nodules in the gut of marine animals is not unknown; the heart urchin *Echinocardium* ingests fragments of wood or stone which act as a substratum for the formation of bacterial nodules which fix and detoxify sulphur as insoluble metal sulphides. There is also a general tendency in marine invertebrates for detoxification by binding metals in insoluble, granular form. It is feasible that the formation of a smooth, rounded object around non-biodegradable garbage may facilitate later defaecation. Leatherbacks not only swallow plastic bags and man-made garbage such as the twine and polystyrene reported here; they are also known to swallow wood, feathers, sand and seaweed (e.g. Brongersma, 1969; Den Hartog & Van Nierop, 1984)). It would appear that they will swallow almost any material swimming or floating at the sea surface; some of this material was presumably difficult to pass through the gut even before man started to throw non-biodegradable garbage into the sea. However, there is an extensive veterinary literature concerned with the consequences for captive animals of swallowing of foreign bodies (see Frye, 1991 for reptilian examples), but except in the case of crocodilian gastroliths (swallowed deliberately for control of buoyancy and/or digestive efficiency) the responses of animals seem to be pathological rather than adaptive. The occurrence of hard masses in the intestine of chelonians is not uncommon either (see Frank, 1981), but these are usually formed from masses of chitinous parts of insects or accumulated indigestible cellulose fibres. Such masses can cause constipation, though intestinal parasitic nematodes may help to break the masses down.

From the form of the leatherback faecolith studied here it is clear that its hardness stems from biomineralization, presumably by the gut bacteria rather than the leatherback itself, since the mineral crystals are deposited between the bacterial lamellae. It is most interesting that the mineral is non-calcareous and composed of struvite which may be formed in the laboratory by mixing magnesium sulphate solution with an acid solution of ammonium phosphate (Palache *et al*., 1951). Struvite is not a common biomineral in a global sense, although it is well recognized in medical and veterinary circles. The principal occurrence in live organisms seems to be as a component of urinary stones in mammals (including cats and humans) resulting from alkalinization due to bacterial infection (e.g. Prien & Frundel, 1947; LeGeros & LeGeros, 1984; Lowenstam & Veiner 1989). Geological struvite occurrences have unusual bulk compositions and are non-marine (e.g. within fossil cave guano deposits); struvite has also been found in dung-peat mixtures and in canned food (Palache *et al*., 1951). In these occurrences too, bacterial activity is probably significant.

In view of the association with bacterial lamellae in the faecolith, a similar origin seems likely in this case. A further factor may be enrichment of the hindgut fluids of the leatherback turtle by divalent ions. *Dermochelys* has to drink seawater like any other marine reptile (or teleost fish). It can only absorb water by pumping Na across the gut wall until sufficient osmotic gradient exists for water to flow osmotically from gut lumen to blood. In consequence, the hind gut fluid is likely to contain relatively high concentrations of magnesium, calcium and sulphate ions, but little sodium or chloride. However, the ammonium and phosphate ions of struvite are presumably derived from the faecal bacteria. LeGeros & LeGeros (1984) report that struvite can be formed in a calcium-rich medium at pH values between 7 and 9, and that formation of small crystals is actually promoted by high calcium concentrations, so it is not necessary to postulate a calcium-poor or acid environment in the hindgut.

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REFERENCES

Balazs, G. H. (1982). Driftnets catch leatherback turtles. *Oryx* **16**, 428-430.

Brongersma, L. D. (1969). Miscellaneous notes on turtles. IIB. *Proceedings of the Koninklijke Nederlanse Akademie Van Wetenschappen Series C* **72**, 90-102.

Den Hartog, J. C. & Van Nierop, M. M. (1984). A study on the gut contents of six leathery turtles *Dermochelys coriacea* (Linnaeus) (Reptilia: Testudines: Dermochelyidae) from British waters and from the Netherlands. *Zoologische Verhanelingen Leiden* **20**, 1-36.

Eckert, K. L. & Luginbuhl, C. (1988). Death of a giant. *Marine Turtle Newsletter* **43**, 1-3.

Frank, W. (1981). Endoparasites. In *Diseases of the Reptilia Vol. 1*, 291-358. Cooper, J. E. & Jackson, O. F. (Eds.). London: Academic Press.

Frye, F. L. (1991). Pathologic conditions related to the captive environment. In *Biomedical Aspects of Captive Reptile Husbandry*,. Frye, F. L. (Ed.). Malabar, Florida: Krieger Publishing Company.

LeGros, R. Z. & LeGros, J. P. (1984). Phosphate minerals in human tissues. In *Phosphate Minerals*,. Nriagu, J. O. & Moore, P. B. (Eds.) Berlin: Springer-Verlag.

Lowenstam, H. A. & Weiner, S. (1989). *On Biomineralization*. Oxford: Oxford University Press.

Morgan, A. J. (1985). X-ray microanalysis in electron microscopy for biologists. Oxford: Oxford University Press/Royal Microscopical Society.

Palache, C., Berman, H. & Frondel, C. (1951). *Dana's System of Mineralogy* (Vol. 2; 7th Hd.) New York: Wiley.

Prien, E. L. & Frundel, C. (1947). Studies in urolithiasis: I. The composition of urinary calculi. *Journal of Urology* **57**, 949-994.