

SPECIAL

**The mineralization of dinosaur soft tissue in the Lower Cretaceous of Las Hoyas, Spain**

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**The mineralized soft tissue of a dinosaur, only the second discovery of its kind, is reported from the Lower Cretaceous of Las Hoyas, Spain. Cellular details of mineralized skin and muscle of *Pelecyanimimus* are replicated in an iron carbonate. The outline of this ornithomimosaur is preserved by a phosphatized microbial mat that enshrouded the carcass. It confirms the existence of either a throat pouch or dewlap, and soft occipital crest. This study confirms the importance of microbial mats in the fossilization of soft tissues and emphasises the need for careful monitoring of vertebrate remains for mineralized soft tissues prior to acid preparation.**

**Keywords:** Cuenca Spain, Lower Cretaceous, dinosaurs, fossilization.

The multitoothed ornithomimosaur dinosaur *Pelecyanimimus polyodon* was recently described from the Lower Cretaceous lacustrine lithographic limestones of Las Hoyas (Cuenca, Spain) (Pérez-Moreno *et al.* 1994). The only known specimen of this, the first ornithomimosaur theropod found in Europe, preserves what were originally described as 'integumentary impressions'. These occur in the throat region, flanking the more proximal neck vertebrae, in the vicinity of the ribs, and behind the elbow. In addition a small triangular area at the rear of the skull was interpreted as a possible occipital crest (Pérez-Moreno *et al.* 1994). Analyses confirm that these features represent mineralized traces of soft tissues. They are preserved both as replicas of the original skin and muscle tissue, and as impressions on microbial mats or veils that grew over them.

In addition to *Pelecyanimimus*, the lacustrine limestones of Las Hoyas (Meléndez 1995) have yielded a well preserved diverse biota of plants, crustaceans, insects, fishes and tetrapods, as well as three birds, some preserving details of the feathers (Sanz *et al.* 1988, 1996; Sanz & Buscalioni 1992). Phosphatized muscle tissue has been reported in some of the fishes (Fregenal-Martínez *et al.* 1995) and in decapods, where they occur in association with crystal bundles of calcium carbonate (Briggs & Wilby 1996). Scanning electron

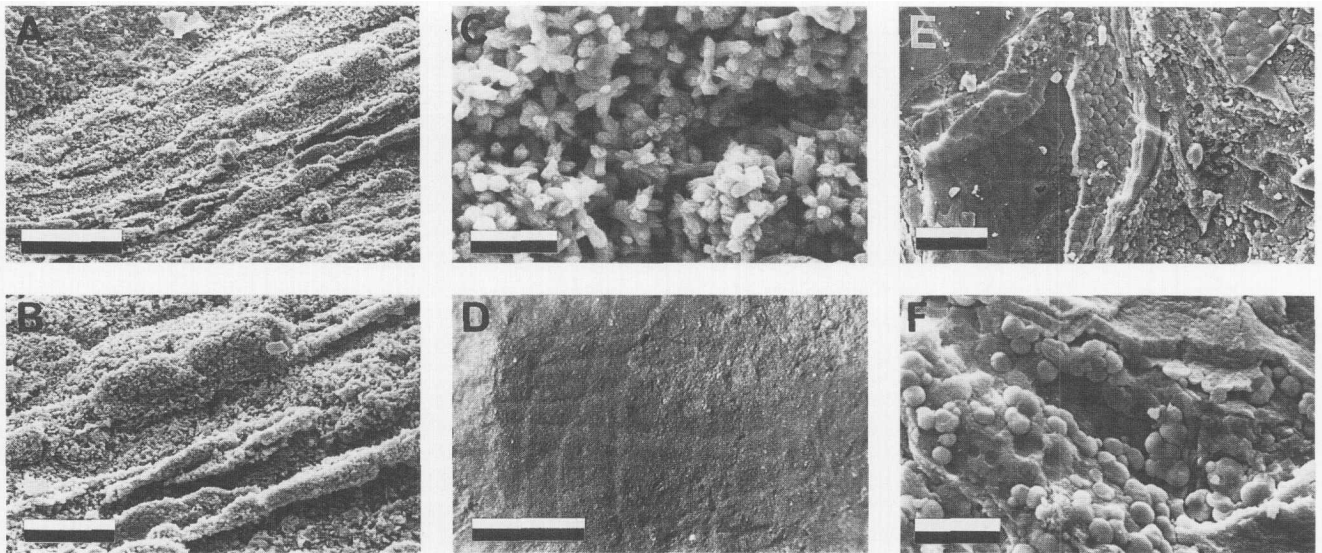
microscopy and electron microprobe analyses reveal that the soft parts of *Pelecyanimimus* are preserved in an unusual manner. In some places, such as the region under the throat, muscle tissues retain some three-dimensional detail, including the sarcolemma (Fig. 1a, b; cf. Briggs *et al.* 1993, fig. 1a, b). They have been replaced in an iron carbonate (Fig. 1c). A distinct cross-hatched patterning on the surface of this material represents wrinkling of the hide of the dinosaur (Fig. 1d). The surface of the skin is smooth and lacks any visible dermal structures (e.g. feathers, scales, hair). The discovery that *Pelecyanimimus* preserves labile tissues mineralized in iron carbonate confirms the importance of minerals like siderite in preserving soft tissues in lake settings (Wuttke 1983; Allison 1988).

Elsewhere the soft tissues of *Pelecyanimimus* are preserved by the outline of phosphatized microbial mats that overgrew the carcass. These mats consist mainly of thin layers of cocci embedded in a film (Fig. 1e, f) that may represent mucopolysaccharide sheaths surrounding the cells (i.e. a glycocalyx; see Kaźmierczak *et al.* 1996). Where the margin of these white phosphatized mats forms a well defined line it is assumed that this represents the outline of the dinosaur. Closely spaced lineations running parallel to the bones are the result of micron-scale cracking of the mats. The mats also display polygonal cracking (Fig. 1e) presumably due to shrinkage associated with the mineralization.

Our analysis confirms the existence of either a throat pouch or dewlap, and soft occipital crest in *Pelecyanimimus*, and demonstrates the importance of microbial mats in preserving such details. The preservation of the outline of soft tissues in microbial mats has been reported in other vertebrates (Martill 1987), but from a marine setting. Microbial mats have recently been shown to promote soft-tissue fossilization in the marine Jurassic lithographic limestones of Cerin, southeastern France, by concentrating dissolved ions in the vicinity of carcasses (Wilby *et al.* 1996). Mineralization of the mats that enshroud the soft tissues of *Pelecyanimimus* was probably facilitated in a similar manner. Phosphorus released by the decaying dinosaur was trapped and precipitated in the mat where it was directly in contact with the carcass. Mats extending beyond the dinosaur did not become mineralized. Mats formed of coccoid cyanobacteria within a glycocalyx become mineralized in aragonite in modern Lake Van (Turkey) (Kaźmierczak *et al.* 1996). The mats on *Pelecyanimimus* are strikingly similar, but this does not imply that they were identical or that they favoured highly alkaline conditions.

A number of examples of impressions of dinosaur skin have been reported from elsewhere (see Martill 1991; Kellner 1996). Preservation of the structure of tissues other than skin, however, is extremely rare. An organic trace of the skin of a *Scelidosaurus* is known from the Jurassic of Charmouth, England, where it was washed into marine sediments (Martill 1991). A small theropod, from the quasi-marine Lower Cretaceous Santana Formation of Brazil, preserves details of soft tissues, including muscle, in apatite (Kellner 1996). This last is the only dinosaur specimen known, besides that described here, with three-dimensionally mineralized soft tissues. The nearest analogue to the preservation of the outline of the Las Hoyas dinosaur in a microbial mat is the preservation of vertebrate outlines in the Tertiary Messel Oil Shale as mineralized microbes (Wuttke 1983).

Apart from demonstrating the potential importance of microbial mats in preserving soft tissues in non-marine



**Fig. 1.** Mineralized soft tissues of the dinosaur *Pelecanimimus* from the Lower Cretaceous of Las Hoyas, Cuenca, Spain (specimen LH 7777, Museo de Cuenca, Cuenca, Spain, provisionally housed at the Unidad de Paleontología, Universidad Autónoma de Madrid). (a) Muscle tissue mineralized in iron carbonate. Scale bar=40 µm. (b) Detail of three-dimensionally preserved muscle. The pronounced linear structures represent the sarcolemma sheaths. Scale bar=20 µm. (c) Microfabric of the iron carbonate mineral that replicates the muscle. Scale bar=4 µm. (d) Surface view of wrinkling on dinosaur skin. Scale bar=1 mm. (e) Layers of mineralized microbial mats overlying the specimen. Scale bar=20 µm. (f) Detail of the phosphatized mats showing the mineralized coccoids and the surrounding glycocalyx. Scale bar=10 µm.

settings, this study emphasizes the need for careful monitoring of vertebrate remains for mineralized soft tissues before consigning them to the acid bath in order to release the skeleton from the matrix.

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## References

- ALLISON, P.A. 1988. *Konservat-Lagerstätten*: cause and classification. *Paleobiology*, **14**, 331–344.
- BRIGGS, D.E.G. & WILBY, P.R. 1996. The role of the calcium carbonate-calcium phosphate switch in the mineralization of soft-bodied fossils. *Journal of the Geological Society, London*, **153**, 665–668.
- , KEAR, A.J., MARTILL, D.M. & WILBY, P.R. 1993. Phosphatization of soft-tissue in experiments and fossils. *Journal of the Geological Society, London*, **150**, 1035–1038.
- FREGENAL-MARTÍNEZ, M.A., BUSCALIONI, A.D. & 11 OTHERS 1995. Taphonomy. In: MELÉNDEZ, M.N. (ed.) *q.v.* 21–27.
- KAZMIERCZAK, J., COLEMAN, M.L., GRUSZCZYŃSKI, M. & KEMPE, S. 1996. Cyanobacterial key to the genesis of micritic and peloidal limestones in ancient seas. *Acta Palaeontologica Polonica*, **41**, 319–338.
- KELLNER, A.W.A. 1996. Fossilised theropod soft tissue. *Nature*, **379**, 32.
- MARTILL, D.M. 1987. Prokaryote mats replacing soft tissues in Mesozoic marine reptiles. *Modern Geology*, **11**, 265–269.
- 1991. Organically preserved dinosaur skin: taphonomic and biological implications. *Modern Geology*, **16**, 61–68.
- MELÉNDEZ, M.N. (ed.) 1995. *Las Hoyas, a lacustrine Konservat-Lagerstätte, Cuenca, Spain*. Field trip guide book, 2nd International Symposium on Lithographic Limestones, Univ. Complutense Madrid.
- PÉREZ-MORENO, B.P., SANZ, J.L., BUSCALIONI, A.D., MORATALLA, J.J., ORTEGA, F. & RASSKIN-GUTMAN, D. 1994. A unique multitoothed ornithomimosaur dinosaur from the Lower Cretaceous of Spain. *Nature*, **370**, 363–367.
- SANZ, J.L. & BUSCALIONI, A.D. 1992. A new bird from the Early Cretaceous of Las Hoyas, Spain, and the early radiation of birds. *Palaeontology*, **35**, 829–845.
- , BONAPARTE, J.F. & LACASA, A. 1988. Unusual Lower Cretaceous birds from Spain. *Nature*, **331**, 433–435.
- , CHIAPPE, L.M., PÉREZ-MORENO, B.P., BUSCALIONI, A.D., MORATALLA, J.J., ORTEGA, F. & POYATO ARIZA, F.J. 1996. An Early Cretaceous bird from Spain and its implications for the evolution of avian flight. *Nature*, **382**, 442–445.
- WILBY, P.R., BRIGGS, D.E.G., BERNIER, P. & GAILLARD, C. 1996. The role of microbial mats in the fossilization of soft-tissues. *Geology*, **24**, 787–790.
- WUTTKE, M. 1983. 'Weichteil-Erhaltung' durch lithifizierte Mikroorganismen bei mittel-erzänen Vetebraten aus den Ölschiefern der 'Grube Messel' bei Darmstadt. *Senckenbergiana lithaea*, **64**, 509–527.

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