ORYCTOS, Vol. 1 : 79 - 85, Octobre 1998

A NEW PTEROSAUR LAGERSTÄTTE IN N. E. BRAZIL (CRATO FORMATION; APTIAN, LOWER CRETACEOUS) : PRELIMINARY OBSERVATIONS

David M. MARTILL[1] and Eberhard FREY[2]

[1]Department of Geology, University of Portsmouth, Portsmouth, PO1 3QL UK.

[2]Staatliches Museum für Naturkunde Karlsruhe, Geowissenschaftliche Abteilung, Erbprinzenstraße 13, D-76133 Karlsruhe, Germany.

Abstract : Although pterosaurs are rare in the Nova Olinda Member of the Crato Formation (Aptian, Lower Cretaceous, Araripe Basin, N.E. Brazil), their remains have been recovered in increasing numbers over the last five years from the numerous stone pits between Nova Olinda and Santana do Cariri. Several distinct forms are known including tapejarids, a possible ornithocheirid and a possible azdharchid. Some specimens exhibit soft tissue preservation and structures previously unknown in related pterosaurs from other sites have been revealed. Preservational styles are variable in that some specimens are articulated, but examples also occur as partially articulated remains; associated, but disarticulated elements and as isolated bones.

Key words: Pterosaur, Lower Cretaceous, Brazil, Lagerstätte

Un nouveau Lagerstätte à ptérosaures au nord est du Brésil (Formation Crato, Aptien, Crétacé inférieur) : observations préliminaires

Résumé : Les ptérosaures sont rares dans le membre Nova Olinda de la Formation Crato (Aptien, Crétacé inférieur, Bassin de l'Araripe, Brésil). Depuis cinq ans, leurs restes ont néanmoins été retrouvés de plus en plus régulièrement dans les nombreuses carrières situées entre Nova Olinda et Santana do Cariri. Plusieurs formes différentes sont connues, incluant des Tapejaridae, un possible Ornithocheiridae et un possible Azdharchidae. Certains spécimens présentent des tissus mous préservés et des structures jusque-là inconnues chez les ptérosaures. (traduit par la rédaction).

Mots clés : Ptérosaure, Crétacé inférieur, Brésil, Lagerstätte.

INTRODUCTION

The Nova Olinda Member of the Crato Formation, Araripe Basin, North East Brazil (fig. 1), is famous for the abundance and exceptional quality of preservation of its fossil insects and plants (Martill, 1993; Maisey, 1991). Remains of the gonorhynchiform fish *Dastilbe elongatus* Silva Santos are very common, but other fish species are rare (Brito *et al.* this volume). Although tetrapod remains are rare, they too are well preserved despite some flattening. They include bird feathers (Martill & Filguiera, 1994; Martill & Frey, 1995), crocodilians (Frey *et al.*, in prep), probable rhynchocephalians (fig. 2), frogs (fig. 3) and turtles (pers. obs.). The main fossil bearing part of the sequence appears to be restricted largely to the region between Santana do Cariri, Nova Olinda and Tatajuba (fig. 1), but this is probably artificial since this region contains hundreds of small stone quarries where the thinly bedded limestones are dug manually for ornamental stone. This labour intensive industry and the commercial value of the fossils assist in making large numbers of fossils available almost daily. Other exposures of the Nova Olinda Member elsewhere in the Chapada appear not to be so fossiliferous, and furthermore they are not so accessible.

Specimen numbers prefixed SMNK are housed in the Staatlisches Museum für Naturkunde, Karlsruhe, Erbprinzenstraße 13, D-76133 Karlsruhe, Germany; Specimens prefixed DNPM are held in the collection of the Departmento Nacional Produçao Mineral, Rio de Janeiro, Brazil.

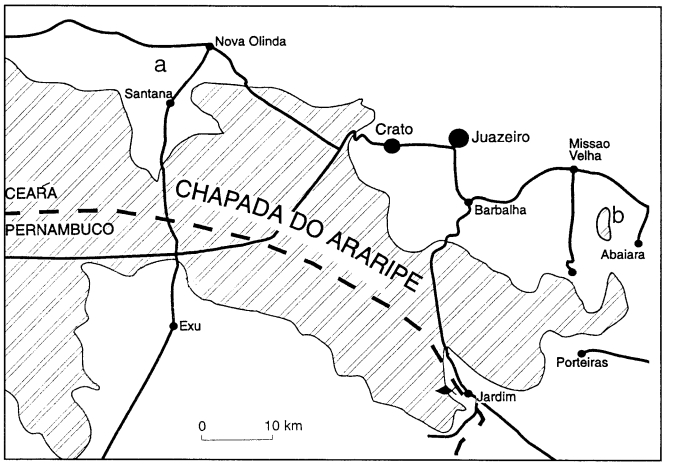
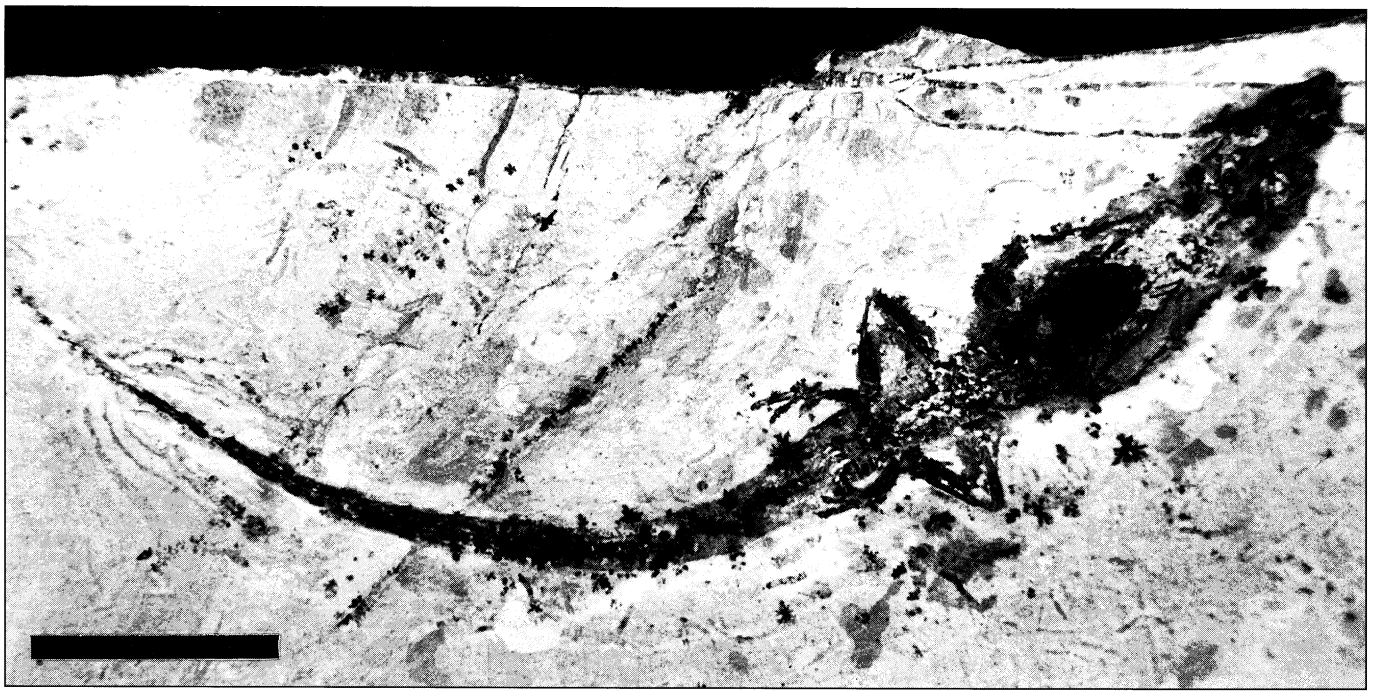


Fig. 1. Locality map showing the Chapada do Araripe in north east Brazil. The Crato Formation crops out around the edge of the Chapada, but is overlapped in the north west. Santana on the map = the small town of Santana do Cariri, which along with Nova Olinda (a) is one of the most important sources of Crato Formation and Santana Formation pterosaurs. The area indicated (b) yields pterosaurs from the Santana Formation.

Fig. 3. Frog from the Nova Olinda Member of the Crato Formation, Ceará, north east Brazil. This specimen is housed in the palaeontological museum in the small town of Santana do Cariri. Scale bar =10 mm.

Fig. 2. Photograph from a slide of a probable rhynchocephalian from the Nova Olinda Member of the Crato Formation, Ceará, north east Brazil. This specimen was shown to one of us (DMM) in 1996. Its present whereabouts is unknown. Scale bar app. 45 mm.



STRATIGRAPHY

The Crato Formation is a series of laminated limestones, silts and silty clays lying in places on the red clays or grey green silts of the Batatieras Formation (details of the stratigraphy and the nomenclature of underlying beds remain to be established) and on late Proterozoic basement (Martill, 1993). It is overlain by a thick evaporite sequence; the Ipubi Formation, which in turn is overlain by the Santana Formation, well known for its fossiliferous carbonate concretions. The thickness of the Crato Formation is variable, but in the Nova Olinda region the formation reaches around 20 metres. In the Nova Olinda region, the base of the Crato Formation is marked by a minor disconformity where laminated limestones rest on a sequence of greenish marls with rhizoconcretions and red clays. Elsewhere, as at Crato and Barbalha, there is a gradual transition from clays with thin limestones to laminated limestones. A sequence of laminated limestones, up to eight metres thick and known as the Nova Olinda Member, is the most important lithology palaeontologically (Martill & Wilby, 1993). The Nova Olinda Member limestone is a millimetrically laminated, organic-rich carbonate which outcrops extensively on the north eastern flanks of the Chapada do Araripe.

A similar limestone also occurs on the south east side of the Chapada between Porteiras and Caririmirim in Pernambuco. The age of the Nova Olinda Member remains to be established accurately, but palynomorph data suggests an Upper Aptian age for the Crato Formation as a whole (Pons *et al.*,1990).

THE PTEROSAURS

Recently the remains of several pterosaurs have been collected from the numerous small stone quarries between the villages of Santana do Cariri, Tatajuba and Nova Olinda. Some of these specimens (ten are known to us) are of articulated remains and some show extensive areas of soft tissue preservation, including the preservation of soft tissue head crests never before seen in pterosaurs.

Four specimens with cranial remains are known to us and of these, three can be referred to the edentulous Tapejaridae.

A photograph of a fourth specimen with an apparent dentate beak was shown to us by a fossil collector in Nova Olinda (Frey & Martill, 1994: fig.19) and is now in the D.N.P.M. collection in Rio de Janeiro (Kellner, pers. com.). Frey & Martill (1994) described an almost complete pterosaur, lacking only the skull and some cervical vertebrae, with a wingspan calculated at 4.6 metres which was referred to the new taxon *Arthurdactylus conandoylei* (SMNK 1132 PAL) and tentatively referred to the Ornithocheiridae. More recently Campos and Kellner (1997) described a new species of tapejarid pterosaur with extensive soft tissue preservation. The specimen is discussed in more detail below.

A partial pterosaurian wing (fig. 4) comprising a fourth metacarpal and first, second and third phalanges of the wing digit (SMNK 2342 PAL) is particularly noteworthy, as the last two digits display the "T" shaped cross section typical of Azdharchidae (fig. 5) (Note, Unwin and Lu, 1997, place the Tapejaridae and the Azhdarchidae together in the Azdarchoidea). Unfortunately, the post cranial skeleton of members of the Tapejaridae has not been described, but an example of a small *Tapejara wellhoferi* from the Santana Formation (SMNK 1137 PAL) does not have the "T" shaped cross-section.

Fig. 4. Partial wing of a pterosaur from the Nova Olinda Member of the Crato Formation (Aptian, Lower Cretaceous), Nova Olinda region, Ceará, Brazil. Wing elements of the flight digit inlude the metacarpal, first, second and third phalanges. There are some small, disarticulated elements associated with the wing finger. Phalanges II and III have the "T" shaped cross-section typical of the Azhdarchidae.
Scale bar = 50 mm.

Fig. 5. Detail of second phalanx of the flight finger of SMNK 2342 PAL showing the "T" shaped cross-sectional shape running the lengh of the phalanx. Scale bar = 10 mm.

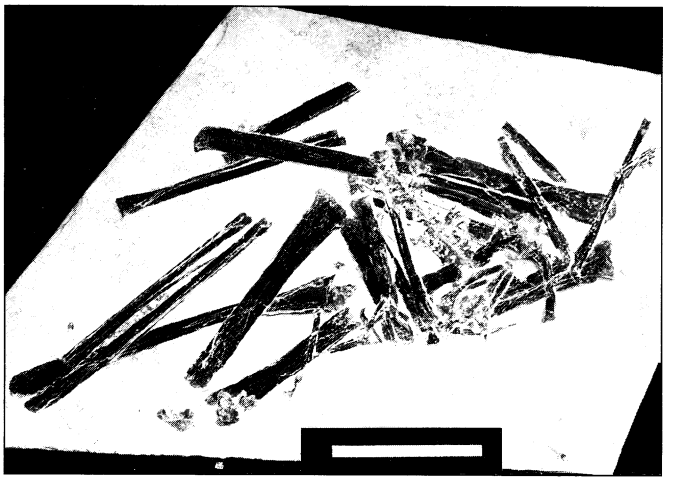


Fig. 6. Holotype of *Arthurdactylus conandoylei* Frey and Martill, 1994, SMNK 1132 PAL from the Nova Olinda Member of the Crato Formation, Ceará, Brazil. Scale bar = 200 mm.

PRESERVATION

In most cases tetrapod remains in the Crato Formation are crushed flat, but are otherwise well-preserved. The skeletons are usually articulated, or partially articulated, but are rarely complete. The incompleteness is, in some cases, a result of careless collecting, in that in most of the examples known to us, the bones have continued beyond the boundaries of the slabs (e.g. figs. 6, 7). Some disarticulation is evident but distances between bones are usually small suggesting that some, if not all, of the disarticulation can be accounted for by gravitational collapse and/or microbial degradation. Some specimens may have been incomplete when they arrived on the lagoon floor due to decay or scavenging during post-mortem drifting (Frey & Martill, 1994). Individual elements, including isolated skulls missing the lower jaws, also occur, but as these specimens have often been obtained by museums from commercial fossil dealers through a chain of collectors and 'middle-men', their relationship to any other bones cannot be established. The bones are usually preserved as shiny, dark brown elements on slabs of buff coloured limestone. Unweathered slabs of Crato Formation limestone are bluish/grey, and bones here are preserved as blackish elements, often with some carbonaceous material (N.B. we have only observed this latter style of preservation in the fish *Dastilbe*).

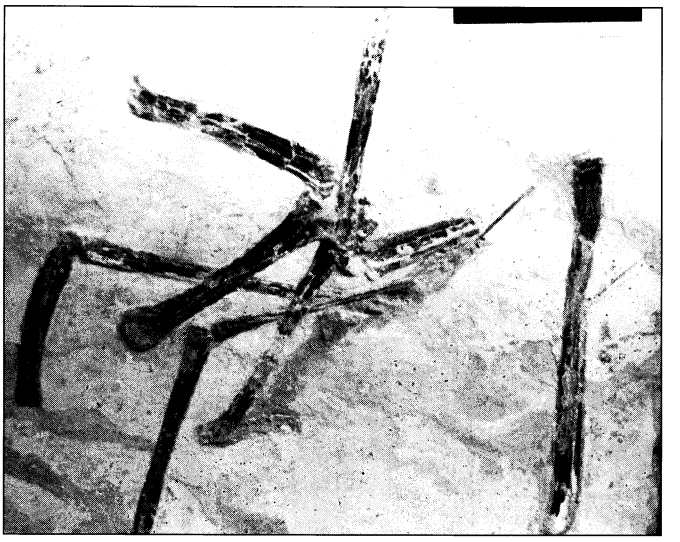


Fig. 7. An indeterminate partial pterosaur skeleton from the Crato Formation. This example is in the palaeontological museum of Santana do Cariri, Ceará, Brazil. One of the pes is articulated, but the wings show considerable disarticulation. The body and skull is missing. Scale bar = 100 mm.

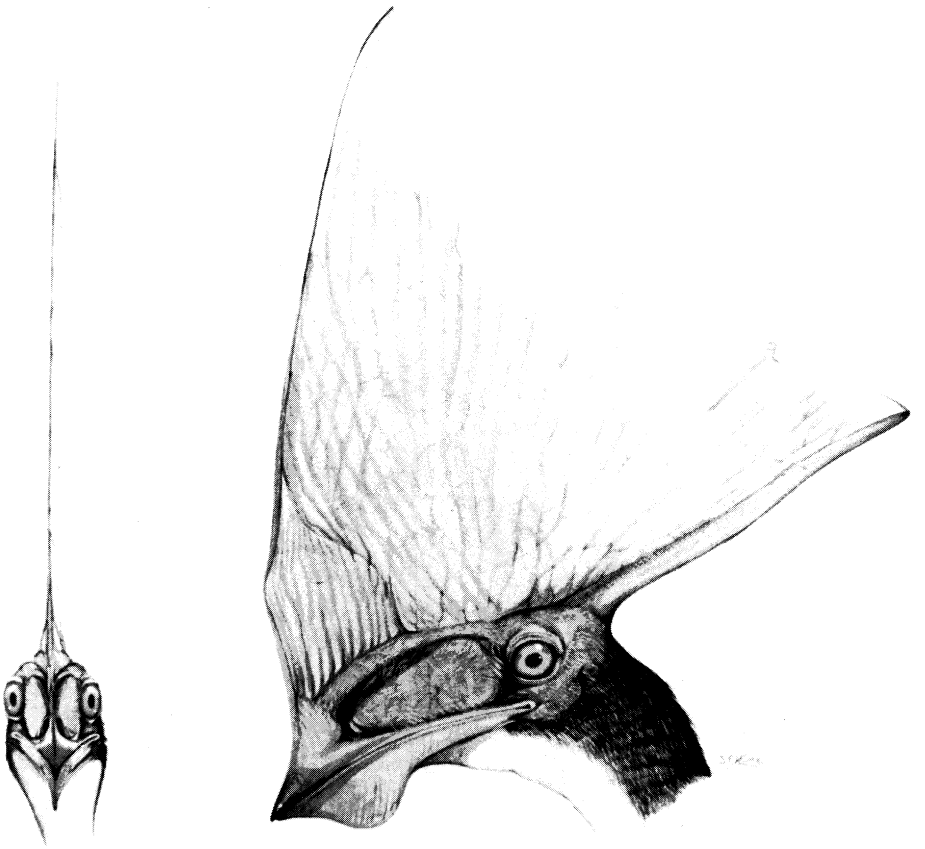


Fig. 8. Tentative reconstruction of the new tapejarid "*Tapejara*" *imperator* with soft tissue head-crest from the Crato Formation, based on figures and photographs in Campos & Kellner 1997.

Frey & Martill (1994) described the post cranial skeleton of *Arthurdactylus conandoyli* (SMNK 1132 PAL) in which only the neck and skull was missing (fig. 6). In this specimen most of the post cranial skeletal elements show original bone to bone relationships. In an undescribed pterosaur specimen in the palaeontological museum of Santana do Cariri, the post cranial skeleton of an indeterminate pterosaur shows considerable disarticulation, but all bones in close association. Some portions of this skeleton do show true bone to bone relationships (fig. 7), especially in the region of the foot. Once again the skull, as well as most of the vertebral column is missing.

THE SOFT TISSUE PTEROSAURS

At least three examples of pterosaurs with soft tissues are known to us from the Crato Formation. All of these are skulls of tapejarids and show evidence of soft tissue extensions to a bony sagittal crest. At least two taxa are known. Campos & Kellner described a new species of *Tapejara* (*T. imperator* Campos & Kellner, 1997; DNPM specimen no. MCT 1622-R) in which an arcuate sheet of preserved soft tissue is situated medially above the skull, and supported anteriorly by an elongate bone (fig. 8). This crest extends posteriorly some distance behind the skull where it is attached to a posterior spina of the parietals. Two examples of another tapejarid species also display soft tissue head crests, but in these specimens the crest is more erect and is at least four times the height of the skull and has a vertical (rather than arcuate) posterior margin (fig. 9) (Frey & Martill, in prep). As in *T. imperator* these specimens display an anterior bony spine. In both examples there is a soft tissue sheet anterior to the beak, and in one specimen (SMNK 2343 PAL) there is a keratinous, hooked, beak-like extension to the anterior tip of the skull which resembles the beak of accipital birds (fig. 10).

The soft tissue portion of the crest contains vertically orientated structural fibres which anchored onto the bony supporting crest below.

Such a large structure on a very lightly constructed animal must have had an aerodynamic effect. We speculate that such a structure could have easily been used as a steering device (anteriorly placed rudder) provided that the animal flew at extremely low speed, but it may also have passively generated thrust, behaving like a sail (Frey & Martill, in prep.), which would be a unique mode of aerial or possibly aquatic locomotion.

DISCUSSION

The Nova Olinda Member of the Crato Formation is already well known as a fossil conservation Lagerstätte, having yielded one of the most diverse Cretaceous non-amber entomofaunas (Grimaldi, 1990) and a wide variety of other organisms, some with soft tissue preservation and colour patterning (Martill & Frey, 1995).

Although pterosaur remains are rare in the Nova Olinda Member, recent efforts by quarry workers to obtain specimens for profit has demonstrated that pterosaurs at least occur regularly, if not abundantly. Although the specimens are rare, they appear to be more abundant than pterosaurs from the Solnhofen Limestone and like examples from this deposit, may show evidence of soft tissue preservation. At present, pterosaur diversity appears not be as great as in other pterosaur bearing Lagerstätte such as the Solnhofen Limestone of Bavaria or the Santana Formation, also from the Araripe Basin. However, this low diversity is more likely a reflection of the relatively small number of specimens so far reported. Continued collecting from this spectacular fossil deposit will almost certainly yield more pterosaur remains, and with the preservation of soft tissues, we expect the Crato Formation to gain in importance for pterosaur studies in the future.

Fig. 9. Skull and soft tissue head crest of a new tapejarid pterosaur from the Nova Olinda Member, Crato Formation, of Nova Olinda region, Ceará, Brazil. The head crest has been cut off at the edge of the slab, but a conservative estimate of its shape suggests it would be four to five times the height of the skull. Specimen number SMNK 2344 PAL.
Lens cap = 50 mm dia.

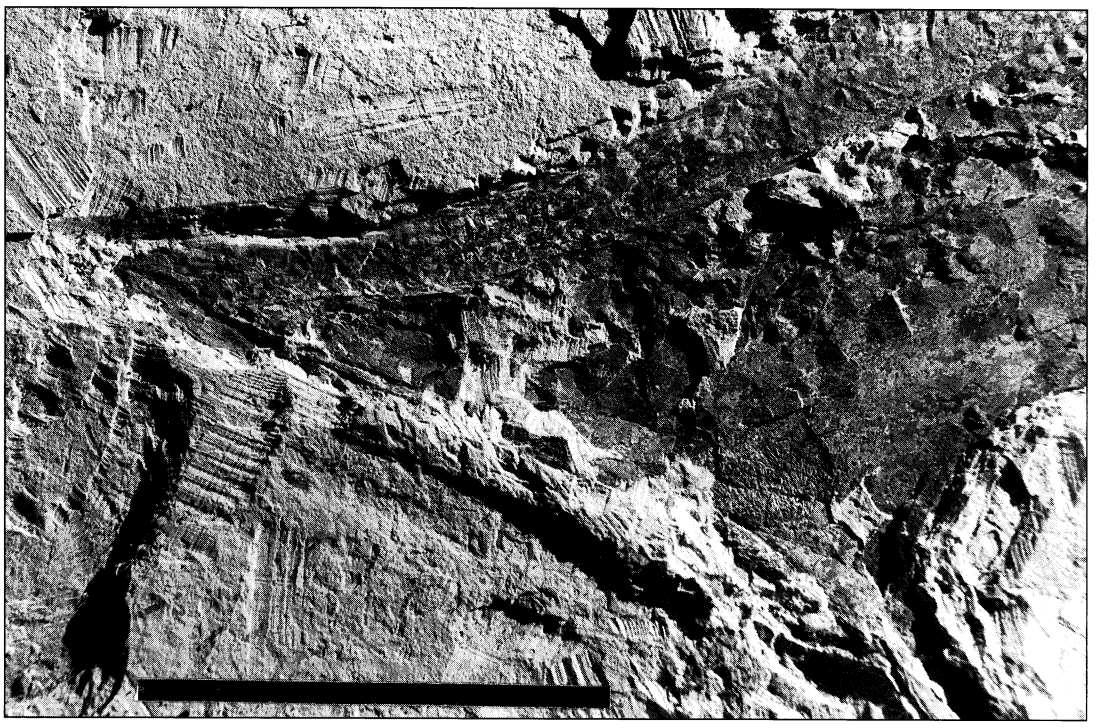


Fig. 10. Distal portion of the premaxilla of a new tapejarid from the Nova Olinda Member, Crato Formation, of Nova Olinda region, Ceará, Brazil. This specimen (SMNK 2343 PAL) shows an anteriorly placed skin "flap" and a "horny" beak - like covering which projects both anteriorly and ventrally beyond the premaxilla and would have overlapped the dentary when the beak was closed.
Scale bar = 50 mm.

ACKNOWLEDGEMENTS

Thanks to Dr Paulo Brito (UERJ) and Dr Betimar Filgueira (D.N.P.M. Fortaleza) for their assistance in the field. Thanks to Mr Robert Loveridge for photography; Dr David Unwin for helpful discussions and Dr Mike Barker for critical reading of the manuscript. We especially would like to thank the staff of the Museo do Paleontologia, Santana do Cariri for kindly allowing us to photograph specimens in their care and M. Julian Hume for allowing us to reproduce Fig. 8.

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Note reçue le 31-07-1997
acceptée après révision le 15-03-1998