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David W. E. Hone & Eric Buffetaut (Guest Editors)

## Flugsaurier: pterosaur papers in honour of Peter Wellnhofer

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**Cover Illustration**: Modell eines *Rhamphorhynchus* aus dem Oberjura von Eichstätt. Entwurf: P. Wellnhofer, Modell: R. Liebreich, Foto und Collage: M. Schellenberger, L. Geißler, BSPG München.

**Umschlagbild**: Reconstitution of a *Rhamphorhynchus* from the Upper Jurassic of Eichstätt, Bavaria. Concept: P. Wellnhofer; design: R. Liebreich; photograph and collage: M. Schellenberger, L. Geißler, BSPG Munich.

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# First pterosaur remains from the Exu Formation (Cretaceous) of the Araripe Basin, Brazil

By
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## Abstract

A fragmentary pterosaur proximal humerus from the basal member of the Exu Formation (Cretaceous) of Piauí, Brazil represents the first pterosaur element from this formation and may even be the first macrofossil from this dominantly arenaceous horizon. The fragment is tentatively assigned to Lophocratia Unwin, 2003. The preservation is inconsistent with it having been reworked from the famously pterosaur-rich Santana Formation which under lies the Exu Formation in the region.

**Key words:** Cretaceous, Pterosauria, Exu Formation, Brazil

## Zusammenfassung

Der fragmentarische proximale Teil des Humerus eines Pterosauriers aus dem basalen Glied der Exuformation (Kreidezeit) von Piaui, Brasilien, repräsentiert das erste Pterosaurierelement aus dieser Formation. Es könnte sogar das erste Makrofossil aus diesem mächtigen Quarzsandsteinhorizont sein. Das Fragment wurde vorläufig Lophocratia Unwin, 2003 zugeordnet. Die Erhaltung des Fossils ist schlecht, da es aus der für ihren Pterosaurierreichtum bekannte Santana Formation, dem Liegenden der Exu Formation in der Region, aufgearbeitet und umgelagert wurde.

**Schlüsselwörter:** Kreide, Pterosauria, Exu Formation, Brasilien

## 1. Introduction

The Araripe Basin of north east Brazil contains a largely Cretaceous sedimentary infill in which two fossil Konservat Lagerstätten occur, the Aptian Nova Olinda Member of the Crato Formation (Martill & Frey 1998; Unwin & Martill 2007) and the ?Albian Romualdo Member of the Santana Formation (Martill 1993). Both of these horizons are well known for the exceptional preservation of fossil vertebrates (Martill 1988, 1997; Wenz & Brito 1990). The sequence is capped by the massively bedded Exu Formation sandstone with conglomerates that form an extensive plateau known as the Chapada do Araripe.

The precise age of the Exu Formation is unknown, but Lima (1978) suggests a mid Albian age on the basis of palynomorphs. However, recent revisions of the age of the underlying Santana Formation based on palynomorphs suggests that the Exu Formation is probably somewhat younger (U. Heimhofer, pers. com. 2007). Although the formation is an important aquifer and supports a productive agriculture, its stratigraphy and sedimentology remain largely unstudied and the internal stratigraphy of the Exu Formation remains to be established. There appears to be a gradational coarsening upward from mudstones of the Santana Formation to the sandstones of the Exu Formation in the east of the region, but widespread slumping and jungle growth at the contact means that the basal boundary of the Exu Formation is rarely exposed. The situation is somewhat different in the west, where a basal unit of highly oxidised laminated mudstones, siltstones and fine sandstones termed the Simões Member by Martill & Wilby (1993) occurs widely, before passing up into massive sandstones with conglomerates.

This formation has largely been regarded as unfossiliferous but, during field work in 2005, a fragment of a pterosaurian humerus and plant remains were collected from exposures of the Exu Formation in the western Araripe Basin. The humerus, described here, apparently represents the first vertebrate fossil from this formation.

## 2. Locality

The pterosaur humerus was collected from slumped exposures of the Exu Formation on the western flanks of the Chapada do Araripe between Marcolandia in Pernambuco and Simões in Piauí. This is close to locality 23 of Martill (1993: 129). These exposures are slumped masses of light brown Exu Formation

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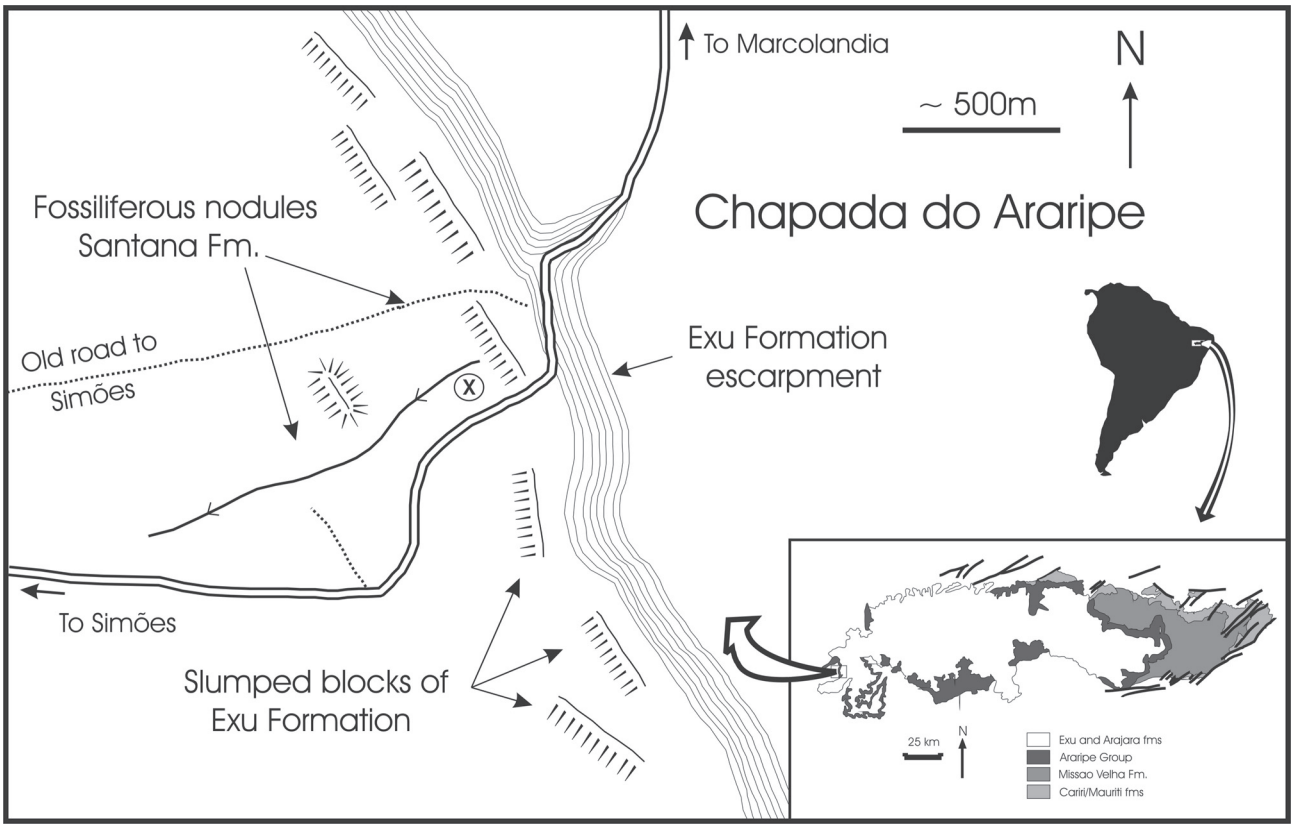



**Textfigure 1:** Sketch map of the new locality where slumped masses of the Exu Formation sandstones yield rare macrofossils. The cross in a circle marks the site where the partial pterosaur humerus was collected.

sandstones that have overridden the mudstones of the Santana Formation. The locality is easily accessed by scrambling down the bank at the side of the asphalted road (Textfig. 1). A small stream dissects the slumped masses of sandstones and a network of small paths provide access through the thorny scrub. Exposure is excellent, but determining the precise stratigraphic relationships of each slumped mass is difficult.

## 3. Stratigraphy

Due to the extensive landslip of the western flank of the Chapada do Araripe details of the stratigraphy are difficult to elucidate. Nevertheless, it is possible to identify the concretion-bearing Romualdo Member of the Santana Formation at the locality on account of its abundant laminated carbonate concretions with fossil fish and, as everywhere, the bright pink sandstones of the Exu Formation make up the escarpment face of the Chapada. Field brash of silicified laminated limestone may represent the Crato Formation, but no in situ material was found. A simplified stratigraphy for the Cretaceous part of the Araripe Basin in this region typically comprises black shales and laminated limestone that can be referred to the Crato Formation, which is overlain by bedded gypsum of the Ipubi Formation. A disconformity usually marks boundary between the Ipubi Formation and the overlying Santana Formation. There then follows a unit of finely laminated silts and fine sands, the Simões Member that near Araripina may reach 5 m in thickness. These laminated silts and sands can be identified at the locality, but their relationship to the underlying Santana Formation cannot be observed. Above the Simões Member are 5 or more metres of well bedded buff coloured sandstones with small (2–10 cm in diameter) dark brown ironstone concretions. These are especially common on weathered ground where they accumulate as a lag (Plate 1) and it is in these concretions that fossils have now been located in the Exu Formation. The buff coloured sands are overlain by several metres of bright pink sandstones and conglomerates that comprise the remainder of the Exu Formation. Although a complete stratigraphic log cannot be constructed for the locality without considerable effort, a simplified stratigraphy is presented in Textfigure 2.

## 4. Palaeontology

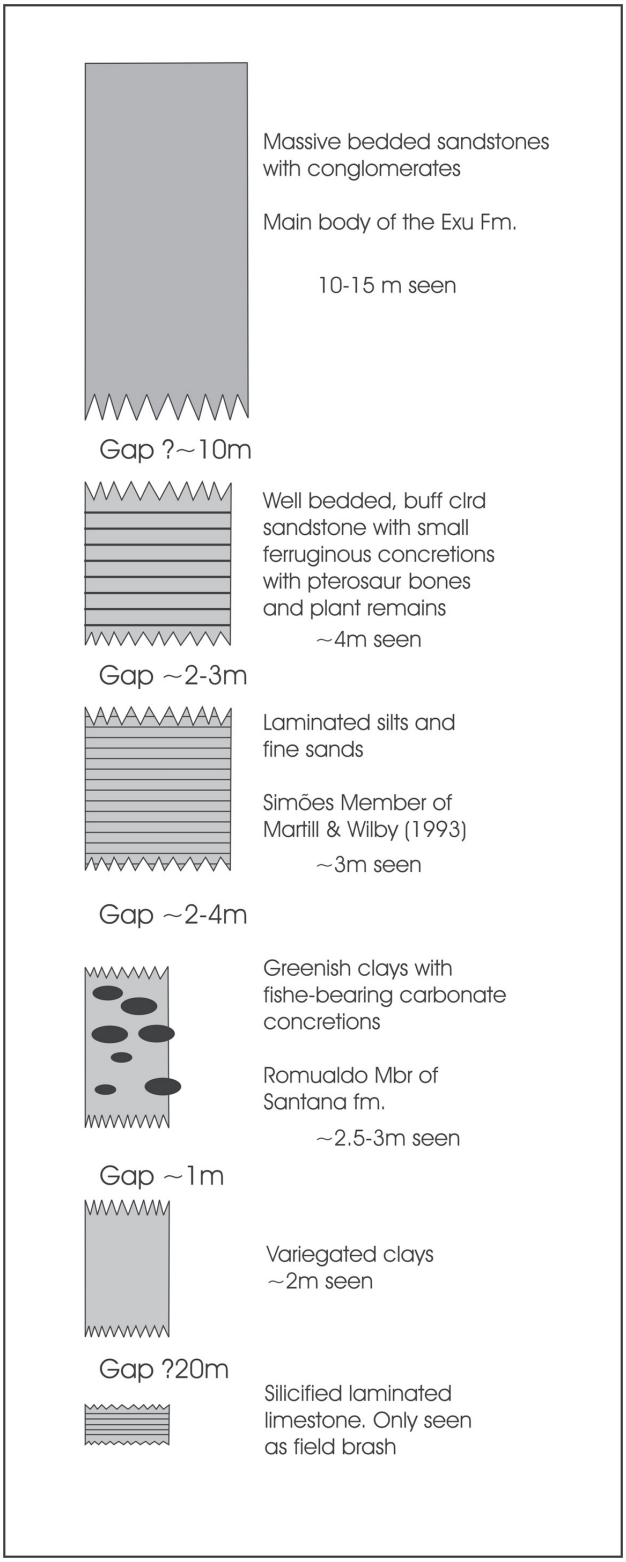
### 4.1 Systematic palaeontology

Pterosauria Kaup, 1834
Pterodactyloidea Plieninger, 1901
Lophocratia Unwin, 2003
Lophocratia Indet.

Specimen: Fragment of proximal right humerus lacking the humeral head. Number SMNK PAL 6414 in the collection of the Staatliches Museum für Naturkunde Karlsruhe, Germany.

Locality: Natural exposure on road approximately 8km east of Simões, Piauí, north east Brazil. Map reference SB.24-


**Plate 1:** New fossil locality for the Exu Formation (Cretaceous) of the Araripe Basin, Brazil. (**1**) View of the western escarpment of the Chapada do Araripe (background) with landslipped mass of buff coloured sands (foreground) that yield the first Exu Formation vertebrate fossils; (**2**) Weathered face of the buff sandstones with ironstone concretions and harder cemented patches weathering out.

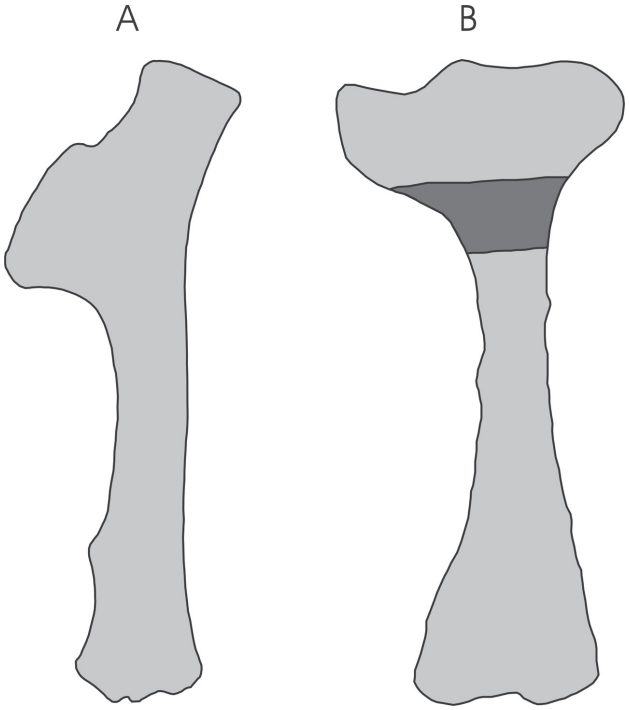



**Textfigure 2:** Simplified stratigraphic log for the slopes of the Chapada do Araripe between Marcolandia and Simões. Bed thicknesses are approximate as widespread slumping prevents accurate measurements.

Y-C-VI $^{3}08\ ^{91}60$.

Horizon: Unnamed member of the Exu Formation, above the Simões Member of Martill & Wilby (1993).

Age: Upper Cretaceous, most probably younger than Albian.



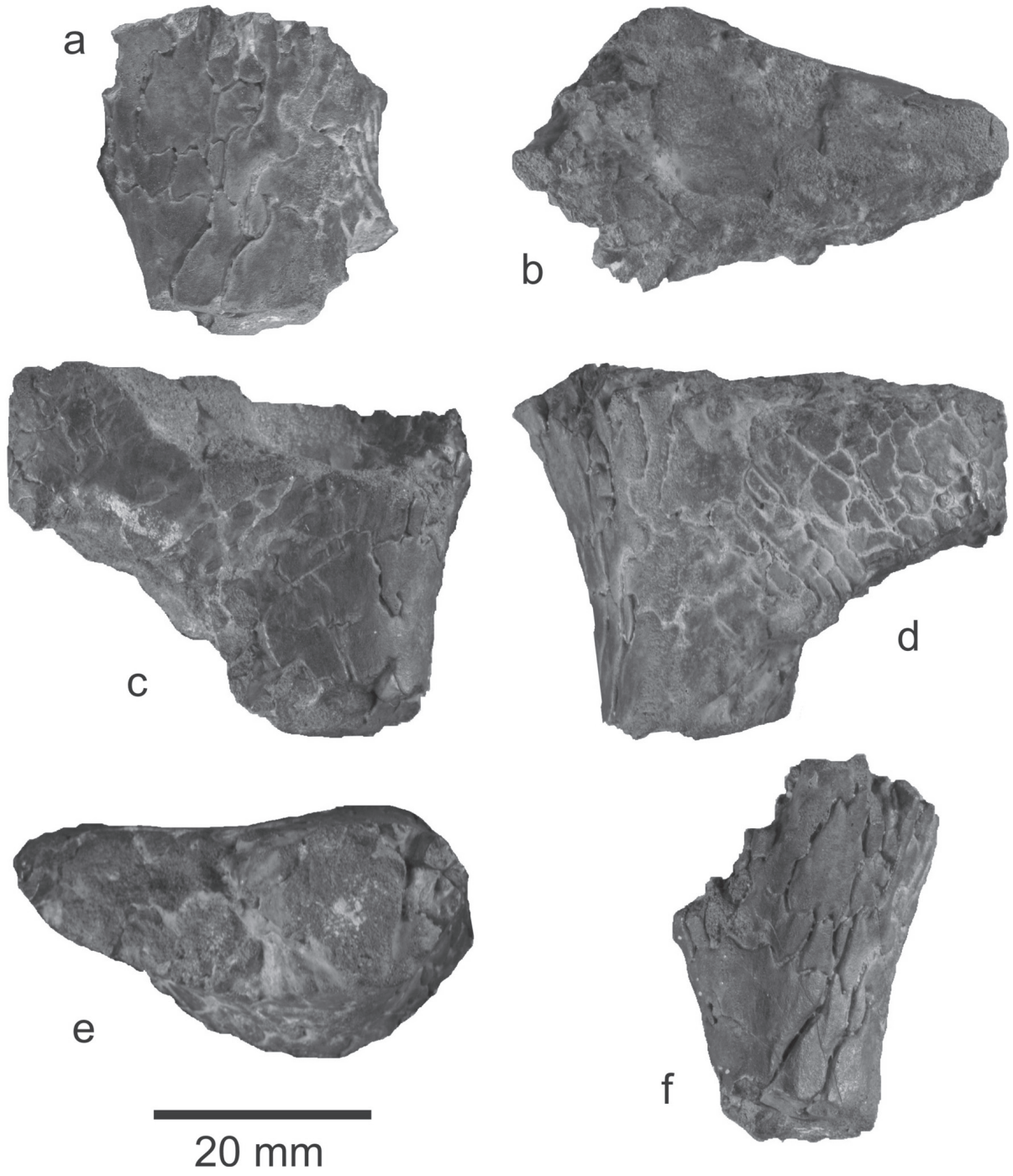

**Textfigure 3:** Pterosaur humeri. A, ornithocheirid type; B, lophocratan humerus, *Tapejara wellnhoferi* with the Exu Formation fragment shaded in dark grey. A, based on Welnhoffer (1991); B, based of Frey et al. (2003: fig. 4B' SMNK PAL 1137).

### 4.2 Description

The humeral fragment measures 33 mm in length, with a maximum proximal diameter of 47 mm and 18 mm distally. The bone is preserved as an iron oxide (presumed to be goethite on account of its dark brown colour) cemented fine sandstone infill of the void space of the humerus. All cortical bone has flaked away to reveal an internal mould of the bone with trabeculae intact. There is no crushing and the missing termini have clean fractures suggesting that more of the bone was originally preserved. Although the cortical bone is missing, there is no evidence of wear due to abrasion, but the trabeculae are incised perhaps due to some slight chemical weathering. The exposed trabeculae are widely spaced, forming irregular polygonal cells that become denser proximally (Textfig. 4a,f) with individual trabeculae approximately 0.75 mm thick. The cross-sectional shape at the distal termination is a rounded asymmetrical triangle (Textfig. 4b), whereas the cross section is a flattened 'D' shape proximally (Textfig. 4e). The palmar surface expands proximally equating to the base of the deltopectoral crest (Textfig. 4c,d). Fossil plant material was also found at this locality and is enclosed within ironstone concretions, but the bone lacks any ironstone overgrowths.

## 5. Discussion

The internal structure of this bone fragment is typical of the proximal and distal parts of the larger long bones of pterodac-




**Textfigure 4:** Partial pterosaur proximal humerus from the lower units of the Exu Formation between Marcolandia and Simões, Piauí, Brazil. Specimen no. SMNK 6414. a: detail of trabeculae, b: proximal view, c: ventral fascia, d: dorsal fascia, e: distal view, f, cranial fascia.

tyloids (de Ricqlès 2000). The gentle proximal expansion of the diaphysis into the deltopectoral crest is reminiscent of the condition found in the humeri of the lophocratian pterosaurs *Tapejara* (Textfig. 4b) and *Lonchodectes* (Unwin 2003: fig. 17j), rather than the near 90 degree deflection seen in ornithocheirids. Although referral here to Lophocratia Unwin, 2003 is speculative given the highly fragmentary nature of the specimen, it is worth noting that the lophocratians *Tupuxuara Tapejara*, *Tupandactylus* and possibly *Cearadactylus* occur in the underlying Santana and Crato Formations (Unwin & Martill 2007). Regardless, despite the lack of taxonomic precision, the discovery of this pterosaur fragment is significant in two respects. Firstly, it demonstrates that body fossils, although clearly rare, do occur in the Exu Formation. Perhaps this locality represents an unusual facies of this dominantly sandy unit, and further work should be undertaken to determine the geographical distribution of this fossiliferous horizon. Secondly, the preservation, although far from ideal, is of an uncrushed bone that is not enclosed within a calcareous concretion. Although the possibility exists that originally the

fragment was indeed enclosed in a concretion, and subsequent weathering released the fossil, perhaps with the bone compacta remaining on the concretion, it seems more parsimonious that the bone was preserved in three dimensions in uncompacted sandstone. If this latter scenario is correct, then it is most likely that the pterosaur bone is at least penecontemporaneous with the sediment and does not represent an element reworked from the underlying Santana Formation. If this is the case, then this specimen represents another occurrence of a pterosaur in a non-marine horizon.

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