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SUPPLEMENTARY ONLINE MATERIAL FOR

# Pterosauria of the Great Oolite Group (Bathonian, Middle Jurassic) of Oxfordshire and Gloucestershire, England

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**Supplementary Online Material**

**SOM 1.** A complete list of pterosaur specimens from the Great Oolite Group accessioned in British collections recorded as coming from the "Stonesfield Slate"
available at http://app.pan.pl/SOM/app63-OSullivan_Martill_SOM/SOM_1.xlsx

**SOM 2.** Further specimen description.

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As described in the main text and listed in SOM 1, the British Middle Jurassic pterosaur collection contains several hundred isolated fossils. Many of these are fragmentary and almost impossible to properly describe while others are more complete but lack robust taxonomic identifiers. Providing detailed descriptions of many of these specimens as part of our primary dialogue would needless inflate the text and so in this SOM 2, we provide description of some of the largest, most complete or most notable fossils which are suitable for discussion but do not have the taxonomic significance of the material we cover in the main text.

## 1. Mandibular specimens

*OUM J.28275, OUM J.28500, OUM J. 28501*

OUM J.28275 (SOM 2: Fig. 1a) is a fragmentary pterosaur jaw 72 mm long anteroposteriorly and 12 mm long dorsoventrally. It has an oval cross-section with thin bone walls. Several concavities are present on what is assumed to be the dorsal surface which may be alveoli but are irregularly shaped and very widely spaced. While the thin bone walls and generally smooth texture supports the positive identification of OUM J.28275 as a pterosaur and its fragmentary leads it to be identified as Pterosauria indet.

OUM J.28500 and OUM J.28501 (SOM 2: Fig. 1b,c) are two fragmentary jaws with thin bone walls. OUM J.28500 is almost featureless, its only distinguishing feature being the unusually bright colour of the bone. OUM J.28501 has several concavities which may be alveoli but are difficult to distinguish from breakage across the jaw. OUM J.28500 and OUM 28501 are very cautiously identified as Pterosauria indet. based on their thin bone walls but require further examination. It is possible that these characters are ontogenetic not taxonomic, which may place them in another group altogether.

*GSM 113723, GSM 113725, GSM 6028*

GSM 113725 (SOM 2: Fig. 2a,c) is an isolated anterior lower jaw with a short symphysis. It is 45 mm anteroposteriorly and exposed in a ventrolateral view. Much of the bone is worn and broken with no left ramus. The exposed anterior alveoli are all approximately 5 mm mesiodistally. They are dorsally oriented with slightly widening spacing posteriorly. The alveolar spacing and mesiodistal length is like GSM 113723 (see main text) but it lacks the slightly splaying alveoli. The poor preservation of GSM 113725 limits its comparison to GSM 113723, but its alveolar spacing and mandibular symphysis do identify it as a probable Rhamphorhynchid.

GSM 6028 (SOM 2: Fig. 2b) is a 72 mm long jaw fragment. It has a thin bone wall with a rugose and pitted surface texture. It preserves 10 dorsolaterally oriented alveoli, all ~4-5 mm mesiodistally and spaced 2-4 mm apart which gives the dorsal margin a strongly undulating appearance. A trapezoidal fragment is positioned apart from the jaw but on the same plane. While this specimen has been accessioned amongst the Middle Jurassic pterosaur material, it is can confidently be identified as non-pterosaurian. Raised alveoli are unique to lonchodecthids pterosaurs (Witton, 2013) and are not associated with a strongly rugose bone texture (SOM 2: Fig. 2d), a distinctly non-pterosaurian characteristic. In the Bathonian, both these features are more typical of crocodylomorphs (Phillips, 1871), specifically thallattosuchians (Jouve, 2009) leading GSM 6028 to be identified as Thallattosuchia indet.

## 2. Axial specimens: Ribs

Ribs accessioned within pterosaur collections occur in most Taynton Limestone Formation. pterosaur collections (SOM 2: Fig. 3, see SOM 1 for a complete list of specimens) and there are multiple morphotypes. Some are hyper-elongate with distinctive distal curvature (SOM 2: Fig. 3a,b) which are most likely either posterior thoracic ribs or gastralia. Others are relatively short with 90° curves and broad proximal bases, identified here as cervical ribs (SOM 2: Fig. 3c). The final dominant form is a long continually curving rib (SOM 2: Fig. 3d) identified as thoracics (Schachner et al., 2009). Taxonomically differentiating isolated ribs is extremely difficult as beyond size and without good comparative material, they lack strong identifiers. At best, we can say that the cervical ribs are likely too large to be pterosaurs reaching the ~2m wingspan we find in the Great Oolite Group.

## 3. Appendicular material: Scapulae and coracoids

Several isolated scapulae or coracoids (SOM 2: Plate 1) have been found in the British Bathonian collections. Most are difficult to identify due to the lack of articulation and their poor preservation. At least one scapula, OUM J.28299, (SOM 2: Plate 1: fig. c) is dubiously pterosaurian as it broader than is common in pterosaurs. The coracoids are frequently broken with only a small few (e.g. NHMUK PV R 876, SOM 2: Plate 1: fig. b) were preserved in their entirety. Like the scapulae, isolated coracoids have limited taxonomic value but currently all are confidently identified as pterosaur.

## 4. Appendicular specimens: Forelimb

*Ulnae and radii*

Ulnae and radii are common components of the Bathonian pterosaur assemblage (SOM 2: Plate 2) with their preservation quality poor impressions (e.g. NMW GD 93.99G.2, SOM 2:

Plate 2: fig. b) to pristine (e.g. MUM LL15941.645 and NHMUK PV R 38016, SOM 2: Plate 2: figs. a, d). There is a single prominent ulnar morphotype within the British Middle Jurassic pterosaur collections, as demonstrated by NHMUK PV R 38016. It has a straight diaphysis with a rectangular process on the dorsal side of the proximal ulna. The distal margin is sloped and there is a broad sub-rounded dorsal process. This compares well with that of several basal pterosaurs including *Rhamphorhynchus*, *Eudimorphodon* and *Campylognathoides* (Wellnhofer, 1975; Wild, 1978; Padian, 2008a). Unfortunately, non-pterodactyloid radii and ulnae are generally poorly figured elements in the literature, and therefore NHMUK PV R 38016 is only identified here as Pterosauria indet.

While most ulnae fall into the above morphotype, NHMUK PV R 28610 (SOM 2: Plate 2: fig. c) from the Eyeford Member of the Fuller's Earth Formation in Gloucestershire presents a distinct second morphotype. The specimen is a distal ulna and is distinguished from the main morphotype by its dorsal process being more elongate and narrower giving it a more triangular appearance, making it longer relative to the diaphysis. Like NHMUK PV R 38016, NHMUK PV R 28610a is difficult to identify taxonomically but its presence confirms that at least two ulnar morphotypes occur in the British Middle Jurassic.

Bathonian pterosaur radii are similarly diverse, with two distinct forms. The first, as demonstrated by NHMUK PV R 40126 (SOM 2: Plate 2: fig. e), has a noticeably bowed distal shaft, a broad proximal articulation with a rounded ventral expansion on one side and a sub-triangular process on the dorsal surface. The distal articulation is 'boxy' with two rounded processes on the dorsal and ventral sides of the posterior face, separated by a slight concavity. The second morphotype, exemplified by MUM REP985/LL15941.645 (SOM 2: Plate 2: fig. a), has a proximal process that is more well developed, particularly along the ventral tubercle. This gives the proximal articulation a somewhat T-shaped appearance. As with the ulnae, both morphotypes occur in a variety of pterosaurs and as radii are equally poorly figured in the literature so they are identified here as Pterosauria indet. Their significance here is the confirmation of at least two pterosaur radial morphotypes within the Middle Jurassic of Britain which presumably corresponds to the two ulnar morphotypes. Furthermore, the ulnae (which measure up to 128 mm) and the radii (up to 136 mm) allow for a wingspan estimate that suggests a range of between 1.4-2.5 m

*Metacarpals*

Pterosaur metacarpals are present but uncommon in the British Middle Jurassic collections. (SOM 2: Fig. 3). There is one probable example of a MCI-III (OUM J.28269) with 3 MCIV. MUM STR1244b is a 20 mm long MCIV with a slight curve to the shaft and a large double condyle. It is preserved in anterior view with a more strongly expanded ventral condyle. NHMUK PV R 28160b a 41 mm MCIV with a preserved length/width ratio of 8/1. It has a prominent distal condyle and above this is a shard which can be interpreted as either a broken piece of the shaft or the remnants of the associated metacarpals. While the two fossils are similar, NHMUK PV R 28160b is shows a distinct morphotype. Basal pterosaurs have MCIVs with a maximum length/width ratio of approximately 5:1 (Wild, 1978; Wellnhofer, 1991; Martill et al., 2013) while pterodactyloids have metacarpals with a length/width ratio of 9:1-20:1 (Martill et al., 2013). A ratio of 8:1 in NHMUK PV R 28160b is closer to the pterodactyloid condition but the proximal and distal diaphyses are more akin to those of basal pterosaurs. The non-pterodactyloid monofenestratan *Darwinopterus* has a MCIV with a ratio of ~10:1, with a similar constricted medial shaft along with wider proximal and distal diaphyses (Lü et al., 2010). It is therefore likely it represents another monofenestratan specimen.

*Wing phalanges*

A number of isolated wing phalanges can be fund in the Great Oolite Group (SOM 2: Plate 3, see SOM 1 for a complete list of specimens). The majority belong to the same phalangeal morphology and are likely rhamphorhynchid (SOM 2: Plate 3, see Main Text)
but one specimen may demonstrate a second phalangeal morphotype. OUM J.28534 (SOM 2: Plate 3: fig. a) is a left WP1 mounted on card in dorsal view. Its proximal articulation was figured by Phillips (1871, p 224 fig. 74.) who described it as "*Rhamphorhynchus" bucklandi*. It is 50 mm proximodistally with a diaphysis 3 mm anteroposteriorly and missing its distal articulation. The diaphysis appears straighter than other similarly sized specimens. It also appears to have a more elongate extensor tendon process. As it has been glued in place, OUM J.28534 cannot be examined in other views but it may have a shallow posterior groove. This grove suggests it is a rhamphorhynchine distinct from the other phalanges.

Several WP2-4 are accessioned in the OUM, NHMUK, MUM and GSM (SOM 2: Plate 3). These have a more variable state of completeness with several preserved primarily as impressions or articulatory ends with no complete WP2-3 (see Appendix 4 for a complete list of specimens). All fossils are contained within cut slabs of oolitic limestone. Unlike the first phalanges there appear to be no anterior curve. The WP4s have a posterior curve in their distal half. WP 2-4 are usually taxonomically uninformative in isolation, as much of their diagnostic value comes from their relative proportions with associated bones (Unwin, 1988b; Bennett, 1995). On their own they are more valuable for an indication of pterosaur size ranges. The WP2 assemblage ranges between 93-195 mm, the WP3 assemblage 89-144 mm and the WP4 assemblage 37-157 mm, suggesting a range of 0.5-1.8 m, with phalanges from larger animals being more common than those of smaller ones.

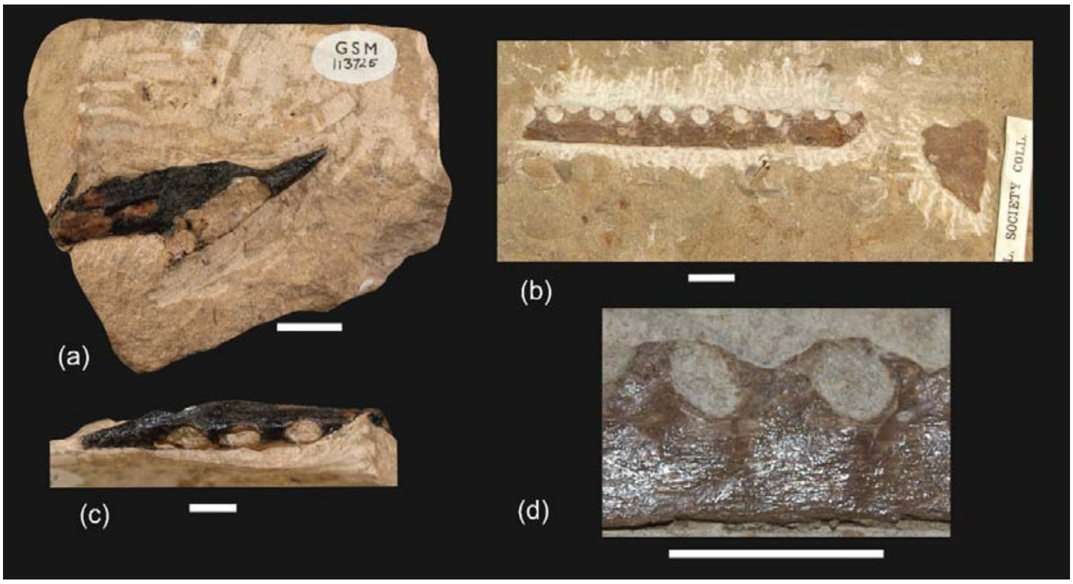
## 5. Axial specimens: Hindlimb

Several Taynton Limestone Formation femora and tibiae have been accessioned in the OUM, GSM and NHMUK collections (SOM: Fig. 5, 6, see SOM 1). While complete femora are known, they are uncommon with most being only the proximal articulation. The size range of these complete femora is quite large, going from 19-97 mm long with femoral heads angled at 130-160° relative the diaphysis. Taxonomically, the most significant part of the femur is the head, as the angle can be diagnostic. Lower angles being found in basal pterosaurs and higher angles in pterodactyloids. However, while this can be informative when dealing with extremes, there is a large amount of overlap between pterodactyloids and other Jurassic pterosaurs. Several non-pterodactyloid pterosaurs including Wukongopteridae, Rhamphorhynchidae *Campylognathoides* and *Preondactylus* can have femoral necks angled between 130-150°. Jurassic pterodactyloids such as ctenochasmatoids and dsungaripteroids can have femoral necks angled as low as 120°. Therefore, there is a large enough overlap that they should only be considered diagnostic when dealing with outlier values. The "Stonesfield" femora (SOM 2: Fig. 5) possess a length/width ratio ranging from 10:1 to 22:1. This morphotype is found in derived non-pterodactyloids such as Rhamphorhynchidae (Wellnhofer, 1991; Padian, 2008a), but also the monofenestratan Wukongopteridae (Wang et al., 2009; Lü et al., 2010) and Pterodactyloidea (Wellnhofer, 1991). They are considered here to be Pterosauria indet. based on the available information.

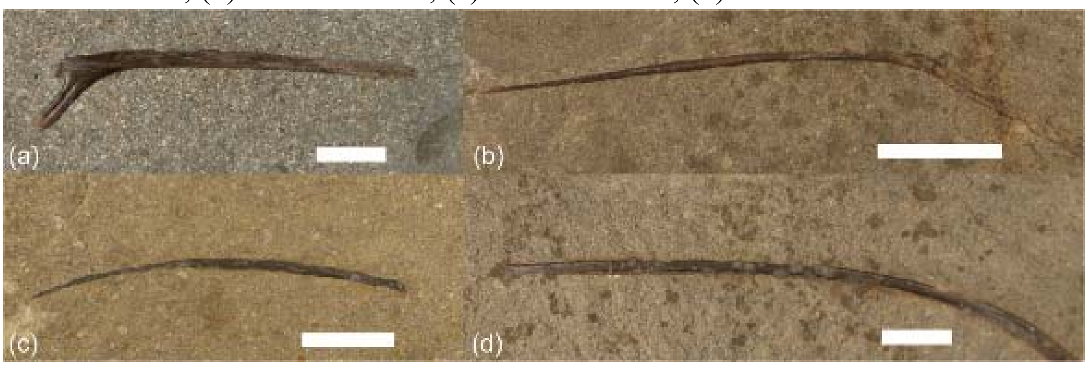
Pterosaur tibiae (SOM 2: Fig. 6) are typified by being elongate bones with rounded shafts and relatively broad proximal epiphyses, which in basal pterosaurs are associated with a thin fibula. As pterosaurs become more derived the fibula is reduced and more heavily fused to the tibia, disappearing in more derived pterodactyloids (Wellnhofer, 1991; Bennett, 2001; Buffetaut et al., 2010). The distal tibia has a sharply angled epiphysis which fuses to the tarsal bones to form a tibiotarsus, in a similar manner to birds (Buffetaut, 2010). The diaphysis is extremely difficult to identify in isolation, as a round shaft is also present in the ulna and the radius. Ultimately tibiae are one of the hardest elements to identify when fragmented and have very little taxonomic information. Furthermore, the British Bathonian collections do not preserve any complete tibiae. Combine this with the general lack of well figured tibiae (Bennett, 2001a) and tibia are considered here to be the least useful elements in the assemblage.

SOM 2 Fig. 1. Three pterosaur mandibles held in the OUM collections. (a) OUM J.28275. (b) OUM J.28500. (c) OUM J.28501. From the Great Oolite Group, Oxfordshire. Scale = 10 mm.

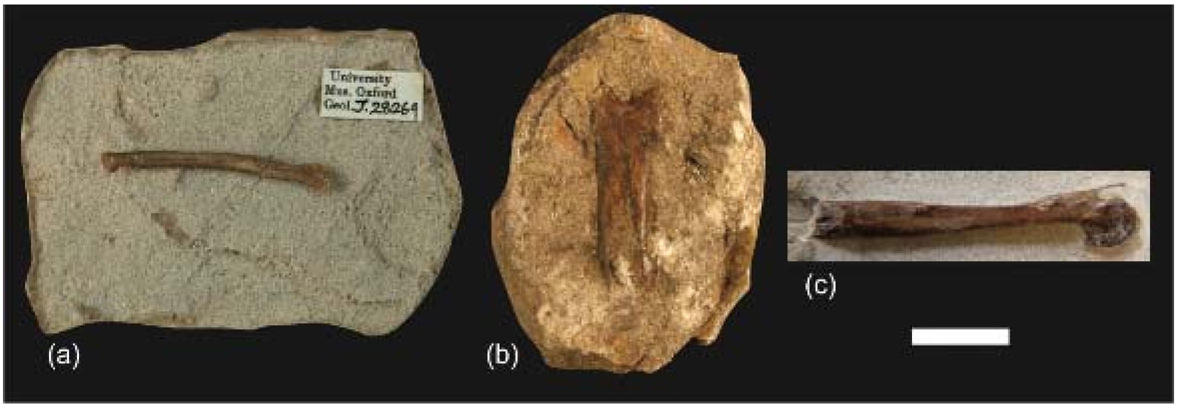

SOM 2 Fig. 2. Jaw material accessioned as pterosaur in the GSM collection. GSM 113723 in (a) right lateral and (c) dorsal views. (b) GSM 6028 with (d) an insert the raised alveoli and rugose surface texture. From the Great Oolite Group, Oxfordshire. Scale = 10 mm.




SOM 2 Fig. 3. Examples of possible pterosaur ribs accessioned in the OUM collection. (a) OUM J.28288; (b) OUM J.28393; (c) OUM J.28404; (d) OUM J.28286. Scale = 10 mm.



SOM 2 Fig. 4. Several elements identified as metacarpi from the Great Oolite Group. (a) OUM J.28269, a probable MCI-III. (b) A non-monofenestratan MCIV MUM STR1244b. (c) A probable monofenestratan MCIV NHMUK PV R 28160b. Scale = 10 mm.




SOM 2 Figure 5. Examples of pterosaur femora from the Great Oolite Group. (a) OUM J.28273, a femur that has been crushed anteroposteriorly. (b) OUM J.28354, a three-dimensional femur. Scale = 10 mm.


SOM 2 Fig. 6. Several Taynton Limestone pterosaur tibiae (a) NHMUK PV R 47993; (b) NHMUK PV R 28160c; (c) OUM J.28337. Scale = 10 mm.

SOM 2 Plate 1. Examples of pterosaur scapulae and coracoids from the Taynton Limestone Formation of Oxfordshire and Gloucestershire. (fig. a) OUM J.28270, right coracoid in posterolateral view; (fig. b) NHMUK PV R 876, left coracoid in anteromedial view; (fig. c) OUM J.28299, left scapula in posterolateral view; (fig. d) OUM J.28296, indet scapula in anteroposterior lateromedial view; (fig. e) NHMUK PV R 40126, indet scapula in anteroposterior lateromedial view. All scale bars 10 mm.

SOM 2 Plate 2. Examples of pterosaur radii and ulnae from the Taynton Limestone Formation of Oxfordshire and Gloucestershire. (fig. a) MUM LL15941.645, right radius in posterior view; (fig. b) NMW GD 93.99G.2, impression of a radius and ulna; (fig. c) NHMUK PV R 28610, left ulna in anterior view; (fig. d) NHMUK PV R 38016, right ulna? in posterior view; (fig. e) NHMUK PV R 40126, right? radius in posterior view; (fig. f) NHMUK PV R 40126, proximal right? radius in anteroposterior view; (fig. g) OUM J.28334, left? ulna in posterior view; (fig. h) OUM J.28471, proximal right ulna in posterior view. All scale bars 10 mm.

SOM 2 Plate 3. Examples of pterosaur wing phalanges from the Taynton Limestone Formation of Oxfordshire and Gloucestershire. (fig. a) OUM J.28534, left wing phalanx 1 in dorsal view; (fig. b) NHMUK PV R 40126, right wing phalanx 3? in dorsal view; (fig. c) GSM 113726, left wing phalanx 1 in dorsal view; (fig. d) NHMUK PV R 38015, left wing phalanx 3 in dorsal view; (fig. e) OUM J.28336, wing phalanx 2 in dorsal view; (fig. f) Indet right wing phalanx 4 in dorsal view. All scale bars 10 mm.