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A sauropod dinosaur tooth from the Middle Jurassic of Skye, Scotland

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ABSTRACT: A sauropod dinosaur tooth has been recovered from the Kilmaluag Formation (Middle Jurassic: late Bathonian) of Strathaird, Isle of Skye, Western Scotland. It represents the first dinosaur tooth to be described from Scotland. The combination of character states present indicates that it cannot be referred to either *Cetiosaurus* or *Cardiodon* and that it may pertain to a basal eusauropod or a basal titanosauriform. A diversity of sauropods was present in the UK in the Middle Jurassic and these faunas have the potential to illuminate many aspects of sauropod evolutionary history.

KEY WORDS: Great Estuarine Group, Kilmaluag Formation, late Bathonian, Sauropoda.

The fossil record of Scottish dinosaurs is poor: to date only a handful of isolated skeletal remains and trackways have been recovered, all of which pertain to the Lower–Middle Jurassic sequence of the Isle of Skye, Western Scotland (Weishampel *et al*. 2004). The majority of these specimens have been recovered from the Great Estuarine Group (Bathonian) of the Trotternish Peninsula (north-eastern Skye), comprising: theropod trackways, an isolated vertebra and humerus of an indeterminate sauropod, and various undescribed elements from the Valtos Sandstone Formation (Clark *et al*. 1995, 2004; Clark & Barco Rodriguez 1998; Liston 2004); an isolated footprint from the Lealt Shale Formation (Andrews & Hudson 1984); and several tracks (including a partial trackway) from the Duntulm Formation (Clark *et al*. 2004). The only other confirmed Scottish dinosaur occurrences are a tibia of an indeterminate theropod from the Lower Jurassic Broadford Beds (Sinemurian) of the Strath area, southern Skye (Benton *et al*. 1995) and partial forelimb elements of an indeterminate thyreophoran from the Bearreraig Sandstone Formation (Middle Jurassic: Bajocian) of Trotternish (Clark 2001).

This present paper reports on a new dinosaur specimen from the Kilmaluag Formation (Great Estuarine Group) of the Strathaird Peninsula, southern Skye. This material, an isolated sauropod tooth, is the first dinosaur specimen to be recovered from either the Kilmaluag Formation or the Strathaird Peninsula, and is the only known dinosaur tooth from Scotland. Although the specimen offers limited anatomical information, it does provide additional evidence for a diversity of sauropods in the British Isles during the Middle Jurassic.

The following institutional abbreviations are used throughout: BMNH, Department of Palaeontology, The Natural History Museum, London; NMS, Department of Geology, National Museums of Scotland, Edinburgh; OUMNH, Oxford University Museum of Natural History, Oxford.

1. Locality and horizon

In the Spring of 2004, fieldwork was conducted on the foreshore at Cladach a'Ghlinne, located at the mouth of Glen Scaladal, near Elgol, Strathaird Peninsula (OS grid reference [NG 519 165]: see Waldman & Evans 1994). This cliff section exposes Middle Jurassic sediments of the Great Estuarine Group, including those of the Kilmaluag Formation, which is of late Bathonian age (Harris & Hudson 1980; Andrews 1985; Bell & Harris 1986). The latter consists of intercalated calcareous mudstones, shales and occasional limestone horizons, which have been partially altered by the intrusion of numerous dykes associated with the Tertiary volcanics on Skye (Harris & Hudson 1980; Bell & Harris 1986). The combined presence of freshwater molluscs and various sedimentological features indicative of evaporation suggests that these deposits formed in closed freshwater systems, namely alternating low-salinity coastal lagoons and floodplain lakes, which periodically dried out to form extensive mudflats (Hudson 1980; Andrews 1985).

The Kilmaluag Formation of Cladach a'Ghlinne has yielded a diverse and important microvertebrate fauna that includes sharks, semionotiform fishes, salamanders, turtles, the choristodere *Cteniogenys*, crocodilians, the lepidosauromorph *Marmoretta*, various squamates, the synapsid *Stereognathus* and early mammals (Waldman & Savage 1972; Savage 1984; Evans & Milner 1994; Waldman & Evans 1994; Evans & Waldman 1996; Evans *et al*. 2006; PMB and S. E. Evans, unpublished data).

2. Description

The specimen (NMS G 2004.31.1: Fig. 1) consists of an isolated tooth with a complete crown and partial root. Although the tooth is slightly cracked, it is otherwise well preserved and fine surface details are visible. Both surfaces of the crown possess finely woven, reticulate enamel ornamentation.

In labial view (Fig. 1a), the crown (defined herein as that part of the tooth covered with reticulate enamel) is only slightly expanded mesiodistally with respect to the root, giving it an elongate, slender appearance. A slight constriction separates the crown into an expanded apical region and narrower basal portion, which are sub-equal in length. The slenderness index (SI) of the crown (the ratio between apicobasal height and mesiodistal width of the crown: Upchurch 1998) is 2·6. The labial surface of the crown is strongly convex mesiodistally and apicobasally and lacks well-defined mesial and distal grooves. In contrast, the apical portion of the lingual surface (Fig. 1b–c) is strongly concave mesiodistally and apicobasally. In combination with the labial morphology, this gives the crown an approximately 'D'-shaped transverse cross-section.

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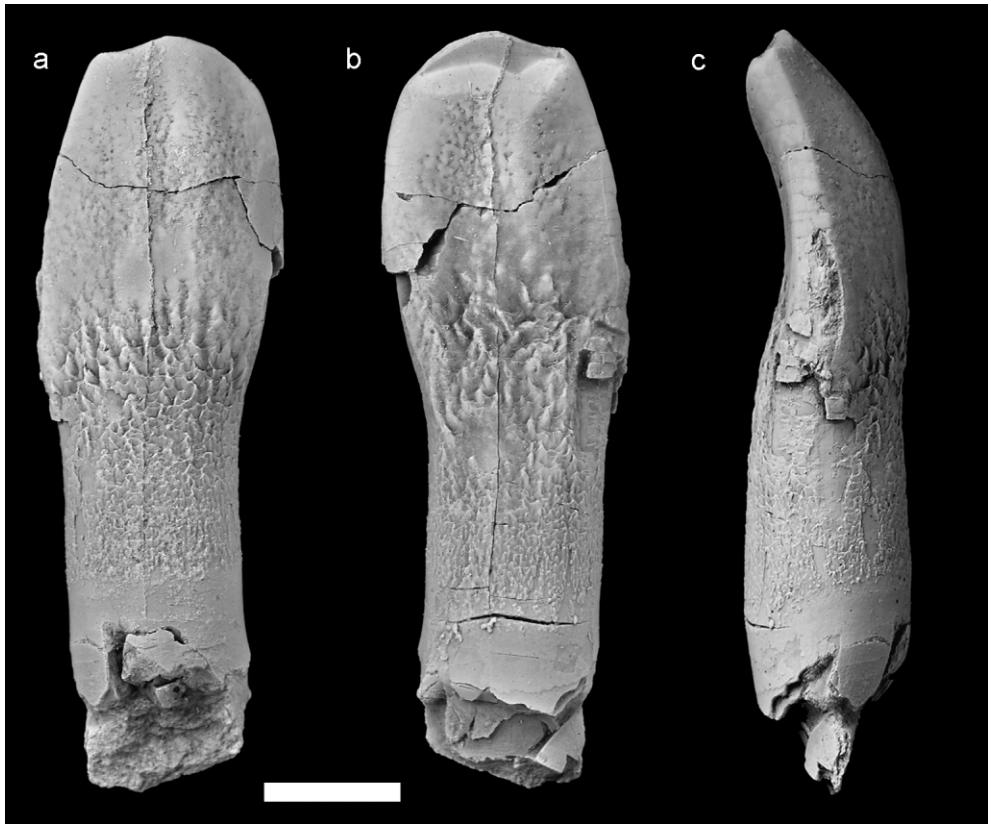

Figure 1 Tooth of a sauropod dinosaur (NMS G 2004.31.1) from the Kilmaluag Formation (late Bathonian) of Cladach a'Ghlinne, Strathaird, Isle of Skye: (a) labial view; (b) lingual view; (c) ?mesial or ?distal view. Scale bar = 5 mm.

The lingual concavity is traversed by a low, apicobasally extending ridge, situated off-centre, that is strongest apically and decreases in prominence basally.

Both crown margins lack denticles. A small, high-angled wear facet is present on the crown apex. In mesial or distal view, the apical region of the crown is labiolingually compressed relative to the crown base and is inclined lingually. Both the basal part of the crown and the root display a sub-cylindrical transverse cross-section.

3. Identification and comparison

The combination of character states present in the specimen allows some general comments to be made regarding its systematic position. For example, the presence of a well-developed lingual concavity and ridge, reticulate enamel and 'D'-shaped crown cross-section all indicate that NMS G 2004.31.1 is referable to the sauropod clade Eusauropoda (Upchurch 1998; Wilson & Sereno 1998; Wilson 2002; Upchurch *et al*. 2004). Within eusauropods, the absence of mesial and distal denticles is often considered to be a synapomorphy of neosauropods (Wilson 2002; Upchurch *et al*. 2004), but it should be noted that some teeth of non-neosauropods, such as *Shunosaurus* (Zhang 1988; Chatterjee & Zheng 2002) and *Patagosaurus* (Bonaparte 1986), also display this feature. The low SI (<4·0) indicates that NMS G 2004.31.1 is neither a diplodocoid nor a derived titanosauriform (Upchurch 1998). The SI of the Skye tooth is slightly higher than that seen in the majority of non-titanosauriform and non-diplodocoid sauropods (such as non-neosauropods and basal macronarians), which generally have SI values ranging between 1·5 and 2·5 (Barrett *et al*. 2002). The basal eusauropod *Shunosaurus* and basal titanosauriforms (such as *Brachiosaurus*) have SIs of approximately 3·0 (Chatterjee & Zheng 2002) and 2·0–4·0 (Barrett *et al*. 2002), respectively. In addition, the apical wear facet of NMS G 2004.31.1 is similar to some of those present on the teeth of both *Shunosaurus* (Chatterjee & Zheng 2002) and basal titanosauriforms (Upchurch & Barrett 2000). On the basis of the dental character states present, a process of elimination suggests that the Skye tooth pertains either to a basal eusauropod similar to *Shunosaurus* or a basal titanosauriform (on the basis of the SI values and the presence of an apical wear facet). Unfortunately, it is not possible to choose between these alternatives on the basis of the available material.

Sauropod postcranial material is relatively common in the British Middle Jurassic, but cranial material (including teeth) is extremely rare (Upchurch & Martin 2002, 2003). Owen (1840–1845) described an isolated tooth from the Forest Marble Formation (late Bathonian) of Wiltshire as *Cardiodon rugulosus* (p. 291, Pl. 75A, fig. 7a–b,d) and referred a second tooth to the same taxon (p. 291, Pl. 75A, fig. 7c), though it is unknown if the latter came from the same locality. Unfortunately, the whereabouts of both of these specimens are unknown. A third tooth (BMNH R1527: Fig. 2a–b) from the Great Oolite (late Bathonian) of Gloucestershire has also been referred to *Cardiodon* (Lydekker 1890; Upchurch & Martin 2003). In spite of the fragmentary nature of the material, *Cardiodon* does display a unique combination of character states and is provisionally regarded as a valid taxon (Upchurch *et al*. 2004). The available information indicates that the Skye tooth differs substantially from *Cardiodon*: the latter lacks the lingual concavity and apical wear present in the Skye taxon. Moreover, the teeth of *Cardiodon* possess more prominent 'labial grooves' (Upchurch 1998) than NMS G 2004.31.1, display mesial/distal tooth wear, and have much stouter crowns, with an SI of 1·2 for the holotype tooth (Owen 1840–1845: Pl. 75A, fig. 7a). *Cardiodon* tooth crowns exhibit greater mesiodistal

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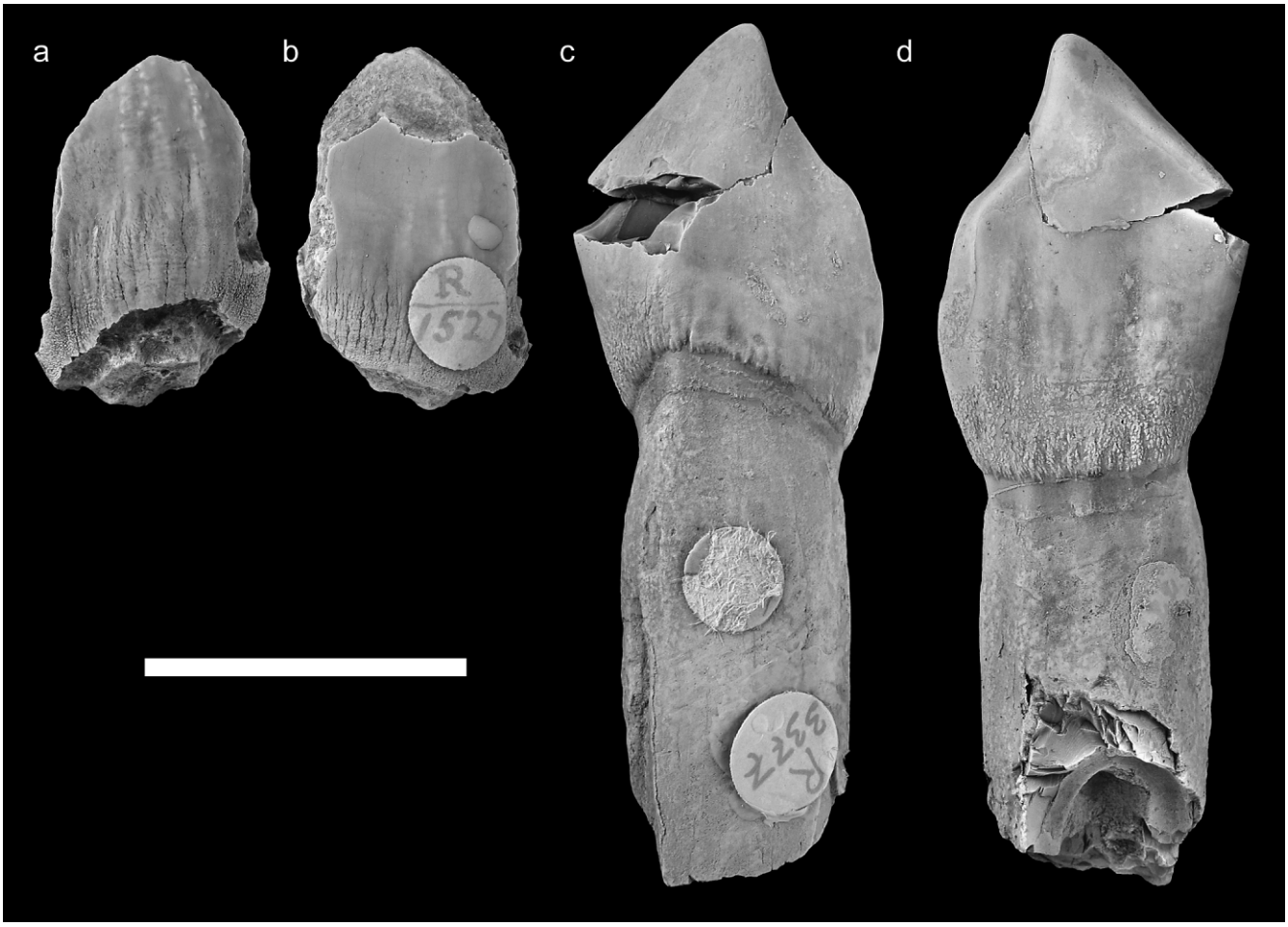

Figure 2 Teeth of sauropod dinosaurs from the Middle Jurassic of England. (a)–(b): referred tooth of *Cardiodon rugulosus* (BMNH R1527) in labial (a) and lingual (b) views; (c)–(d): tooth of '*Cetiosauriscus leedsi*' (BMNH R3377) in labial (c) and lingual (d) views. Scale bar = 20 mm.

expansion with respect to the root than seen in the Skye sauropod.

Phillips (1871, fig. 85) referred a tooth crown from the middle Bathonian White Limestone Formation of Oxfordshire to *Cetiosaurus* (OUMNH J13597: see Upchurch & Martin 2003, fig. 4). This tooth differs from that of the Skye sauropod in its possession of marked labial grooves and a crown that is strongly mesiodistally expanded relative to the width of the root. The same differences distinguish the Skye tooth from two other undescribed teeth from Oxfordshire (OUMNH J.29843 and OUMNH J.51323) that are catalogued as *Cetiosaurus* (from the lower Bathonian Sharp's Hill Formation and an unrecorded Middle Jurassic unit, respectively (H. P. Powell, pers. comm. 2005)).

Finally, three sauropod teeth (BMNH R3377: Fig. 2c–d) from the Lower Oxford Clay (middle Callovian) of Cambridgeshire have been ascribed to *Cetiosauriscus* (Martill 1988). However, these teeth were not closely associated with the holotype specimen, which consists of a partial skeleton lacking cranial material (Woodward 1905), and their referral to this taxon is questionable. Indeed, one of the three teeth differs substantially in morphology from the other two and may be referable to a distinct taxon. Nevertheless, all three '*Cetiosauriscus*' teeth display greater mesiodistal expansion of the crown than the Skye tooth. Two of the teeth have well-developed mesial and distal wear facets: none show evidence of apical wear (PMB, pers. obs.). In addition, the two most complete teeth have SIs of 1·2 and 1·5, respectively, differing considerably from the SI of NMS G 2004.31.1.

4. Discussion

Discovery of a sauropod tooth in the Kilmaluag Formation of Skye adds significantly to the Scottish dinosaur record. Comparisons with other Middle Jurassic sauropod teeth from the UK indicate that the Skye tooth is not referable to any named taxon. Other penecontemporaneous British sauropod genera are known (e.g., *Cetiosauriscus*), but cannot be compared directly with the Skye material as they are based solely on postcranial material (Upchurch *et al*. 2004).

Phylogenetic studies indicate that the Middle Jurassic was a critical time in sauropod evolution, with the first appearance of many of the lineages that radiated in the Late Jurassic and Cretaceous (Wilson 2002; Upchurch *et al*. 2004). Nevertheless, Middle Jurassic dinosaur localities are relatively rare (Weishampel *et al*. 2004), so the British sequences have the potential to add greatly to our knowledge of sauropod diversification. Until relatively recently, almost all of the British sauropod material from this interval was thought to pertain to the genus *Cetiosaurus* (e.g., Steel 1970; McIntosh 1990). However, re-interpretation of historical material held in museum collections has revealed the presence of four potentially valid genera from the English Middle Jurassic, representing a minimum of three sauropod lineages (Upchurch & Martin 2002, 2003; Wilson 2002; Heathcote & Upchurch 2003; Upchurch *et al*. 2004): Cetiosauridae (*Cetiosaurus*), Diplodocoidea ('*Cetiosaurus*' *glymptonensis*) and a non-cetiosaurid, non-neosauropod eusauropod (*Cetiosauriscus*). The higher-level relationships of one taxon (*Cardiodon*) are currently unknown.

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Other generically indeterminate material ('*Ornithopsis leedsi*') probably represents a basal titanosauriform (Upchurch & Martin 2002, 2003). New material, such as the Skye tooth (see above) and wide-gauged titanosaur trackways from Oxfordshire (Day *et al*. 2002, 2004), confirms the presence of additional sauropod taxa in the British Middle Jurassic and indicates that these sauropod faunas were much more diverse (in terms of species richness and the number of clades sampled) than previously supposed (Steel 1970; McIntosh 1990).

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