# New Bathonian (Middle Jurassic) sauropod remains from the Valtos Formation, Isle of Skye, Scotland.

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**Abstract:** The discovery of a sauropod tooth and a single sauropod footprint from the Valtos Formation supplements our knowledge of these dinosaurs from the Middle Jurassic of the Isle of Skye. Although the family cannot be determined from this single tooth, it is thought that it represents a primitive eusauropod and may belong to a similar sauropod to that previously described from limited isolated osteological evidence (caudal vertebra, damaged humerus and a rib). The characteristics that suggest this affinity include evidence of denticles on one edge of the tooth, wrinkling and granulation of the enamel, wear suggesting crown-to-crown occlusion, and the spatulate tooth shape. The single sauropod footprint is the oldest record of a sauropod footprint from the Middle Jurassic of Skye.

Dinosaurs from the Middle Jurassic of the Isle of Skye have been known of since 1982 when a large tridactyl footprint was discovered (Andrews and Hudson 1984). Since then there has been much interest in the Jurassic terrestrial fauna from the Isle of Skye resulting in many important ichnological and osteological discoveries (Clark & Barco Rodriguez 1998, Clark *et al.* 1995, 2004, 2005, Clark 2001, Liston 2004, Marshall 2005, Barrett 2006, Wills *et al.* 2014, Brusatte *et al.* 2015a, Brusatte & Clark 2015) (Fig. 1). The marine reptile fauna has also generated a lot of interest with research being carried out more recently by the inter-institutional collaborative group: PalAlba (Clark *et al.* 1993, Rees & Underwood 2005, Brusatte *et al.* 2015b).

Sauropod dinosaurs are known from the Middle Jurassic of Scotland from isolated bones and teeth (Clark *et al.* 1995; Liston 2004; Barrett 2006) and their footprints (Brusatte *et al.* 2015a). One of the first dinosaur bones found in Scotland (NG517639) was a large limb bone (SM 1977.1994.1, Clark *et al.* 1995) that was originally considered as a possible femur of a ?cetiosaurid (Clark *et al.* 1995). It was later suggested to be a left humerus of a gracile sauropod, and unlikely to be that of a member of the Cetiosauridae (Liston 2004). Similarly, a caudal vertebra (SM 1977.1996.1) that was collected north of Kilt Rock (NG502673), but also from the Valtos Formation, was also not thought to belong to the Cetiosauridae (Liston 2004). Neither of these bones exhibited diagnostic features that would allow a more reliable assignation (Liston 2004). Other bones that may belong to sauropods from the Valtos Formation include a fragmentary rib that was found at Dun Dearg, near Valtos (NG517639) and the tooth being described here from just south of Kilt Rock near Ellishadder

(NG510653). The isolated tooth described here was found in a loose boulder of grey calcareous sandstone containing the bivalve *Neomiodon* in abundance. This is characteristic of the sediments of the Bathonian Valtos Formation (Clark and Barco Rodriguez 1998, Marshall 2005).

**<Figure 1>**

The only other sauropod specimen known from the Jurassic of the Isle of Skye is a tooth which comes from the younger Kilmaluag Formation near Glen Scaladal, Strathaird (NG519165) (Barrett 2006). The peg-like tooth could belong to either a basal eusauropod or a basal titanosauriform (Barrett 2006). A new discovery of a single sauropod footprint (Fig. 2) on an overturned loose block of Valtos Formation on the foreshore at Port Earlish (NG520630) supports the concept that the sauropods were living in the deltaic and lagoonal shoreline deposits (Hudson and Harris 1979, Hudson 1983, Clark *et al.* 1995, Hesslebo & Coe 2000) in the sediments of which the bones and tooth were found. The footprint is a natural cast that has an arcuate ridge (deeper arcuate impression in the mould) and shallower rounded impression surrounded by a groove (a ridge of sediment in the mould). The arcuate structure is interpreted as being caused by the downward force of the digits similar to that seen in the Paluxy River footprints (Farlow 1992, see figure 10). It is interpreted as a pes due to the overall circular shape of the footprint and similarity in preservation and form to the concave epirelief footprints of beds 34 and 35 from the Duntulm Formation of Cairidh Ghlumaig (Brusatte *et al.* 2015a). The Duntulm Formation footprints are generally larger (up to 70cm in length) than the Valtos Formation footprint, which measures only about 40cm in length.

**<Figure 2>**

***Systematic Palaeontology***

SAUROPODA Marsh 1878

SAUROPODA indet.

Figures 3, 4, 5

*Material.* SM. 1977.2007.1: isolated crown (Fig. 3, 4, 5a)

*Provenance.* Collected by PG from a loose block just south of Kilt Rock (NG510653).

*Description.* The present tooth, in the collections of the Staffin Museum (SM.1977.2007.1), is an isolated tooth with overlapping wear facets on the margins that suggest the teeth overlapped and inserted into each other creating a continuous line of teeth (Fig. 3a, e). It is spatulate, and is missing much of the root with the top half of the crown being slightly convex and more 'D' shaped and the lower half, which is more convex. The crown has a rugose and pitted lower surface becoming more wrinkled in the upper half of the lingual side (Fig. 3b). The upper part of the labial side is relatively smooth and has a distal and mesial groove (Fig. 5a).

**<Figure 3>**

Tooth wear is variable. Much of the wear is along the edges of the tooth where occlusion has occurred. Wear facets occur along the margin of the crown and mostly on the lingual side, although the facet near the tip of the crown faces lingually, suggesting almost complete occlusion with the opposite line of teeth (Fig. 3c, d, e).

The sinuous shape of the wear facets are perhaps due to the wear of marginal denticles. Only a few of these much worn denticle bases can still be observed (Fig. 4). The lingual surface of the tooth is convex (Fig. 3b, d, e). The slenderness index (SI), measured by dividing the length of the crown (30.9 mm) by the maximum mesiodistal width (19.4 mm) (Upchurch 1998), gives a low value of 1.6 indicating a short broad crown which is in the middle of the range for basal sauropods of the Middle Jurassic (Chure *et al.* 2010). The maximum width occurs about half the crown height. All these characters suggest a primitive sauropod (Upchurch 1995, Upchurch & Barrett 2000, Upchurch *et al.* 2004, Barrett & Upchurch 2005, Chure *et al.* 2010, Mannion *et al.* 2013).

**<Figure 4>**

## Discussion

Sauropods that have spatulate teeth include the basal sauropods and the basal macronarians. Although there are several titanosauriforms that appear to have spatulate teeth also (Steel 1970; Carpenter and Tidwell 2005) their SI value is much greater (approximately 3.0 (Barrett 2006) or between 2.7-6.5 (D'Emic *et al.* 2013)). Titanosaurs are not usually found to have labiolingually compressed crowns and tend to have peg-like crowns (Díez Díaz *et al.* 2012).

The teeth of sauropods have recently been used in studies to measure diversity as well as to recognise particular clades. Certain characters, such as the tooth shape, the presence of denticles, the shape of the wear facets, and the form of the enamel wrinkling have been used in sauropod taxonomy (Holwerda *et al.* 2015). Although wrinkling is considered a synapomorphic character of Eusauropods (Holwerda *et al.* 2015), it is apparent that it also occurred in basal sauropodomorphs, such as *Anchisaurus polyzelus* (Wilson & Sereno 1998, Pol & Powell 2007).

The facet wear on the tooth is important in determining the position of the teeth during occlusion. In the case of the tooth described here, the wear pattern and shape of the tooth is consistent with a similar tooth row as that seen in *Camarasaurus* (see Holwerda *et al.* 2015, fig 7a).

Although cladistic analysis including data from teeth has been done in the past as part of an overall analysis of a number of genera (Upchurch 1998, Wilson 2002), there are not enough characters to use the teeth alone in a taxonomically useful way. Upchurch (1998) used seven characters (C66-C72) that describe the shape and ornamentation of the tooth and Wilson (2002) uses eight (67-72, 75, 76) that can be used or at least inferred from isolated teeth. More recent studies use similar numbers of characters for teeth (Manion *et al.* 2013 uses 9 and Tschopp *et al.* 2015 uses 10 that could be used here). The number of sauropods with associated teeth with enough characters preserved to make a meaningful analysis is few. Of the 81 skeletal remains used by Tschopp *et al.* (2015), only 28 exhibit any of the characters C116-C125 that can also be observed in the Skye tooth and these are not enough to determine even higher taxonomic level relationships.

Upchurch & Martin (2003) stated that the isolated tooth crown from Enslow Bridge (OUMNH J.13597, Fig. 5b) lacked serrations on the tooth margins and that there was only weak circumstantial evidence to link it with skeletal material of *Cetiosaurus* found in that area. Although the Skye tooth is similar in form to the Enslow Bridge tooth, it is clearly more rugose and has evidence of denticles on the distal margin. Another tooth that has been recorded as *Cetiosaurus* is from Padley's Quarry (also known as *Cetiosaurus* Quarry), Rock Hill, Chipping Norton where some of the first cetiosaur material came from (OUMNH J.29843, Fig. 4c). The tooth was donated to Oxford University by James Widoes who was active in the late 19th century. The tooth is more rugose than the Enslow Bridge tooth and is missing the top half of the crown. Comparisons can be made with the Skye tooth. The rugosity of the Rock Hill tooth is greater than that of the Skye tooth and there is no evidence in this tooth of serrations either suggesting that the evidence that this tooth belongs to *Cetiosaurus* is also circumstantial.

**<Figure 5>**

It would seem that the Skye tooth does not belong to *Cetiosaurus*, but may be from a more primitive sauropod. The presence of serrations on the distal margin of the tooth, albeit very worn, would suggest a more primitive trait than is present in *Cetiosaurus* according to Upchurch and Martin (2002). Of the other more primitive sauropods included by Upchurch (1998) and Upchurch and Martin (2002): *Omeisaurus* has a slender tooth that has a faint vertical ridge and lacks a basal lingual swelling (Young 1939); *Shunosaurus* has cylindrical teeth with a spoon-shaped crown that varies from triangular to oval spatulate within the jaw and wear facets are only on the lingual side (Zheng 1996); no teeth are known for *Vulcanodon*; and *Barapasaurus* is perhaps most similar with the spatulate profile, coarse serrations, asymmetric bulge of the crown although the enamel is only weakly wrinkled (Bandyopadhyay *et al.* 2010) and lacks the rugosity of the Skye tooth.

Although teeth are not presently known for *Vulcanodon*, teeth from the closely related *Tazoudasaurus* are (Allain *et al.* 2004). The serrations are more obvious in the teeth of *Tazoudasaurus* and it is less asymmetric. It also lacks the overlap facets that occur in the Skye tooth (Allain *et al.* 2004). The teeth of *Chebsaurus* have the rugose texture and are wrinkled with v-shaped occlusal wear and a spoon-shaped crown lacking the lingual basal bulge seen on the Skye tooth (Mahammed *et al*. 2005). *Patagosaurus* lacks prominent grooves on the labial side o the tooth that was identified as a synapomorphy of the eusauropods and *Barapasaurus* by Upchurch (1998), but has serrations (Rauhut 2003). *Mamenchisaurus* lacks wear facets on the elongated crowns, but does have serrations on the anterior carina (Russell & Zheng 1993). One of the most primitive sauropods from the early Jurassic of China, *Gongxianosaurus*, has an asymmetric spoon-shaped crown and lacks the lingual ridge and serrations (He *et al*. 1998). The dental serrations were identified as apomorphic at a higher node in the sauropod tree (Upchurch & Martin 2002), perhaps even at the level of the Neosauropoda, as suggested by Rauhut (2003). The presence or absence of serrations may be homoplastic however, as suggested by Upchurch (1998).

Another tooth that is very similar in character to the Skye tooth is that assigned to the eusauropods *Turiasauria* and *Neosodon* as described by Royo-Torres *et al.* (2009, p1015 – "heartshaped crowns (when unworn), a pointed and asymmetrical crown apex that is strongly compressed labiolingually and tooth crowns with convex labial surfaces with a bulge that extends from the base towards the apex").

The sauropod tooth from the Valtos Formation cannot be positively identified beyond basal sauropod on the basis of the asymmetric broad spatulate shape with low SI (1.56), the remnants of serrations on the distal side of the tooth, the rugosity and wrinkling of the enamel on the labial and lingual sides, the two lateral grooves on the labial side and the occlusal pattern.

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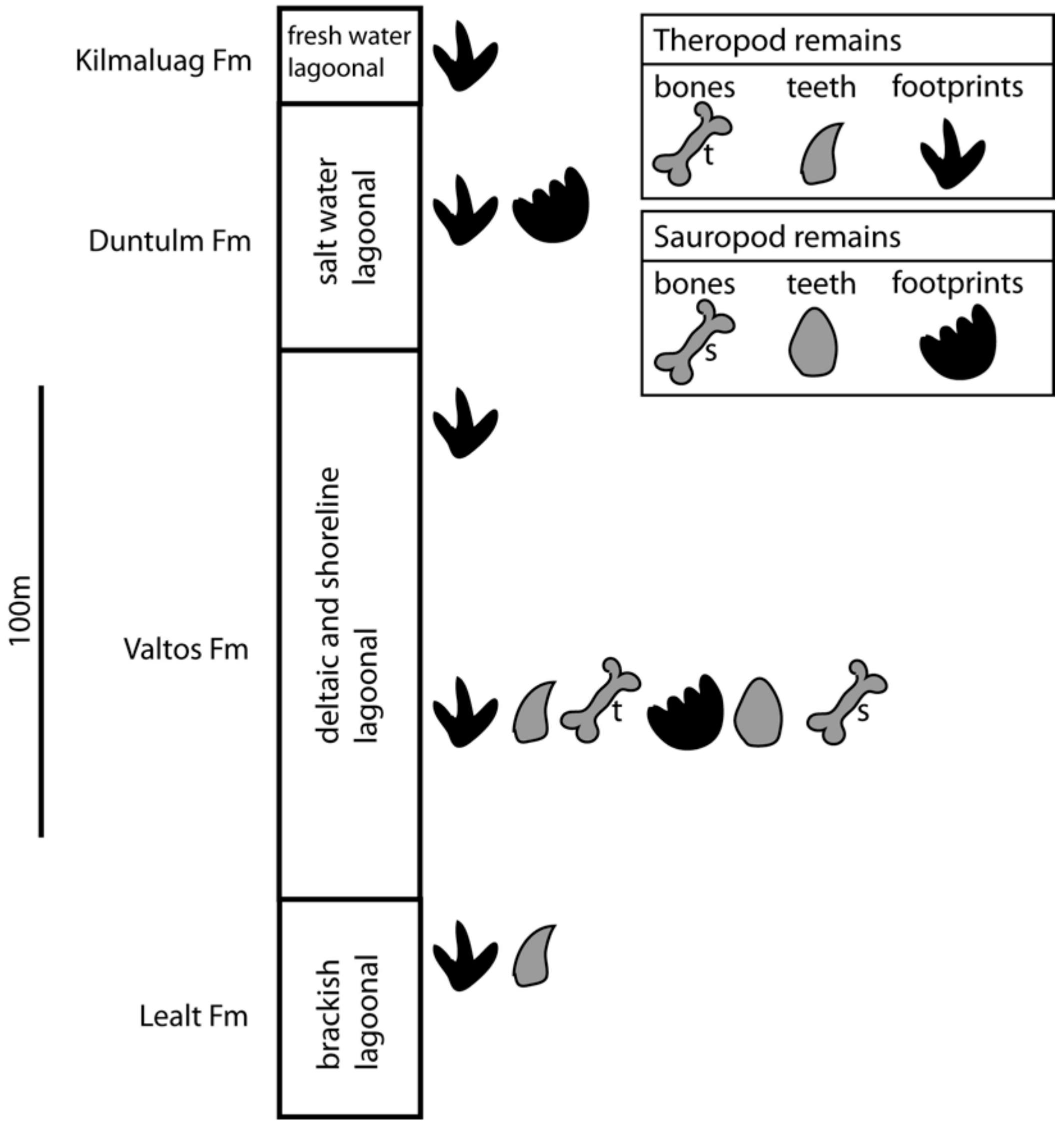
Figure 1. Thicknesses and broad environmental conditions of the formations from the Bathonian, Middle Jurassic of Trotternish, Isle of Skye, based on Hesselbo & Coe (2000) with associated dinosaur remains (Clark *et al.* 1995, 2004, 2005, Brusatte & Clark 2015, Brusatte *et al.* 2015a).




<online> Figure 2. a. Isolated ?sauropod footprint cast from the Valtos Formation at Port Earlish (NG 520630) (scale  = 10cm); b. digital elevation map (DEM) of the footprint produced using Agisoft Photoscan. The green indicates a shallow depression with some raised (blue) areas due to being a cast (yellow

and red are deeper impressions or close to the edge of the boulder in the bottom right). Individual digit impressions are not clearly visible as is common with sauropod footprints; c. DEM at 34% opacity overlying footprint image. < > = dip direction on circum-footprint ridge (cfr) which appears as a groove in the cast, the arcuate digit impression (D) is a ridge in this instance.

Figure 1

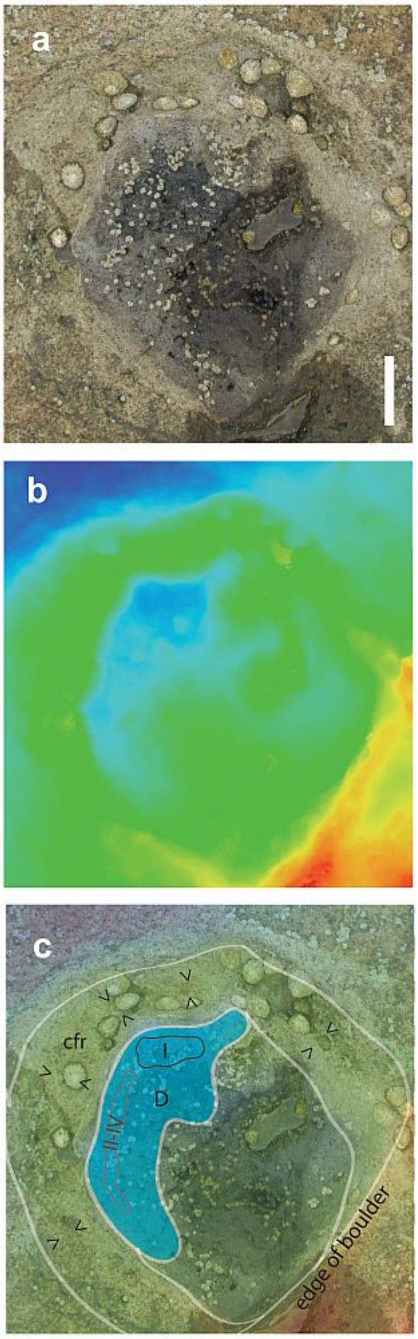
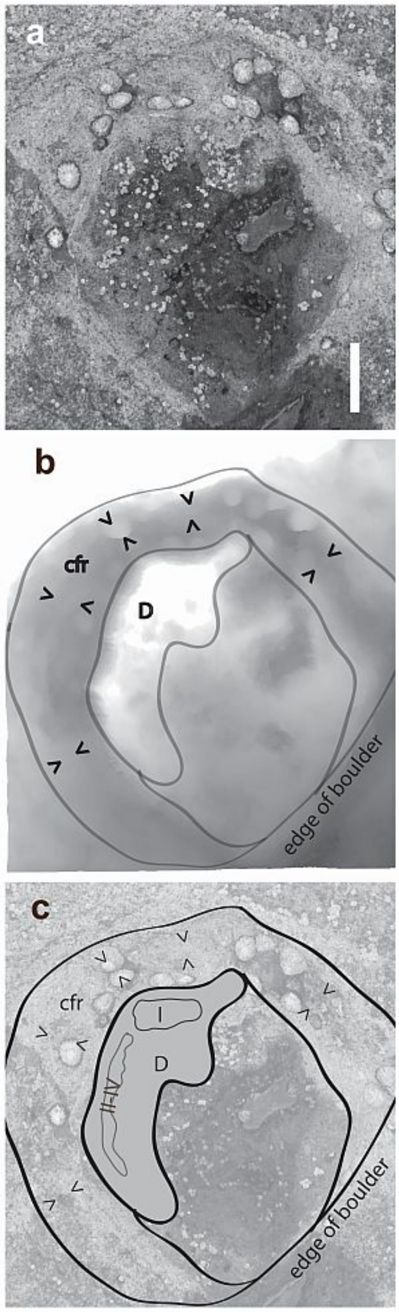


Figure 1 B&W




<printed> Figure 2. a. Isolated ?sauropod footprint cast from the Valtos Formation at Port Earlish (NG 520630) (scale = 10cm); b. digital elevation map (DEM) of the footprint produced using Agisoft Photoscan with interpretative overlay (see also the supplementary object files to view in 3D). The grey

shading (green in online article) indicates a shallow depression compared with the darker grey raised areas (blue in online article; the inverse of the natural mould as the footprint is a cast). The lighter shades are at the bottom right of the image (yellow and red in online article), indicating the edge of the boulder. Individual digit impressions are not clearly visible as is common with sauropod footprints; c. Image at 34% opacity with overlying footprint interpretation. < > denotes dip direction on circum-footprint ridge (cfr) which appears as a groove in the cast, the arcuate digit impression (D) is a ridge in this instance.

Figure 3. Isolated sauropod tooth from the Valtos Formation, Isle of Skye (SM.1977.2007.1) with associated diagrammatic representations showing wrinkling on enamel, wear on tooth (thick black areas) and the midline ridge (dashed line) viewed in: a. labial view (of = overlap facet); b. lingual view; c. top of crown view; d. distal view; and e. mesial view (scale = 10mm); lab = labial side; lin = lingual side.

Figure 2

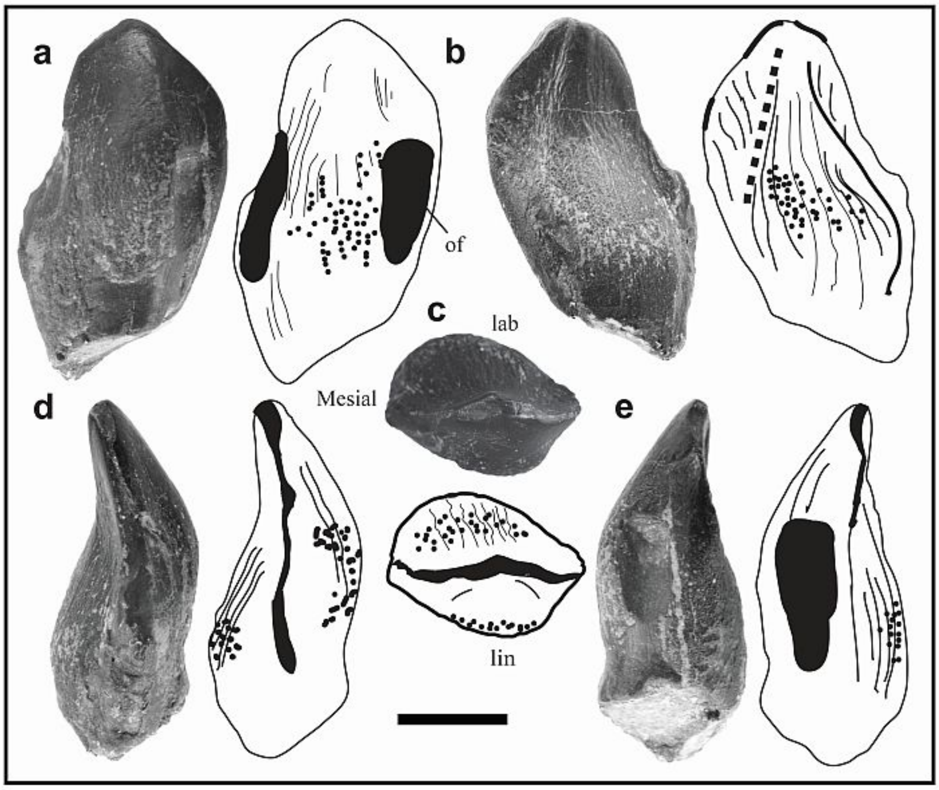



Figure 4. Distal view of Skye tooth (SM.1977.2007.1) showing: a. distal view of tooth and; b. enlargement of area marked in ‘a’ showing worn bases of serrations (scale = 10mm).

Figure 3

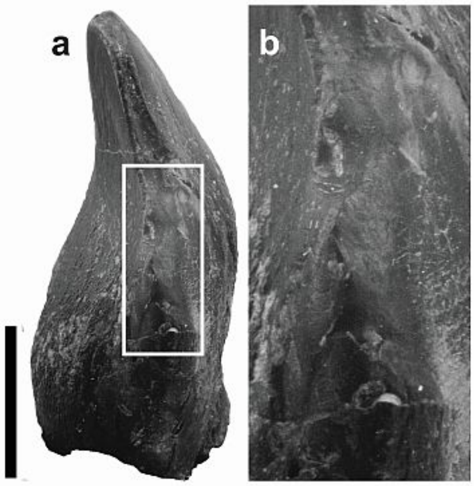


Figure 4

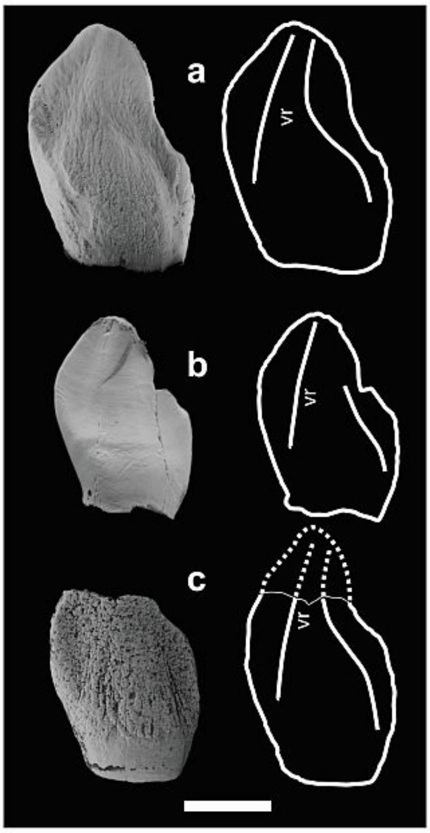



Figure 5. Comparisons of lingual views of: a. the Skye tooth (SM.1977.2007.1); b. ‘*Cetiosaurus*’ sp. from the Bathonian of Enslow Bridge, Oxfordshire (OUMNH J.13597); ‘*Cetiosaurus*’ sp. from the Bathonian of Chipping Norton, Oxfordshire (OUMNH J.29843) (scale = 10mm); vr = vertical ridge.