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## SUPPLEMENTARY ONLINE MATERIAL FOR

### **New findings reveal that the Middle Triassic ichthyosaur *Mixosaurus cornalianus* is the oldest amniote with a dorsal fin**

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Published in *Acta Palaeontologica Polonica* 2020 65 (3): 511-522.

<https://doi.org/10.4202/app.00731.2020>

#### **Supplementary Online Material**

Table 1. Selected measurements of the specimens studied herein.

Figure 1. Sasso Caldo Site (Besano, Italy), February 1993.

Figure 2. *Mixosaurus cornalianus*, photographs of skulls.

Figure 3. Drawing of the skull.

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Figure 6. *Mixosaurus cornalianus*, left hindfin of specimen BES SC 1001.

## SUPPLEMENTARY ONLINE MATERIAL

**General remarks.** The two specimens of *Mixosaurus cornalianus* described in the main article have been collected from the Sasso Caldo quarry, near Besano (Varese, Italy) where the Anisian-Ladinian layers of the Formazione di Besano crop out. In particular, these specimens come from a bed (stratum 63 of the Sasso Caldo log) that lie below the tuffitic layers that mark the limit between the Anisian and the Ladinian (Brack et al. 2005), thus are of late Anisian age.

In situ, both skeletons were laying so close/proximal to the upper surface of the depositional layer 63 that the skulls and the vertebral columns were visible as prominences with apparent anatomical correspondence (Fig. 1A).

Interestingly, the two specimens laid parallel each other but head-to-tail reversed, only 60-70 cm from one another. The thickness of the layer (11 cm), the close proximity to the back cut of the slope section, along with the firm contact with the underlying layers 64 and 65, the second of which contained the complete skeleton of a large shastasaurid ichthyosaur later named *Besanosaurus* (Dal Sasso & Pinna, 1996), recommended to cut a trench around the specimens with a diamond blade, and then carefully introduce metal foils in between the two layers to lift them (Fig. 1B). Preparation was mechanical, steel needle and sand-blasting machine were used under binocular microscope.



Figure 1. Sasso Caldo Site (Besano, Italy), February 1993. A) Specimen BES SC 1001 visible as a relief of the thin bituminous layer still covering the skeleton, before removal of stratum 63. B) The two specimens here described laid parallel each other but head-to-tail reversed, only 60-70 cm from one another.

**Selected measurements (in mm) of the specimens studied herein. Brackets indicate incomplete elements.**

Specimen	BES SC 1000	BES SC 1001
Total length	985	990
Skull length	190	(176)
Preorbital length of the skull	130	124
Orbit anteroposterior width	41	35
Postorbital length of the skull	10.5	11
Forefin total length	(~130)	132
Hindfin total length	58	74
Humerus proximodistal length	25	27.3
Ulna proximodistal length	-	20
Radius proximodistal length	-	20.4
Femur proximodistal length	17	19
Tibia proximodistal length	-	13
Fibula proximodistal length	-	14

**Osteological description.**

*Skull and lower jaw.* The skull is preserved mostly in right lateral view in specimen BES SC 1000 (Fig. 2A, 3A) and in dorsal view in specimen BES SC 1001 (Fig. 2B, 3B). The premaxillae are elongate and posteriorly pointed, lacking supranarial processes and thus forming only the anterior margin of the external naris. The maxillae bear a high and wide postnarial process that meets the prefrontal excluding the lacrimal from the external naris. The nasals, frontals and parietals form a low but well-defined sagittal crest and there is a large rostral terrace of the upper temporal fenestra; postfrontal and supratemporal meet each other excluding the postorbital from the laterodorsal margin of the temporal fenestra. The nasal is relatively short and do not reach the postfrontal; prefrontal and postfrontal are large, each forming about 1/2 of the dorsal orbital margin; the postorbital is small, limited to the posterior border of the orbit. The supratemporal forms an anterior lamina that projects above the temporal fenestra. The latter is small and slit-like, hardly visible, as it

is bordered only by supra-temporal and parietal. The squamosal is large and subrectangular, firmly sutured to the supratemporal and to the postorbital. The orbit is very large, and the length of the postorbital portion of the skull does not exceed one quarter of the rostrocaudal diameter of the orbit. The lower jaw is narrow and elongate, almost straight, with the dentary contributing to more than half of its length. The articular is transversely enlarged and has a wide and distinctly concave retroarticular portion.



Figure 2. *Mixosaurus cornalianus*, Skulls of specimen BES SC 1000 (A) and BES SC 1001 (B).  
Scale bars equal 50mm

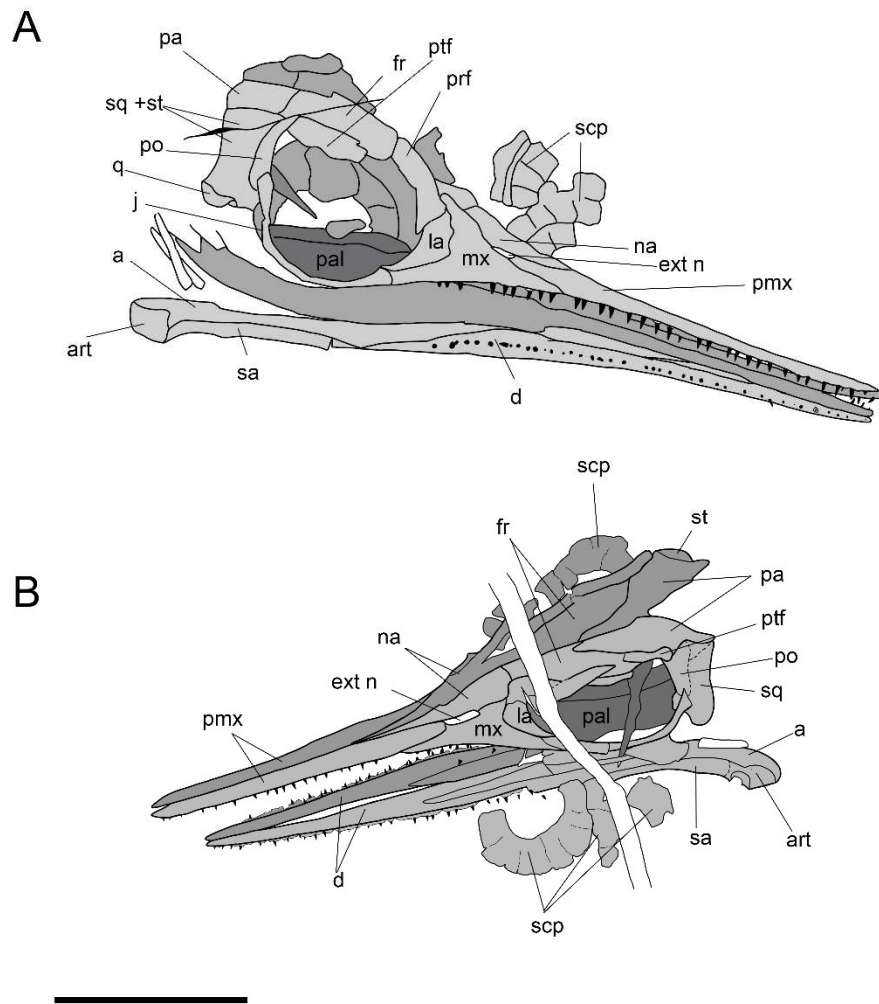


Figure 3. Drawing of the skull of specimen BES SC 1000 (A) and BES SC 1001 (B). Contralateral elements in dark grey, palatal elements in darker grey. Abbreviations: a) angular, art) articular, d) dentary, ext n) external naris, fr) frontal, j) jugal, la) lacrimal, mx) maxilla, na) nasal, pa) parietal, po) postorbital, prf) prefrontal, ptf) postfrontal, q) quadrate, sa) surangular, scp) plates of the scleral ring, sq) squamosal, st) supratemporal. Scale bar equals 50mm.

*Dentition.* 22 teeth are present on the premaxilla of BES SC 1000, about 5 mm spaced each other, and 18 on the premaxilla of BES SC 1001. The teeth are slender, conical and sharply pointed; few of the largest teeth show faint apicobasal striations. The teeth of the caudal portion of the premaxilla

are more robust, with an apex somewhat blunter than the preceding ones. In BES SC 1000 the maxilla bears 15 teeth, but two empty alveoli are also visible so that the total number should have been 17; the first five-six maxillary teeth are similar to those of the premaxilla, whereas posteriorly they become gradually more robust, with a wider tooth base; the last four-five teeth are much smaller but remain sharp-pointed. At least 34 teeth are present on the dentary, with conical crowns and pointed apices, and spacing similar to the upper teeth. Also, similar to the latter, the dentary teeth become stouter and wider caudally. Teeth are set in separate alveoli.

*Axial skeleton.* The entire vertebral column is preserved, almost fully articulated in both specimens. Only some centra are disarticulated in the cervical/anterior dorsal region and, curiously, in both specimens the last sixteen vertebrae are detached and shifted posteriorly. The vertebral count amounts to 120 vertebrae (48 precaudals and 72 caudals) in BES SC 1000, and to 117 (50 precaudals and 67 caudals) in BES SC 1001 all centra are higher than long, the height/length ratio varying from 1.45 (mid-dorsal centrum) to 1.82 (proximal caudal centrum). The neural arches bear tall and craniocaudally narrow neural spines that are approximately three times higher than the corresponding centrum. In the anterior dorsal region the neural spines are slightly inclined posteriorly, becoming nearly vertical in the mid-dorsal region and in the posterior dorsal region. The neural spines of the first 16-17 caudal vertebrae are only slightly inclined posteriorly. In both specimens the caudal peak occurs at the level of the 18<sup>th</sup>-19<sup>th</sup> caudal vertebra, where the neural spines become wider and distinctly inclined anteriorly. The haemal arches show a typical Y shape, are more developed in the proximal and distal portion of the tail, and are reduced in the middle portion.

At the level of the caudal peak the haemal spines shorten abruptly, becoming more elongate just distal to the caudal peak, then decreasing gradually toward the tip of the tail. The rib articular facets are single in the anterior and mid-dorsal region (vertebrae 23 to 30) and in the anterior caudals,

whereas they are double in the posterior dorsals to anteriormost caudals (corresponding approximately to vertebrae 38–57).

*Pectoral girdle and forefin.* The right coracoid and scapula are well visible in specimen BES SC 1000, superimposed to the corresponding elements of the left side (Fig. 4A, 5A). The coracoid shows a thick glenoid process and a large, flattened fan-shaped ventral expansion that is typical of mixosaurids (Mc Gowan & Motani, 2003); the ratio between the posterior expansion of the coracoid (measured as in Jiang et al., 2006) and the total length of the bone is 0.18. The scapula shows a fan-shaped outline with a small glenoid and coracoidal articular area placed on a peduncle set off the scapular blade. The interclavicle, better preserved in BES SC 1000, is T-shaped, and bears a distinct medial flange that housed the medial margins of the boomerang-shaped clavicles, which are also well visible in this specimen.

In both specimens the right forefin is superimposed to the left one, the humerus and the proximal portion of the radius are partially obscured by the right coracoid in BES SC 1000, whereas they are fully exposed and still perfectly articulated in BES SC 1001 (Fig. 4B, 5B) along with the carpal bones and the phalanges. The humerus widens distally, with distinct articular facets for radius and ulna. The radius bears a notch on its anterior margin; the ulna is almost as wide as the radius, with a convex posterior margin and a concave anterior margin that mirrors the concave posterior margin of the radius, so that the two bones enclose a distinct *spatium interosseum*.

The carpal series consists of four proximal carpals (radiale, intermedium, ulnare, and pisiform - this character is unknown in *M. kuhnschnyderi* (Brinkmann 2004) and *P. callawayi* (Schmitz et al. 2004), and five distal carpals. Interestingly, distal to the pisiform a neomorph (*sensu* Liu et al., 2013) is present, as in the holotype of *M. panxianensis*, some other adult specimens of *M. cornalianus*, and *P. fraasi* (Motani, 1999). The radiale is wider than long and distally bears two facets for the distal carpal 1 and 2; the intermedium is polygonal, with the two main facets articulating with the radius and the ulna, and distal contacts with the second, third and fourth distal carpal. The proximal apex of the intermedium separates slightly the radius from the ulna so that the



two bones do not meet each other at their distal end. The ulnare is subcircular, proximo-caudally contacts the ulna, the rounded pisiform and the smaller but equally rounded neomorphic carpal, and distally it contacts distal carpal 4 and metacarpal 5. Distal carpal 1 is the largest one and it is wider than long, the posterodorsal margin of distal carpal 2 is inserted between the radiale and intermedium, and the same occurs to distal carpal 4 between the intermedium and ulnare. The metacarpal series is also complete, with five elements that retain constricted shafts (an autapomorphy of mixosaurids - Maisch & Matzke, 2000), whereas some of the distalmost phalanges are disarticulated in both specimens. The phalangeal arrangement is typically pentadacyl (Mc Gowan & Motani, 2003). The phalanges of the first digit show emargination only on the caudal side, whereas the phalanges of the other digits are emarginated on both sides.

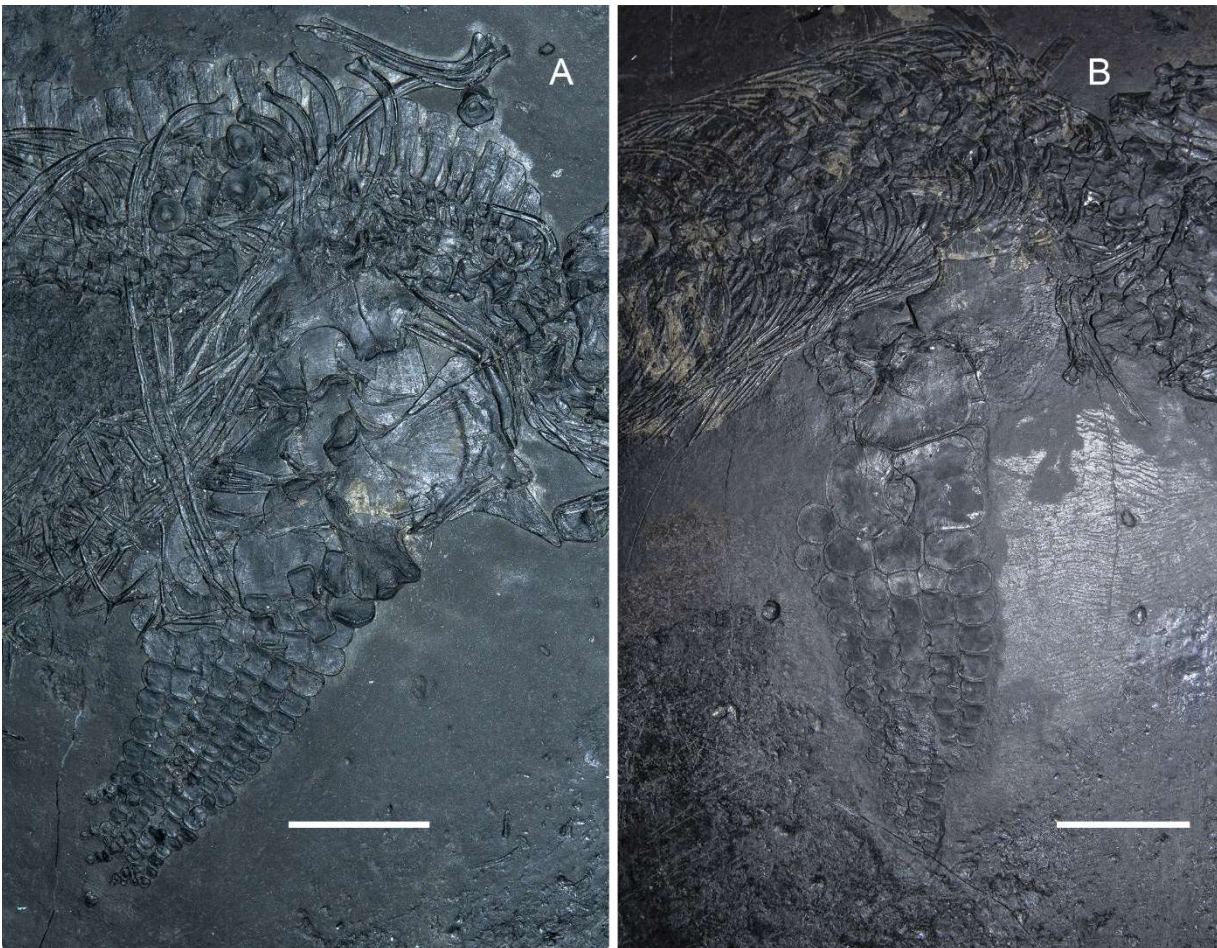


Figure 4. *Mixosaurus cornalianus* Forefins and pectoral girdles of specimen BES SC 1000 (A) and BES SC 1001 (B). Scale bars equal 50mm.

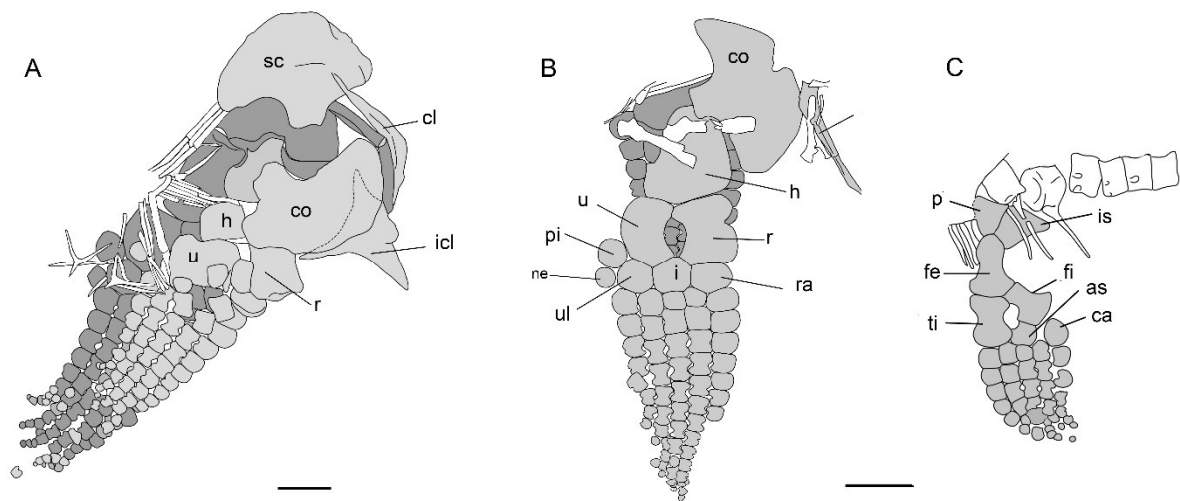


Figure 5. Drawing of the pectoral girdles and forefins of specimen BES SC 1000 (A) and BES SC 1001 (B), and drawing of the pelvic girdle and left hindfin of specimen BES SC 1001 (C). Contralateral elements in dark grey. Abbreviations: as) astragalus, ca) calcaneum, cl) clavicle, co) coracoid, fe) femur, fi) fibula, h) humerus, i) intermedium, icl) interclavicle, is) ischium, ne) neomorph, p) pubis (broken anteriorly), pi) pisiform, r) radius, ra) radiale, sc) scapula, u) ulna, ul) ulnare. Scale bars equal 20mm (scale bar is the same for B and C).

*Pelvic girdle and hindfin.* The pelvic girdle is only partially visible in both specimens. In BES SC 1000 the pubis is visible, it is much longer than high and its anterior portion is expanded; in BES SC 1001 the pelvic girdle is obscured by overlying vertebrae and ribs, thus only the distal portion of pubis and ischium can be detected. The hindfin measures about half the length of the forefin in both specimens (Tab. 1). The left hindfin of BES SC 1001 is excellently preserved (Fig. 5C-6), nearly complete and articulated (Fig. 3C). The femur is longer than wide, and distally expanded with a slightly convex articular area for the tibia, which is nearly two times wider than the slightly concave articular area for the fibula. The tibia, still longer than wide, has a short straight shaft and equally expanded proximal and distal ends. The fibula is as long as wide and, like the femur, has a distal end much wider than the proximal one. Both tibia and fibula contact the astragalus that separates the two bones distally. forming a well-defined *spatium interosseum*.

The rounded calcaneum is somewhat shifted from its original position. Four distal tarsals are present, the first two being the largest ones; distal tarsals 1 and 3 are roughly squared in shape, distal tarsal 2 is sub-pentagonal, distal tarsal 4 is medially constricted. Five metatarsals are present: metatarsal I has a convex lateral margin, metatarsals II-IV are emarginated on both sides; the fifth metatarsal has a concave outer margin.

The exact number of preserved phalanges cannot be established due to superimposition of phalanges from counterlateral digits. With regards to their shape, the phalanges of the first digit show no emargination, whereas the phalanges of the second digit are emarginated on their caudal side, and the first three-four phalanges of digit III - V show distinct emarginations on both sides.



Figure 6: *Mixosaurus cornalianus*, Left hindfin of specimen BES SC 1001. Scale bar equals 50mm.

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