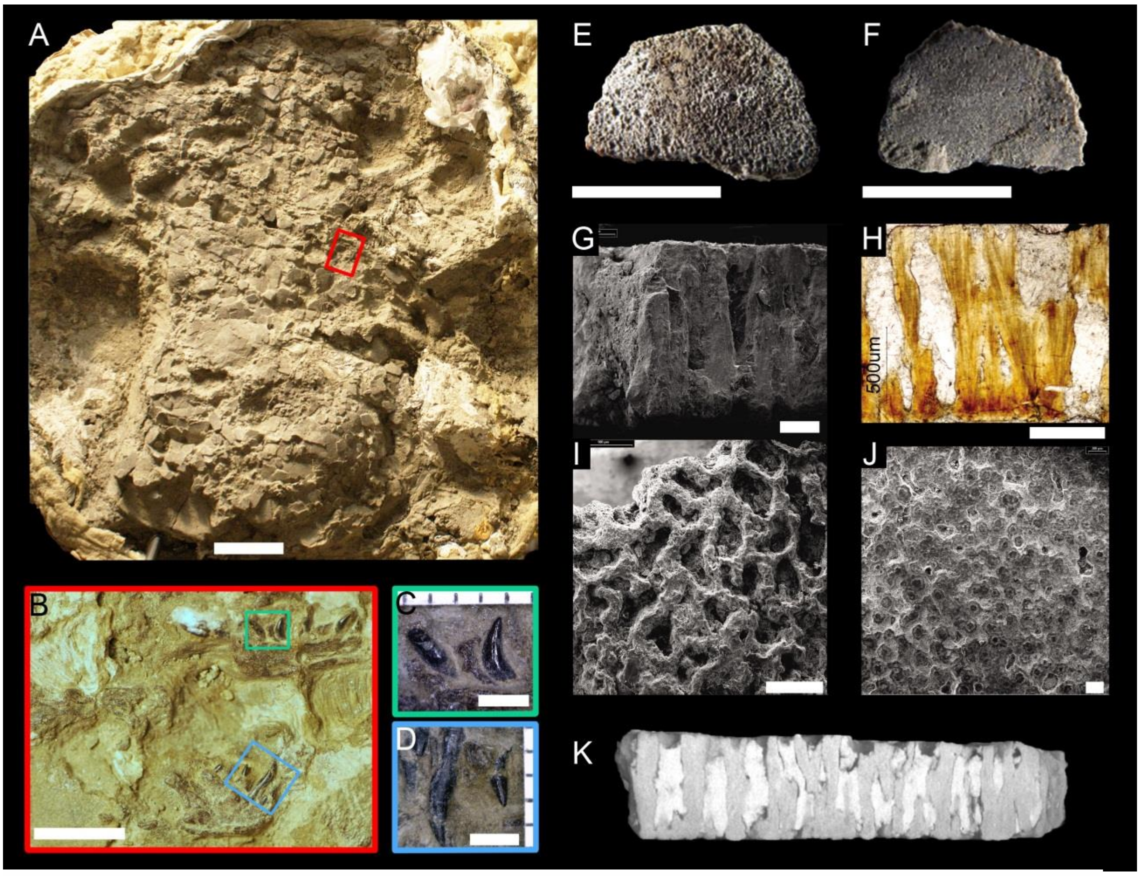
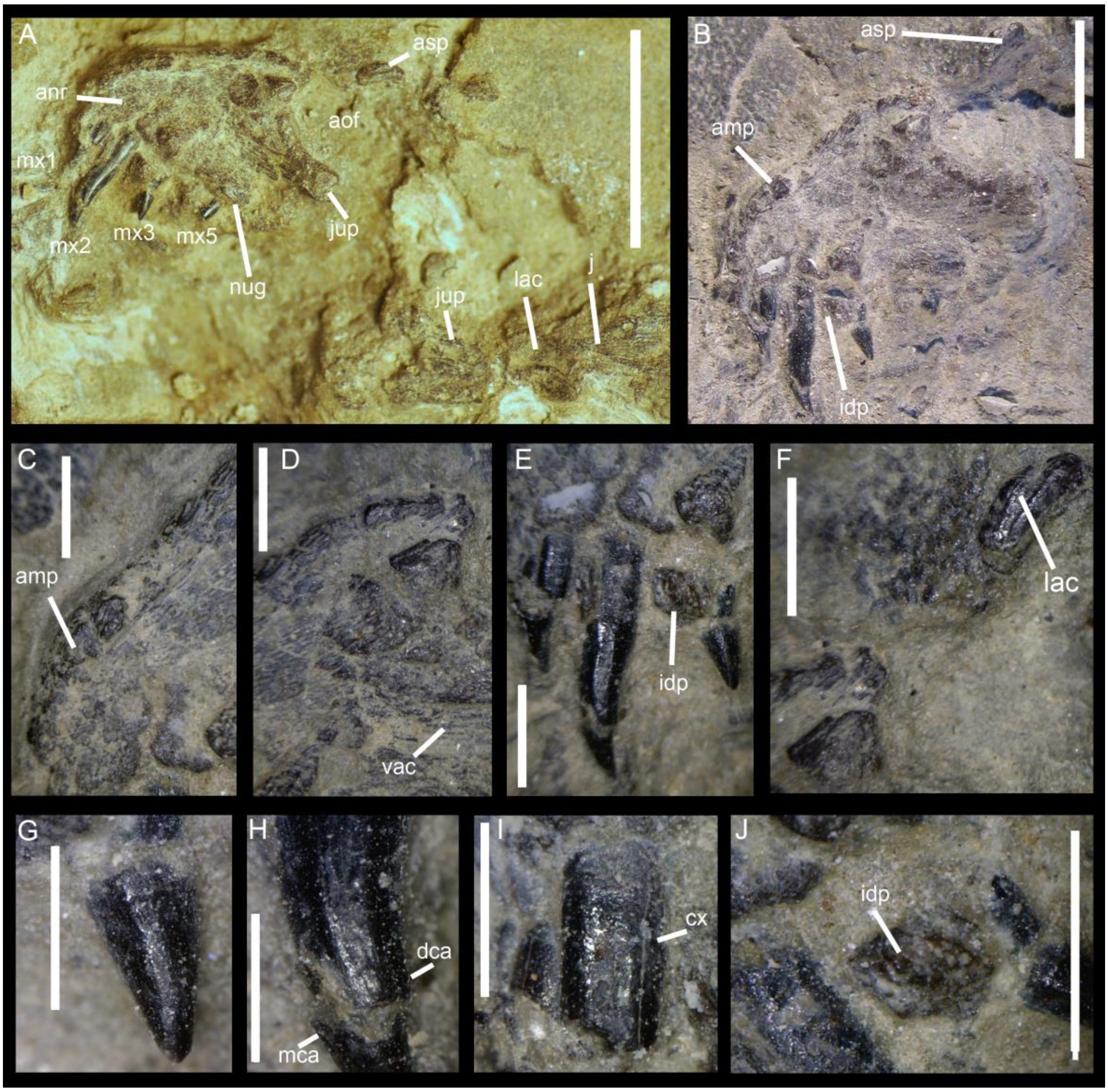
SUPPLEMENTARY NOTES

Filling the gaps of dinosaur eggshell phylogeny: Late Jurassic theropod clutch with embryos from Portugal

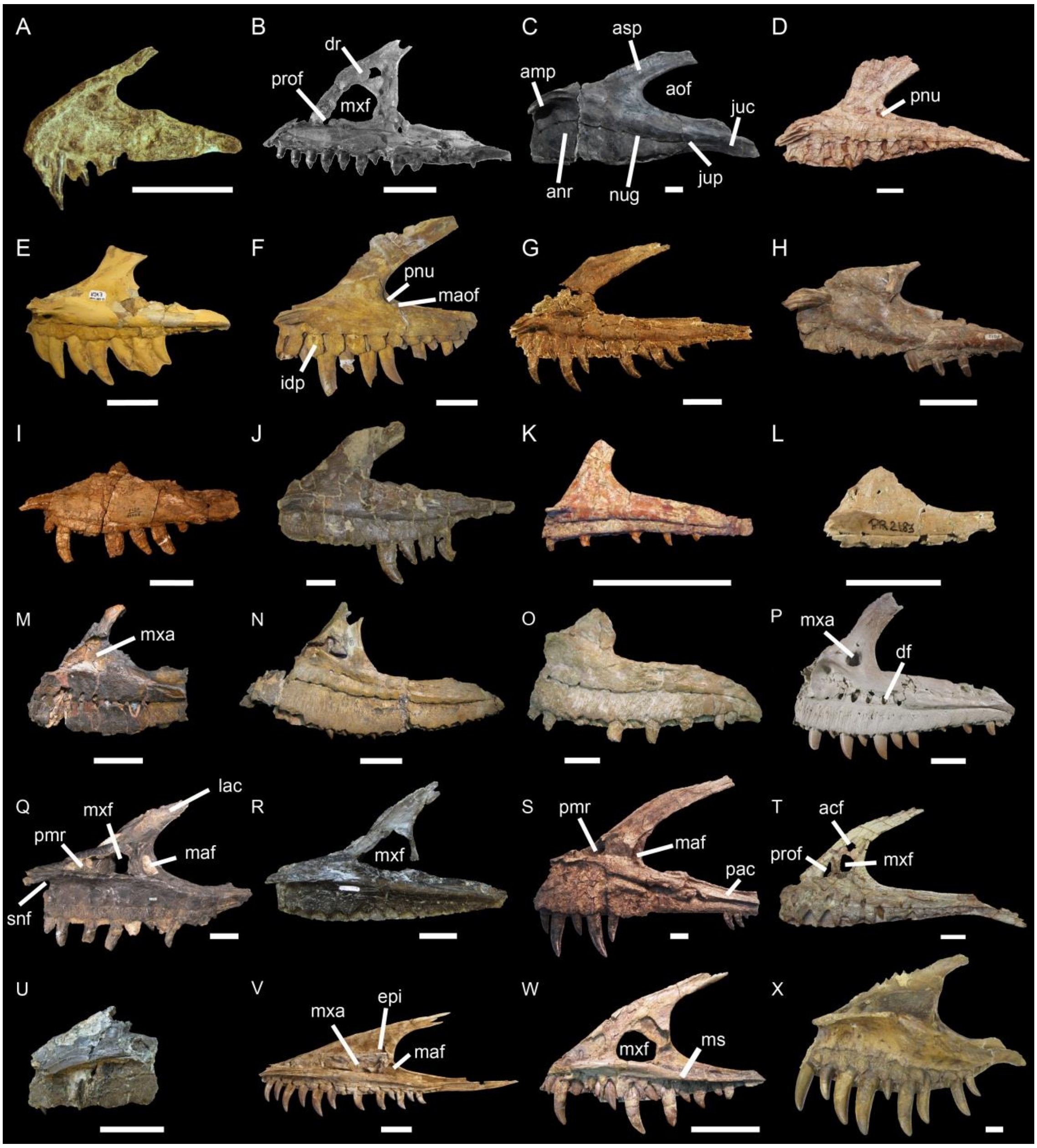
Ricardo Araújo, Rui Castanhinha, Rui M.S. Martins, Octávio Mateus, Christophe Hendrickx, F. Beckmann, N. Schell, & L.C. Alves



Note 1 – **A.** Clutch of *Torvosaurus* eggs (ML1188). **B.** Dentary and maxilla in medial view of *Torvosaurus* sp.. **C.** Second and third dentary teeth, separated by interdental plate in medial view. **D.** Second and third maxillary teeth, separated by interdental plate in medial view. **E.** Eggshell external morphology in lateral view. **F.** Eggshell internal morphology in medial view. **G.** SEM micrograph of the eggshell radial section showing acicular crystals and a single layer. **H.** Eggshell radial section. **I.** Eggshell external morphology SEM photograph. **J.** Eggshell internal morphology SEM photograph. **K.** SR-µCT image of an eggshell radial section. Scale bars 10 cm (A), 5 mm (B), 2 mm (C, D), 500 µm (E, F, H, I), 200 µm (G, J).

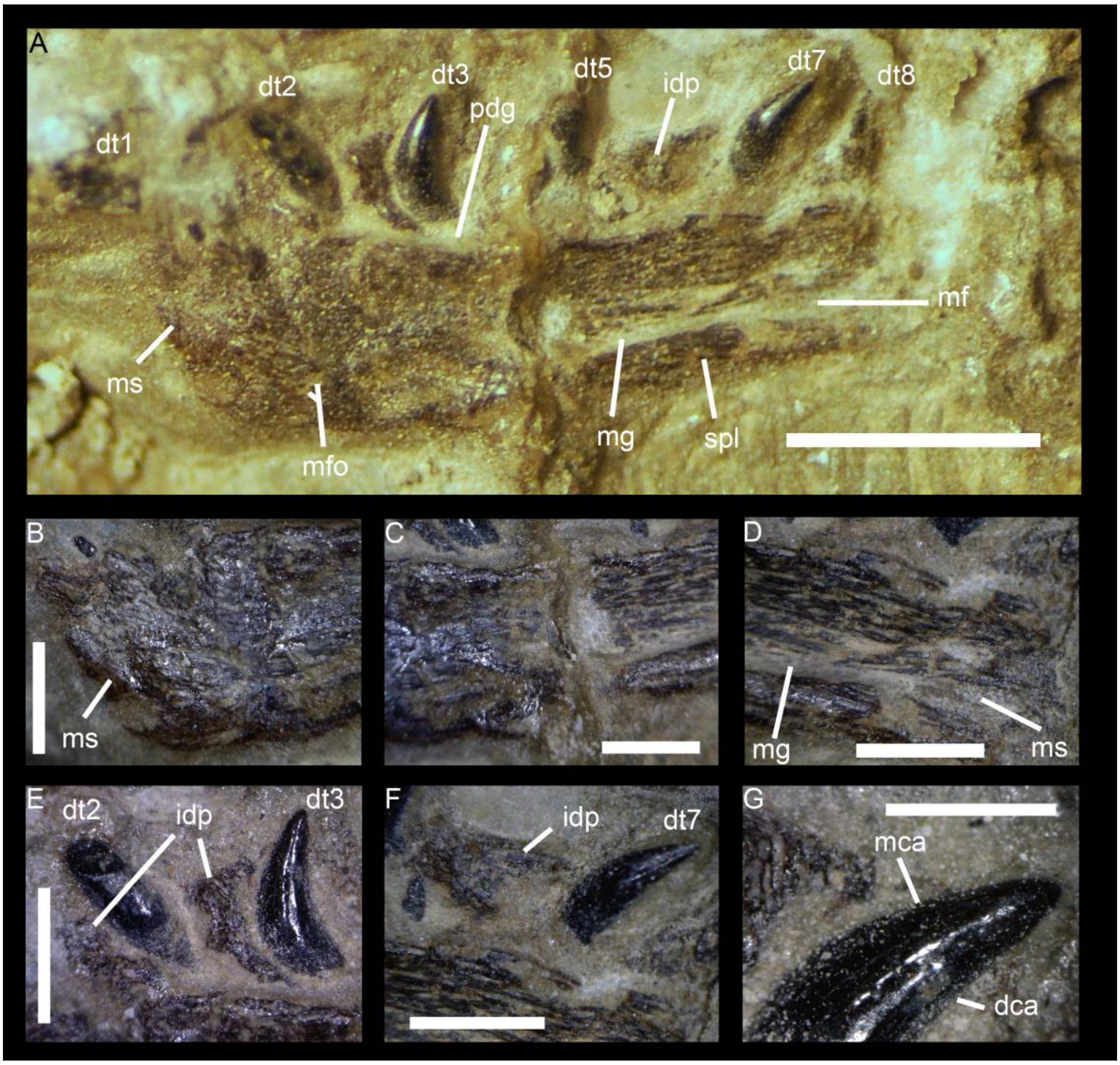


Note 2 – **A.** Incomplete right maxilla of *Torvosaurus* sp. embryo (ML 1188) in articulation with the jugal in medial view. **B.** Anterior part of maxilla (jugal process not included). **C**. Anterior part of anterior ramus. **D.** Ventral part of ascending process. **E.** Anteriormost maxillary teeth. **F.** Dorsal part of ascending process. **G.** Apex of the crown of first maxillary tooth. **H.** Medial part of the crown of second maxillary tooth. **I.** Roots of first and second maxillary teeth. **J.** Interdental plate in between second and fourth maxillary tooth. Abbreviations: amp, anteromedial process; anr, anterior ramus; aof, antorbital fenestra; cx, cervix dentis; dca, distal carina; idp, interdental plate; j, jugal; jug, jugal process; lac, lacrimal contact of the maxilla; mca, mesial carina; mx1,first maxillary tooth; mx2, second maxillary tooth; mx4, fourth maxillary tooth; nug, nutrient groove; vac, vascular canals. Scale: 10 mm (A); 5 mm (B and C); 2 mm (D to G, K); 1 mm (H to J).

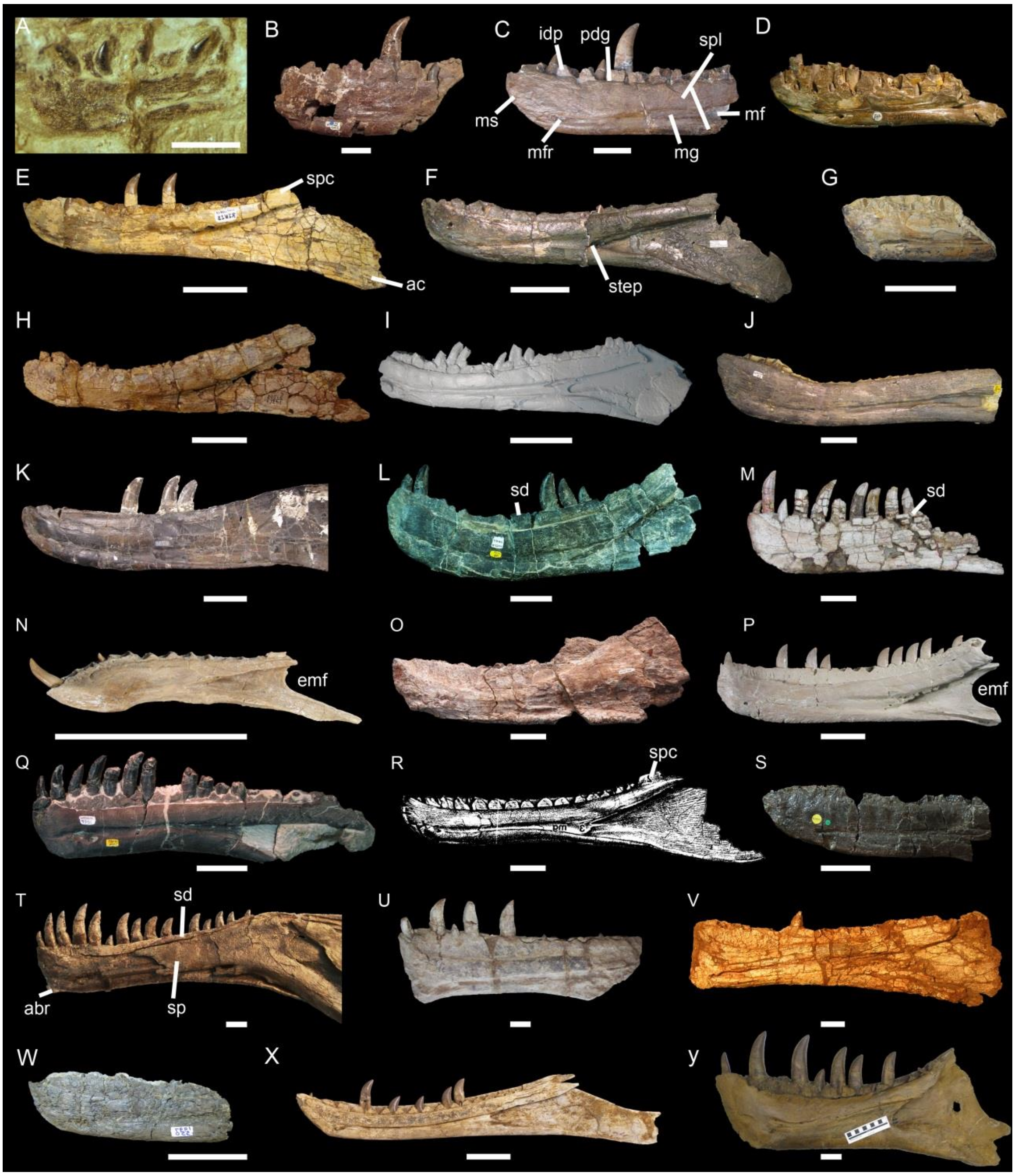


Note 3 – Maxillae of nonavian theropods in medial view. **A.** Embryo of *Torvosaurus* sp. **(**ML 1188, reconstructed). **B.** Hatchling of *Allosaurus* (IPFUB Gui Th 4; Rauhut & Fechner, 2005: fig. 1B). **C.** *Torvosaurus tanneri* (ML1100). **D.** *Afrovenator abakensis* (MNN UBA1; courtesy of Juan Canale). **E.** *Dubreuillosaurus valesdunensis* (MNHN 1998-13). **F.** *Duriavenator hesperis* (NHM R.332). **G.** *Marshosaurus bicentesimus* (DINO 16455; courtesy of Matt Carrano) **H.** *Piatnitzkysaurus floresi* (PVL 4073; courtesy of Martín Ezcurra). **I.** *Dilophosaurus wetherilli* (UCMP 37303; courtesy of Martín Ezcurra). **J.** *Ceratosaurus magnicornis* (USNM 4735). **K.** *Noasaurus leali* (PVL 4061). **L.** *Masiakasaurus knopfleri* (FMNH PR 2183). **M.** *Kryptops palaios* (MNN GAD1−1). **N.** *Rugops primus* (MNN IGU1). **O.** *Indosuchus raptorius* (AMNH 1955). **P.** *Majungasaurus crenatissimus* (FMNH PR 2100). **Q.** *Allosaurus fragilis* (USNM 8335). **R.** *Neovenator salerii* (MIWG 6348). **S.** *Acrocanthosaurus atokensis* (NCSM 14345; courtesy of Drew Eddy). **T.** *Eocarcharia dinops* (MNN GAD2). **U.** *Eotyrannus lengi* (MIWG 1997.550). **V.** *Alioramus altai* (IGM 100/1844; courtesy of Mike Ellison

©AMNH). **W.** *Raptorex kriegsteini* (LH PV18). **X.** *Tyrannosaurus rex* (CM 9380). Abbreviations: acf, accessory fenestra; amp, anteromedial process; anr, anterior ramus; aof, antorbital fenestra; df, dental foramina; dr, dorsal recess; epi, epiantral recess; idp, interdental plate; juc, jugal contact; jup, jugal process; lac, lacrimal contact; maf, maxillary antrum fenestra; maof, medial antorbital fossa; mxa, maxillary antrum; mxf, maxillary fenestra; ms, maxillary shelf; nug, nutrient groove; pac, palatal contact; pmr, premaxillary recess; pnu, pneumatic fossa of the medial antorbital fossa; prof, promaxillary fenestra; snf, subnarial foramen. Scale: 5 mm (A, B), 2 cm (L), 5 cm (C to K and M to X).

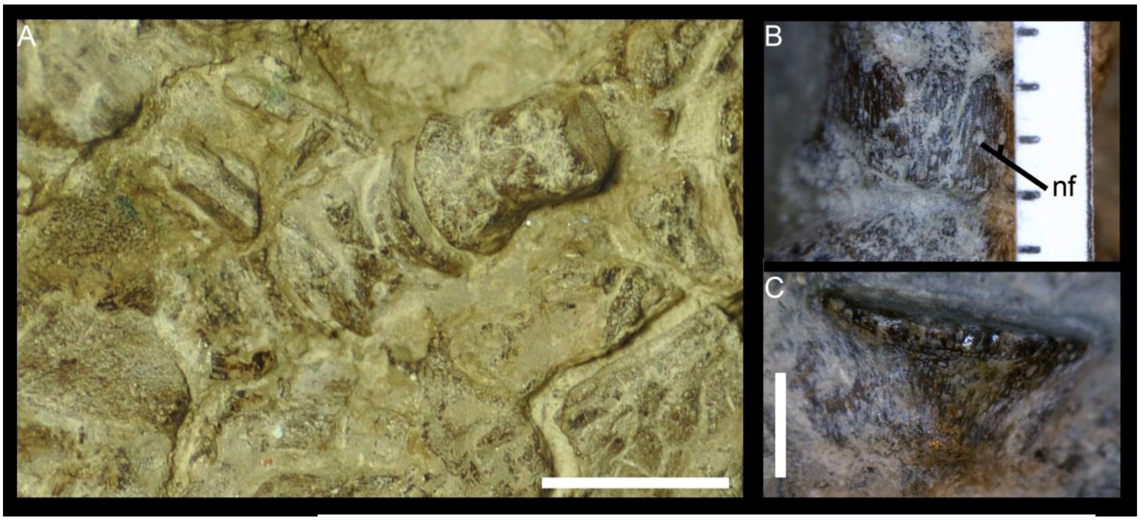


Note 4 – **A.** Incomplete right dentary of *Torvosaurus* sp. embryo (ML 1188) in medial view. **B.** Anterior part of medial wall of dentary. **C**. Mesial part of medial wall of dentary. **D.** Posterior part of medial wall of dentary. **E.** Anteriormost interdental plates and dentary teeth. **F.** Mesial interdental plate and tooth. **G.** Apex of the crown of seventh dentary tooth. Abbreviations: dca, distal carina; dt1, first dentary tooth; dt2, second dentary tooth; dt3, third dentary tooth; dt5, fifth dentary tooth; dt7, seventh dentary tooth; dt8, height dentary tooth; idp, interdental plate; mca, mesial carina; mf, Meckelian fossa; mfo, Meckelian foramina; mg, Meckelian groove; ms, mandibular symphysis; pdg, paradental groove; spl, splenial contact. Scale: 5 mm (A); 2 mm (B to F), 1 mm (G).



Note 5 – Dentaries of nonavian theropods in medial view. **A.** Embryo of *Torvosaurus* sp. (ML 1188, reconstructed). **B.** *Torvosaurus tanneri* (BYUVP 2003). **C.** *Megalosaurus bucklandii* (OUMNH J13505). **D.** *Magnosaurus nethercombensis* (OUMNH J.12143). **E.** *Dubreuillosaurus valesdunensis* (MNHN 1998-13). **F.** *Eustreptospondylus oxoniensis* (OUMNH J.13558). **G.** *Piatnitzkysaurus floresi* (PVL 4073). **H.** *Dilophosaurus wetherilli* (UCMP 37303; courtesy of Martín Ezcurra). **I.** *Marshosaurus bicentesimus* (AMNH 27641) **J.** *Baryonyx walkeri* (BMNH R.9951). **K.** *Ceratosaurus nasicornis* (USNM 4735). **L.** *Ceratosaurus dentisulcatus* (UUVP 158). **M.** *Genyodectes serus* (MLP 26-39). **N.** *Masiakasaurus knopfleri* (FMNH PR 2471). **O.** *Ekrixinatosaurus novasi* (MUCPv 294; courtesy of Matthew Lamanna). **P.** *Majungasaurus crenatissimus* (FMNH PR 2100). **Q.** *Allosaurus fragilis* (UUVP 10.093; courtesy of Stephen Brusatte). **R.** *Sinraptor dongi* (Currie & Zhao, 1993; fig. 11B). **S.** *Neovenator salerii* (BMNH R10001; courtesy of Roger Benson). **T.** *Acrocanthosaurus atokensis* (NCSM 14345; courtesy of Drew Eddy). **U.** *Giganotosaurus carolinii*

(MUCPv-CH-1; courtesy of Matthew Lamanna). **V.** *Tyrannotitan chubutensis* (MPEF-PV 1157; courtesy of Juan Canale). **W.** *Eotyrannus lengi* (MIWG 1997.550). **X.** *Alioramus altai* (IGM 100/1844; courtesy of Mick Ellison © AMNH). **Y.** *Tyrannosaurus rex* (CM 9380). Abbreviations: abr, articular brace; ac, angular contact; emf, external mandìbular fenestra; idp, interdental plate; mf, Meckelian fossa; mfr, Meckelian foramen; mg, Meckelian groove; ms, mandibular symphysis; pdg, paradental groove; sd, supradentary; sdc, supradentary contact; sp, splenial; spl, splenial contact; step, step between Meckelian fossa and Meckelian groove. Scale: 5 mm (A), 5 cm (B to Y).



Note 6 – **A.** Set of three amphiplatyan centra in articulation in dorsal view. **B.** Mesial part of the first centrum in dorsal view. **C.** Fourth isolated centrum in dorsal view. Abbreviation: nf, neurovascular foramina. Scale: 10 mm (A), 2 mm (B, C).

Institutional abbreviations: AMNH: American Museum of Natural History, New York; **CM**: Carnegie Museum of Natural History, Pittsburgh; **BYUVP:** Brigham Young University Vertebrate Paleontology, Provo, Utah, USA; **DINO/DNM**: Dinosaur National Monument, Vernal; **IGM:** Institute of Geology, Mongolia. **LH**: Museu de Cuenca, Cuenca, Spain; **IPFUB**: Institute for Paleontology of the Freie Universität, Berlin, Germany; **MIWG :** Dinosaur Isle, Isle of Wight Museum Services, Sandown, United Kingdom; **ML**: Museu da Lourinhã, Lourinhã, Portugal; **NCSM**: North Carolina Museum of Natural Sciences, Raleigh; **NHM/BMNH**: The Natural History Museum, London, United Kingdom; **MNHN**: Muséum national d'Histoire naturelle, Paris, France; **MNN**: Musée National du Niger, Niamey, Niger; **PVL**: Fundacíon Miguel Lillo, Universidad Nacional de Tucumán, San Miguel de Tucumán; **SGM**: Ministère de l'Énergie et des Mines, Rabat; **UCMP**: University of California Museum of Paleontology, Berkeley; **USNM**: National Museum of Natural History, Smithsonian Institution, Washington.

Note 7 – Details of the phylogenetic analysis (Method & Results, Character List, Datamatrix, Synapomorphy list)

Method & Results

In order to assess the phylogenetic affinities of ML1188, we performed a cladistic analysis by using a recently published datamatrix focusing on the relationships of basal tetanurans[1]. This datamatrix includes 351 characters coded in 59 operational taxonomic units and two outgroup taxa (*Eoraptor* and *Herrerasaurus*). We coded ML1188, as well as the maxilla of the embryonic specimens of *Lourinhanosaurus*[2] (ML565 122 & ML565 125) and *Allosaurus*[3] (IPFUB Gui Th 4). Two characters were modified and twelve additional characters were created in order to take into consideration the morphological variations of the medial view of the maxilla.

TNT v1.1[4] was employed to search for most-parsimonious trees (MPTs). As a first step, the matrix was analysed under the 'New Technology search' with the 'driven search' option, TreeDrift, Tree Fusing, Ratchet, and Sectorial Searches selected with default parameters, and stabilizing the consensus twice with a factor of 75. The generated trees were then analysed under traditional TBR (tree bisection and reconnection) branch[4]. Bremer support[5] and Reduced Cladistic Consensus Support Trees[6] were calculated with TNT by saving 10,000 suboptimal trees up to 10 steps longer than the MPTs. The consistency and retention indexes as well as the Bremer and relative Bremer supports were calculated using the "stats" and the "aquickie" commands, respectively.

Cladistic analysis of the datamatrix using TNT v1.1 yielded 95 MPTs, length 1099, with a consistency index of 0.371 and a retention index of 0.632 for the resulting consensus tree (Figure S1). The strict consensus tree did not resolve completely the clade of Tetanurae. However, the combinable components of the 96 MPTs retrieved the clades of Spinosauridae, Megalosauridae, Piatnitzkysauridae and Allosauria (Figure S1). Nevertheless, by using the 50% Majority rule consensus tree the Tetanurae phylogeny is fully resolved, retrieving the major clades of Megalosauroidea, Avetheropoda, Allosauroidea and Coelurosauria (Figure S2). Most clades have low Bremer support except for Averostra, Neotheropoda, Coelophysoidea and Ceratosauria. Likewise, high Bootstrap values (>65) are found for Averostra, Neotheropoda, Coelophysoidea, Ceratosauria and Spinosauridae.

The majority rule consensus mirror to a large degree the topology obtained by Carrano *et al.* (2012). However, a major difference occurs in the topology of the Megalosauridae where *Duriavenator* is retrieved among the Afrovenatorinae, and the sister-clade of Megalosaurinae encompasses six taxa such as *Dubreuillosaurus* and *Eustreptospondylus*. This change can be explained by the inclusion of additional maxillary and dentary characters. Indeed, among five synapomorphies, the clade of Megalosaurinae is defined by one synapomorphic characters of the maxilla, and one of the dentary: absence of a medial antorbital fossa in the maxilla (char. 352) and dentary tooth count, from the anteriormost part of the dentary, to the step between the Meckelian groove and the Meckelian fossa (char. 363). The absence of a medial antorbital fossa, as well as less than ten dentary teeth along the tooth row from the mandibular symphysis to the Meckelian fossa can indeed be observed in *Torvosaurus*, *Eustreptospondylus* and *Dubreuillosaurus*, but not in *Afrovenator* and *Duriavenator*.

In both analyses, ML1188 was retrieved with *Torvosaurus* among megalosaurine Megalosauroidea. Although the comparison of the embryonic maxilla with the maxilla of *Torvosaurus* is not straightforward, the two bones, as well as the dentaries of both ML1188 and *Torvosaurus*, share many features: anterior end of the junction between medial maxillary wall and paradental plates is inclined anteroventrally (Megalosauridae); strongly convergent ventral and dorsal margins of the jugal ramus of the maxilla (Megalosauridae); dentary, from the anteriormost point of the mandibular symphysis to the anteriormost point of the Meckelian fossa, bearing less than 10 teeth (Megalosaurinae); blunt anteroventral margin of the dentary (*Megalosaurus* + *Torvosaurus*); elongated (CHR > 2.5) maxillary teeth (*Megalosaurus* + *Torvosaurus*); unfused and tall (vertical subrectangular outline) anteriormost interdental plates of the dentary (*Megalosaurus* + *Torvosaurus*); maxilla lacking of promaxillary and maxillary fenestrae, as well as any pneumatic complex in medial view (*Torvosaurus*); broad tongue-like process of the posterior extremity of the jugal ramus (*Torvosaurus*); angle of the base of the ascending process with the ventral margin of the maxilla of less than 35° (*Torvosaurus*).

There are three main differences between the ML1188 and *Torvosaurus* maxillae. (1) A short anterior ramus bearing less than 6 teeth. These may be ontogenetic and plesiomorphic features of *Torvosaurus* embryos that are present in the closely related taxon *Megalosaurus*. (2) Unfused maxillary interdental plates once again an ontogenetic and plesiomorphic feature present in the *Torvosaurus* embryo and the closely related taxon *Megalosaurus*. (3) Unserrated teeth which is an ontogenetic character visible in *Troodon* embryos as well.

The cranial material (maxilla and dentary) of *Lourinhanosaurus* embryo ML565 was recovered among Allosauroidea in the strict consensus tree, and as a non allosaurian Allosauroidea in the 50% majority rule consensus (Figure S1). The taxon *Lourinhanosaurus* and ML565 were not retrieved in the same clade. In some trees, *Lourinhanosaurus* and ML565 are closely related when the embryo is retrieved as the most basal member of the Allosauroidea and *Lourinhanosaurus* as the most basal member of the Coelurosauria. In some trees, *Lourinhanosaurus* is also found retrieved as a basal allosauroid, whereas ML565 is a member of Metriacanthosauridae. In fact, *Lourinhanosaurus* was recently found among coelurosaur theropod[1], yet it was also formerly assigned to the metriacanthosaurid Allosauroidea[7,8]. According to Carrano *et al.* (2012), only two steps are required to recover *Lourinhanosaurus* as a basal Allosauroidea or a basal Avetheropoda in their analysis[1]. Since *Lourinhanosaurus* skull material is missing and does not allow any comparison with the skull material of the embryo, the position of ML565 among basal Allosauroidea, or Sinraptoridae, is therefore not surprising. A single autapomorphy of *Lourinhanosaurus* holotype was used to assign ML565 to this taxon: the medial condyle of the tibia is half the transverse width of the fibular condyle. However, the variation of this trait has not yet been studied through ontogeny.

The maxilla IPFUB Gui Th 4 described as an *Allosaurus* embryo[3] was retrieved as the mostbasal taxon of Allosauria, and closely related to Allosauridae, in the Majority rule consensus tree. In the strict consensus tree, it was retrieved among the clade of Allosauria, sometimes being also found at the base of the clade of Carcharodontosauridae in some trees. IPFUB Gui Th 4 was identified as belonging to Allosauridae by the presence of an excavation pneumatica in the ascending ramus and the lack of a greatly enlarged promaxillary fenestra (a condition present in Metriacanthosauridae), and to the genus *Allosaurus* by the apomorphically large maxillary fenestra and the presence of this taxon in the Late Jurassic of Portugal[3].

Nonetheless, a pneumatic fossa is also present in the basal carcharodontosaurids *Acrocanthosaurus atokensis* and *Eocarcharia dinops*[1] but the fossa is perforated by an accessory fenestra in these taxa[9,10]. In IPFUB Gui Th 4, the ascending process of the maxilla is damaged and the perforation in the large pneumatic fossa is missing bone[3], therefore an accessory fenestra inside the pneumatic fossa of the ascending process cannot be excluded. Among Allosauroidea, a large maxillary fenestra is also present in the carcharodontosaurids *Eocarcharia dinops*[10], *Acrocanthosaurus atokensis*[11] and *Giganotosaurus carolinii* (MUCPv CH1). Moreover, IPFUB Gui Th 4 shares several anatomical features with basal carcharodontosaurids that are absent in *Allosaurus* such as a promaxillary fenestra clearly visible in lateral view (char. 354) and an anteromedial process in which the most posterior point is situated on the anterior part of the anterior ramus (char. 356). Nevertheless, these features might be changing through ontogeny and the referral to *Allosaurus*, that is present in the Late Jurassic of Portugal, remains highly plausible.

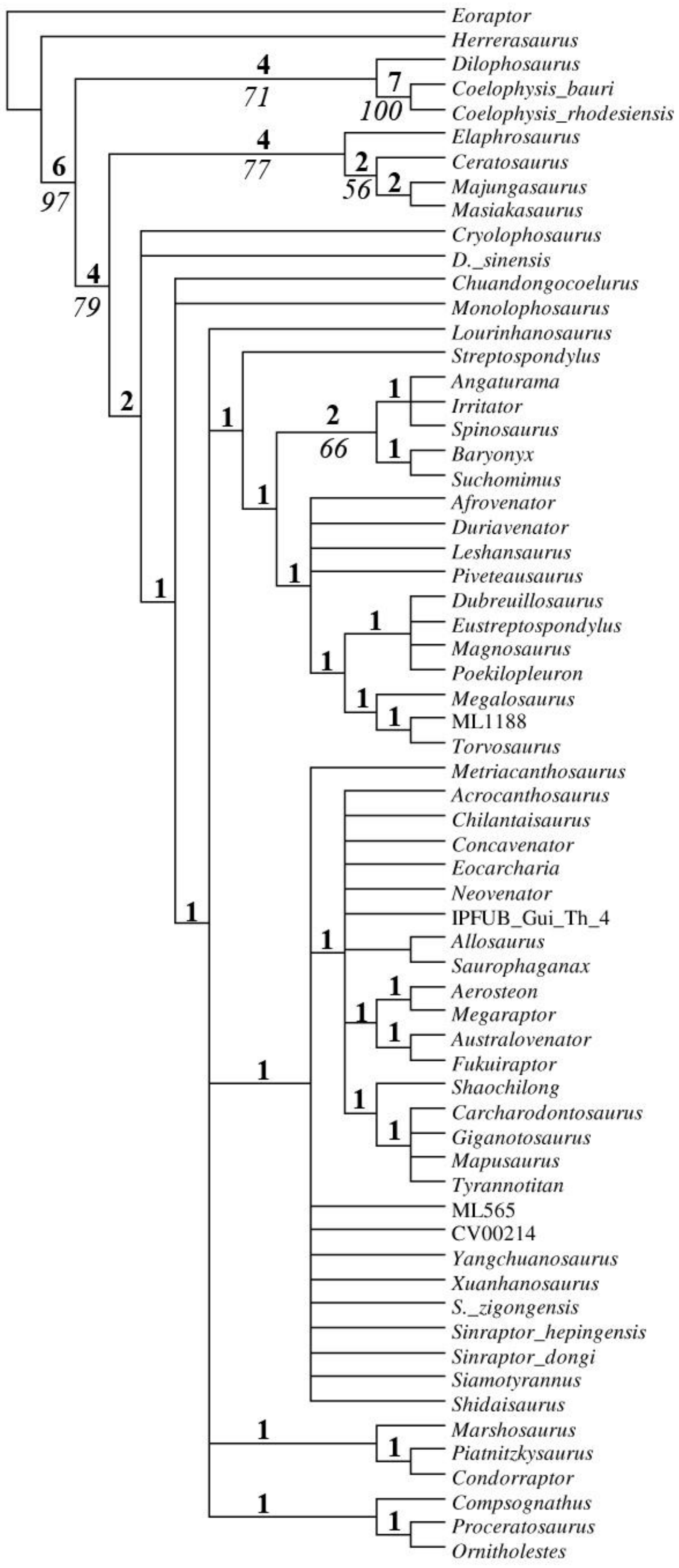


Figure S1. Strict consensus cladogram from 96 most parsimonious trees. Initial analysis used New Technology Search using TNT v.1.1 of a data matrix comprising 361 characters for two outgroup (*Eoraptor* and *Herrerasaurus*) and 62 nonavian theropod taxa. Tree length = 1094 steps; CI = 0.371; RI = 0.632. Bremer support values are in bold and above the stem. Bootstrap values, in italic, and unambiguous character support are below the stem of each clade.

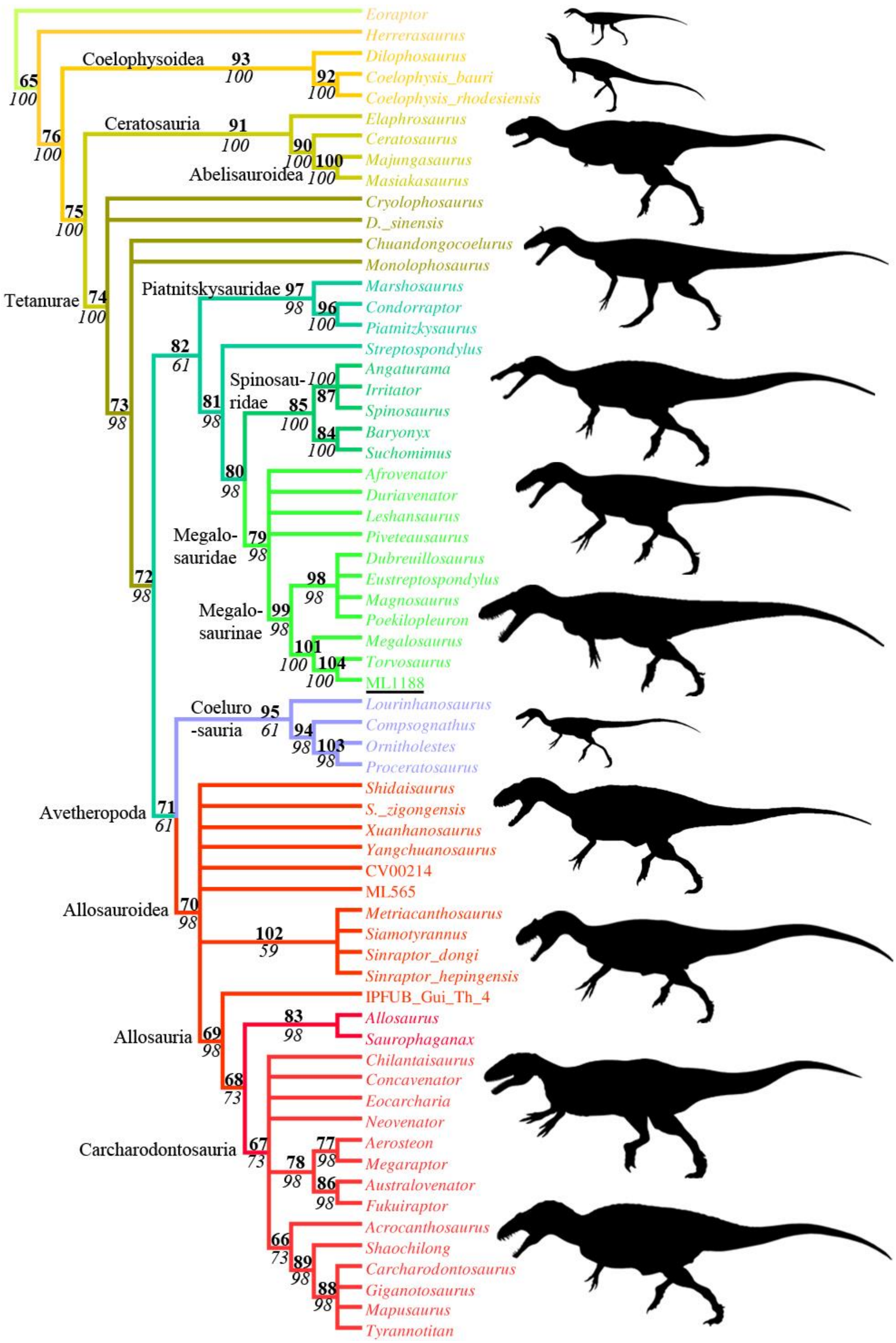


Figure S2. 50% Majority Rule cladogram from 96 most parsimonious trees. Initial analysis was a New Technology Search using TNT v.1.1 of a data matrix comprising 363 characters for two outgroup (*Eoraptor* and *Herrerasaurus*) and 62 nonavian theropod taxa. Tree length = 1094 steps; CI = 0.394; RI = 0.665. Clade number, in bold, and above the stem of each clade, is used in the synapomorphy list below. The percentage of clade occurrence is below each clade and in italic. For attribution information on the individual elements of this figure please see the end of the Supplementary Information.

Character list

Characters 1-352: from Carrano *et al.*, 2012, with the modification of character 12, 28 and 146.

12. **Maxilla,** development of anterior ramus <u>in adults</u>: anteroposteriorly short or absent (0), moderate (1), anteroposteriorly long (2). As noticed by Carr (1999), Rauhut & Fechner (2005), Loewen (2012), the relative proportion of the anterior ramus changes through ontogeny, therefore this ontogenetic feature was coded for adults only.

28. **Maxilla**, dimensions of promaxillary fenestra opening in lateral view: small foramen (0), small fenestra, smaller than maxillary fenestra (1), large fenestra, larger than maxillary fenestra.

146. **Teeth**, maxillary and dentary, serrations <u>in adults</u>: present (0), absent (1). Absence of denticles on the crown occurs in embryonic specimens of theropods with serrated carinae (Varricchio *et al.*, 2002; pers. observ.), therefore this ontogenetic feature was coded for adults only.

352. **Maxilla**, medial antorbital fossa in medial view: absent (0), present (1).

353. **Maxilla**, maxillary fenestra in medial view: absent (0), present as a crescentic aperture in the anteriormost corner of the medial antorbital fossa (1), present as a large maxillary recess/antrum (2), present as a fenestra (3).

354. **Maxilla**, promaxillary fenestra in medial view: absent (0), present as a promaxillary recess/antrum (1), present as a fenestra (2).

355. **Maxilla**, shape of promaxillary fenestra in lateral view: circular (0), subtrapezoidal (1), bean-shaped (2), D-shaped (3) drop-shaped (4).

356. **Maxilla**, position of the most posterior point of anteromedial process: on the anterior part of the anterior ramus (0), on the posterior part of the anterior ramus (1) at the level of the antorbital fenestra (2).

357. **Maxilla**, angle formed by the main axis of the base of the ascending process with the ventral margin of the maxilla: > 50° (0), 50°-35° (1); 34°-15 (2); <15°(3).

358. **Maxilla**, dorsal and ventral margins of the jugal ramus: slightly convergent, subparallel (0), strongly convergent (1).

359. **Maxilla**, shape of posterior part of jugal ramus: elongated and tapering process (0), large tongue-like process (1).

360. **Maxillary teeth**, number of teeth borne by the anterior ramus (anterior to the antorbital fenestra) in medial view: <6 (0), 6 (1), 7 or 8 (2) >8 (3)

361. **Maxillary and dentary teeth**, baso-apical elongation of the most elongated crown (CHR = CH/CBL): < 2.5(0), >2.5 (1).

362. **Dentary**, anteriormost paradental plates of the dentary, when unfused: wider than tall, horizontal subrectangular outline (0); as tall as high, subquadrangular outline (1); taller than wide, vertical subrectangular outline (2).

363. **Dentary**, number of teeth along the tooth row, from the anteriormost point of the mandibular symphysis to the anteriormost point of the Meckelian fossa: <10 (0); 10 – 15 (1); >15 (2).

Taxa	Maxillary teeth, number of teeth borne by the anterior ramus (anterior to the antorbital fenestra)	Number of teeth borne by the dentary, from the anteriormost point of the mandibular symphysis to the Meckelian fossa	Angle formed by the main axis of the base of the ascending process with the anteroventral margin of the maxilla.
Eoraptor	6	?	68°
Herrerasaurus	5	?	55°
Acrocanthosaurus	7	12-13	39°
Aerosteon	?	?	?
Afrovenator	6	?	32°
Allosaurus	8	11-14	55-41°
Angaturama	?	?	?
Australovenator	?	13	?
Baryonyx	>8	>18	?
Carcharodontosaurus	6	?	47°
Ceratosaurus	5	10	44°
Chilantaisaurus	?	?	?
Chuandongocoelurus	?	?	?
Coelophysis bauri	7	?	57°
Coelophysis rhodesiensis	7-8?	?	50°
Compsognathus	9	>15	45°
Concavenator	?	?	44°
Condorraptor	?	?	?
Cryolophosaurus	?	?	?
D. sinensis	5	?	46°
Dilophosaurus	5	11	44°
Dubreuillosaurus	5	8	38°
Duriavenator	6	11	39°
Elaphrosaurus	?	?	?
Eocarcharia	6	?	52°
Eustreptospondylu	6	6	50°

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Fukuiraptor	?	?	?
Giganotosaurus	?	11	65°
Irritator	>8	?	12°
Leshansaurus	5	?	41°
Lourinhanosaurus	?	?	?
Magnosaurus	?	9	?
Majungasaurus	5	12	59°
Mapusaurus	6	?	36°
Marshosaurus	6	14	40°
Masiakasaurus	3	8	?
Megalosaurus	5	5	40°
Megaraptor	?	?	?
Metriacanthosaurus	?	?	?
Monolophosaurus	6	?	45°
Neovenator	8	?	51°
Ornitholestes	?	?	?
Piatnitzkysaurus	7-8?	?	40°
Piveteausaurus	?	?	?
Poekilopleuron	?	?	?
Proceratosaurus	10	?	37°
Saurophaganax	?	?	?
Shaochilong	4-5	?	58°
Shidaisaurus	?	?	?
Siamotyrannus	?	?	?
Sinraptor dongi	6	12	52°
Sinraptor hepingensis	7	?	41°
Spinosaurus	11	>15	42°
Streptospondylus	?	?	?
Suchomimus	17	>18	~0°
S. zigongensis	?	?	?
Torvosaurus	6	?	27-31°
Tyrannotitan	?	11-12	?
Xuanhanosaurus	?	?	?
Yangchuanosaurus	6-7	?	52°
CV00214	?	?	?
ML1188	4-5	7	30°
IPFUB_Gui_Th_4	7	?	51°
ML565_122	7-8	?	52°

Data matrix

We here present a copy of our TNT matrix. An excel spreadsheet, with characters and taxa separated into columns and rows, is available from the authors by request.

nstates 5
xread

363 64

Eoraptor

00010000?00000??????0101000-
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Herrerasaurus

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000101000100000000000010000000?00000000000?0?001000000?00000??000010000
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Acrocanthosaurus

020?1100?000000111100000021111110001 0?00000021110121110002021 2011?11211
11020110?02??11012100000100110100012011111?11100210010102001 0?11111?000
10001000001001101 2?00110011?00?0012110001000110011211110?0021000000101?
1?110110120012001210?001011110000113110111111000????010?10??11101102012
01?120?201111000220111011110000110010312?1010?1110?1??01210111001?11123
110021-1

Aerosteon

??01?000?111??????????10
000200???1
10121???????11?01001?1?000100010110101 11?????2?110??0?????????0101100121??
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Afrovenator

?????????001010110000010012001 1000?????0?000201001?011001011000?????????0
0?001111001???000000001???
??10?11001?0?011000010001101100001?001?000001???????100000???1?01010?????
?????0121?????00?0?????0?31001111?100001?10?01101011?011?2012?1?00?001011
1000111011000011000010000 21?11010110???111011?011100??1110-02101???

Allosaurus

00101[01]00000100010100000002111111000110110000 2[01]2[01]001011000000010
111110001102000000200110110001101001001020120111111111200010011020 1111
111110000100011020010011001100110010[01]10000101100010000100010111100 00
11?0000000101?110110120012001210101100001000111310011111100001110100102
111101102012 01?1100200111000[12]1011101111000011001021221010111102 11101
21011100101131-1[01][01]021-1

Angaturama

11???201?1121?11???0?????????????0???
???1?0?????????????????110111701311????

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Australovenator
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???00001???????????100001000110???????
???0?????????????????????????
???00010101????01?1111??101???????????????????????????????????????22012101111
00011100114122101011121211101211????010????-??????-1

Baryonyx
111?0201011210110?0000???02???1??01????0?001202011?0??????0??0?1111100????
??0?11011010001011?01??010210?011??????????001101010?[12]101???1??01001011
00013001011100[12]?1001001001000110111110100011000101010?0???000?00??1??
1?00??0?1?010001211110001001 1010????????????10?0?11010?101?1110110[01]0?2?
1?0????0011000????1????00110100????????110?0??????????????0???????????-
????3002

Carcharodontosaurus
??????0??000000111100001001101110101111000?02?1?0??111100??21211211?211?
???0????????110121?0??0100??01121121???1???????2?10???????????????1000020000
?????10?110?2?????0??01?0?00101?0???1????0??????????????100?0???1???1???????
??1??1???????11?????0?????0??11?????2
2??1101111??01?100???????010??????????????????????121-011?10-?

Ceratosaurus
021010001000000000000000001010001012 0?000000202001100000000100001111110
0010100100100010101000000001101000011100 00?100010000001??10000001001000
10000010100100011021?0100010000000021100000010100001010211??10000210?01
00001101011110100100110000????0??1??1?01?00010?010?11100?000011101111011
0100001[01]0001001100110[01]0011021000101002002111010 01021??1?0001??10???
000-011000-1

Chilantaisaurus
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??01201100
00??????????????????????11??????10????2110??????????????????????????22??111???100
0?1100??41221????1?????????2101??0???????-????????

Chuandongocoelurus
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0?????????????????????0??????????????0?????????0?????????????????????????????????????
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00?1000041?2121011???21110?100??100??????-????????

Coelophysis_bauri

00101211000010????0?011010100?0000000?0000101??0000000000000000?0?000001
10110100000?0000000?0?2??1????0??1?0?0?0?00??00110?0?0000?00?000000001000
0?000000001100?100011000?000001011000000?00000000010000000000011?1100?0
1?000001002000101000000?0[01]?0010111010100000010010001100001101111010 0
?10000001000010000110[01]00?00?000?010001100021000000101111000110000000?0
0-?00021??

Coelophysis_rhodesiensis
00???211000010???00?0110110-
?00000000?020010100001[01]00000000?000100000000?0110?000000000000000200
100?000?10000000001000100000000000000000100000000100000000011011?000110
0000000010110000000?000000010000?0000?11?1100001?000001002000101000?00
10[01]000110110101000000100100011000111011110000?1000?011100010000111[01
]001102000?0100?110002100000010111100011010000000-01002???

Compsognathus
00???100000100????0?010002100?1??0000?0000000??00000?000?00?00????1?00???
?????0??0????0??00?????0??0?0??????1?1????1?0000?00??0??100??10100?0000?0??
0000100?100[12]???????100?001??001100?000????0000??1??0??000?0?00?1?0?0111
?011100?0??[12]??0???0???0??01?1310011????0?000??010?11??110011?20?201?011
?11?10??002???111?????????1?0???????01011???????01??0?11?0101?3?-?1003002

Concavenator
?????0???????0??????001002??0?1?00?1111?10102010000?110??10??2????1????????
??1020?0??????[0
1]0??100?????????????????[12]?1??10????1???0211?1?1??[01]100?000????1?111110?
10?1??0?1??10??0?1010001??????????????0?0?0?10?11??111011020????????02011??
?1?22??1100??????????????[12]2??0?0?1?1?????0???0?1?00??????-?110?1??

Condorraptor
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??0010001????????01
001????????0000?00101?00001000?2001?011101001?0002???01??101??????????????
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?01000001?00??11?????????????????1?01???0??????-????????

Cryolophosaurus
???????????????????00??????????1??00?1001?01010?000?0111??0?00[01]0?1?10000?1
0??000000??10001000001??1?0010????0??????1??0????????????10?000000000?0?01
??????0?01000????????00?0?000?0?1000??001000??010?0?????000200????0?01?????
?????????????????0?10001??????????????00???00???0?????011??0????0???0?0??1001
1001?0?00110100000000?2??????01001011??0???????????????-????????

D._sinensis
?0?0?000?0010???????000202??0?1??0??101300100??000?00?00?01?000???1??0????
?1?0???00??0?00???1?????????0??0?0??????
10?0100[12]?1?00??00010000?001000000100?000001??000?1000020??01?010??0100
01?000112111000000010001???1010111?000000?0101?0000111011?[01]002010000?
2000101110011100001010 00?1000022001010?0????0???110011100??1?3?-?1000???

Dilophosaurus
01?1121100001000000[01]001000100000000?100200100??00?200100001?000100100
0?110110100000000?00000020010100001??0??0?????201100010000?1000000[01]
1000000010000010101101??00011100100000101100000000000001010100001000020 1
??10000100000010010011010000001010001?11101100010001001000110000110011 0
[01]000?10000010001?00100110[01]000000000000100021100210000101011010001 10
00?0?000-010?0101

Dubreuillosaurus
01???100?0010101?000001001[12]0001??0??0??0??002??001?0????1011?001011?000
000??????????10??2011100?0??110010??0??????010?0110111??201???????0000000?
0100000100?1001?????????0?????????0?00??0?1??????1???????1??000?10????0110?
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Duriavenator
00???100??0101011000?0?0?120?1???0???
???110101????????????0000010?0??0?0010
0??
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??110-011?1001

Elaphrosaurus
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0[12]????????00100000?011000001?0000000002111?0000011??010???????0??11?01
110100001000???????????????????0001110000000?111111100?[12]??????0?0?000011
00110?00110??00010000210??21?0??????111?001???1???????-????????

Eocarcharia
?????????000000111001010021211111?0??????????????????????01?00201111???1????
??1000010?01?????1
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???1323?0001???

Eustreptospondylus
?1???20000011?01100000010120?1???0???????100200001??????10?10001?1??00000
???0111100010??1001000100?11000012??????????00110111????????????00000?0?01
0000010011001???01101001000110110000010011000101?100??1?0000????1????????
111?0???0121210?00????????????????????????0011010110001 1?011300?2?1?0000010
10100?111111000011000010000211 1101?110102111??1001??000??000-01??1?00

Fukuiraptor
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??0????????????????1000010?0110????001
10?[12]?????????1???????????0????0????????11????????????????????????????????120012
11101?001?1010???????????????10?????10????????????????????????????????2101210
1?1100011??01??12????01112121??012?1???0???????-????????

Giganotosaurus
02???000??0?00?11?100001001101???10?1110100021110????????2021211??11211??
0??1?00020?110121???00100?0011211?1??????111??201010?????1?1111110?002000
0??00010011012?01?0??111001?01?1?00?100?11001?21?2??????2?00000???1??0?10?
?0???01?0??????????????????????????????????00?11010010211110110201201?1200201
11100022011101??1?0???1001?31221010?10????????????????????121-?00??0-1

Irritator
?????2????02?0???????01100200?100010??0000010?201110010000??00011?11000??
??0?0???11?10??10?10010001021000?101?10?????0????????????10?11?0???1101?1-
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1???3?-?30031??

Leshansaurus
???????????1?1?1?001??1?0[01]???1??????????????????????????????????????10000????
?????????000000010021001??00????0??????????????????????????????00???0????????
[01]0?1100?1?0010??0110000121?0000??0????000001100?????????????????????????
?????????????????????1?????????????0?0??????0110?0111011?[12]0?????????0??0????
??[01]????100001???1?10???211110?0??????????????????0???110-0110?0??

Lourinhanosaurus
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0?????????0??????1?1?000?000?0?00???1?1?0??1100000?????0?111????????????????
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0110?????01?21?2101???????????????????????????-????????

Magnosaurus
?????????????????????????????????0???
??110?11????????????0000000?0????????0??
?0????????????????????????????????0?????????????00??????????????????????????????
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001000?21?????0?11???????????????????????-??????10

Majungasaurus
0210100010000001000000010010000011120?10020000?101200000020202012?11110
110110000100010100?00000010?01101?1000000010101100101001100100010010100
000001000010001102100110010011000121100000010100000001021?1111001201?010
00011?1011?10?011102000010??????0?????????????0??001110000000111111??????0
???1?????????0????100110?100010100210211111111021111?0001??1101?000-
100100-1

Mapusaurus
??????0???00000111100001001101?101011110100021110??1111102?2121121???????
?[02]01?000?0??????????????????????????????????00201010?01001??????100002000
0?0???10011012???01???1??0?0010??0001??01?00102012?????210000?????????1?11
012?0????1???10?10???????0????1????????000???0?0?102?1110110[12]?????????0?0
11?100022??1101111?00?1100??31221010110??2111012101??0010?121-011?10-?

Marshosaurus
000??000000001001000110201100 1?000010?000??????????0?1001?10000????100000
0?10?0?01?01000200000001001?0?00?1?0???????????10001??0???1?011??001001000
1000001001100 1?011111000100001211000000000 12001101?1??????????????10??????
?0?1?????????????1????????????????????????00?110100101011?0110010201?0000?00
111000?????1????????????????????21???????0?????????????????110-010011[01]1

Masiakasaurus
0?????0???001001000001000010 00???0?????????10???????????0??20101?10????????
?0?001??00????000?0001??00???0100?????????11101000011-
0??00?001100000000???0020001102?0011001001100011 1?000000101000000002011
110001011?0100001?0101111100111010000 1???????????????????001001?10000000
11?1111111201000010010 01??1001101001102100010100210 2?1111112021111?0011
??1101?000-0?0?0?-0

Megalosaurus
?????????0000?01101100?00110?1?000?????????????????1?111????????????????????
??000101?????0?011000010010?01??00?
100???01????????0??????1?????0?1????1000201110000 1?0000???010?????01110?000
001212110?000010000??????????????0010101011010111011 3?00[12]??????0?10??1?
0011101100001?000010000221??0?0?1????1????1001??00???010-011001[12]0

Megaraptor
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???110
12????????11?0100121?0?????????1??????????????110?0???????1?111011?0121??????
??????0101011?2?01011111110??????????????????????2????????????????????????????
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Metriacanthosaurus
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01?????????0??0??1?1?00011?00?00012111?????1?000?0???1????1?????????????????
??????????????????????????00??10100101111?011??012?1?0?00?101?01?111??110?1
1110001??0???21??????????????????????????????-????????

Monolophosaurus
001?1000?00100??????0000020-0?100011101300100?-
0012[01]11000110010?11110001?021000000??1000100000010?????0????01?1??????
00100001002010 0?0???00?0010?0??0000101110010?0010010010?0010110000000?10
000101?10?0?1?000?00?010???00110
00101010111011?00?[12]0100???0001000?0???????????????????????????????????????
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Neovenator
00???10000010001010100000210 01???10110110???????????????????????????????????
??????????????????????????????????1?????????110000????????????1000010001?0200
10011012?1?????11110100121100010001101010110?0???2100001???1?10?10?1011?
0120????????????????????????????????01?11010010221110110201201?12000001?10
11020?110111100011100113122101 0?10???1????210111?010??31-101?2?-?

Ornitholestes
000??000?00000??????000002100?1?00001000001010?0012?11000001000?1??10001
?020?00??0??1000?00???0????0??0??????????????00000?0??0?0?0?0100111?000000?
?00001001100[12]?????????0100101?0?000?0001000000010100??1?00010??010??11
??????????00111100000000???01??11??111??1??00?0001011121111011020????????0
10010000021??211??0100001???????2??0?0????????????2001??0???????-???0??-?

Piatnitzkysaurus
??????????000?01000010020110?1???0????????????????????????????????1???0??????
???????10?0100000010?1101000?10????????????2010?1????????????0010010?01?????
00001001?0011110001000012110000100012 00?1011100001?000?0??010????01011?
112001211101100??100?1??????????????001?10100101011?011?0002?100000000110
00011?11100001000001000022121010?10???1????1001??0????110-011?2?1?

Piveteausaurus
???011?000????????
?????1000?0?1002100??1002?110??
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Poekilopleuron
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??100?0??1?????111??????????012??101
10001000001????0?11????0??
???10???2????0?01111021?10????????000????-????????

Proceratosaurus
000??000?00100??????000002100?1??0?????????0???????201100000????????????1??2
0??0??0????????????????????0??????????????00[02]00?0??0???00??1?1?110000?0??0
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???3?-?10030??

Saurophaganax
???0?????????????????????
?0??110
0?1???????????0?001?1?000?0??0??????11????????00??0????????10??????????012?01
01100????????????????????00001?1010010?????????20?[12]01?1?00??01?????210?110
??01???011001?21???????????????????00????????????-????????

Shaochilong
??????????000??11?10100100110111?00???1????????????????????????????1?011?????
0?00020011???1?0000100?0011??120??????????????????????????????1??????????????
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??121-?00?0???

Shidaisaurus
???0??11000????????
?????110?0??????????0???????????????????????????????????????0??0?00?????????
?0??0110000???????1????001?00????01211010000 1?00???????0??????????????????
???????????????????????????00??0?1??1???111011020?[12]0??00??20??0??0????????
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Siamotyrannus
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0[12]??????????????????????????????0???1101000?0?000????010???????????????????
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Sinraptor_dongi
00001000000000000000010002121111000110100000211000011100010001001?1100
0011200100020011011000100100100112010011 1?111110000001100200111110 0000
0010?0?10000100110011011000100100001211000110001100121101 0?0?1?000?0000
10???1?01011100??????????????????????2???????11?00020101001010111011220121
110000210110101110111011110000110000221210101101021110121011100101 1121
000011[02]1

Sinraptor_hepingensis
000010000000000??????010002121?1?000110110000211000011100010001001?11000
0112001000???11?12000?00?????01??????1?1??????0000001?00?001???1?000?00?00
0?1000010011001101100010010000121100011000 1?001211?1100011000100?0101?1
1001011100?0????????????????????????????????000010100101?1110112[12]0021110
100210110?10110?1101111?00??22?1102???

Spinosaurus
110?1201011210????0??0000020??1??0?????0???????????????????????????????????????
???00110?0??011????????010110111-
01311?101100[12]??????????1000??21?0100?00???0?02010?00????000?0??0????????
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??110-210?3?02

Streptospondylus
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??110
0[12]?????????0??0?01??1?0000010?1?0???010???????000?0??0?0???????????????????
???0??1?000????????0???????????0
1000?01????2????????110102111?????????????????-????????

Suchomimus
1111020101121 01?0?00000100200?1??0?????0???????????????????????????1????????
???110110????????????????????????????????????110??????1????????010010110?0130
01011100[12]???????100?0001121?1110100011000201?10?0???00000???1001?00010
11?010001211110001001101 0????????????100011?010?1000110110 00?[12]?0?00?0
00011?00?11??110100110100100??41211010?102021??0?1??????????110-230?3??2

S._zigongensis
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???00?0??1?????00?11
00[12]?????0010??000012110001000?1?00?011?1??0??000?100?????????01011?0???
01102100100001000 1??2?00111111??00001010?10??1110110101[12]0?100?0200110
11111?1??0??110?000?00??211[12]10?0??010????????????????????-????????

Torvosaurus
00???100?0010001101[01]0001012000??00????00?101200001?011111011000?[01]??
????????001111?01?????????????????????????????????????010?0??????????????[01]0000
1000100100100110110102100100100011211000011001100010111000011100 00??010
?101001110000000121211000000100?0[12]???001101101000001010110101110113 00
0[12]?10000020010100011 10?10000110000100002121101011010211 10?1001??0????
000-0211112?

Tyrannotitan
???????????????????????????????????1??????????????????1111?????????????????????????
???20?010?0??????????1??0?20?0????????011
01?1???????1???1001?1?00??00?1?001?2?1???????000??0???????????11????01???????
??0????0?201?????20?????0?220?1?0111
1?0?01???????2?????????????????????????010????-??????-1

Xuanhanosaurus
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??110
0?????????0??????1??????000?0??00??11???????1???????????????0?1???1?200?2111?
01000010001102?001101?100???
??-????????

Yangchuanosaurus
0000?000000000??????000002121?1?0001101100002?1000011100010?010?1?1??0?0
?120???0?0??????????????????????????0111???1??00000?1?00???1???1?0???00?0?0??
00001001100[12]?0110001?01000012110001000?1?000111010000?0000100?010????
??000000100101?111011010120?100?020
011?11111??0101?110????100??211??0101101021??0????????????????21?010[12]1??

CV00214
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0[12]?0110001??100001211000100 0???000[12]11??0?????00?1?????????????????????
012010?0?00101000??0??000???????000?0010?10?????0110[12]0?[12]0??00?0?001??
?1?[12]1?10111?110?00???0???1???0?0?1???????01???????0?0????-????????

ML1188
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0001100???0??????01??
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IPFUB_Gui_Th_4
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ML565
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proc/;

Synapomorphy List from Phylogenetic Analysis (50% Majority Rule):

Eoraptor:
No autapomorphies

Herrerasaurus:
Char. 53: 0 --> 1
Char. 59: 1 --> 0
Char. 82: 0 --> 2
Char. 116: 1 --> 0
Char. 118: 0 --> 1
Char. 219: 0 --> 1

Acrocanthosaurus:
Char. 6: 0 --> 1
Char. 37: 1 --> 0
Char. 39: 1 --> 0
Char. 100: 0 --> 1
Char. 104: 2 --> 0
Char. 121: 0 --> 1

Aerosteon:
Char. 219: 1 --> 0

Afrovenator:
Char. 166: 0 --> 1
Char. 168: 1 --> 0
Char. 177: 2 --> 0
Char. 283: 0 --> 1
Char. 357: 1 --> 2

Allosaurus:
No autapomorphies

Angaturama:
No autapomorphies

Australovenator:
Char. 240: 1 --> 0

Baryonyx:
Char. 177: 2 --> 0
Char. 193: 2 --> 1

Carcharodontosaurus:
Char. 169: 1 --> 0
Char. 184: 0 --> 1
Char. 204: 0 --> 1

Ceratosaurus:
Char. 29: 0 --> 1
Char. 45: 0 --> 2
Char. 51: 2 --> 1
Char. 72: 1 --> 0
Char. 76: 1 --> 0
Char. 107: 0 --> 1
Char. 108: 0 --> 1
Char. 116: 1 --> 0
Char. 142: 0 --> 1
Char. 150: 0 --> 1
Char. 171: 1 --> 0
Char. 193: 0 --> 1
Char. 227: 0 --> 1
Char. 231: 1 --> 0
Char. 234: 0 --> 1
Char. 284: 2 --> 1
Char. 296: 0 --> 1
Char. 323: 1 --> 0
Char. 358: 0 --> 1

Chilantaisaurus:
Char. 232: 1 --> 0
Char. 237: 1 --> 0
Char. 276: 1 --> 0
Char. 307: 0 --> 1

Chuandongocoelurus:

Char. 269: 0 --> 1
Char. 322: 2 --> 4

Coelophysis_bauri:
Char. 138: 1 --> 0
Char. 142: 0 --> 1
Char. 160: 1 --> 0
Char. 282: 0 --> 1
Char. 357: 1 --> 0

Coelophysis_rhodesiensis:
Char. 26: 0 --> 1
Char. 27: 1 --> 0
Char. 72: 1 --> 0
Char. 248: 1 --> 0
Char. 273: 0 --> 1
Char. 294: 0 --> 1
Char. 305: 0 --> 1
Char. 310: 0 --> 1
Char. 347: 0 --> 1

Compsognathus:
Char. 6: 0 --> 1
Char. 22: 0 --> 1
Char. 37: 1 --> 0
Char. 54: 1 --> 0
Char. 180: 0 --> 1
Char. 216: 1 --> 0
Char. 276: 1 --> 0
Char. 293: 0 --> 1

Concavenator:
Char. 23: 0 --> 1
Char. 41: 0 --> 1
Char. 43: 0 --> 1
Char. 141: 0 --> 1
Char. 143: 1 --> 2
Char. 159: 1 --> 0
Char. 182: 0 --> 1
Char. 183: 1 --> 0
Char. 192: 1 --> 0
Char. 202: 2 --> 01
Char. 218: 0 --> 1
Char. 231: 2 --> 1
Char. 265: 1 --> 0
Char. 271: 0 --> 1
Char. 308: 1 --> 0
Char. 357: 0 --> 1

Condorraptor:
Char. 171: 1 --> 0
Char. 177: 2 --> 0
Char. 199: 0 --> 1

Cryolophosaurus:
Char. 40: 03 --> 1
Char. 45: 0 --> 1
Char. 55: 0 --> 1
Char. 95: 0 --> 1
Char. 160: 1 --> 0
Char. 180: 0 --> 1
Char. 317: 1 --> 0

D._sinensis:
Char. 24: 0 --> 2
Char. 39: 0 --> 1
Char. 186: 0 --> 1
Char. 266: 0 --> 1
Char. 292: 0 --> 2
Char. 298: 0 --> 1
Char. 305: 0 --> 1
Char. 323: 1 --> 2
Char. 336: 1 --> 0

Dilophosaurus:
Char. 2: 0 --> 1
Char. 4: 0 --> 1
Char. 37: 0 --> 1
Char. 54: 0 --> 1
Char. 100: 0 --> 1
Char. 118: 0 --> 2
Char. 139: 0 --> 1
Char. 155: 0 --> 1
Char. 193: 0 --> 1
Char. 253: 0 --> 1
Char. 296: 0 --> 1
Char. 309: 1 --> 0
Char. 324: 0 --> 1

Dubreuillosaurus:
Char. 30: 1 --> 0
Char. 89: 1 --> 2
Char. 91: 0 --> 1
Char. 93: 0 --> 1
Char. 104: 0 --> 1
Char. 311: 1 --> 0

Duriavenator:
No autapomorphies

Elaphrosaurus:
Char. 180: 0 --> 1
Char. 207: 2 --> 1
Char. 226: 0 --> 1
Char. 343: 0 --> 1

Eocarcharia:
Char. 21: 0 --> 1
Char. 23: 0 --> 1
Char. 28: 1 --> 2
Char. 360: 2 --> 1

Eustreptospondylus:
Char. 6: 1 --> 2
Char. 13: 0 --> 1
Char. 24: 0 --> 1

Fukuiraptor:
Char. 302: 2 --> 1

Giganotosaurus:
Char. 165: 1 --> 0

Irritator:
Char. 11: 1 --> 0
Char. 23: 0 --> 1
Char. 353: 1 --> 3

Leshansaurus:
Char. 20: 0 --> 1
Char. 85: 1 --> 0
Char. 89: 1 --> 0
Char. 170: 0 --> 1
Char. 175: 1 --> 0
Char. 195: 1 --> 0
Char. 315: 0 --> 1

Lourinhanosaurus:
Char. 312: 0 --> 1

Magnosaurus:
Char. 362: 0 --> 1

Majungasaurus:
Char. 24: 0 --> 1
Char. 34: 0 --> 1
Char. 124: 0 --> 1
Char. 140: 0 --> 1
Char. 203: 0 --> 1
Char. 208: 1 --> 0
Char. 233: 1 --> 2
Char. 356: 0 --> 1

Mapusaurus:
Char. 56: 0 --> 1
Char. 194: 1 --> 0

Marshosaurus:
Char. 17: 0 --> 1
Char. 22: 0 --> 1
Char. 89: 1 --> 2
Char. 163: 0 --> 1
Char. 282: 0 --> 1
Char. 297: 0 --> 1

Masiakasaurus:
Char. 13: 0 --> 1
Char. 22: 0 --> 1
Char. 44: 0 --> 1
Char. 67: 1 --> 0
Char. 85: 1 --> 0
Char. 120: 0 --> 1
Char. 139: 0 --> 1
Char. 153: 1 --> 2
Char. 177: 2 --> 1
Char. 198: 1 --> 0
Char. 207: 2 --> 0
Char. 226: 0 --> 1
Char. 333: 1 --> 2
Char. 343: 0 --> 1
Char. 363: 1 --> 0

Megalosaurus:
Char. 12: 1 --> 0
Char. 27: 2 --> 1
Char. 52: 0 --> 1
Char. 121: 1 --> 0
Char. 140: 0 --> 1
Char. 193: 1 --> 2
Char. 323: 1 --> 2

Megaraptor:
No autapomorphies

Metriacanthosaurus:
Char. 196: 0 --> 1
Char. 312: 0 --> 1

Monolophosaurus:
Char. 27: 1 --> 0
Char. 35: 0 --> 1
Char. 39: 0 --> 1
Char. 58: 0 --> 1
Char. 62: 0 --> 1
Char. 131: 1 --> 0
Char. 155: 0 --> 1
Char. 161: 1 --> 0
Char. 193: 0 --> 1
Char. 296: 1 --> 0

Neovenator:
Char. 6: 0 --> 1
Char. 12: 0 --> 1
Char. 20: 0 --> 1
Char. 28: 1 --> 0
Char. 34: 0 --> 1
Char. 121: 0 --> 1
Char. 162: 0 --> 1
Char. 196: 1 --> 0
Char. 208: 0 --> 1
Char. 292: 2 --> 0
Char. 301: 2 --> 0

Ornitholestes:
Char. 12: 1 --> 0
Char. 43: 0 --> 1
Char. 135: 1 --> 0

Piatnitzkysaurus:
Char. 323: 1 --> 2

Piveteausaurus:
Char. 104: 0 --> 2

Poekilopleuron:
Char. 216: 0 --> 1
Char. 237: 0 --> 1

Proceratosaurus:
Char. 153: 1 --> 0

Saurophaganax:
Char. 310: 1 --> 0
Char. 342: 1 --> 0

Shaochilong:
Char. 21: 0 --> 1
Char. 77: 1 --> 0

Shidaisaurus:
Char. 89: 1 --> 0
Char. 147: 1 --> 0
Char. 168: 1 --> 0
Char. 296: 1 --> 0
Char. 299: 1 --> 0

Siamotyrannus:

Char. 202: 1 --> 0
Char. 272: 1 --> 2
Char. 287: 1 --> 0

*Sinraptor*_dongi:
Char. 40: 1 --> 0
Char. 189: 0 --> 1
Char. 273: 1 --> 0
Char. 299: 1 --> 0
Char. 360: 2 --> 1

Sinraptor_hepingensis:
Char. 89: 1 --> 2
Char. 198: 0 --> 1
Char. 283: 1 --> 0
Char. 289: 0 --> 1
Char. 300: 1 --> 0
Char. 355: 1 --> 2
Char. 357: 0 --> 1

Spinosaurus:
No autapomorphies

Streptospondylus:
No autapomorphies

Suchomimus:
Char. 272: 1 --> 0
Char. 286: 1 --> 0

S._zigongensis:
Char. 153: 1 --> 0
Char. 203: 1 --> 0
Char. 231: 2 --> 1
Char. 232: 1 --> 0
Char. 233: 1 --> 2
Char. 281: 2 --> 1
Char. 316: 1 --> 0

Torvosaurus:
No autapomorphies

Tyrannotitan:
Char. 203: 1 --> 0

Xuanhanosaurus:
Char. 183: 1 --> 0
Char. 221: 0 --> 1
Char. 225: 0 --> 1
Char. 255: 1 --> 0

Yangchuanosaurus:
Char. 193: 02 --> 1
Char. 203: 1 --> 0
Char. 281: 2 --> 1
Char. 305: 1 --> 0
CV00214:
Char. 232: 1 --> 0
Char. 234: 1 --> 0
Char. 240: 0 --> 1
Char. 253: 1 --> 0
Char. 305: 1 --> 0
Char. 307: 0 --> 1

ML1188:
No autapomorphies

IPFUB_Gui_Th_4:
No autapomorphies

ML565:
Char. 355: 1 --> 4
Char. 361: 1 --> 0

Node 65:
No synapomorphies

Node 66:
Char. 2: 0 --> 2
Char. 19: 0 --> 1
Char. 40: 1 --> 0
Char. 48: 0 --> 1
Char. 58: 1 --> 2
Char. 60: 0 --> 2
Char. 61: 0 --> 1
Char. 124: 0 --> 1
Char. 171: 1 --> 0
Char. 191: 0 --> 1
Char. 223: 1 --> 2
Char. 246: 1 --> 0
Char. 251: 0 --> 1
Char. 299: 1 --> 0

Node 67:
Char. 62: 1 --> 2
Char. 71: 0 --> 1
Char. 77: 0 --> 1
Char. 125: 1 --> 0
Char. 159: 0 --> 1
Char. 160: 1 --> 2
Char. 169: 0 --> 1
Char. 173: 0 --> 1
Char. 187: 0 --> 1
Char. 202: 1 --> 2
Char. 240: 0 --> 1
Char. 273: 1 --> 2
Char. 302: 1 --> 2
Char. 322: 2 --> 34

Node 68:
Char. 356: 0 --> 1

Node 69: Allosauria
Char. 18: 0 --> 1
Char. 28: 2 --> 1

Node 70: Allosauroidea
Char. 12: 1 --> 0
Char. 28: 0 --> 2
Char. 29: 0 --> 1
Char. 39: 0 --> 1
Char. 40: 0 --> 1
Char. 52: 0 --> 1
Char. 58: 0 --> 1
Char. 62: 0 --> 1
Char. 86: 0 --> 1
Char. 88: 0 --> 1
Char. 124: 0 --> 1

Char. 133: 0 --> 1
Char. 194: 0 --> 1
Char. 214: 0 --> 1
Char. 237: 0 --> 1
Char. 249: 13 --> 2
Char. 298: 0 --> 1
Char. 300: 0 --> 1
Char. 342: 0 --> 1
Char. 357: 1 --> 0
Char. 361: 0 --> 1

Node 71:
Char. 59: 1 --> 0
Char. 216: 0 --> 1
Char. 264: 1 --> 0
Char. 273: 0 --> 1
Char. 281: 0 --> 2
Char. 287: 0 --> 1
Char. 303: 1 --> 0
Char. 308: 0 --> 1
Char. 316: 0 --> 1
Char. 341: 1 --> 2
Char. 349: 0 --> 1

Node 72:
Char. 3: 1 --> 0
Char. 43: 1 --> 0
Char. 134: 0 --> 1
Char. 267: 0 --> 1
Char. 268: 1 --> 0
Char. 301: 0 --> 1
Char. 302: 0 --> 1
Char. 305: 0 --> 1
Char. 311: 0 --> 1

Node 73:
Char. 156: 0 --> 1
Char. 176: 0 --> 1
Char. 178: 0 --> 1
Char. 270: 0 --> 1
Char. 272: 0 --> 1
Char. 295: 0 --> 1
Char. 310: 1 --> 0
Char. 331: 0 --> 1
Char. 360: 0 --> 1

Node 74: Tetanurae
Char. 12: 0 --> 1
Char. 26: 0 --> 2
Char. 31: 0 --> 1
Char. 37: 0 --> 1
Char. 54: 0 --> 1
Char. 138: 1 --> 0
Char. 231: 1 --> 2
Char. 232: 0 --> 1
Char. 234: 0 --> 1
Char. 254: 0 --> 1
Char. 255: 0 --> 1
Char. 256: 0 --> 1
Char. 296: 0 --> 1
Char. 341: 0 --> 1
Char. 353: 0 --> 3

Node 75: Averostra
Char. 65: 0 --> 1
Char. 85: 0 --> 1
Char. 99: 0 --> 1
Char. 167: 1 --> 0
Char. 220: 0 --> 1
Char. 276: 0 --> 1
Char. 284: 0 --> 2
Char. 299: 0 --> 1
Char. 310: 0 --> 1
Char. 317: 0 --> 1
Char. 336: 0 --> 1

Node 76: Neotheropoda
Char. 3: 0 --> 1
Char. 24: 1 --> 0
Char. 27: 0 --> 1
Char. 64: 0 --> 1
Char. 73: 0 --> 1
Char. 75: 0 --> 1
Char. 76: 0 --> 1
Char. 106: 0 --> 1
Char. 157: 0 --> 1
Char. 160: 0 --> 1
Char. 179: 0 --> 1
Char. 197: 0 --> 1
Char. 212: 0 --> 1
Char. 213: 1 --> 0
Char. 217: 0 --> 1
Char. 242: 0 --> 1
Char. 249: 0 --> 1
Char. 250: 0 --> 1
Char. 264: 0 --> 1
Char. 274: 0 --> 1
Char. 275: 0 --> 1
Char. 278: 0 --> 1
Char. 279: 0 --> 1
Char. 322: 0 --> 2
Char. 337: 0 --> 1
Char. 338: 0 --> 1
Char. 340: 0 --> 1
Char. 344: 0 --> 1
Char. 345: 0 --> 1
Char. 357: 0 --> 1

Node 77:
Char. 228: 0 --> 1

Node 78:
Char. 244: 0 --> 1
Char. 252: 0 --> 1
Char. 333: 1 --> 2
Char. 343: 0 --> 1

Node 79: Megalosauridae
Char. 17: 0 --> 1
Char. 65: 1 --> 0
Char. 78: 0 --> 1
Char. 81: 0 --> 1
Char. 102: 1 --> 0
Char. 196: 0 --> 1
Char. 293: 0 --> 1
Char. 297: 0 --> 1
Char. 358: 0 --> 1

Node 80:
Char. 184: 0 --> 1
Char. 312: 0 --> 1

Node 81:
Char. 175: 0 --> 1

Node 82: Megalosauroidea
Char. 26: 2 --> 1
Char. 37: 1 --> 0
Char. 73: 1 --> 0
Char. 107: 0 --> 1
Char. 353: 3 --> 1

Node 83: Allosauridae
Char. 58: 1 --> 0
Char. 233: 1 --> 0
Char. 236: 0 --> 1
Char. 263: 0 --> 1

Node 84: Spinosaurinae
Char. 141: 0 --> 1
Char. 146: 0 --> 1
Char. 151: 0 --> 1
Char. 152: 0 --> 1
Char. 154: 0 --> 1

Node 85: Spinosauridae
Char. 1: 0 --> 1
Char. 2: 0 --> 1
Char. 8: 0 --> 1
Char. 10: 0 --> 1
Char. 11: 0 --> 1
Char. 12: 1 --> 2
Char. 13: 0 --> 1
Char. 15: 0 --> 1
Char. 26: 1 --> 0
Char. 44: 0 --> 1
Char. 49: 0 --> 1
Char. 83: 0 --> 1
Char. 129: 0 --> 1
Char. 139: 0 --> 1
Char. 142: 0 --> 1
Char. 144: 0 --> 1
Char. 145: 0 --> 1
Char. 149: 0 --> 1
Char. 150: 0 --> 3
Char. 181: 0 --> 1
Char. 193: 0 --> 2
Char. 356: 0 --> 2
Char. 360: 1 --> 3
Char. 363: 1 --> 2

Node 86:
Char. 334: 0 --> 1

Node 87: Baryonychinae
Char. 3: 0 --> 1
Char. 5: 1 --> 0
Char. 155: 0 --> 1
Char. 180: 0 --> 1
Char. 182: 0 --> 1

Node 88:
Char. 34: 0 --> 1
Char. 108: 0 --> 1

Node 89:
Char. 24: 0 --> 1
Char. 26: 2 --> 0
Char. 103: 0 --> 1

Node 90:
Char. 178: 0 --> 1
Char. 261: 0 --> 1
Char. 281: 0 --> 1
Char. 291: 0 --> 1
Char. 319: 0 --> 1

Node 91: Ceratosauria
Char. 186: 0 --> 1
Char. 197: 1 --> 2
Char. 198: 0 --> 1
Char. 199: 0 --> 1
Char. 200: 0 --> 1
Char. 208: 0 --> 1
Char. 225: 0 --> 1
Char. 266: 0 --> 1
Char. 280: 0 --> 1
Char. 339: 0 --> 1
Char. 347: 0 --> 1

Node 92:
Char. 22: 0 --> 1
Char. 25: 0 --> 1
Char. 45: 0 --> 1
Char. 51: 2 --> 0
Char. 59: 1 --> 0
Char. 208: 0 --> 1
Char. 254: 0 --> 1
Char. 277: 0 --> 1
Char. 280: 0 --> 1
Char. 293: 0 --> 1
Char. 298: 0 --> 1
Char. 322: 2 --> 1
Char. 333: 1 --> 0
Char. 339: 0 --> 1
Char. 360: 0 --> 2

Node 93: Coelophysoidea
Char. 6: 0 --> 2
Char. 7: 0 --> 1
Char. 8: 0 --> 1
Char. 13: 0 --> 1
Char. 23: 0 --> 1
Char. 89: 1 --> 0
Char. 95: 0 --> 2
Char. 120: 0 --> 1
Char. 166: 0 --> 1
Char. 177: 0 --> 1
Char. 180: 0 --> 1
Char. 261: 0 --> 1
Char. 269: 0 --> 1

Char. 318: 0 --> 1
Char. 361: 0 --> 1

Node 94:
Char. 178: 1 --> 0
Char. 271: 0 --> 1
Char. 296: 1 --> 0
Char. 301: 1 --> 2
Char. 307: 0 --> 1

Node 95: Coelurosauria
Char. 188: 1 --> 0
Char. 218: 0 --> 1

Node 96:
Char. 156: 1 --> 0
Char. 184: 0 --> 1

Node 97: Piatnitzkysauridae
Char. 12: 1 --> 0
Char. 21: 0 --> 1
Char. 24: 0 --> 2
Char. 140: 0 --> 1
Char. 166: 0 --> 1
Char. 167: 0 --> 1
Char. 168: 1 --> 0
Char. 192: 0 --> 1
Char. 193: 0 --> 1
Char. 236: 0 --> 1

Node 98:
Char. 2: 0 --> 1
Char. 124: 0 --> 1
Char. 218: 0 --> 1

Node 99: Megalosaurinae
Char. 42: 0 --> 1
Char. 193: 0 --> 1
Char. 296: 1 --> 0
Char. 352: 1 --> 0
Char. 363: 1 --> 0

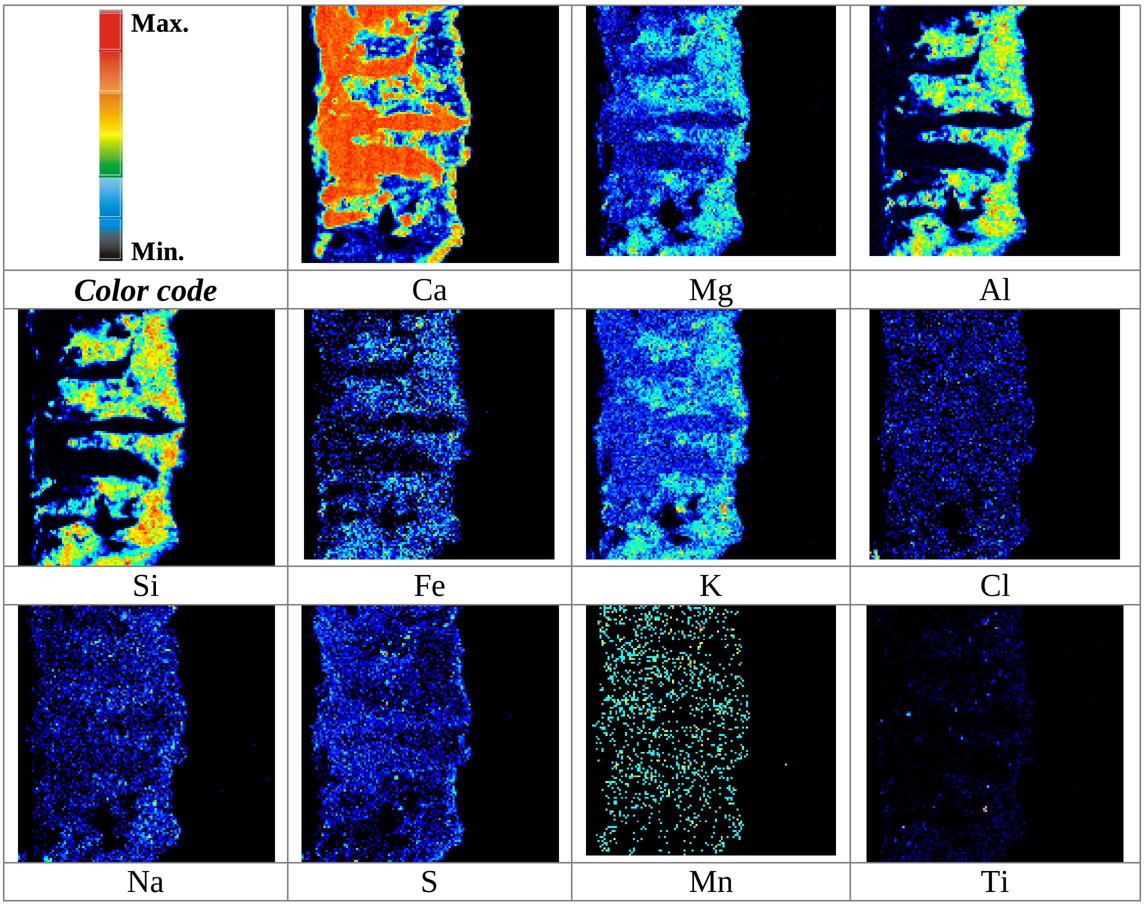
Node 100:
Char. 60: 0 --> 2
Char. 97: 0 --> 1
Char. 119: 0 --> 1
Char. 122: 0 --> 1
Char. 125: 1 --> 0
Char. 165: 0 --> 1
Char. 172: 0 --> 1
Char. 176: 0 --> 1
Char. 206: 0 --> 1
Char. 329: 0 --> 1
Char. 331: 0 --> 1
Char. 332: 0 --> 1
Char. 348: 0 --> 1

Node 101: *Megalosaurus* + *Torvosaurus*
Char. 120: 1 --> 0
Char. 223: 1 --> 0
Char. 264: 1 --> 0
Char. 361: 0 --> 1
Char. 362: 0 --> 2

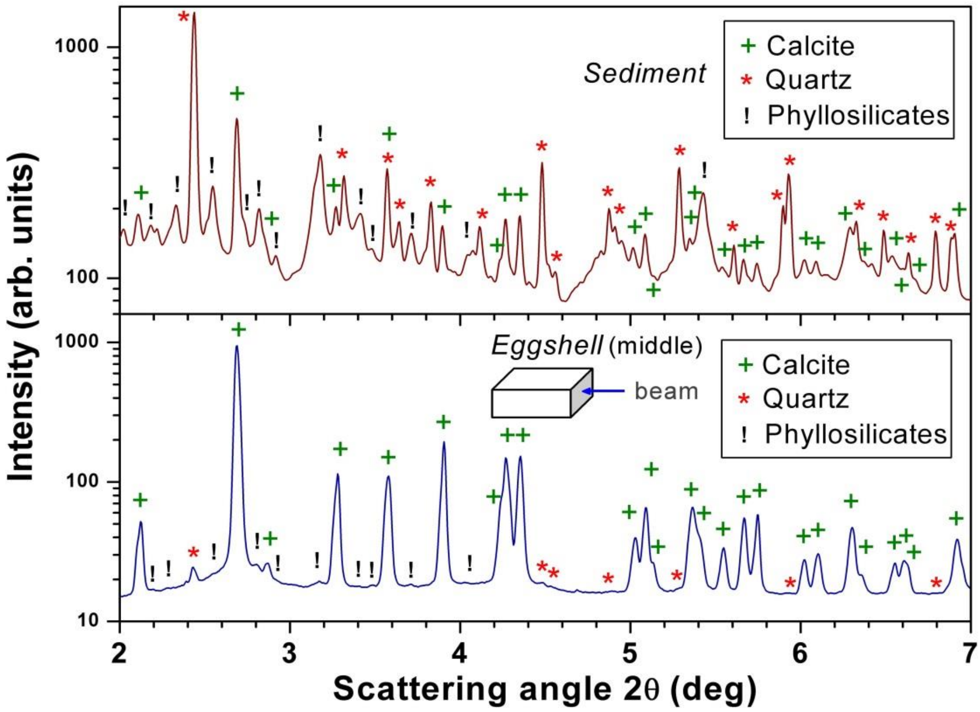
Node 102:
Char. 22: 0 --> 1
Char. 78: 0 --> 1
Char. 184: 0 --> 1
Char. 280: 0 --> 2
Char. 285: 0 --> 1
Char. 293: 0 --> 1
Char. 323: 1 --> 2

Node 103:
Char. 139: 0 --> 1

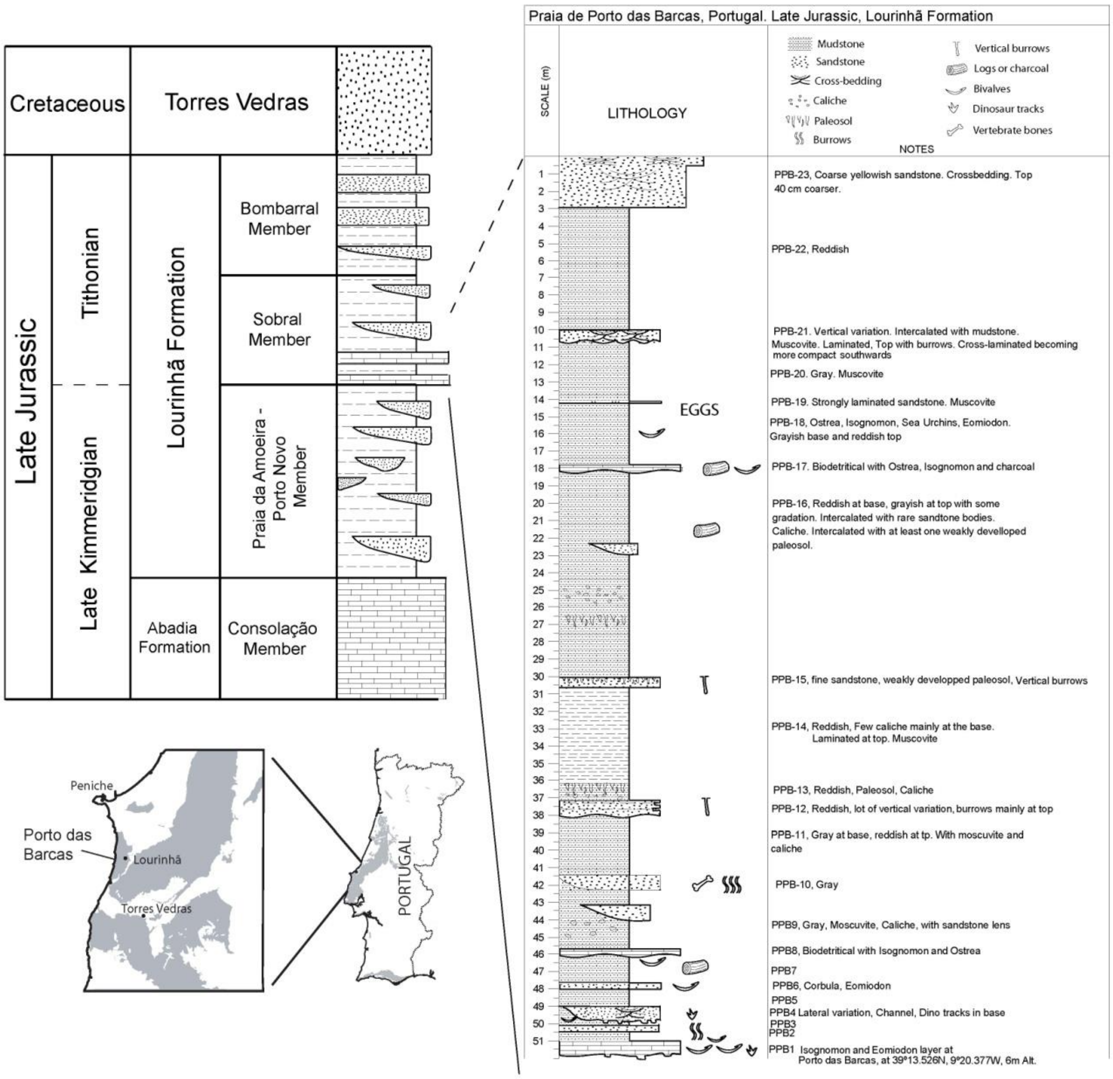
Node 104: *Torvosaurus*
Char. 30: 1 --> 0
Char. 357: 1 --> 2
Char. 359: 0 --> 1



Note 8 – Micro-PIXE elemental distribution maps on an eggshell cross-section from ML1188 (image size: 1860 µm × 1860 µm). The eggshell external surface is located on the right-hand side of the images. Each of the figures depicts the relative quantity of a certain element per pixel (red indicates abundance and blue indicates scarcity, black is absence).



Note 9 – SR-XRD patterns obtained for samples from ML1188 clutch: (top) sediment collected 20 mm away from several eggshells, (bottom) eggshell - at the middle zone.



Note 10 – Geographical, geological[11] and stratigraphic context of the ML1188 clutch and containing embryos. Top left: main formations and members in the Lourinhã area related to the chronostratigraphic scale (rectangles: limestone, dotted pattern: sandstone, dashed pattern: mudstone). Bottom left: geographic location of Lourinhã and Porto das Barcas (adapted from Liñán, 2001 [12]). The grey in the Portugal map depicts Mesozoic strata, and the grey on the inset Jurassic strata. Right: stratigraphic column and the level where the nest was collected (dashed pattern: mudstone, dotted pattern: sandstone).

Attribution information for Figure 6 and Figure S2.

All the dinosaur silhouettes in figures 6 and S2 have been downloaded from phylopic.org. All images are under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License unless stated otherwise.

Fig. 6

- Massospondylus: Joseph J. W. Sertich and Mark A. Loewen

- Macronaria: T. Tischler

- Diplodocoidea: Scott Hartman

- Coelophysoidea: Funkmonk (Public Domain)

- Abelisauridae: S. Hartman

- Megalosauroidea: S. Hartman

- Allosauridae: S. Hartman

- Tyrannosauridae: S. Hartman

- Compsognathidae: S. Hartman

- Ornithomimosauria: S. Hartman

- Therizinosauria: Martin Kevil

- Oviraptorosauria: Matt Martyniuk

- Troodontidae: T. Michael Keesey

- Dromaeosauridae: S. Hartman

- Birds: Steven Traver (Public Domain)

Fig. S2

- *Eoraptor*: S. Hartman

- Coelophysoidea: Funkmonk (Public Domain)

- Abelisauridae: S. Hartman

- *Cryolophosaurus*: S. Hartman

- Spinosauridae: S. Hartman

- Basal Megalosauroidea: S. Hartman

- *Torvosaurus*: S. Hartman

- Compsognathidae: S. Hartman

- *Yangchuanosaurus*: Gregory Paul

- Allosauridae: S. Hartman

- *Aerosteon*: C. Abraczinskas

- Carcharodontosauridae: S. Hartman

References:

1. Carrano, M. T., Benson, R. B. J. & Sampson, S. D. The phylogeny of Tetanurae (Dinosauria: Theropoda). *Journal of Systematic Palaeontology* **10**, 211–300 (2012).
2. Mateus, I., Mateus, H., Antunes, M. T., Mateus, O., Taquet, P., Ribeiro, V. & Manuppella, G. Upper Jurassic theropod dinosaur embryos from Lourinhã (Portugal). *Memórias da Academia das Ciências de Lisboa* **37**, 101–110 (1998).
3. Rauhut, O. W. M. & Fechner, R. Early development of the facial region in a non-avian theropod dinosaur. *Proc. R. Soc. B* **272**, 1179–1183 (2005).
4. Goloboff, P. A., Farris, J. S. & Nixon, K. C. TNT, a free program for phylogenetic analysis. *Cladistics* **24**, 774–786 (2008).
5. Bremer, K. Branch support and tree stability. *Cladistics* **10**, 295–304 (1994).
6. Wilkinson, M. Common Cladistic Information and its Consensus Representation: Reduced Adams and Reduced Cladistic Consensus Trees and Profiles. *Syst Biol* **43**, 343–368 (1994).
7. Benson, R. B. J. A description of *Megalosaurus bucklandii* (Dinosauria: Theropoda) from the Bathonian of the UK and the relationships of Middle Jurassic theropods. *Zoological Journal of the Linnean Society* **158**, 882–935 (2010).
8. Benson, R., Carrano, M. & Brusatte, S. A new clade of archaic large-bodied predatory dinosaurs (Theropoda: Allosauroidea) that survived to the latest Mesozoic. *Naturwissenschaften* **97**, 71–78 (2010).
9. Sereno, P. C. & Brusatte, S. L. Basal abelisaurid and carcharodontosaurid theropods from the Lower Cretaceous Elrhaz Formation of Niger. *Acta Palaeontologica Polonica* **53**, 15–46 (2008).
10. Eddy, D. R. & Clarke, J. A. New information on the cranial anatomy of *Acrocanthosaurus atokensis* and its implications for the phylogeny of Allosauroidea (Dinosauria: Theropoda). *PloS one* **6**, e17932 (2011).

11. Manuppella, G., Antunes, M. T., Pais, J., Ramalho, M. M. & Rey, J. Carta Geológica de Portugal, Notícia explicativa da folha 30-A (Lourinhã) Escala 1:50000, 2nd ed., 83 pp., Lisboa (Instituto Geológico e Mineiro, 1999)

12. Liñán, C.C. Mapa geológico de la Península Ibérica, Baleares Y Canarias. Escala 1:1.000.000. Instituto Tecnológico de España. (2001)