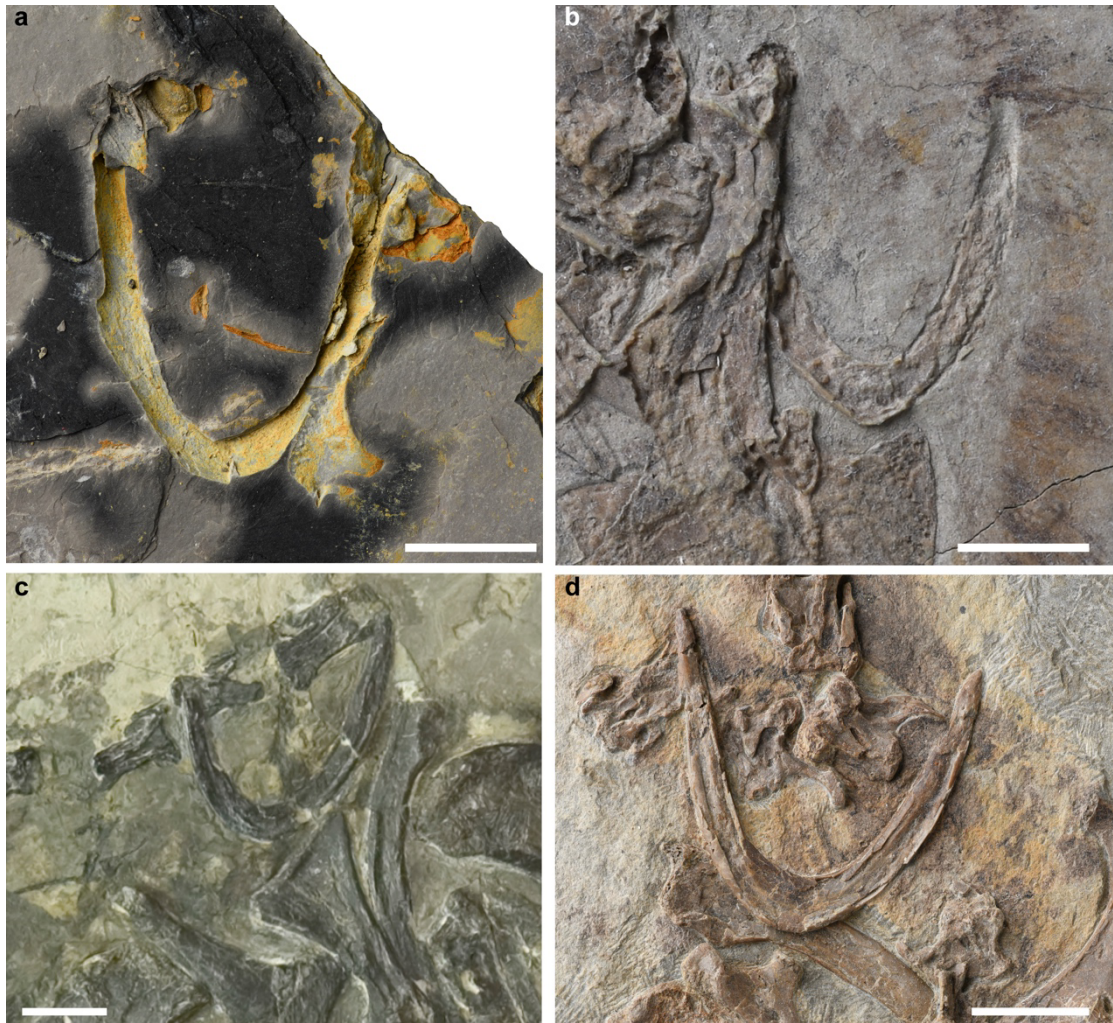

Supplementary information

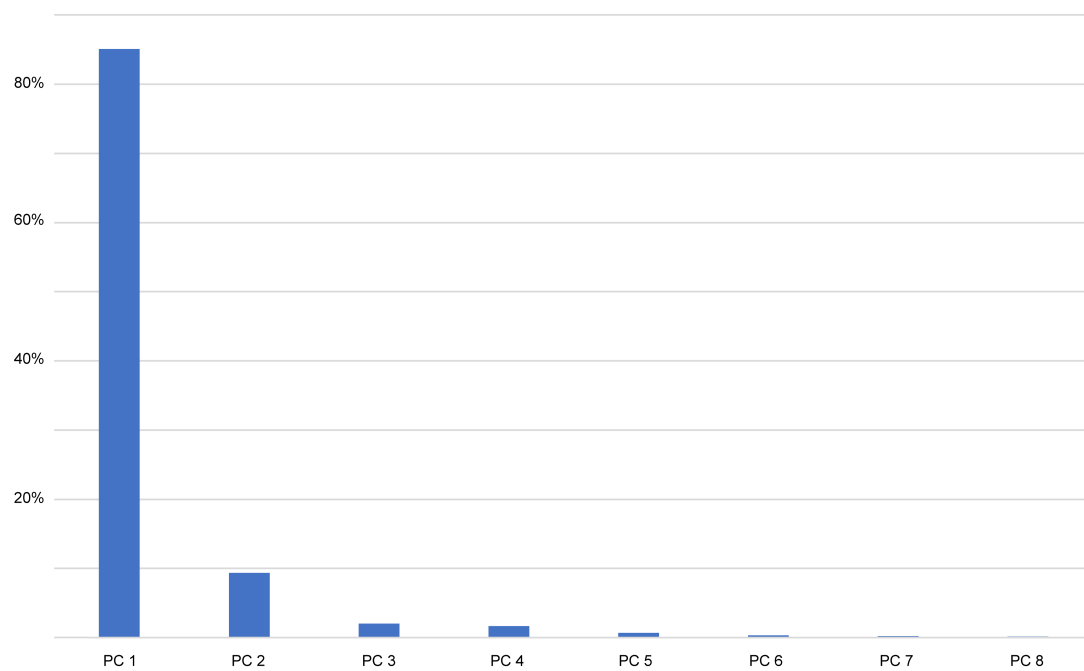
Earliest short-tailed bird from the Late Jurassic of China

In the format provided by the
authors and unedited

1. Supplementary Figure



Supplementary Fig. 1. Comparison of IVPP V33260 with selected furcula of Early Cretaceous ornithuromorphs. a, IVPP V33260. b, *Yanornis* (IVPP V13358). c, *Jianchangornis* (IVPP V16708). d, *Abitusavis* (IVPP V14606). Scale bars, 10 mm.



Supplementary Fig. 2. Result of geometric morphometric of furcula of selected Mesozoic non-avialan and avialan pennaraptorans. Proportions of variances accounted by the first six principal components (PC).



Supplementary Fig. 4. Phylogenetic position of IVPP V33260 using the MAP

matrix. a, Strict consensus tree (1433 steps; Consistency index = 0.271; Retention index = 0.662). **b**, 50% majority consensus tree.

evolved in *Baminornis* and the clade that unites *Sapeornis* and more crownward taxa.

Changes of the pygostyle optimized in TNT (blue arrow) show that the ancestral condition along the branch subtending to *Baminornis* and other taxa is ambiguous.

2. Supplementary Table 1. Selected measurements of *Baminornis zhenghensis* (IVPP V33259).

Element	Measurements (mm)
Scapula length	26.7
Coracoid length	16.6
Coracoid distal end width	12.2
Radius length	32.0*
Pygostyle length	17.9
Metacarpal I, II, III length	4.9, 15.0, 14.7
Phalanx I-1, I-2 length	12.8, 8.0
Phalanx II-1 length	8.7
Phalanx III-1, III-2, III-3, III-4 length	3.3, 2.5, 3.5, 2.7
Ilium length	24.1
Ischium length	17.1
Femur length	40.6

* Estimation

Supplementary Table 2. Comparison of selected measurements of early-diverging avialans (length in mm)

Taxon	m I	m II	m III	p I-1	p II-1	p III-1	p III-2	p III-3	Source
<i>Baminornis</i>	4.9	15.0	14.7	12.8	8.7	3.3	2.5	3.5	this study
<i>Fujianvenator</i>	8.4	34.0	31.6	26.6	24.2	5.9	5.1	19.2	ref. 1
<i>Archaeopteryx</i>	6.8	28.2	27.2	20.7	16.0	7.1	4.6	12.0	ref. 2
<i>Anchiornis</i>	12.4	33.9	30.5	26.2	21.0	7.2	8.1	14.2	ref. 3
<i>Xiaotingia</i>	10.0	24.0	24.0	21.0	15.0	8.0	4.0	15.0	ref. 4
<i>Alcmonavis</i>		40.9	36.8		22.8	8.8	5.9	17.9	ref. 5
<i>Serikornis</i>	12.0	32.0	30.0	27.5	20.0	7.5	6.5	16.0	ref. 6
<i>Jeholornis</i>	6.3	31.1	26.9	16.3	12.3	6.4	3.2	7.2	this study

m I to m III, metacarpal I to III; p I-1, phalanx I-1; p II-1, phalanx II-1; p III-1 to III-3, phalanx III-1 to III-3

Supplementary Table 3. Specimens used in geometric morphometric analysis of furcula.

Taxon	Collection No.	Source
<i>Abitusavis</i>	IVPP V14606	ref. 7
<i>Anchiornis</i>	LPM-B00169	ref. 3
<i>Archaeopteryx</i>	WDC-CSG-100	ref. 8
<i>Archaeorhynchus</i>	IVPP V20312	ref. 9
<i>Baminornis</i>	IVPP V33259	this study
<i>Bambiraptor</i>	AMNH FR 30554	ref. 10
<i>Changchengornis</i>	GMV 2129	ref. 11
<i>Changzuinia</i>	AGB 5840	ref. 12
<i>Confuciusornis</i>	IVPP V12352	this study
<i>Cratonavis</i>	IVPP V31106	ref. 13
<i>Eoconfuciusornis</i>	IVPP V11977	ref. 14
<i>Gansus</i>	CM 004	ref. 15
IGM 100/976	IGM 100/976	ref. 10
<i>Iteravis</i>	IVPP V18958	ref. 16
<i>Jeholornis</i>	STM 2-19	ref. 17
<i>Jianchangornis</i>	IVPP V16708	ref. 18
<i>Jinguoortis</i>	IVPP V24194	ref. 19
<i>Jiuquanornis</i>	GSGM-05-CM-021	ref. 20
<i>Khaan</i>	IGM 100/1127	ref. 10
<i>Microraptor</i>	IVPP uncatalogued	ref. 10
<i>Serikornis</i>	PMOL-AB00200	ref. 6
<i>Tianyuraptor</i>	STM 1-3	ref. 21
<i>Yanornis</i>	IVPP V12558	ref. 22
<i>Yixianornis</i>	IVPP V12631	ref. 22
IVPP V33260	IVPP V33260	this study

Supplementary Table 4. Results of nonparametric multivariate analysis of variance (PERMANOVA). The first three PCs (> 96% shape variation of the furcula) were used.

pairwise comparison	<i>F</i> Model	R ²	Pr (> <i>F</i>)
Ornithuromorpha: non-ornithothoracine avialans	5.985	0.249	0.003
Ornithuromorpha: non-avialan pennaraptorans	2.650	0.169	0.063
non-ornithothoracine avialans: non-avialan pennaraptorans	4.033	0.268	0.021

3. Morphological characters supporting the identification of IVPP V33260

Characters in Theropod Working Group matrix (TWiG) that can be coded for IVPP V33260 and supports its identification as avialan furcula: character states 130 (0), 332 (0), 333 (0), 465 (1), 466 (0), 467 (0), 468 (0), 469 (1), 470 (1).

Characters in Mesozoic Avian Phylogeny (MAP) that can be coded for IVPP V33260 and supports its identification as avialan furcula: character states 104 (2), 105 (1), 106 (0), 107 (0), 276 (1).

4. Description of Theropod Working Group matrix used in present phylogenetic analyses.

The character description follows previous studies^{23,24} with modification from recent studies¹.

Character 1: Feathers, vaned feathers on forelimb, form:

0: symmetric

1: asymmetric

Character 2: Orbit, shape

0: circular in lateral or dorsolateral view

1: dorsoventrally elongate

Character 3: Postorbital, ventral ramus, projection into orbit: (ORDERED)

0: does not project into orbit, suborbital process absent

1: projects into orbit, suborbital process present and large in adults and small and unpronounced in sub-adults

2: projects into orbit, suborbital process present and large in sub-adults and adults

Character 4: Postorbital, shape of anterior (frontal) process in lateral view:

0: straight

1: curving anterodorsally, such that dorsal border of temporal bar is dorsally concave

Character 5: Postorbital, ventral ramus, orientation: (UNORDERED)

0: parallels quadrate, lower temporal fenestra rectangular in shape

1: oriented strongly obliquely relative to quadrate, jugal and postorbital approach or contact quadratojugal to constrict lower temporal fenestra

2: oriented anteroventrally relative to the long axes of the quadrate and lacrimal, angle of postorbital ventral ramus long axis with the lacrimal long axis (if lacrimal is approximately vertical) greater than 30 degrees

Character 6: Braincase, otosphenoidal crest, form and position:

0: vertical on basisphenoid and prootic, and does not border an enlarged pneumatic recess

1: well developed, crescent shaped, thin crest forms anterior edge of enlarged pneumatic recess

Character 7: Braincase, crista interfenestralis, location:

0: confluent with lateral surface of prootic and opisthotic

1: distinctly depressed within middle ear opening

Character 8: Braincase, subotic recess (pneumatic fossa ventral to fenestra ovalis):

0: absent

1: present

Character 9: Basisphenoid recess: (UNORDERED)

0: present between basisphenoid and basioccipital

1: entirely within basisphenoid

2: absent

Character 10: Basisphenoid recess, posterior opening, form:

0: single opening

1: divided into two small, circular foramina by a thin bar of bone

Character 11: Parasphenoid, base of cultriform process (parasphenoid rostrum),

pneumatization:

0: not highly pneumatized

1: expanded and pneumatic (parasphenoid bulla present)

**Character 12: Braincase, basiptyergoid processes, direction of projection:
(UNORDERED)**

0: ventral or anteroventrally projecting

1: lateroventrally projecting

2: laterally projecting

Character 13: Braincase, basiptyergoid processes, form:

0: well developed, extending as a distinct process from the base of the basisphenoid

1: processes abbreviated or absent

Character 14: Braincase, basiptyergoid processes, pneumatization:

0: absent or very subtle, process solid

1: processes hollow, invaded by pneumatic recess (anterior tympanic recess and/or basisphenoid recess)

Character 15: Basisphenoid, basiptyergoid recesses on dorsolateral surfaces of basiptyergoid processes:

0: absent

1: present

**Character 16: Prootic, depression for pneumatic recess (Dorsal Tympanic Recess):
(ORDERED)**

0: absent

1: present as dorsally open fossa on prootic/opisthotic

2: present as deep, posterolaterally directed concavity

Character 17: Braincase, accessory tympanic recess dorsal to crista interfenestralis: (ORDERED)

0: absent

1: small pocket present

2: extensive with indirect pneumatization

Character 18: Braincase, caudal (posterior) tympanic recess: (ORDERED)

0: absent

1: present as opening on anterior surface of paroccipital process

2: extends into opisthotic posterodorsal to fenestra ovalis, confluent with this fenestra

Character 19: Braincase, exits of cranial nerves X-XII, location and form: (ORDERED)

0: flush with surface of exoccipital

1: located together in a shallow bowl-like depression

2: located together in a deep, funnel-like depression

Character 20: Premaxilla, maxillary process, extent and articulation: (UNORDERED)

0: contacts nasal to form posterior border of nares

1: reduced so that maxilla participates broadly in external naris

2: extends posteriorly to separate maxilla from nasal posterior to nares

Character 21: Premaxilla and nasal, internarial bar, morphology of external surface:

0: rounded

1: flat

Character 22: Premaxilla, crenulated margin on buccal edge of bone:

0: absent

1: present

Character 23: External naris, position of posterior margin:

0: farther anterior than antorbital fossa

1: nearly reaching or overlapping the anterior border of the antorbital fossa

Character 24: Premaxilla, shape of conjoined left and right bones in ventral view: (ORDERED)

0: acute, V-shaped

1: rounded, U-shaped, first two teeth oriented mediolaterally and third and fourth teeth oriented parasagittally

2: rounded, U-shaped, entire tooth row oriented mediolaterally

Character 25: Maxilla, anteromedial process (= “secondary palate”): (ORDERED)

0: short

1: long, with extensive palatal shelves on maxilla

2: extremely elongated, extending back at least to the level of alveolus 4

Character 26: Maxilla, palatal shelf, midline ventral “tooth-like” projection:

0: absent, palatal shelf flat

1: present

Character 27: Maxilla, maxillary fenestra: (ORDERED)

0: absent

1: present, fenestra occupies less than half of the depressed area between the anterior margins of the antorbital fossa and antorbital fenestra

2: present, fenestra large and takes up most of the space between the anterior margins of the antorbital fenestra and fossa

Character 28: Maxilla, maxillary fenestra, location:

0: situated at anterior border of antorbital fossa

1: situated posterior to anterior border of fossa

Character 29: Maxilla, promaxillary fenestra:

0: absent

1: present

Character 30: Nasal, pneumatization: (UNORDERED)

0: apneumatic or poorly pneumatized

1: with extensive pneumatic fossae, especially along posterodorsal rim of naris

2: with 2-3 large pneumatic openings, set into a fossa, on the lateral surface above the antorbital fenestra, leading into an extensive internal pneumatic cavity

Character 31: Jugal and postorbital, contribution to postorbital bar:

0: contribute equally to postorbital bar

1: ascending process of jugal reduced and descending process of postorbital ventrally elongate

Character 32: Jugal, dorsoventral height beneath lower temporal fenestra:

0: tall, twice or more as tall dorsoventrally as it is wide transversely

1: very short, jugal rod-like

Character 33: Jugal, pneumatic recess in posteroventral corner of antorbital fossa:

0: present

1: absent

Character 34: Jugal, medial jugal foramen:

0: present on medial surface ventral to postorbital bar

1: absent

Character 35: Quadratojugal, shape:

0: without horizontal process posterior to ascending process (reversed “L” shape)

1: with horizontal posterior process (i.e., inverted ‘T’ or ‘Y’ shape)

Character 36: Jugal and quadratojugal, fusion:

0: absent

1: present, the two bones are not distinguishable from one another

Character 37: Lacrimal, supraorbital crests in adult individuals: (UNORDERED)

0: absent

1: dorsal crest above orbit

2: lateral expansion anterior and dorsal to orbit

Character 38: Lacrimal, pneumatic foramina opening laterally at the junction of the anterior and ventral processes above the antorbital fenestra: (ORDERED)

0: absent

1: present, extent of pneumaticity limited to partially hollowing the bone in the region where the anterior and ventral rami meet

2: present and extensive, completely hollowing the bone where the anterior and ventral rami meet

Character 39: Lacrimal, posterodorsal process: (ORDERED)

0: absent, lacrimal is inverted ‘L’ shaped or ‘7’ shaped in lateral view

1: present, lacrimal ‘T’ shaped in lateral view

2: present but reduced, anterodorsal process much longer than posterodorsal

process

Character 40: Prefrontal, exposure in dorsal view: (ORDERED)

0: large, dorsal exposure similar to that of lacrimal, forms much of orbital rim and usually separates or nearly separates frontal and lacrimal

1: greatly reduced in size, not exposed widely along the orbital rim and allows for wide contact between frontal and lacrimal

2: absent

Character 41: Frontals, shape of conjoined left and right elements in dorsal view:

0: triangular, narrowing anteriorly as a wedge between nasals

1: rectangular, end abruptly anteriorly, suture with nasal transversely oriented

Character 42: Frontal, outline of anterior emargination of supratemporal fossa:

0: straight or slightly curved

1: strongly sinusoidal and reaching onto postorbital process

Character 43: Frontal, form of articulation between postorbital process and frontal orbital margin in dorsal view:

0: smooth transition from orbital margin

1: sharply demarcated from orbital margin

Character 44: Frontal, form of lateral margin of lacrimal (or prefrontal) suture:

0: smooth

1: with discrete notch

Character 45: Parietals, form of dorsal surface and presence of sagittal crest(s): (ORDERED)

0: flat, lateral ridge borders supratemporal fenestra, sagittal crest (or crests) absent

1: convex with very low sagittal crest (or crests) along midline

2: convex with well developed sagittal crest (or crests)

Character 46: Parietals, fusion of left and right elements:

0: unfused

1: fused on the midline in sub-adults and adults (when known)

Character 47: Squamosal, quadratojugal (descending) process, orientation of long axis:

0: dorsoventral or slightly oblique, essentially parallels quadrate shaft

1: anteroposterior, nearly perpendicular to quadrate shaft

Character 48: Squamosal, contact of descending (ventral) process with quadratojugal:

0: present

1: absent, squamosal does not contact quadratojugal

Character 49: Squamosal, posterolateral shelf overhanging quadrate head:

0: absent

1: present

Character 50: Quadrate, orientation of shaft when in articulation:

0: vertical

1: strongly inclined anteroventrally so that ventral end lies far forward of dorsal end

Character 51: Quadrate shaft, form of lateral surface:

0: straight, without any prominent processes projecting laterally; quadrate foramen not visible in lateral view

1: with broad, triangular process along lateral edge of shaft contacting squamosal and quadratojugal above an enlarged quadrate foramen, which is often partially or largely visible in lateral view

Character 52: Foramen magnum, shape:

0: subcircular, slightly wider than tall

1: oval, taller than wide

Character 53: Occipital condyle, mediolateral width and dorsoventral height of neck linking condyle to remainder of braincase:

0: approximately the same width and height as the condyle

1: constricted in width and height relative to the condyle

Character 54: Paroccipital processes, shape:

0: elongate mediolaterally and slender dorsoventrally compared to mediolateral length, with dorsal and ventral edges nearly parallel

1: process short mediolaterally, deep dorsoventrally compared to mediolateral

length, with convex distal end

Character 55: Paroccipital processes, orientation in posterior view:

0: straight, projects laterally or slightly posterolaterally

1: downturned, distal end curves ventrally and is pendant

Character 56: Paroccipital process, orientation of dorsal edge:

0: straight

1: twisted anterolaterally at distal end

Character 57: Ectopterygoid, form of the opening into the pneumatic fossa on the ventral surface:

0: constricted opening relative to fossa

1: widely opened fossa

Character 58: Ectopterygoid: dorsal recess:

0: absent

1: present

Character 59: Pterygoid, morphology of the posterior flange for articulation with quadrate and epipterygoid:

0: well developed

1: reduced in size or absent

Character 60: Palatine and ectopterygoid, articulation between the two bones:

0: absent, the two bones separated from each other by the pterygoid

1: present, the two bones contact each other

Character 61: Palatine, jugal process:

0: present, palatine tetra-radiate in shape

1: absent, palatine tri-radiate in shape

Character 62: Skull, suborbital fenestra, size:

0: large, similar in anteroposterior length to the anteroposterior length of the orbit

1: reduced in size (less than one quarter orbital length) or absent

**Character 63: Dentary, form of symphyseal region in dorsal or ventral view:
(ORDERED)**

0: approximately straight anteroposteriorly, paralleling lateral margin of the remainder of bone; conjoined dentaries narrow

1: recurved slightly medially relative to remainder of bone, conjoined dentaries U-shaped

2: recurved strongly medially relative to remainder of bone, conjoined dentaries forming broad U-shaped muzzle

Character 64: Dentary, orientation of dorsal margin of symphyseal region in lateral view:

0: in line with the remainder of the dorsal (alveolar) margin of the dentary

1: downturned relative to the remainder of the dorsal margin

Character 65: Lower Jaw, coronoid prominence (usually located on surangular):

0: absent

1: present

Character 66: Dentary, contribution to the dorsal margin of the external mandibular fenestra: (ORDERED)

0: absent or slight, without discrete posterodorsal process

1: present, with discrete posterodorsal process above anterior end of fenestra

2: present and extensive, with elongate posterodorsal process extending over most of fenestra

Character 67: Dentary, morphology of lateral surface:

0: flat, tooth row approximately in line with the remainder of the lateral surface

1: bearing lateral ridge, tooth row inset from remainder of lateral surface

Character 68: Dentary, shape:

0: subtriangular in lateral view, with dorsoventral depth expanding posteriorly

1: strap-like in lateral view, with subparallel dorsal and ventral edges and a consistent dorsoventral depth across its length

Character 69: Dentary, primary neurovascular foramina on lateral surface, arrangement:

0: distinct but superficial foramina

1: distinct foramina lie within a deep and sharp groove across the middle and

posterior regions of the dentary

Character 70: Lower jaw, external mandibular fenestra, shape

0: oval

1: subdivided by a spinous anterior process of the surangular

Character 71: Lower jaw, internal mandibular fenestra (opening between splenial and prearticular on medial surface of mandible), size and shape:

0: small and slit-like

1: large and rounded

Character 72: Surangular, foramen in lateral surface of surangular anterior to the mandibular articulation: (ORDERED)

0: absent

1: present but small

2) present and large, approximately 30% of the dorsoventral depth of the posterior surangular

Character 73: Splenial, exposure in lateral view:

0: not widely exposed on lateral surface of mandible

1: exposed as a broad triangle between dentary and angular on lateral surface of mandible

Character 74: Lower jaw, coronoid ossification, presence and shape: (ORDERED)

0: present as a large, triangular bone (fused with the supradentary)

1: present but reduced to a thin splint

2: absent

Character 75: Articular, elongate and slender medial process emanating from retroarticular process (can project medially, posteromedially, or dorsomedially):

0: absent

1: present

Character 76: Articular, retroarticular process, presence and shape: (UNORDERED)

0: present, short and stout, with a distinct region between the glenoid and the portion of the retroarticular process to which the jaw depressors attached

1: present, elongate and slender

2: present but extremely reduced, with no (or only a very short) margin between the glenoid and the muscle attachment region

Character 77: Lower jaw, glenoid articular surface for mandible, anteroposterior length:

0: approximately as long as distal quadrate condyles

1: twice or more as long as distal quadrate condyles, allowing anteroposterior movement of mandible

Character 78: Premaxilla, teeth:

0: present

1: absent

Character 79: Premaxillary dentition, size of second premaxillary tooth:

0: approximately equivalent in size to other premaxillary teeth

1: markedly larger than third and fourth premaxillary teeth

Character 80: Maxilla, teeth:

0: present

1: absent

Character 81: Maxillary and dentary teeth, serrations: (UNORDERED)

0: present on all known teeth

1: some teeth without serrations on mesial (anterior) carina (except at base in *S. mongoliensis*)

2: all known teeth without serrations on both mesial and distal carinae

Character 82: Maxillary and dentary teeth, size:

0: large

1: small (25-or more teeth in dentary when complete series is observable)

Character 83: Dentary teeth, implantation:

0: in separate alveoli

1: set in open groove

Character 84: Maxillary and dentary teeth, serrations (denticles):

0: large

1: small

Character 85: Maxillary and dentary teeth, serrations, form:

0: simple, convex, and approximately perpendicular to the long axis of the tooth

1: large, hooked and pointing toward the tip of the crown on the distal and often mesial carinae

Character 86: Maxillary and dentary teeth, constriction between root and crown:

0: present

1: absent, root and crown confluent

Character 87: Dentary teeth, spacing between teeth:

0: evenly spaced across tooth row

1: anterior dentary teeth smaller, more numerous, and more closely appressed than those in middle of tooth row

Character 88: Dentary, interdental plates, form:

0: distinct internal plates absent (although a homologue to the plates is probably present)

1: distinct, clearly demarcated interdental plates medially between teeth

Character 89: Premaxillary tooth crowns, position of mesial carina: (ORDERED)

0: along mesial margin of tooth, tooth cross section sub-oval to sub-circular

1: rotated distally on premaxillary teeth 1 and 2, such that anterior teeth have an asymmetrical cross section (D-shaped, with highly convex labial surface and flat lingual surface, with narrow spacing between mesial and distal carinae)

2: rotated distally on all premaxillary teeth, such that all teeth are D-shaped in cross section.

Character 90: Cervical vertebrae, number:

0: ≤ 11

1: 12 or more

Character 91: Axis, epipophyses, form:

0: absent or poorly developed as a small pyramidal mound, not extending past posterior edge of postzygapophyses

1: large, rugose, and posteriorly directed flange, extending far beyond

postzygapophyses

Character 92: Axis, neural spine, form of dorsal portion:

- 0: flared transversely
- 1: compressed mediolaterally

Character 93: Cervical vertebrae, epiphyses, position:

- 0: placed distally on postzygapophyses, above postzygapophyseal facets
- 1: placed proximally, anterior to postzygapophyseal facets

Character 94: Cervical vertebrae, position of centrum in anterior cervical vertebrae:

- 0: terminates level with or anterior to the posterior extent of the neural arch
- 1: extending beyond the posterior limit of the neural arch

Character 95: Cervical vertebrae, carotid process on posterior cervical vertebrae:

- 0: absent
- 1: present

Character 96: Cervical vertebrae, shape of anterior articular surface of anterior cervical centra:

- 0: subcircular or square in anterior view
- 1: distinctly wider than high, kidney shaped

Character 97: Cervical vertebrae, neural spines, shape in dorsal view:

- 0: anteroposteriorly long
- 1: short and centered on neural arch, giving arch an “X” shape in dorsal view

Character 98: Cervical vertebrae, number of pneumatic foramina on lateral surface of centra:

- 0: one on each side
- 1: two on each side

Character 99: Cervical and anterior trunk vertebrae, form: (UNORDERED)

- 0: amphiplatyan or weakly opisthocoelous (anterior surface flat or weakly convex, posterior surface is flat or weakly concave)
- 1: strongly opisthocoelous (anterior surface is convex and posterior surface concave)

2: at least partially heterocoelous

Character 100: Dorsal vertebrae, hypapophyses in anterior trunk vertebrae:

0: absent or very small

1: large and pronounced

Character 101: Dorsal vertebrae, parapophyses in posterior trunk vertebrae, form:

0: flush with neural arch

1: distinctly projected on pedicels

Character 102: Dorsal vertebrae, hyposphene-hypantrum articulations:

0: absent

1: present

**Character 103: Dorsal vertebrae, opposing zygapophyses on the same vertebra:
(ORDERED)**

0: abutting or nearly abutting one another above neural canal, opposite hyposphenes (if present) meet to form a single structure (lamina or rectangular projection)

1: zygapophyses placed distinctly lateral to neural canal and hyposphenes (if present) separated as two widely-spaced laminae, which are joined medially by an inset web of bone

2: zygapophyses placed distinctly lateral to neural canal and hyposphenes (if present) separated as two widely-spaced lamina, which are separated medially by a deep groove (the inset web of bone in state 1 is absent)

Character 104: Cervical vertebrae, pneumaticity:

0: absent

1: present

Character 105: Dorsal vertebrae, transverse processes of anterior dorsals, form:

0: long (in mediolateral direction) and thin (in anteroposterior direction)

1: short (in mediolateral direction), wide (in anteroposterior direction), and only slightly inclined

Character 106: Dorsal vertebrae, neural spines, mediolateral expansion of dorsal end:

0: absent

1: present, expanded to form 'spine table'

Character 107: Dorsal vertebrae, scars for interspinous ligaments, position:

0: terminate at apex of neural spines

1: terminate below apex of neural spine

Character 108: Sacral vertebrae, number: (ORDERED)

0: 5 or less

1: 6

2: 7

3: 8

4: 9

5: 10

6: 11 or more

7: 15 or more

Character 109: Sacral vertebrae, fusion of zygapophyses:

0: absent, or zygapophyses partially fused to each other but still retaining the morphology of the original discrete structures

1: present, completely fused zygapophyses forming a sinuous ridge in dorsal view

Character 110: Sacral centra, ventral surface of posterior sacra, form: (UNORDERED)

0: gently rounded, convex

1: ventrally flattened, sometimes with shallow sulcus

2: centrum strongly constricted transversely, ventral surface keeled

Character 111: Sacral vertebrae, pneumatic foramina on lateral surfaces of centra: (ORDERED)

0: absent on sacral vertebrae

1: present on anterior sacra only

2: present on all sacra

Character 112: Sacral vertebrae, morphology of the posterior articular face of the

last sacral centrum:

0: flat or slightly concave

1: convex

Character 113: Caudal vertebrae, change in morphology of free caudals along the tail:

0: present, with distinct transition point from shorter centra with long transverse processes proximally to longer centra with small or no transverse processes distally

1: absent, vertebrae homogeneous in shape, without transition point

Character 114: Caudal vertebrae, location of transition point along the tail: (ORDERED)

0: begins distal to the 10th caudal vertebra

1: between the 7th and 10th caudal vertebra

2: or proximal to the 7th caudal vertebra

Character 115: Caudal vertebrae, morphology of anterior caudal centra: (UNORDERED)

0: tall, oval in cross section

1: with box-like centra in caudals I-V

2: anterior caudal centra laterally compressed with ventral keel

Character 116: Caudal vertebrae, neural spines, form:

0: simple, undivided

1: separated into anterior and posterior alae throughout much of caudal sequence

Character 117: Caudal vertebrae, neural spines on distal caudals (distal to ~caudal 15), form: (ORDERED)

0: present as a low ridge

1: absent

2: absent and location of spine replaced by midline sulcus in center of neural arch

Character 118: Caudal vertebrae, length of prezygapophyses of distal caudals: (UNORDERED)

0: between 1/3 and whole centrum length

- 1: extremely long (up to 10 vertebral segments long in some taxa)
- 2: strongly reduced or absent, terminate at approximately the anterior level of the centrum
- 3: prezygapophyses present but negligible in size, clasping the posterior surface of neural arch of preceding vertebrae, postzygapophyses negligible (this is an autapomorphy of *Ichthyornis dispar*)

Character 119: Caudal vertebrae, number: (ORDERED)

- 0: more than 40
- 1: 35-40
- 2: 25-35
- 3: 8-25
- 4: less than 8 free caudal vertebrae, tail very short

Character 120: Chevrons, form of chevrons from proximal part of tail:

- 0: long and slender, proximal end short anteroposteriorly and shaft cylindrical
- 1: short and stout, proximal end elongate anteroposteriorly and shaft flattened and plate-like

Character 121: Chevrons, form of chevrons from distal part of tail: (ORDERED)

- 0: simple
- 1: anteriorly bifurcate
- 2: bifurcate at both ends

Character 122: Cervical ribs, shaft: (UNORDERED)

- 0: slender and longer than vertebra to which they articulate
- 1: broad and shorter than vertebra
- 2: extremely thin and slender, hair-like

Character 123: Ossified uncinate processes: (ORDERED)

- 0: absent
- 1: present and unfused to ribs
- 2: present and fused to ribs

Character 124: Ossified ventral (sternal) rib segments:

- 0: absent

1: present

Character 125: Gastralia, lateral gastral segment, size:

0: shorter than medial one in each lateral-medial gastralium set

1: longer than the medial one

Character 126: Sternum, ossified sternal plates, fusion:

0: absent, left and right plates separate in adults

1: present, left and right plates fused

Character 127: Sternum, lateral xiphoid process posterior to costal margin:

0: absent

1: present

Character 128: Sternum, groove on anterior edge for reception of coracoid:

0: present

1: absent

Character 129: Sternum, position of articular facet for coracoid (conditions may be determined by the position of the articular facet on coracoid in taxa without ossified sternum):

0: anterolateral or more lateral than anterior

1: almost anterior

Character 130: Furcula, hypocleidium: (ORDERED)

0: absent

1: present as tubercle

2: present as an elongate process

Character 131: Scapula, orientation of acromion margin:

0: continuous with blade

1: anterior edge laterally everted relative to blade

Character 132: Coracoid, expansion of posterolateral surface ventral to glenoid fossa:

0: unexpanded

1: posterolateral edge of coracoid expanded to form triangular subglenoid fossa bounded laterally by enlarged coracoid tuber

Character 133: Scapula and coracoid, fusion:

- 0: absent, two bones separate
- 1: present, two bones fused into scapulacoracoid

Character 134: Coracoid, shape in lateral view: (UNORDERED)

- 0: subcircular, with shallow ventral blade
- 1: subquadrangular with extensive ventral blade
- 2: shallow ventral blade with elongate posteroventral process
- 3: height more than twice width, coracoid strut-like

Character 135: Scapula and coracoid, form of their articulation:

- 0: form a continuous arc in posterior and anterior views
- 1: coracoid inflected medially relative to scapula, scapulocoracoid 'L' shaped in lateral view

Character 136: Scapula and coracoid, glenoid fossa, orientation of articular surface:

- 0: faces posteriorly or posterolaterally
- 1: faces laterally

Character 137: Scapula, length compared to length of humerus:

- 0: longer
- 1: approximately same length or shorter

Character 138: Humerus, deltopectoral crest, extent and morphology: (UNORDERED)

- 0: large and distinct, proximal end of humerus quadrangular or triangular in anterior view
- 1: deltopectoral crest less pronounced, forming an arc rather than being quadrangular
- 2: deltopectoral crest very weakly developed, proximal end of humerus with rounded edges
- 3: deltopectoral crest extremely long and rectangular

Character 139: Humerus, deltopectoral crest, form of anterior surface:

- 0: smooth

1: with distinct muscle scar near lateral edge along distal end of crest for insertion of biceps muscle

Character 140: Ulna, olecranon process, size:

0: weakly developed

1: distinct and large

Character 141: Ulna, morphology of distal articular surface (dorsal condyle and dorsal trochlea in birds):

0: flat

1: convex, semilunate surface

Character 142: Ulna, morphology of proximal surface:

0: a single continuous articular facet

1: divided into two distinct fossae (one convex, the other concave) separated by a median ridge

Character 143: Lateral proximal carpal (ulnare?), shape in proximal view:

0: quadrangular

1: triangular

Character 144: Distal carpals in contact with metacarpals, number:

0: two separate carpals, one covering the base of metacarpal I (and perhaps contacting metacarpal II) the other covering the base of metacarpal II

1: a single distal carpal capping metacarpals I and II

Character 145: Semilunate distal carpal, size: (UNORDERED)

0: well developed, covering all of proximal ends of metacarpals I and II

1: small, covers about half of base of metacarpals I and II

2: covers bases of all metacarpals

3: covers MC II and MC III

Character 146: Metacarpal I, length: (ORDERED)

0: less than half the length of metacarpal II

1: approximately half of the length (~50-70%) of metacarpal II

2: subequal in length to metacarpal II

Character 147: Third manual digit, size:

0: present and large, phalanges present

1: reduced to no more than metacarpal splint

Character 148: Manual unguals, curvature: (ORDERED)

0: strongly curved, flexor margin deeply concave

1: weakly curved, flexor margin shallowly concave (third ungual may be straight)

2: all manual unguals straight

Character 149: Manual unguals, size of ungual on digit I compared to the other manual unguals in the hand:

0: generally similar in size

1: distinctly larger

Character 150: Manual unguals, a transverse ridge immediately dorsal to the articulating surface (“proximodorsal lip”):

0: absent

1: present

Character 151: Ilium, preacetabular process, anteroventral corner, form: (UNORDERED)

0: subtriangular, ventral margin of preacetabular process is shallowly concave

1: subquadrate with recurved anterior margin, ventral margin of preacetabular process is deeply concave such that the open region between the pubic peduncle and anteroventral region of the preacetabular process defines much of a circle

2: process strongly hooked

Character 152: Ilium, preacetabular process, length: (ORDERED)

0: roughly as long as postacetabular process

1: markedly longer (more than 2/3 of total ilium length) than postacetabular process

2: postacetabular blade much longer than postacetabular process

Character 153: Ilium, morphology of anterior margin of preacetabular process: (UNORDERED)

0: gently rounded or straight

- 1: anterior end strongly convex, lobate
- 2: pointed at anterodorsal corner with concave anteroventral edge
- 3: distinctly concave dorsally

Character 154: Ilium, supraacetabular crest on ilium, form: (ORDERED)

0: present as a separate process from the antitrochanter, and forming a “hood” over the femoral head

- 1: reduced but still separate from the antitrochanter, not forming “hood”
- 2: absent

Character 155: Ilium, postacetabular process, shape of distal end: (UNORDERED)

- 0: squared
- 1: acuminate
- 2: squared, with nearly vertical posterior margin that is nearly equivalent in depth to the anterior margin of the preacetabular process

Character 156: Ilium, opposing postacetabular blades, orientation in dorsal view:

- 0: subparallel to each other
- 1: diverge posteriorly from each other

Character 157: Ilium, tuber along dorsal edge of ilium dorsal or slightly posterior to acetabulum:

- 0: absent
- 1: present

Character 158: Ilium, brevis fossa, form:

- 0: shallowly inset into bone, brevis shelf projects strongly medially
- 1: deeply inset into bone, with both lateral lamina and medial brevis shelf curving ventrally to demarcate the deeply concave fossa

Character 159: Ilium, antitrochanter, form:

- 0: absent or poorly developed
- 1: prominent

Character 160: Ilium, ridge bounding cuppedicus fossa, extension:

- 0: terminates anterior to acetabulum or curves ventrally onto anterior end of pubic peduncle

1: extends far posteriorly and to become confluent or almost confluent with acetabular rim

Character 161: Ilium, cuppedicus fossa, form: (ORDERED)

0: deeply inset into the anterior and lateral surfaces of the pubic peduncle, with a pronounced dorsal rim

1: reduced, fossa shallow or flat, with little or no overhanging dorsal rim

2: absent

Character 162: Ischium, prominent median posterior process along posterior edge of bone:

0: absent, posterior edge of bone straight

1: present

Character 163: Ischium, morphology of shaft distal to the acetabular (obturator) region: (ORDERED)

0: extremely rod-like, midshaft diameter 30-50% midshaft diameter of pubis

1: rod-like, midshaft diameter 60-100% midshaft diameter of pubis

2: wide, flat, and plate-like, midshaft diameter greater than midshaft diameter of pubis

Character 164: Ischium, orientation of shaft: (UNORDERED)

0: straight

1: curved anteriorly at the ventral end

2: hooked posteriorly at the ventral end

Character 165: Ischium, surface morphology of lateral face of ischiadic blade: (UNORDERED)

0: flat or gently rounded

1: concave

2: with longitudinal ridge subdividing lateral surface into anterior (including obturator process) and posterior parts

This character is revised to “0” for *Jeholornis*, *Yanornis*.

Character 166: Ischium, obturator process of ischium: (ORDERED)

0: absent

1: proximal in position (midpoint of process positioned at less than 30% of the total length of the ischium)

2: located near middle of ischiadic shaft (midpoint of process positioned at approximately 40-50% of the total length of the ischium)

3: located at distal end of ischium (midpoint of process positioned distal to the midpoint of the ischium)

Character 167: Ischium, obturator process, contact with pubis:

0: absent

1: present

Character 168: Ischium, obturator foramen or notch in proximal portion of obturator process: (ORDERED)

0: enclosed foramen present

1: open notch present (i.e., a foramen that is no longer completely enclosed)

2: notch or foramen absent

Character 169: Ischium, ischial tubercle (“semicircular scar”) ventral to iliac peduncle on the posterior margin of the proximal end of ischium: (ORDERED)

0: absent or potentially homologous structure present as a groove

1: present as a convex bulge on the posterior surface of the ischium

2: present as a rugose, ovoid or triangular flange whose lateral surface is depressed relative to the remainder of the ischium

Character 170: Ischium, length of bone:

0: greater than two-thirds of pubis length

1: two-thirds or less of pubis length

Character 171: Ischium, morphology of distal ends of opposing ischia: (ORDERED)

0: form symphysis

1: approach one another but do not form symphysis

2: widely separated

Character 172: Ischium, distal end, expansion relative to midshaft:

0: present, resulting in an ischial “boot”

1: absent, ischial “boot” absent

Character 173: Ischium, tubercle on anterior edge of bone:

0: absent

1: present

Character 174: Pubis, orientation of shaft when in articulation: (UNORDERED)

0: projecting anteroventrally (propubic)

1: vertical

2: projecting posteroventrally (opisthopubic)

3: appressed to ischium

Character 175: Pubis, pubic boot, anterior projection of boot relative to posterior projection: (ORDERED)

0: equal in size or anterior process larger than posterior process

1: anterior process small, approximately 10-40%

2: anterior process completely absent, posterior process large

3: both anterior and posterior processes absent (i.e., boot present but without distinct anterior and posterior projections)

Character 176: Pubis, shelf on shaft proximal to symphysis (‘pubic apron’): (UNORDERED)

0: extends medially from middle of shaft

1: shelf extends medially from anterior edge of shaft

2: strongly reduced (restricted to distal end of pubis) or absent

Character 177: Pubis, curvature of shaft: (UNORDERED)

0: absent, shaft straight

1: distal end curves anteriorly, anterior surface of shaft concave

2: distal end curves posteriorly, anterior surface of shaft convex

Character 178: Pubis, length of pubic apron: (ORDERED)

0: about half of pubic shaft length

1: less than 1/3 of shaft length

2: greatly reduced, restricted to far distal end of pubis

3: absent

**Character 179: Pubic apron, form of contact between opposing pubes distally:
(ORDERED)**

0: both pubes meet extensively

1: contact between pubes disrupted by a slit (pubic foramen)

2: no contact between pubes distally, pubic apron absent in this part of pubis but present further proximally

Character 180: Femur, head, fovea capitalis for attachment of capital ligament:

0: absent or subtle

1: present as a distinct circular fovea located in center of the medial surface of the head

Character 181: Femur, interaction of lesser and greater trochanters: (ORDERED)

0: separated from each other by deep cleft

1: separated from each other by small groove

2: completely fused to each other (absent as distinct structures), forming a trochanteric crest

Character 182: Femur, lesser trochanter, shape in lateral view:

0: alariform, projects anteriorly as a broad flange that is anteroposteriorly wider than the greater trochanter

1: reduced to approximately the same anteroposterior width as the greater trochanter, cylindrical in cross section

Character 183: Femur, ridge on lateral surface distal to lesser and greater trochanters (homologous to the trochanteric shelf):

0: absent or represented only by faint rugosity or bulge

1: distinctly raised from shaft as a pronounced, mound-like ridge

Character 184: Femur, fourth trochanter:

0: present

1: absent (or reduced to a subtle and barely distinguishable margin)

Character 185: Femur, accessory trochanteric crest distal to lesser trochanter:

0: absent

1: present

Character 186: Femur, mesiodistal crest, form:

0: absent or present as a subtle structure

1: present as a pronounced longitudinal crest extending proximally from medial condyle, which is seen to strongly overhang the remainder of the medial margin of the femur in posterior view (i.e., is visible as a broad flange in posterior view)

Character 187: Femur, flexor groove, morphology of distal end:

0: open distally, smoothly confluent with distal articular surface

1: closed off distally by contact between distal condyles, separated from distal articular surface

Character 188: Fibula, distal extent:

0: reaches proximal tarsals

1: short, tapering distally, and not in contact with proximal tarsals

Character 189: Fibula, medial margin of proximal end in proximal view:

0: concave

1: flat

Character 190: Fibula, deep oval fossa, with well defined margins, on medial surface near proximal end:

0: absent

1: present

Character 191: Astragalus and calcaneum, morphology of distal condyles:

0: condyles separated by shallow, indefinite sulcus

1: condyles separated by prominent tendoneal groove on anterior surface

Character 192: Tibia, number of cnemial crests:

0: single pronounced crest

1: two crests (main crest with accessory anterior crest)

Character 193: Astragalus, ascending process, form: (UNORDERED)

0: tall and broad, covering most of anterior surface of distal end of tibia (70% or more of mediolateral width of surface) and dorsoventral height greater than twice the height of the main body of the astragalus

1: process short and slender, covering only lateral half of anterior surface of

tibia (includes derived therizinosauroid condition in which a lateral extension of the ascending process contacts the fibula) and dorsoventral height less than twice the height of the main body of the astragalus

2: ascending process tall, but with medial notch that restricts it to lateral side of anterior face of distal tibia

Character 194: Astragalus, ascending process, articulation with condyles distally:

0: confluent with condylar region of astragalus

1: separated from condylar region by transverse groove or fossa across base

Character 195: Astragalus and calcaneum, fusion: (ORDERED)

0: absent, astragalus and calcaneum unfused to each other or to tibia in adults

1: present, astragalus and calcaneum fused to each other, unfused to tibia

2: present, astragalus and calcaneum completely fused to each other and to tibia

Character 196: Distal tarsals, fusion with metatarsals:

0: absent, distal tarsals and metatarsals separate

1: present, distal tarsals and metatarsals fused into tarsometatarsus

Character 197: Metatarsals, fusion: (ORDERED)

0: absent, metatarsals not co-ossified

1: present, metatarsals co-ossified proximally

2: present, metatarsals co-ossified proximally and distally

3: present, metatarsals co-ossified proximally and distally, with distal fusion extreme and distal vascular foramen closed

Character 198: Metatarsal II, morphology of distal end:

0: smooth, not ginglymoid

1: with developed ginglymus that extends onto extensor surface, giving the distal end a strongly concave profile in extensor (anterior) view

Character 199: Metatarsal III, morphology of distal end:

0: smooth, not ginglymoid

1: with developed ginglymus: smooth articular region extends proximally onto extensor surface and is broadly exposed

Character 200: Metatarsal III, exposure of proximal shaft in extensor view:

(ORDERED)

0: prominently exposed between MT II and MT IV along entire metapodium

1: MT III proximal shaft constricted and much narrower than either II or IV, but still exposed along most of metapodium, subarctometatarsal

2: very pinched, not exposed along proximal section of metapodium, arctometatarsal

3: proximal part of MT III lost entirely

Character 201: Pedal digit II, ungual and penultimate phalanx, morphology:

0: similar to those of III

1: penultimate phalanx highly modified for extreme hyper-extension, ungual more strongly curved and significantly larger than that of digit III

Character 202: Metatarsal II, site of articular surface for metatarsal I:

(UNORDERED)

0: the middle of the medial surface of metatarsal II

1: the posterior surface of distal quarter

2: the medial surface near the proximal end

3: the medial surface at or near the distal end

Character 203: Metatarsal I, form of proximal end:

0: attenuates proximally, articular surface for metatarsal II is a simple butt joint lying against the shaft of metatarsal II

1: large and robust, similar to those of metatarsals II-IV

Character 204: Metatarsal IV, shaft thickness:

0: round or thicker dorsoventrally (extensor-flexor direction) than wide mediolaterally in cross section

1: mediolaterally widened and flat in cross section

Character 205: Foot, symmetry:

0: symmetrical

1: asymmetrical with slender MTII and very robust MT IV, excluding flange

Character 206: Dorsal vertebrae, neural spines on posterior dorsals, shape in lateral view:

0: rectangular or square

1: fan-shaped, anteroposterior length of spine expanding dorsally

Character 207: Manual phalanx I-1, shaft diameter:

0: less than or approximately equal to the shaft diameter of radius.

1: greater than the shaft diameter of radius.

Character 208: Angular, extent in lateral view:

0: widely exposed, suture between surangular and angular reaches or nearly reaches posterior end of mandible

1: reduced in exposure, suture between surangular and angular does not reach posterior end of the mandible

Character 209: Surangular, laterally inclined flange along dorsal edge of bone for articulation with the lateral process of lateral quadrate condyle:

0: absent

1: present

Character 210: Distal articular ends of metacarpals I + II: (UNORDERED)

0: ginglymoid

1: rounded, smooth

2: II ginglymoid and MC I shelf

Character 211: Radius and ulna, articulation with each other:

0: well separated

1: with distinct adherence or syndesmosis distally

Character 212: Upper and lower jaws, occlusion:

0: occlude for their full length

1: diverge anteriorly due to kink and downward deflection of the dentary (pronounced downward deflection of dentary buccal margin anteriorly)

Character 213: Quadrate, exposure of head in lateral view:

0: absent, covered by squamosal laterally

1: present, exposed because quadrate cotyle of squamosal opens laterally due to a wide notch between the ventral and posterior processes

Character 214: Ilium, brevis fossa, orientation and exposure in lateral view:

0: faces primarily ventrally, but it is widely visible in lateral view (especially anteriorly)

1: faces primarily ventrally and medially, and it is obscured in lateral view across its entire length by a well developed lateral lamina of the postacetabular process of the ilium

Character 215: Lesser trochanter, vertical ridge on lateral surface:

0: present

1: absent

Character 216: Supratemporal fossa, extension onto the squamosal:

0: absent, fenestra bounded laterally and posteriorly by the squamosal, with no distinct fossa present on the dorsal surface of the squamosal

1: present, distinct fossa extends onto the dorsal surface of the squamosal

Character 217: Dentary, teeth: (ORDERED)

0: present across much of bone, dentary fully toothed

1: present but only at the far anterior tip

2: absent, dentary edentulous

Character 218: Coracoid, ventral (=anterior) margin of bone anterior (=ventral) to glenoid, form:

0: straight or shallowly indented by a notch

1: deeply indented by a pronounced notch separating the glenoid and postglenoid process, glenoid lip everted

Character 219: Articular, retroarticular process, orientation:

0: points posteriorly

1: curves gently posterodorsally

Character 220: Scapula, flange on supraglenoid buttress:

0: absent

1: present

Character 221: Laterosphenoid, depression (possibly pneumatic) on ventral surface of postorbital process of bone:

0: absent

1: present

Character 222: Braincase, basal tubera, mediolateral width of conjoined tubera relative to occipital condyle: (ORDERED)

0: as wide as or wider than the occipital condyle

1: narrower than occipital condyle, reduced to a set of small processes directly below the condyle and separated by a narrow notch

2: tubera absent

Character 223: Ilium, postacetabular process, morphology of dorsal edge:

0: convex or straight

1: deeply concave, ventral portion of postacetabular process (housing brevis shelf medially) extending posterior to dorsal portion of the postacetabular process as a tab-like structure

Character 224: Ilium, posterior end of postacetabular process, morphology in dorsal view:

0: terminating in rounded or square end, due to a brevis shelf that extends no farther than the posterior margin of the lateral lamina (lateral surface) of the postacetabular process

1: with lobate brevis shelf projecting beyond posterior end of lateral lamina of postacetabular process

Character 225: Pedal phalanx II-2, flexor heel, form:

0: small and asymmetrically developed only on medial side of vertical ridge subdividing proximal articulation

1: heel long and lobate, with extension of midline ridge extending onto its dorsal surface

Character 226: Metatarsal IV, large, longitudinal flange along posterior or lateral surface of bone:

0: absent

1: present

Character 227: Ischium, proximodorsal (or proximocaudal) process, form:

0: small, tab-like or pointed process along posterior edge of ischium

1: large, proximodorsally hooked, and separated from iliac peduncle of the ischium by a notch

2: absent

Character 228: Pubis, prominent tubercle on lateral surface of shaft, at approximately the midpoint of the shaft:

0: absent, shaft smooth

1: present

Character 229: Ischium, distally placed dorsal process along posterior edge of shaft:

0: absent

1: present

Character 230: Ischium, obturator process, shape:

0: tab-like, with distal end separated from shaft by a discrete notch

1: triangular, with distal end confluent with shaft

Character 231: Ischium, morphology of triangular obturator process (only in those taxa with a triangular process as defined in character 233):

0: longer proximodistally than wide anteroposteriorly at the center of the process

1: shorter proximodistally than wide anteroposteriorly at the center of the process, resembles an elongate triangle extending anteriorly

Character 232: Metatarsal II, tuber along extensor surface (associated with the insertion of the tendon of the m. tibialis cranialis in Aves): (ORDERED)

0: absent

1: present, on approximately the center of the proximodorsal surface of metatarsal II

2: present, developed on lateral surface of metatarsal II, at contact with metatarsal III or on lateral edge of metatarsal III

Character 233: Ulna: femur length ratio:

0: substantially less than one

1: equal to or greater than one

Character 234: Maxilla, position of maxillary fenestra relative to ventral margin of antorbital fossa: (ORDERED)

0: abuts ventral margin

1: dorsal to ventral margin, at approximately the dorsoventral midpoint of the antorbital fossa

2: far dorsal to the ventral margin, dorsal to the dorsoventral midpoint of the antorbital fossa

Character 235: Maxilla, dorsoventral depth of main body of bone (=jugal process) at the midpoint of the antorbital fenestra compared to the depth of the entire skull at this measuring point: (ORDERED)

0: shallow, less than 16% of the depth of the entire skull

1: between 16-22% of skull depth

2: deep, greater than 22% of skull depth

Character 236: Maxilla, maxillary fenestra, recessed within a shallow, posteriorly or posterodorsally open fossa, which is itself located within the maxillary antorbital fossa:

0: absent

1: present

Character 237: Maxilla, ascending process (=dorsal ramus or nasal process), form:

0: prominent, exposed medially and laterally

1: absent or reduced to a process with slight medial and no lateral exposure

Character 238: Maxilla, participation of the ventral ramus of the nasal process (=ascending process) in the anterior margin of the antorbital fenestra (as seen in lateral view): (ORDERED)

0: present extensively

1: small dorsal projection of the maxilla participates in the anterior margin

2: no dorsal projection of maxilla participates in the anterior margin

Character 239: Antorbital fenestra, composition of the dorsal border (as seen in lateral view):

0: lacrimal and maxilla

1: lacrimal and nasal

Character 240: Antorbital fossa, composition of the dorsal border (as seen in lateral view): (UNORDERED)

0: lacrimal and maxilla

1: lacrimal and nasal

2: maxilla, premaxilla, and lacrimal

Character 241: Maxilla, lateral lamina of the ascending ramus:

0: present and broadly exposed in lateral view

1: present but reduced to small triangular exposure in lateral view

Character 242: Frontal, supratemporal fossa, anteroposterior length compared to overall length of exposed portion of frontal on skull roof: (ORDERED)

0: less than 30%

1: between 30-60%

2: greater than 60%

Character 243: Jugal, contribution to antorbital fenestra margin (in lateral view):

0: absent

1: present

Character 244: Maxillary and dentary teeth, size of mesial (=anterior) and distal (=posterior) denticles:

0: not substantially different in size

1: mesial denticles, when present, substantially smaller than distal denticles

Character 245: Maxillary teeth, orientation relative to the long axis of the lower jaw:

0: almost perpendicular to jaw margin

1: inclined strongly posteroventrally

Character 246: Maxillary teeth, apicobasal height of teeth along tooth row:

0: highly variable with gaps evident for replacement

1: almost isodont with no replacement gaps

Character 247: Splenial, posterior margin (anterior margin of internal mandibular fenestra):

0: smooth

1: with distinct notch

Character 248: Premaxillary teeth, cross sectional size of first tooth crown compared with crowns of premaxillary teeth 2 and 3: (UNORDERED)

0: slightly smaller or same size

1: much smaller

2: much larger

Character 249: Maxilla, promaxillary fenestra in adults, visibility in lateral view:

0: visible (either as complete fenestra or portion of the fenestra)

1: completely obscured by ascending ramus of maxilla

Character 250: Nasal, shape of dorsal surface: (ORDERED)

0: flat or slightly convex

1: convex (vaulted) anteriorly, above and immediately posterior to the external naris

2: vaulted across most of their length

Character 251: Nasal, fusion between left and right nasals:

0: absent

1: present

Character 252: Quadratojugal and squamosal, constriction of lateral temporal fenestra: (ORDERED)

0: absent, anterior margins of both bones are approximately vertical

1: present, convex kink along the suture between the two bones that projects into the fenestra, constricting it to approximately one half or less of its maximum anteroposterior length

2: present, dorsal region of quadratojugal moderately expanded anteroposteriorly relative to the remainder of the bone, constricting fenestra to approximately one half of its maximum anteroposterior length

3: present, dorsal region of quadratojugal expanded anteroposteriorly by at least twice the minimum anteroposterior dimension of the bone, forming a flange that meets the ventral ramus of the squamosal to nearly divide the fenestra

Character 253: Supraoccipital, pronounced and strongly demarcated median ridge on posterior (occipital) surface:

0: absent

1: present

Character 254: Surangular, anteroventral extension divides external mandibular fenestra by contacting angular anteriorly

0: absent

1: present

Character 255: Ilium, vertical ridge on lateral surface of iliac blade above acetabulum: (ORDERED)

0: absent or poorly developed

1: present as a well-developed, linear structure extending vertically or anterodorsally

2: present as a well-developed, linear structure extending posterodorsally

Character 256: Premaxilla, main body, dorsoventral depth compared to anteroposterior length: (ORDERED)

0: less than or equal to

1: between 1.0-1.9 times larger

2: greater than 2 times larger

Character 257: Nasal, external texture of mid section of bone:

0: smooth to slightly rugose

1: pronounced rugosities and accessory vascular foramina present

Character 258: Jugal, shape of anterior process underneath the lacrimal: (UNORDERED)

0: tapering

1: bluntly squared anteriorly

2: expanded

3: bifurcated

Character 259: Axis, neural spine, morphology in lateral view:

0: extensive and anteroposteriorly elongate, sheet-like

1: anteroposteriorly reduced, rod-like

Character 260: Cervical vertebrae, prezygapophyses in anterior postaxial cervicals, orientation:

0: straight across their lengths

1: anteroposteriorly convex, flexed ventrally anteriorly

Character 261: Dorsal vertebrae, extent of pneumaticity (pneumatic foramina on lateral surfaces): (ORDERED)

0: foramina absent

1: foramina present in anterior dorsals

2: present in all dorsals

Character 262: Femur/humerus length ratio: (ORDERED)

0: more than 3.3

1: between 3.3-2.5

2: between 1.2 and 2.5

3: less than 1

Character 263: Humerus, shape in lateral view:

0: sigmoidal

1: straight

Character 264: Radius, length compared to that of humerus:

0: more than half the length of humerus

1: less than half the length of humerus

Character 265: Premaxilla, fusion of opposing premaxillae at the symphysis: (ORDERED)

0: unfused in adults

1: fused anteriorly in adults, posterior nasal [frontal] processes not fused to each other

2: fused anteriorly and opposing frontal processes completely fused

Character 266: Dentary, form of articulation between opposing dentaries at the symphysis:

0: joined proximally by ligaments

1: joined by bone

Character 267: Dentary, symphysis region, two strong grooves forming an anteriorly opening 'v' in ventral view:

0: absent

1: present

Character 268: Cranium, facial margin, composition: (ORDERED)

0: primarily formed by the maxilla, with the maxillary process of the premaxilla restricted to the anterior tip

1: maxillary process of the premaxilla extending along half of facial margin

2: maxillary process of the premaxilla extending more than half of facial margin

Character 269: Premaxilla, nasal (frontal) process, length:

0: short

1: long, closely approaching frontal

Character 270: External naris, size compared to the antorbital fenestra: (ORDERED)

0: considerably smaller

1: long axis approximately same length as long axis of antorbital fenestra

2: larger

Character 271: Ectopterygoid:

0: present

1: absent

Character 272: Vomer and pterygoid, form of articulation between bones: (UNORDERED)

0: present, well developed

1: reduced, narrow process of pterygoid passes dorsally over palatine to contact vomer

2: absent, pterygoid and vomer do not contact

Character 273: Palatine and pterygoid, form of articulation between bones:

0: long, anteroposteriorly overlapping contact

1: short, primarily dorsoventral contact

Character 274: Palatine, contacts with bones of the facial region:

- 0: contacts maxillae only
- 1: contacts premaxillae and maxillae

Character 275: Vomer, contact with premaxilla:

- 0: present
- 1: absent

Character 276: Basisphenoid, projecting articulation with pterygoid via discrete basipterygoid processes:

- 0: present
- 1: absent

Character 277: Basisphenoid, location of pterygoid articular surface:

- 0: located basal on basisphenoid
- 1: located markedly anterior on basisphenoid (parasphenoid rostrum) such that the articulations are subadjacent on the narrow rostrum

Character 278: Basisphenoid and pterygoid articulation, orientation of contact: (UNORDERED)

- 0: anteroventral
- 1: mediolateral
- 2: entirely dorsoventral

Character 279: Pterygoid, articular surface for basisphenoid, morphology: (ORDERED)

- 0: concave 'socket' or short groove enclosed by dorsal and ventral flanges
- 1: flat to convex
- 2: flat to convex facet, stalked, variably projected

Character 280: Pterygoid, shape of bone:

- 0: kinked, surface for basisphenoid articulation at high angle to axis of palatal process of pterygoid
- 1: straight, basisphenoid articulation in line with axis of palatal process

Character 281: Ossified interorbital septum, sphenethmoid:

- 0: absent

1: present

Character 282: Ossified interorbital septum, mesethmoid:

0: unossified or small, restricted to the ventral surface of the frontal or marginally extends anteriorly past the premaxillae/frontal contact but does not surpass posterior edge of external nares

1: large, extends anterior to the posterior extent of the frontal processes of premaxillae and anterior to the posterior edge of the external nares

Character 283: Eustachian tubes, morphology: (UNORDERED)

0: paired and lateral

1: paired, close to cranial midline

2: paired and adjacent on midline or single anterior opening

Character 284: Eustachian tubes, ossification:

0: absent

1: present

Character 285: Squamosal, ventral (=zygomatic) process, morphology:

0: large and elongate, dorsally encloses otic process of the quadrate and extends anteroventrally along shaft of quadrate, dorsal head of quadrate not visible in lateral view

1: short, head of quadrate exposed in lateral view

Character 286: Quadrate, orbital process (=pterygoid flange) of quadrate, form of articulation with pterygoid:

0: pterygoid broadly overlapping medial surface of orbital process (i.e., 'pterygoid ramus' present)

1: pterygoid contact restricted to anteromedial edge of orbital process

Character 287: Quadrate, form of pterygoid articulation with orbital process in those taxa where the contact is restricted to the anteromedial edge of the process: (ORDERED)

0: pterygoid articulates with anterior-most tip

1: pterygoid articulation does not reach tip

2: pterygoid articulation with no extent up orbital process, restricted to quadrate

corpus

Character 288: Quadrate/pterygoid contact, morphology in those taxa where the contact is restricted to the anteromedial edge of the orbital process:

0: as a facet, variably with slight anteromedial projection cradling base

1: condylar, with a well-projected tubercle on the quadrate

Character 289: Quadrate, well-developed tubercle on anterior surface of dorsal process:

0: absent

1: present

Character 290: Quadrate, form of articulation with quadratojugal:

0: overlapping

1: peg and socket articulation

Character 291: Quadrate, dorsal process, articulation with other bones:

0: with squamosal only

1: with squamosal and prootic

Character 292: Quadrate, dorsal process, development of intercotylar incisure between prootic and squamosal cotylae: (ORDERED)

0: absent, articular surfaces not differentiated (usually meaning prootic contact was absent)

1: two distinct articular facets, incisure not developed

2: incisure present, 'double headed'

Character 293: Quadrate, mandibular articulation, form:

0: divided into two condyles

1: divided into three condyles, due to additional posterior condyle or broad surface

Character 294: Quadrate, pneumaticity:

0: absent

1: present

Character 295: Quadrate, cluster of pneumatic foramina on the posterior surface of the tip of the dorsal process:

0: absent

1: present

Character 296: Quadrate, form of pneumatization, large single pneumatic foramen on the posterior or posteromedial surface of the shaft:

0: absent

1: present

Character 297: Articular, pneumaticity:

0: absent

1: present

Character 298: Dentary, morphology of posterior end:

0: approximately straight or with a weakly developed separation into dorsal and ventral forks (i.e., small dorsal ramus)

1: strongly forked with the dorsal and ventral rami approximately equal in posterior extent

Character 299: Splenial, anterior extent: (ORDERED)

0: limited, stops well posterior to mandibular symphysis

1: elongate, extends to mandibular symphysis but does not participate in symphysis

2: elongate, extends to anterior tip of mandible to contacting on midline and participate in symphysis

Character 300: Mandibular symphysis, anteroposteriorly extensive, flat to convex, dorsal-facing surface:

0: absent, symphysis concave

1: present

Character 301: Mandibular symphysis, symphyseal foramina:

0: absent

1: present

Character 302: Mandibular symphysis, symphyseal foramina, number:

0: single

1: paired

Character 303: Mandibular symphysis, symphyseal foramina, location:

0: opening on posterior edge of symphysis

1: opening on dorsal surface of symphysis

Character 304: Dentary, Meckelian groove, exposure in medial view:

0: exposed as deep and conspicuous groove, not completely covered by splenial

1: not exposed, covered by splenial

Character 305: Lower jaw, anterior external mandibular fenestra:

0: absent

1: present

Character 306: Jugal, contact with postorbital:

0: present

1: absent

Character 307: Frontal/parietal suture

0: open

1: fused

Character 308: Thoracic vertebrae (with ribs articulating with the sternum, or in the middle-posterior dorsal series of theropods without preserved sterna), one or more with prominent hypapophyses:

0: absent

1: present

Character 309: Thoracic vertebrae, number: (ORDERED)

0: 12 or more

1: 11

2: 10 or fewer

Character 310: Thoracic vertebrae, form of articular surfaces:

0: at least part of series with round or ovoid articular surfaces (e.g. amphicoelous/ opisthocoelous) that lack the dorsoventral compression seen in heterocoelous vertebrae

1: series completely heterocoelous

Character 311: Thoracic vertebrae, parapophysis, position:

0: anterior to transverse process

1: directly ventral to transverse process (close to midpoint of vertebra)

Character 312: Thoracic vertebrae, centrum, proportions:

0: approximately equal in anteroposterior length and midpoint mediolateral width

1: length markedly greater than midpoint width

Character 313: Thoracic vertebrae, morphology of lateral surfaces of centra: (UNORDERED)

0: flat to slightly depressed

1: deep, emarginated fossae

2: central ovoid foramina

Character 314: Thoracic vertebrae with ossified connective tissue bridging transverse processes:

0: absent

1: present

Character 315: Notarium:

0: absent

1: present

Character 316: Sacral vertebrae, series of short vertebrae, with dorsally directed parapophyses just anterior to the acetabulum: (ORDERED)

0: absent

1: present, three such vertebrae

2: present, four such vertebrae

Character 317: Caudal vertebrae, anterior free caudals prior to transition point, length of transverse processes:

0: subequal to width of centrum

1: substantially shorter than centrum width

Character 318: Caudal vertebrae, fusion of distal caudals:

0: unfused to each other

1: fused to each other

Character 319: Caudal vertebrae, extent of fused distal caudals: (ORDERED)

- 0: fused element length equal or greater than 4 free caudal vertebrae
- 1: length less than 4 caudal vertebrae
- 2: less than 2 caudal vertebrae in length

Character 320: Gastralia:

- 0: present
- 1: absent

Character 321: Sternum, carina or midline ridge, morphology: (ORDERED)

- 0: absent
- 1: slightly raised
- 2: distinctly projected

Character 322: Sternum, position of carina or midline ridge: (UNORDERED)

- 0: restricted to posterior half of sternum
- 1: approaches anterior limit of sternum
- 2: restricted to the anterior half of the sternum

Character 323: Sternum, dorsal surface, pneumatic foramen (or foramina):

- 0: absent
- 1: present

Character 324: Sternum, pneumatic foramina in the depressions (loculi costalis) between rib articulations (processi articularis sternocostalis):

- 0: absent
- 1: present

Character 325: Sternum, coracoidal sulci spacing on anterior edge: (UNORDERED)

- 0: widely separated mediolaterally
- 1: adjacent
- 2: crossed on midline

Character 326: Sternum, number of processes for articulation with the sternal ribs: (ORDERED)

- 0: three

1: four

2: five

3: six

4: seven or more

Character 327: Sternum, raised, paired intermuscular ridges (linea intermuscularis) parallel to sternal midline:

0: absent

1: present

Character 328: Sternum, posterior margin, distinct posteriorly projected medial and/or lateral processes, morphology: (ORDERED)

0: absent

1: with distinct posterior processes

2: midpoint of posterior sternal margin connected to medial posterior processes

to enclose paired fenestrae

Character 329: Clavicles, fusion:

0: left and right bones fused together

1: left and right bones unfused

Character 330: Clavicles, interclavicular angle between left and right clavicles:

0: greater than, or equal, to 90 degrees

1: less than 90 degrees

Character 331: Furcula, lateral excavation:

0: absent

1: present

Character 332: Furcula, dorsal (omal) tip, form:

0: flat or blunt

1: with a pronounced posteriorly pointed tip

Character 333: Furcula, ventral margin of apophysis, form:

0: curved, angling

1: with a truncated or squared base

Character 334: Scapula and coracoid, form of articulation: (UNORDERED)

0: pit-shaped scapular cotyla developed on the coracoid, and coracoidal tubercle developed on the scapula ('ball and socket' articulation)

1: scapular articular surface of coracoid convex

2: flat

Character 335: Coracoid, procoracoid process:

0: absent

1: present

Character 336: Coracoid, lateral margin, form:

0: straight to slightly concave

1: nearly concave to straight for most part and the convex portion is restricted at sternal end, which measures less than half the width of sternal end

2: strongly convex, and the convex portion measuring more than half the sternal end

Character 337: Coracoid, dorsal surface (= posterior surface of taxa less derived than Paraves), form:

0: strongly concave

1: flat to convex

Character 338: Coracoid, pneumaticity:

0: absent

1: present

Character 339: Coracoid, position of pneumatic foramen:

0: proximal

1: distal

Character 340: Coracoid, lateral process:

0: absent

1: present

Character 341: Coracoid, ventral surface (=anterior surface of taxa less derived than Paraves), lateral intermuscular line or ridge:

0: absent

1: present

Character 342: Coracoid, position of glenoid facet:

0: dorsal to, or at approximately same level as, acrocoracoid process/'biceps tubercle' (or estimated position of biceps tubercle is a discrete tubercle is absent)

1: far ventral to acrocoracoid process

Character 343: Coracoid, acrocoracoid process, shape:

0: straight

1: hooked medially

Character 344: Coracoid, n. supracoracoideus passes through coracoid (usually via coracoid foramen):

0: present

1: absent

Character 345: Coracoid, medial surface, area of the foramen n. supracoracoideus (when developed)

0: strongly depressed

1: flat to convex

Character 346: Coracoid and scapula, angle between bones at glenoid:

0: greater than 90 degrees

1: 90 degrees or less

Character 347: Scapula, ratio of dorsoventral depth of distal end to minimum dorsoventral depth of blade: (ORDERED)

0: greater than 2.5

1: slightly taller or approximately the same depth as proximal dorsoventral shaft width, ratio between 1.0 and 2.5

2: tapering distally, ratio less than 1.0

Character 348: Scapula, curvature in lateral view:

0: straight, both dorsal and ventral margins straight

1: straight shaft with convex dorsal margin and straight ventral margin

2: curved shaft

Character 349: Scapula, position of acromion process:

0: extends anteriorly to surpass the articular surface for coracoid (facies

articularis coracoidea)

1: does not extend further anteriorly than the articular surface for coracoid

Character 350: Scapula, orientation of acromion process:

0: straight

1: laterally hooked tip

Character 351: Humerus and ulna, length comparison: (ORDERED)

0: humerus longer than ulna

1: ulna and humerus approximately the same length (within ~10% of each other)

2: ulna substantially longer than humerus

Character 352: Humerus, head, shape in anterior or posterior view

0: strap-like, articular surface flat or weakly convex, no proximal midline convexity

1: prominent and highly convex (domed) proximally

2: concave in its central portion, rising ventrally and dorsally

Character 353: Humerus, proximal end, shape of proximal projection:

0: dorsal edge projected farthest

1: midline projected farthest

Character 354: Humerus, ventral tubercle and capital incisure:

0: absent

1: present

Character 355: Humerus, capital incisure, morphology:

0: an open groove

1: closed by tubercle associated with a muscle insertion just distal to humeral head

Character 356: Humerus, anterior surface, well-developed fossa on midline making proximal articular surface appear v-shaped in proximal view:

0: absent

1: present

Character 357: Humerus, 'transverse groove':

0: absent

1: present, developed as a discrete, depressed scar on the proximal surface of the bicipital crest or as a slight transverse groove

Character 358: Humerus, deltopectoral crest, orientation:

0: projected laterally or dorsally, such that it is in line with the long axis of humeral head

1: projected anteriorly, such that it is approximately perpendicular to the long axis of the head

Character 359: Humerus, deltopectoral crest, thickness compared with thickness of shaft: (ORDERED)

0: less

1: same width

2: dorsoventral thickness greater than shaft thickness

Character 360: Humerus, deltopectoral crest, proximoposterior surface (=proximolateral surface in most non-avian theropods), form:

0: flat to convex

1: concave

Character 361: Humerus, deltopectoral crest, large fenestra:

0: absent, crest not perforate

1: present, crest perforate

Character 362: Humerus, bicipital crest, pit-shaped scar/fossa for muscular attachment on anterodistal, distal, or posterodistal surface of crest:

0: absent

1: present

Character 363: Humerus, bicipital crest, position of pit-shaped fossa for muscular attachment: (UNORDERED)

0: anterodistal on bicipital crest

1: directly ventrodistal at tip of bicipital crest

2: posterodistal, variably developed as a fossa

Character 364: Humerus, bicipital crest, anterior projection: (ORDERED)

0: absent or subtle

1: present, developed as an anterior projection relative to shaft surface in ventral view

2: present as a hypertrophied, rounded tumescence

Character 365: Humerus, proximal end, one or more pneumatic foramina:

0: absent

1: present

Character 366: Humerus, distal articular condyles, position:

0: on distal surface of bone

1: on anterior surface of bone

Character 367: Humerus, long axis of dorsal (lateral) distal condyle, orientation:

0: at low angle to humeral axis, proximodistally orientated

1: at high angle to humeral axis, almost transversely orientated

Character 368: Humerus, distal condyles, form:

0: prominent, subround and bulbous

1: weakly defined, 'strap-like'

Character 369: Humerus, distal margin, orientation:

0: approximately perpendicular to long axis of humeral shaft

1: oblique (angling strongly ventrally) to long axis of humeral shaft, ventrodistal margin projected significantly distal to dorsodistal margin (sometimes described as a well-projected flexor process)

Character 370: Humerus, distal end, compressed anteroposteriorly and flared dorsoventrally:

0: absent

1: present

Character 371: Humerus, brachial fossa:

0: absent

1: present, developed as a flat scar or as a scar-impressed fossa

Character 372: Humerus, ventral (medial) distal condyle, length of long axis:

0: less than the long axis of the dorsal (lateral) condyle

1: the same or greater than the long axis of the dorsal (lateral) condyle

Character 373: Humerus, demarcation of muscle origins (e.g. m. extensor metacarpi radialis in Aves) on the dorsal (=lateral in non-avian theropods) edge of the distal humerus:

0: no indication of origin as a scar, a pit, or a tubercle

1: indication as a pit-shaped scar or as a variably projected scar-bearing tubercle or facet

Character 374: Humerus, groove for passage of m. scapulotriceps on distal end of posterior surface:

0: absent

1: present

Character 375: Humerus, m. humerotricipitalis groove:

0: absent

1: present as a ventral depression contiguous with the olecranon fossa

Character 376: Ulna, cotylae, orientation of dorsal (lateral) and ventral (medial) cotylae:

0: dorsoventrally adjacent

1: widely separated by a deep groove

Character 377: Ulna, dorsal cotyla, form: convex

0: flat or non-distinct

1: convex

Character 378: Ulna, distal end, dorsal (lateral) condyle, dorsal trochlear surface, extent along posterior margin:

0: less than transverse measure of dorsal trochlear surface

1: approximately equal in extent

Character 379: Ulna, bicipital scar: (ORDERED)

0: absent

1: present, developed as a slightly raised scar

2: present, developed as a conspicuous tubercle

Character 380: Ulna, brachial scar

0: absent

1: present

Character 381: Radius, posteroventral surface (=posteromedial surface of non-avialans), texture: (UNORDERED)

0: smooth

1: with muscle impression along most of surface

2: deep longitudinal groove

Character 382: Ulnare:

0: absent

1: present

Character 383: Ulnare, shape:

0: circular, triangular, or 'heart-shaped', with no or minimal differentiation into short dorsal and ventral rami

1: V-shaped, well- developed dorsal and ventral rami

Character 384: Ulnare, ventral ramus (crus longus), length: (ORDERED)

0: shorter than dorsal ramus (crus brevis)

1: same length as dorsal ramus

2: longer than dorsal ramus

Character 385: Semilunate carpal and metacarpals, fusion: (ORDERED)

0: separate from each other, no fusion

1: incomplete proximal fusion

2: complete proximal fusion

3: complete proximal and distal fusion

Character 386: Metacarpal III, anteroposterior (extensor-flexor) diameter at midshaft compared to anteroposterior diameter of metacarpal II:

0: approximately equal or greater than 50%

1: less than 50%

Character 387: Metacarpal I, anteroproximally projected muscular process, form: (ORDERED)

0: absent, no distinct process visible

1: present as small knob at anteroproximal tip of metacarpal

2: present, tip of process marginally surpasses the distal articular facet for phalanx 1 in anterior extent

3: present, tip of process conspicuously surpasses articular facet by approximately half the width of the facet, producing a pronounced knob

4: present, tip of process conspicuously surpasses articular facet by approximately the entire width of the facet, producing a pronounced knob

Character 388: Metacarpal I, anterior (extensor) surface, shape:

0: roughly hourglass-shaped proximally, at least moderately expanded anteroposteriorly, and constricted just before flare of articulation for phalanx 1

1: anterior surface broadly convex

Character 389: Carpometacarpus, pisiform process:

0: absent

1: present

Character 390: Carpometacarpus, ventral surface, supratrochlear fossa deeply excavating proximal surface of pisiform process or adjacent region:

0: absent

1: present

Character 391: Carpometacarpus, intermetacarpal space (between metacarpals II and III):

0: reaches proximally as far as the distal end of metacarpal I

1: terminates distal to end of metacarpal I

Character 392: Metacarpals II and III, distal ends, position of articular surfaces for digits:

0: articular surface on metacarpal II located at same distal level as, or surpasses distally, articular surface on metacarpal III

1: articular surface on metacarpal III extends further distally than articular surface on metacarpal II

Character 393: Metacarpals, intermetacarpal process or tubercle: (ORDERED)

0: absent

1: present as scar

2: present as tubercle or flange

Character 394: Manual digit II, phalanx 1, shape:

0: subcylindrical to subtriangular in cross section

1: strongly dorsoventrally compressed, flat posterior surface

Character 395: Manual digit II, length of phalanx II-1 compared to that of II-2:

0: less than or equal to

1: longer

Character 396: Manual digit II, phalanx 2, internal index process on posterodistal edge:

0: absent

1: present

Character 397: Pelvis, ilium, ischium, and pubis, proximal contact between bones in adult individuals: (ORDERED)

0: unfused to each other

1: partially fused to each other (pubis not ankylosed)

2: completely fused to each other

Character 398: Ilium/ischium, distal co-ossification to completely enclose the ilioischial fenestra:

0: absent

1: present

Character 399: Ischium, dorsal process

0: does not contact ilium

1: contacts ilium

Character 400: Ilium, antitrochanter, position:

0: directly posterior to acetabulum

1: posterodorsal to acetabulum

Character 401: Ilium, preacetabular pectineal process: (ORDERED)

0: absent

1: present as a small flange

2: present as a well-projected flange

Character 402: Ilium, preacetabular processes, orientation of left and right processes:

0: approach on midline but do not contact (open space between them, possibly a cartilaginous connection)

1: make contact with each other on midline and fuse, dorsal closure of ‘iliosynsacral canals’

Character 403: Ilium, preacetabular process, morphology of process as it extends anterior to first sacral vertebra:

0: no free ribs overlapped

1: one or more ribs overlapped

Character 404: Ilium, postacetabular process, orientation:

0: dorsoventrally orientated, such that broad external surface faces laterally

1: mediolaterally orientated, such that broad external surface faces dorsally

Character 405: Ilium, postacetabular process, ventral surface, renal fossa:

0: absent

1: present

Character 406: Ilium, cuppedicus fossa, form:

0: broad, mediolaterally oriented surface directly anteroventral to acetabulum

1: small and entirely laterally facing fossa anterior to the acetabulum

Character 407: Pubis, cross section:

0: suboval

1: compressed mediolaterally

Character 408: Pubes, contact of distal ends of left and right pubes:

0: present, variably co-ossified into symphysis

1: absent, pubes noncontacting

Character 409: Femur, posterior trochanter: (ORDERED)

0: present, developed as a slightly projected tubercle or flange

1: present, hypertrophied into a ‘shelf-like’ conformation (in combination with development of the trochanteric shelf)

2: absent

Character 410: Femur, patellar groove

0: absent

1: present

Character 411: Femur, ectocondylar tubercle and lateral condyle, separation:

0: present, separated by deep notch

1: ectocondylar tubercle and lateral condyle contiguous but without developing a tibiofibular crest

2: tibiofibular crest present, defining laterally a fibular trochlea

Character 412: Femur, posterior projection of the lateral border of the distal end, continuous with lateral condyle:

0: absent

1: present

Character 413: Femur, laterally projected fibular trochlea: (ORDERED)

0: absent

1: present, developed as small notch

2: present, developed as a shelf-like projection

Character 414: Tibia/tarsals, condyles, extent of medial and lateral condyles:

0: medial condyle projecting further anteriorly than lateral

1: equal in anterior projection

Character 415: Tibia/tarsals, condyles, extensor canal: (ORDERED)

0: absent

1: present as an emarginated groove

2: present as a groove bridged by an ossified supratendoneal bridge

Character 416: Tibia/tarsals, condyles, tuberositas retinaculi extensoris indicated by short medial ridge or tubercle proximal to the condyles close to the midline and a more proximal second ridge on the medial edge:

0: absent

1: present

Character 417: Tibia/tarsals, condyles, mediolateral widths of lateral and medial condyles: (ORDERED)

0: medial condyle wider

1: approximately equal

2: lateral condyle wider

Character 418: Tibia/tarsals, condyles, medial constriction of lateral and medial condyles:

0: present, gradual sloping medial constriction of condyles

1: absent, no medial tapering of either condyle

Character 419: Tibia/tarsals, condyles, intercondylar groove, mediolateral width:

0: broad, approximately 1/3 width of anterior surface

1: narrow, less than 1/3 width of total anterior surface

Character 420: Tibia/tarsals, position of articular surface for distal tarsals/tarsometatarsus: (ORDERED)

0: on distal surface or restricted to distal-most edge of posterior surface, no broad extension of trochlear surface onto posterior surface of bone

1: well-developed articular surface extending up the posterior surface of the tibiotarsus (sulcus cartilaginis tibialis of Aves)

2: well-developed articular surface extending up the posterior surface of the tibiotarsus, with well-developed and posteriorly projecting medial and lateral crests

Character 421: Tibia, mediolateral width of distal end:

0: wider than midpoint of shaft, giving distal profile a weakly developed triangular form

1: approximately equal to midshaft width, no distal expansion of whole shaft (although condyles may be variably splayed mediolaterally)

Character 422: Metatarsal V:

0: present

1: absent

Character 423: Metatarsal III, position of proximal end:

0: proximally in same plane with II and IV

1: proximally displaced plantarly (to the extensor surface), relative to metatarsals II and IV

Character 424: Tarsometatarsus or metatarsals, intercotylar eminence:

0: absent

1: well developed, globose

Character 425: Tarsometatarsus or metatarsals, projected surface or grooves on proximoposterior surface (associated with the passage of tendons of the pes flexors in Aves; hypotarsus): (ORDERED)

0: absent

1: developed as posterior projection with flat posterior surface

2: developed as a posterior projection, with distinct crests and grooves

3: developed as a posterior project with distinct crests and grooves, at least one groove enclosed by bone posteriorly

Character 426: Tarsometatarsus or metatarsals, proximal vascular foramina: (ORDERED)

0: absent

1: single foramen present, between metatarsals III and IV

2: two foramina present

Character 427: Metatarsal I, shape: (ORDERED)

0: straight

1: curved or distally deflected but not twisted, ventral surface convex ('J shaped')

2: distally deflected and twisted, such that the ventromedial surface is concave proximal to trochlear surface for phalanx I

Character 428: Metatarsal II, distal extensor surface, fossa for metatarsal I: (ORDERED)

0: absent

1: present as a shallow notch

2: present as a conspicuous ovoid fossa

Character 429: Metatarsal IV, mediolateral width at midshaft: (UNORDERED)

0: metatarsal IV approximately the same width as metatarsals II and III

1: metatarsal IV narrower than MII and MIII

2: metatarsal IV greater in width than either metatarsal II or III

Character 430: Metatarsals, comparative trochlear width (UNORDERED):

0: II approximately the same size as III and/or IV (this includes taxa in which metatarsal III is slightly wider than the other metatarsals distally)

1: II markedly wider than III and/or IV

2: II markedly narrower than III and/or IV

3: IV markedly narrowest.

Character 431: Metatarsus, distal vascular foramen, form:

0: simple, with one exit

1: forked, two exits (plantar and distal) between metatarsals III and IV.

Character 432: Metatarsal III, distal trochlea in extensor view, proximal extent of lateral and medial edges:

0: equally extended proximally

1: lateral edge extends further proximally

Character 433: Metatarsal II, distal extent of metatarsal II relative to metatarsal IV: (ORDERED)

0: approximately equal in distal extent

1: metatarsal II shorter than metatarsal IV, but reaching distally further than base of metatarsal IV trochlea

2: metatarsal II shorter than metatarsal IV, reaching distally only as far as base of metatarsal IV trochlea

Character 434: Caudal vertebrae, middle to posterior caudals, anteroposterior length: (ORDERED)

0: shortened, less than 1.5x length of dorsal vertebrae (where known) and anteroposterior length of centrum less than twice its maximum mediolateral width

1: 1.5x-2x or less the length of dorsal vertebrae

2: 3x-4x length of dorsal vertebrae

Character 435: Coracoid, coracoid fenestra:

0: absent

1: present

Character 436: Metatarsal V, elongated and bowed

0: absent

1: present

Character 437: Chevrons, degree of posterior extension of posterior chevrons:

0: not substantially elongated

1: very elongated

Character 438: Radius, width at midshaft:

0: roughly half or greater than width of ulna

1: less than half width of ulna

Character 439: Manus, combined length of metacarpal I and phalanx I-1:

0: greater than length of MC II

1: equal to or less than length of MC II

Character 440: Metacarpal III, shape:

0: straight

1: bowed

Character 441: Metatarsal I, position of distal trochlea:

0: proximally placed relative to trochleae of other metatarsals

1: inline distally with others

Character 442: Metatarsal I:

0: present

1: absent

Character 443: Braincase, preotic pendant, form: (ORDERED)

0: absent

1: present but small

2: present and robust

Character 444: Braincase, metotic strut, shape:

0: short and robust

1: long and narrow

Character 445: Prootic, pneumatic excavation on lateral surface leading into anterior tympanic recess: (ORDERED)

0: absent

1: present and shallow

2: present and deep

Character 446: Braincase, anterior tympanic recess (ATR), manifestation on external surface of basisphenoid: (ORDERED)

0: subtle, external fossa not deeply impressed into the lateral surface of the basisphenoid

1: deeply impressed into the lateral surface of the basisphenoid in juveniles but not adults

2: deeply impressed into the lateral surface of the basisphenoid in adults

Character 447: Braincase, anterior tympanic recess and anterior tympanic crista (crest marking the posterior and dorsal border of the ATR), location:

0: below the exit foramen of cranial nerve VII exit and just proximal to the otic recess

1: anteriorly, with little or no development of the recess posterior to the basiptyergoid processes

Character 448: Braincase, anterior tympanic recess confluent with the subotic recess:

0: absent

1: present, forming the Lateral Depression

Character 449: Braincase, V-shaped opening between basal tubera (or remnants of tubera):

0: absent

1: present

Character 450: Braincase, small tubera medial to basal tubera (or remnants of basal tubera) and ventral to occipital condyle:

0: absent

1: present

Character 451: Pedal phalanx II-2, size of distal articular surface relative to proximal articular surface:

0: approximately equal in size or distal surface slightly smaller than proximal

surface

1: distal surface less than half the size of proximal surface

Character 452: Sternum, ossification of sternal plates:

0: absent, plates unossified

1: present, plates ossified

Character 453: Ulna, size of proximal cotylae:

0: unequal in size, lateral (=dorsal in avialans) condyle smaller

1: equal in size

Character 454: Braincase, middle ear resides within the Lateral Depression (formed by merged anterior tympanic recess and subotic recess):

0: absent

1: present

Character 455: Feathers, filamentous integumentary structures (Stage 1 feathers):

0: absent

1: present

Character 456: Feathers, vaned feathers (Stage 4 feathers):

0: absent

1: present

Character 457: Quadratojugal, size:

0: large

1: greatly reduced

Character 458: Frontal, notch for postorbital contact on postorbital process of frontal:

0: absent, process smooth or facet small

1: large notch present

Character 459: Frontal and parietal, position of fronto-parietal suture relative to postorbital processes of frontal: (ORDERED)

0: well posterior to the postorbital processes

1: at the level of the postorbital processes

2: anterior to postorbital processes

Character 460: Cervical vertebrae, orientation of articular surfaces between cervical vertebrae:

0: surfaces vertical to subvertical

1: strongly slanted anteroventrally

Character 461: Skull roof, accessory depression in supratemporal fossa:

0: absent

1: present

Character 462: Ilium, relative ventral extension of pubic and ischiadic peduncles: (ORDERED)

0: equal

1: pubic peduncle extends farther ventrally

2: pubic peduncle hyperelongate, approximately 2.5-3 times the proximodistal length of the ischial peduncle

Character 463: Parasphenoid, ala parasphenoidalis:

0: absent

1: present, well-developed and crest-shaped forming anterior edge of enlarged pneumatic recess with the ala continuous with the anterior tympanic crista

Character 464: Furcula, cross-section:

0: nearly circular

1: anteroposteriorly compressed near the symphysis

Character 465: Furcula, shape:

0: V-shaped

1: U-shaped

Character 466: Furcula, epicledial processes, form:

0: unexpanded

1: expanded

Character 467: Furcula, lateral expansion of the rami between the hypocleidium and the epicledial process:

0: absent

1: present

Character 468: Furcular, hypocleideum:

- 0: absent
- 1: present as a tubercle or short process
- 2: present as an elongate process approximately 30% rami length
- 3: hypertrophied, exceeding 50% rami length

Character 469: Furcula, symmetry:

- 0: asymmetrical
- 1: nearly symmetrical

Character 470: Furcula, thickness of rami:

- 0: thin
- 1: thick

Character 471: Metatarsal III, extensor (=anterior or dorsal) surface, shape:

- 0: relatively narrow and flat
- 1: transversely expanded and slightly concave

Character 472: Metatarsal IV, accessory longitudinal ridge on anterolateral side of the distal end of the bone:

- 0: absent
- 1: present

Character 473: Metacarpal I, width of proximal articular surface compared to proximodistal length of entire metacarpal:

- 0: shorter
- 1: wider

Character 474: Manual unguals:

- 0: present in all digits
- 1: present in all digits but not digit III (minor digit in avialans)
- 2: absent in all digits.

Character 475: Manual unguals, form of flexor tubercle: (ORDERED)

- 0: large, robust, rugose, conical structure
- 1: reduced to a small convexity
- 2: absent

Character 476: Skull, occipital region, orientation:

0: posteriorly

1: posteroventrally

Character 477: Skull, general shape:

0: long and low, length: height ratio greater than 3.2

1: deep, length: height ratio less than 3.2

Character 478: Skull, anteroposterior length:

0: less than 40% trunk length

1: greater than 40% trunk length

Character 479: Lateral temporal fenestra, orientation of long axis relative to long axis of orbit:

0: posterodorsal

1: approximately parallel

Character 480: Premaxilla, nasal process of opposing premaxillae, orientation:

0: divergent from each other, with small process of nasals fitting in between them

1: closely appressed to each other

Character 481: Premaxilla, deep foramen or fossa on the lateral surface of the base of the nasal process, within the anteroventral corner of the narial fossa:

0: absent

1: present

Character 482: Premaxilla, maxillary process orientation: (ORDERED)

0: mostly laterally (and resultantly widely visible in lateral view)

1: dorsolaterally (facing almost equally dorsally and laterally)

2: dorsally (and resultantly mostly hidden in lateral view)

Character 483: Premaxilla, form of narial fossa ventral to external naris:

0: shallowly excavated

1: deeply excavated, anterior margin invaginated as a deep groove

Character 484: Premaxilla, extent of narial fossa:

0: limited to region immediately ventral to external naris

1: extensive, covers most of main body of premaxilla

**Character 485: Premaxilla, orientation and shape of anterior margin:
(ORDERED)**

0: smoothly curved and projecting posterodorsally, angle between ventral margin of premaxilla and anterior margin is less than 90 degrees.

1: smoothly curved and projecting vertically or slightly anterodorsally, angle between ventral margin of premaxilla and anterior margin is equal to or greater than 90 degrees

2: projecting vertically or slightly anterodorsally, with a discrete inflection point between a more vertical ventral portion and a more horizontal dorsal portion

Character 486: Premaxilla, position of palatal process:

0: immediately above interdental plates

1: separated from interdental plates by deep lingual surface of premaxilla

Character 487: Maxilla, promaxillary fenestra, position:

0: anterior margin of antorbital fossa

1: extreme anteroventral corner of antorbital fossa

**Character 488: Maxilla, maxillary fenestra, anteroposterior length compared to the distance between the anterior margins of the antorbital fossa and fenestra:
(ORDERED)**

0: less than half

1: greater than half

2: greater than half and also greater than half of the length of the eyeball-bearing portion of the orbit

Character 489: Maxilla, maxillary fenestra, position within maxillary antrum:

0: does not abut dorsal border of the antrum in medial view

1: abuts dorsal border of the antrum in medial view

Character 490: Maxilla, antorbital fossa, extent:

0: reaches nasal suture

1: does not reach nasal suture

Character 491: Maxilla, interfenestral strut, anteroposterior length:

0: greater than 50% of long axis of maxillary fenestra

1: less than 50% of long axis of maxillary fenestra

Character 492: Maxilla, antorbital fossa, trend of dorsoventral depth across main body:

0: uniform

1: diminishes

Character 493: Maxilla, subcutaneous flange bordering the antorbital fossa laterally on the posterior end of the main body, resulting in the fossa forming a channel between the flange and the main body:

0: absent

1: present

Character 494: Maxilla, dorsolateral process, coverage by antorbital fossa: (ORDERED)

0: process absent

1: process covered by subcutaneous surface only

2: ventral half of process covered by antorbital fossa

3: antorbital fossa completely excluded

Character 495: Maxilla, narrow region of smooth surface texture between anterior margin of antorbital fossa and the subcutaneous surface:

0: absent

1: present

Character 496: Maxilla, ventral margin of the anterior region of the bone, profile:

0: straight

1: convex

Character 497: Maxilla, joint surface for palatine, depth:

0: shallow, does not obscure the tooth root bulges from view

1: deep, obscures tooth root bulges from view

Character 498: Maxilla, anterior ramus (demarcated by concave step in anterior margin of maxilla):

0: absent

1: present

**Character 499: Maxilla, form of contact with nasal in subadult to adult specimens:
(ORDERED)**

0: smooth

1: weakly scalloped

2: deeply scalloped with interlocking transverse ridges on both elements

Character 500: Maxilla, form of external subcutaneous surface texturing:

0: random foramina and shallow grooves and ridges

1: deep, prominent, dorsoventrally trending grooves and ridges

Character 501: Maxilla, swollen rim separating antorbital fossa and subcutaneous surface:

0: present

1: absent

Character 502: Maxilla, size of ascending ramus, anteroposterior chord directly above maxillary fenestra compared to dorsoventral depth of maxilla below anterior edge of antorbital fenestra:

0: greater than 1.75 times (ascending ramus large)

1: less than 1.60 times (ascending ramus small)

Character 503: Maxilla, posterior region of the main body (portion including the final 3-5 teeth and anterior to the jugal process), shape:

0: maintains a relatively constant dorsoventral depth

1: tapers in depth posteriorly

Character 504: Maxilla, primary row of neurovascular foramina, form:

0: continues as a row posteriorly

1: transitions posteriorly into a sharp groove, paralleling the antorbital fossa rim

Character 505: Maxilla, antorbital fossa, extent on main body:

0: covers more than half of the depth of the main body beneath the anterior margin of the antorbital fenestra

1: covers less than half of this depth

Character 506: Nasals, midline crest on dorsal surface:

0: absent

1: present

Character 507: Nasal, shape in dorsal view: (UNORDERED)

0: expands in width posteriorly

1: relatively constant width across the length of the bone, due to subparallel lateral sides

2: tapers in width posteriorly

Character 508: Nasal, frontal process, mediolateral width:

0: unconstricted

1: constricted, less than $\frac{1}{2}$ width of widest point of nasal

Character 509: Nasal, posterolateral process that overlaps the lateral surface of the lacrimal:

0: absent

1: present

Character 510: Nasal, extent of narial fossa on premaxillary process:

0: limited to ventral margin of process

1: covers entire process, and thus meets opposite fossa on dorsal midline

Character 511: Nasal, medial processes of frontal articulation, shape: (UNORDERED)

0: processes absent or very subtle

1: lanceolate

2: tapered

Character 512: Nasal, thin, low, and laterally projecting crest at the corner where lateral and dorsal surfaces meet:

0: absent

1: present

Character 513: Lacrimal, angle between anterior and ventral rami

0: 90 degrees (=inverted L shaped) or greater

1: approximately 70-80 degrees (=7 shaped)

Character 514: Lacrimal, cornual process on dorsal surface, form:

(UNORDERED)

0: barely perceptible ridge across entire length of anterior ramus (equivalent to the state “cornual process absent” in tyrannosauroid-specific datasets)

1: broad, shallow, dorsally convex, laterally overhanging swelling across most of the length of the anterior ramus

2: discrete conical projection

3: small, conical, smooth projection that rises 2-3 millimeters from skull roof

Character 515: Lacrimal, cornual process, form:

0: smoothly rounded

1: discrete apex present

Character 516: Lacrimal, cornual process, position of apex:

0: dorsal to ventral ramus

1: anterior to ventral ramus

Character 517: Lacrimal, anterior ramus, pneumaticity:

0: not inflated

1: inflated by pneumatic recess

Character 518: Lacrimal, size of primary external opening for lacrimal recess:

0: small, anterior end located approximately at the same level as the anterior end of the ventral ramus

1: large, anterior end located far anterior to the ventral ramus

Character 519: Lacrimal, interaction of primary external opening for lacrimal recess and antorbital fossa:

0: separate

1: blend

Character 520: Lacrimal, accessory external openings for lacrimal recess on the anterior ramus: (ORDERED)

0: absent

1: present and proximally located (i.e., near to primary recess)

2: present and distally located

Character 521: Lacrimal, pneumatic recess opening internally onto medial surface

of bone as a discrete pneumatic fenestra (pneumatopore):

0: absent

1: present

Character 522: Lacrimal, dorsal prong of anterior ramus for articulation with maxilla (“anterodorsal process”), size:

0: absent or small

1: present and elongate

Character 523: Lacrimal, ventral ramus, extent of medial lamina:

0: greater than half of the dorsoventral depth of the ramus

1: half or less of the dorsoventral depth of the ramus

Character 524: Lacrimal, orbitonasal ridge on medial surface, position:

0: anterior to posterior margin of ventral ramus

1: adjacent to or contacting posterior margin of ventral ramus

Character 525: Lacrimal, articulation with frontal, form:

0: squamous

1: conical lacrimal process set into deep pit in frontal

Character 526: Lacrimal, posterior process for articulation with frontal, inflated by pneumatic recess:

0: no

1: yes

Character 527: Lacrimal, extent of antorbital fossa on ventral ramus:

0: covers greater than 60% of anteroposterior length along the contact with the jugal

1: covers less than this measure

Character 528: Lacrimal, maxillary process of anterior ramus, visibility in lateral view:

0: both dorsal and ventral margins visible

1: dorsal margin concealed by subcutaneous surface above antorbital fossa and only ventral margin visible

Character 529: Jugal, maxillary ramus, depth:

0: shallow, not expanded relative to suborbital portion of bone

1: deep, expanded relative to suborbital portion of bone

Character 530: Jugal, antorbital fossa, extent on maxillary ramus:

0: edge of fossa undercut and continues posterodorsal to jugal recess

1: fossa edge does not extend past the jugal recess

Character 531: Jugal, pneumatic recess, location relative to ventral ramus of lacrimal:

0: ventral

1: anterior

Character 532: Jugal, pneumatic recess, orientation of long axis:

0: approximately horizontal

1: inclined at approximately 45 degrees relative to the ventral skull margin

Character 533: Jugal, secondary fossa for pneumatic recess, position relative to recess:

0: ventral

1: dorsal

Character 534: Jugal, suture with lacrimal, angle of the posterior half of the contact

0: low

1: steep

Character 535: Jugal, fossa on lateral surface of postorbital ramus, depth inset into bone:

0: shallow

1: deep

Character 536: Jugal, articulation with postorbital, form of ventral extremity of suture:

0: tapering scarf joint

1: interlocking notch for postorbital

Character 537: Jugal, articulation with postorbital, extent of scarf joint on lateral surface of postorbital ramus:

0: limited, occupies less than 50% of anteroposterior length of the process

1: extensive, occupies approximately 50-75% of the anteroposterior length of the process

Character 538: Jugal, articulation with postorbital, braced by a pronounced ridge on the lateral surface of the postorbital ramus, which borders the postorbital posteriorly:

0: no

1: yes

Character 539: Jugal, postorbital ramus, orientation relative to ventral margin of jugal:

0: approximately perpendicular

1: posterodorsal (obtuse angle between the long axis of the process and the ventral margin)

Character 540: Jugal, cornual process: (ORDERED)

0: absent

1: present

2: present and distinctive (mediolaterally wide and heavily rugose)

Character 541: Jugal, dorsal prong of quadratojugal ramus, slope in lateral view:

0: horizontal

1: posterodorsal

Character 542: Jugal, ventral prong of quadratojugal ramus, slope of joint surface in lateral view:

0: approximately anteroposteriorly oriented, angled less than 45 degrees from horizontal

1: angled anterodorsally at greater than 45 degrees from horizontal

Character 543: Jugal, shape of orbital margin:

0: weakly concave, approximately level with lacrimal-jugal suture

1: U-shaped, extends ventral to lacrimal-jugal suture

Character 544: Jugal, raised rim on the lateral surface, paralleling the ventral margin of the bone and anteriorly confluent with the antorbital fossa rim of the

maxilla:

0: absent

1: present

Character 545: Postorbital, cornual process: (ORDERED)

0: absent

1: limited to rugose rim at posterodorsal corner of orbit

2: present as a rugose, convex boss

Character 546: Postorbital, cornual process, position:

0: separated from dorsal margin of postorbital by a smooth, convex region

1: approaches or extends past dorsal margin of bone

Character 547: Postorbital, cornual process, position:

0: located at orbital margin

1: located posterodorsal to orbital margin

Character 548: Postorbital, squamosal ramus, form of posterodorsal margin:

0: uninterrupted convex arc

1: emarginated by squamosal (discrete concave notch within the margin)

Character 549: Postorbital, squamosal ramus, extent relative to posterior margin of lateral temporal fenestra:

0: reaches or extends posterior to

1: terminates anterior to

Character 550: Postorbital, suborbital process, position:

0: at ventral end of ventral process

1: flange-like, separated from ventral tip of the ventral process by a notch

Character 551: Postorbital, anterior ramus, form:

0: short and stout, long axis is approximately half the length of the ventral ramus and the thickness at the base is approximately the same as the thickness of the midpoint of the ventral ramus

1: long and slender, long axis is greater than 60% of the length of the ventral ramus and the thickness at the base is approximately half that of the midpoint of the ventral ramus

**Character 552: Postorbital, ventral ramus, anteroposterior width at midpoint:
(UNORDERED)**

- 0: approximately the same width as ventral ramus of the lacrimal
- 1: substantially wider than ventral ramus of lacrimal
- 2: substantially narrower than ventral ramus of lacrimal

Character 553: Squamosal, lateral ridge delimiting supratemporal fossa, form:

- 0: ridge unpronounced or undivided
- 1: divided

Character 554: Squamosal, supratemporal fossa, surface morphology:

- 0: flat or concave
- 1: convex

Character 555: Squamosal, quadratojugal process, morphology of anterior tip in those taxa with horizontal processes:

- 0: tapered point
- 1: squared off

**Character 556: Squamosal, quadratojugal process, flange that is covered laterally by the quadratojugal, dorsoventral depth of entire process compared to portion of process that is exposed in lateral view when in articulation with quadratojugal:
(ORDERED)**

- 0: flange absent
- 1: thinner
- 2: substantially thicker

Character 557: Squamosal, pneumaticity: posterior process, inflated by squamosal recess: (ORDERED)

- 0: absent
- 1: present as a deep, concave depression on the ventral surface of the main body
- 2: present as a deep, concave depression on the ventral surface of the main body, and extending posteriorly to inflate the squamosal posterior process

Character 558: Squamosal, posterior process, length of the long axis:

- 0: long, approximately 1/3-1/2 length of quadratojugal process

1: short, approximately 1/6 length of quadratojugal process

Character 559: Squamosal, anterior process, flange that extends dorsal to the postorbital posterior process:

0: absent

1: present

Character 560: Quadratojugal, dorsal process, ridge along anterior margin of lateral surface: (ORDERED)

0: absent

1: present, subtle and fades in strength dorsally

2: present, robust and extends to the dorsal margin of the bone

Character 561: Quadratojugal, form of jugal articulation, dorsal prong of posterior process of jugal approaching the base of the quadratojugal (the corner where the anterior and dorsal processes of the quadratojugal meet):

0: absent

1: present

Character 562: Quadratojugal, anterior process for articulation with jugal, form of anterior region: (UNORDERED)

0: tapered

1: rounded

2: squared off or double pronged

Character 563: Quadratojugal, anterior process, extent related to anterior margin of lateral temporal fenestra:

0: terminates posterior to fenestra margin

1: level with or anterior to fenestra margin

Character 564: Quadratojugal, curvature of bone:

0: mediolaterally compressed and flat

1: posterior region flexed so that it curves posteriorly, thus delimiting the lateral edge of a deep pocket that borders the quadrate foramen laterally in posterior view

Character 565: Quadratojugal, posterior process, length and orientation:

0: short, oriented mostly laterally

1: elongate, wraps onto the posterior surface of the quadrate cotyles

Character 566: Quadrate foramen, size:

0: small, long axis approximately 10% of the dorsoventral depth of the quadrate shaft

1: large, long axis greater than 20% of the dorsoventral depth of the quadrate shaft

Character 567: Quadrate, form of pneumatization, deep recess on the anterior surface where the pterygoid wing and condyles meet:

0: absent

1: present

Character 568: Quadrate, condyles, position relative to occipital condyle when skull is in articulation:

0: aligned (i.e., quadrate condyles approximately ventral to occipital condyle, or slightly anterior to condyle)

1: completely posterior

Character 569: Quadrate, quadratojugal articulation, extent on lateral surface of lateral condyle:

0: limited, occupies only part of the surface

1: extensive, covers entire lateral surface and extends dorsally to partially enclose quadrate foramen laterally

Character 570: Quadrate, articular surface for quadratojugal on quadrate lateral condyle, orientation of medial margin as seen in posterior view where quadratojugal wraps around quadrate:

0: vertical or dorsomedial

1: dorsolateral

Character 571: Prefrontal, contacts nasal:

0: yes

1: no, excluded by frontal-lacrimal contact

Character 572: Prefrontal, ventral process, extent:

0: large, extends 1/2-1/4 of the way down the ventral ramus of the lacrimal to

make an extensive contribution to the preorbital bar

1: reduced or absent, ventral process is a thin flange that is continuous with the crista cranii of the frontal, and does not extend more than approximately $\frac{1}{4}$ of the length of the preorbital bar

Character 573: Frontal, shape (in those taxa with frontals that narrow anteriorly as a wedge between the nasals):

0: triangular

1: posterior end expanded into a rectangular shape, with a small anterior triangle

Character 574: Frontal, size of single frontal, ratio of anteroposterior length of exposed portion on skull roof to mediolateral width at midpoint:

0: greater than 2.0 (usually greater than 2.5)

1: less than 2.0

Character 575: Frontal, supratemporal fossa, medial extension:

0: fossa restricted to posterolateral corner of frontal

1: meets opposing fossa at the midline

Character 576: Frontal, sagittal crest: (UNORDERED)

0: absent or subtle, only discernable as a slight midline bulge

1: present and pronounced (dorsoventrally tall), single structure

2: present and pronounced (dorsoventrally tall), paired structure

Character 577: Frontal, sagittal crest, anteroposterior length:

0: short, less than 15% length of the frontal

1: extensive, approximately 25% of the length of the frontal

Character 578: Frontal, postorbital suture: (ORDERED)

0: dorsoventrally shallow and undifferentiated

1: dorsoventrally shallow (approximately 6 times longer than deep) and differentiated into a vertical region anteriorly and a horizontal region posteriorly

2: dorsoventrally deep (approximately twice as long as deep) and subtly differentiated into vertical and horizontal regions

Character 579: Frontal, contribution to orbital rim: (ORDERED)

0: extensive

- 1: present but limited to a small notch
- 2: excluded by postorbital-lacrimar contact in large specimens
- 3: excluded by postorbital-lacrimar articulation and oval “palpebral” ossification

Character 580: Parietal-frontal suture, form:

- 0: transversely smooth
- 1: tab-like wedge from parietal extends anteriorly to overlies frontal on midline

Character 581: Parietal, sagittal crest, form:

- 0: comprised of two parallel crests
- 1: comprised of a single midline crest

Character 582: Parietal, skull table between supratemporal fossae, width:

- 0: broad, more than 10% of the mediolateral width of the fossa
- 1: extremely reduced, sagittal crest or crests (if present) pinched between opposing fossae

Character 583: Parietal, sagittal crest, dorsoventral depth:

- 0: consistent across length of crest
- 1: peaked anteriorly at frontal-parietal suture

Character 584: Parietal, nuchal crest, dorsoventral depth:

- 0: as low as or lower than dorsal surface of the interorbital region
- 1: extends higher than the dorsal surface of the interorbital region

Character 585: Vomer, shape of anterior end:

- 0: lanceolate (lateral margins parallel-sided)
- 1: expanded into a diamond

Character 586: Ectopterygoid, extent of internal recess:

- 0: does not inflate body of the bone and the pterygoid process
- 1: inflates body of the bone and the pterygoid process

Character 587: Ectopterygoid, jugal process, external pneumatic foramina leading into ectopterygoid recess:

- 0: absent
- 1: present

Character 588: Ectopterygoid, jugal process, pneumaticity:

0: is not inflated by the internal recess

1: is visibly inflated by the internal recess

Character 589: Ectopterygoid, external opening of pneumatic recess, shape:

0: thin ovoid slot

1: large, round or triangular

Character 590: Ectopterygoid, surface posteriorly adjacent to external opening of pneumatic recess, form:

0: flat, recess grade smoothly into the floor of the lateral temporal fenestra (=subtemporal fenestra)

1: lip, recess separated from lateral temporal fenestra (=subtemporal fenestra)

Character 591: Palatine, vomeropterygoid process, ratio of anteroposterior length of dorsal margin to length of greatest constriction of process neck:

0: greater than 2.0

1: less than 2.0

Character 592: Palatine, vomeropterygoid process, orientation of neck:

0: inclined anterodorsally

1: vertical

Character 593: Palatine, pneumaticity:

0: absent

1: present

Character 594: Palatine, pneumatic recess, number of external pneumatic openings:

0: one

1: two

Character 595: Palatine, primary external opening of palatine recess, location of posterior margin:

0: level with or extends posterior to posterior margin of the vomeropterygoid process neck

1: located far anterior to posterior margin of the vomeropterygoid process neck

Character 596: Palatine, primary opening of palatine recess, location of anterior margin:

0: level with or extends posterior to anterior margin of the vomeropterygoid process neck

1: located far anterior to anterior margin of the vomeropterygoid process neck

Character 597: Palatine, jugal process, location of contact surface for lacrimal:

0: posterior (“distal”), separated from opening of palatine recess by wide margin

1: anterior (“proximal”), closely approaches opening of palatine recess

Character 598: Palatine, maxillary process, form of maxillary articulation:

0: flat

1: deeply excavated as a slot, demarcated dorsally by a pronounced lip of bone

Character 599: Palatine, extension of pneumatic recess into jugal process:

0: no

1: yes, process visibly inflated

Character 600: Palatine, maxillary articulation, form:

0: maxilla abuts lateral surface of maxillary process and anterior region of jugal process

1: contact reinforced by a “brace” at the anteroventral corner of the jugal process, which sits within internal antorbital fossa

Character 601: Palatine, morphology of maxillary articulation brace:

0: projects ventrally due to a jugal process that extends further ventrally than the maxillary process, such that there is a discrete corner between the two processes in lateral view

1: projects laterally, with no discrete corner between the smoothly confluent jugal and maxillary processes in lateral view

Character 602: Internal choana, shape:

0: anteroposteriorly elongate oval

1: nearly circular

Character 603: Suborbital fenestra, shape:

0: anteroposteriorly elongate oval

1: nearly circular

Character 604: Braincase, orientation of occipital surface:

0: faces posteriorly

1: faces posteroventrally

Character 605: Supraoccipital, contribution to dorsal rim of foramen magnum (ORDERED)

0: forms entire rim

1: makes limited contribution to rim via triangular ventral process

2: completely excluded from rim

Character 606: Supraoccipital, form of dorsal margin

0: smoothly convex and undivided

1: divided into two processes (“forked”)

Character 607: Exoccipital-opisthotic, paroccipital process, ventral flange at distal end:

0: absent

1: present

Character 608: Exoccipital-opisthotic, paroccipital processes, deep fossa on posterior surface dorsolateral to the foramen magnum:

0: present

1: absent

Character 609: Exoccipital-opisthotic, crista tuberalis (=metotic strut), extent in posterior view:

0: limited, mediolateral width across opposing cristae less than one half the dorsoventral depth of the braincase from the dorsal tip of the supraoccipital to the ventral tip of the basal tubera

1: extensive, width greater than one half braincase depth

Character 610: Basioccipital, basal tubera, dorsoventral depth:

0: less than depth of occipital condyle

1: greater than depth of occipital condyle

Character 611: Basioccipital, basal tubera, concave notch ventrally between

opposing tubera, dorsoventral depth:

0: shallow, less than 40% depth of tubera

1: deep, approximately 50% depth of tubera

Character 612: Basioccipital, subcondylar recess, depth of pneumatic fossae on posterior surface of basal tubera:

0: absent or shallow

1: deep

Character 613: Basisphenoid, basisphenoid recess, orientation of central axis: (ORDERED)

0: vertical, recess obscured in posterior view

1: posteroventral, recess partially visible in posterior view

2: extremely posteroventral, recess compressed anteroposteriorly and widely visible in posterior view, and basiptyergoid processes located beneath the basal tubera

Character 614: Basisphenoid, basisphenoid recess, inflation of the ceiling of the recess:

0: absent

1: present

Character 615: Basisphenoid, basisphenoid recess, shape in ventral view:

0: funnel-like, expands in mediolateral width posteriorly

1: ovoid or circular, no posterior expansion

Character 616: Basisphenoid, shape of basicranium (rectangle defined by positions of both basal tubera and both basiptyergoid processes):

0: anteroposteriorly longer than mediolaterally wide

1: wider than long

Character 617: Parasphenoid, shape of rostrum:

0: anteroposteriorly expanded, ventral margin is a smooth concave arch

1: dorsoventrally expanded, ventral margin is nearly vertical posteriorly and then abruptly transitions to horizontal trend anteriorly

Character 618: Laterosphenoid, antotic crest separating lateral wall of braincase from orbital and temporal spaces:

- 0: absent or indistinct
- 1: present, robust and rugose

Character 619: Laterosphenoid, antotic crest, form:

- 0: single structure
- 1: bifurcates ventrally

Character 620: Laterosphenoid, fossa on lateral surface that houses head of epipterygoid:

- 0: absent or shallow
- 1: present, deep and rugose

Character 621: Mandibular ramus, dorsoventral depth of dentary at level of dentary-surangular contact on the dorsal margin of the lower jaw:

- 0: less than 18% of the total anteroposterior length of the lower jaw
- 1: greater than 18% of the total anteroposterior length of the lower jaw

Character 622: External mandibular fenestra, dorsoventral depth relative to depth of mandible at midpoint of fenestra: (ORDERED)

- 0: greater than 25% depth of mandible
- 1: less than 25% depth of mandible
- 2: absent

Character 623: Lower jaw, articulation, glenoid position relative to level of alveolar margin of dentary: (UNORDERED)

- 0: approximately level with
- 1: dorsal to
- 2: strongly ventral to

Character 624: Dentary, position of the transition point between the ventral and anterior margins of the bone in lateral view:

- 0: below alveoli 1-3, anterior margin of bone rounded (or in some cases nearly straight)
- 1: below alveolus 4 (or more posteriorly), anterior margin nearly straight and projects posteroventrally

Character 625: Dentary, ventrally projecting rugose process (“chin”) where the

anterior and ventral margins of the dentary meet:

0: absent

1: present, visible as a pointed projection in lateral view and convex in medial view, braces dentary symphysis

Character 626: Dentary, symphysis, texture:

0: generally smooth

1: strongly rugose and beveled, with interlocking ridges and convexities for articulation with the opposing symphysis

Character 627: Dentary, articular surface for splenial along ventral region of dentary ramus below the Meckelian fossa, form:

0: dorsoventrally shallow and smooth

1: dorsoventrally deep (nearly as deep as anterior depth of fossa) and rugose

Character 628: Dentary, anterior alveoli, size in comparison to alveoli in middle of tooth row: (ORDERED)

0: approximately same size

1: first two alveoli substantially smaller

2: first alveolus substantially smaller

Character 629: Dentary, dorsal margin of bone in lateral view, profile: (UNORDERED)

0: straight

1: strongly concave

2: strongly convex

Character 630: Dentary, Meckelian groove, form:

0: dorsoventrally deep and shallowly inset into medial surface of bone

1: dorsoventrally shallow and deeply inset into bone, groove appears as a thin, sharp structure;

Character 631: Surangular, surangular shelf on lateral surface, form: (ORDERED)

0: low ridge or absent

1: prominent ridge that is offset laterally from the bone but dorsoventrally thin

2: prominent shelf that is dorsoventrally deep

Character 632: Surangular, surangular shelf on lateral surface, position and form: (ORDERED)

0: placed far dorsal to posterior surangular foramen

1: foramen abuts shelf but shelf projects laterally and does not overhang foramen

2: shelf projects ventrolaterally to overhang foramen

Character 633: Surangular, surangular shelf on lateral surface, orientation relative to the long axis of the lower jaw: (UNORDERED)

0: anterodorsal

1: anteroventral

2: straight anteroposteriorly

Character 634: Surangular, pneumatic fossa posterodorsal to posterior surangular foramen:

0: absent

1: present

Character 635: Surangular, adductor muscle attachment site dorsal to surangular shelf, orientation: (ORDERED)

0: faces primarily dorsally

1: faces almost equally dorsally and laterally

2: faces primarily laterally

Character 636: Surangular, triangular fossa on the lateral surface of the surangular shelf immediately anteroventral to glenoid:

0: absent

1: present

Character 637: Surangular, fossa on the lateral surface of the bone immediately ventral to, and separated from, the glenoid:

0: absent

1: present

Character 638: Surangular, anteroposterior length of anterior flange (region

anterior to anterior margin of external mandibular fenestra) compared to overall length of surangular:

0: less than 30%

1: greater than 30%

Character 639: Angular, ventral margin, form:

0: smoothly convex

1: anterior region “flexed” relative to posterior region, such that there is a discrete step between them

Character 640: Articular, mediolateral width of jaw muscle attachment site:

0: less than width of glenoid for articulation with quadrate

1: approximately equal to width of glenoid

Character 641: Articular, smooth non-articular region between glenoid and attachment site for depressor mandibular muscles:

0: present

1: absent

Character 642: Splenial, anterior myloheid foramen, shape and size: (ORDERED)

0: small circular or ovoid opening, or absent

1: large, anteroposteriorly ovoid shape

2: extremely large, approximately as deep dorsoventrally as the anterior process of the splenial

Character 643: Splenial, dorsal region overlapped medially by prearticular:

0: absent

1: present

Character 644: Prearticular, ventral bar, series of ridges on lateral surface to strengthen articulation with angular:

0: absent

1: present

Character 645: Supradentary ossification, shape:

0: elongate, shallow strip

1: deep, crescentic shape

Character 646: Supradentary and coronoid ossifications, form of contact at their zone of fusion:

- 0: ossifications smoothly confluent
- 1: ossifications offset by a concave notch

Character 647: Premaxillary tooth crown 4, apicobasal height relative to largest maxillary crown:

- 0: subequal
- 1: approximately 50%

Character 648: Premaxillary teeth, median vertical ridge on lingual surface: (ORDERED)

- 0: absent
- 1: present as a subtle structure in anterior (mesial) premaxillary teeth
- 2: present as pronounced structure in all premaxillary teeth

Character 649: Premaxillary teeth, curvature of distal (posterior) teeth:

- 0: recurved
- 1: straight

Character 650: Maxillary teeth, number:

- 0: 13 or more
- 1: less than 13 (in the largest adult specimens when growth series are known)

Character 651: Maxillary and dentary teeth, form: (ORDERED)

- 0: ziphodont, transverse width of base less than 60% of mesiodistal length
- 1: incrassate, width greater than 60% of length
- 2: incrassate, width nearly equal to length

Character 652: Axis and postaxial cervicals, anteroposterior length of centrum compared to dorsoventral height of posterior centrum face:

- 0: greater
- 1: less than or equal to

Character 653: Axis, pneumatic foramen (pleurocoel), position:

- 0: near midheight of centrum
- 1: dorsally located, directly underneath neurocentral suture and directly

posterior to diapophysis

Character 654: Axis, pneumatic foramen (pleurocoel), extent of surrounding fossa:

0: limited to margins of foramen

1: extensive, occupies most of lateral surface of centrum

Character 655: Axis, ridge on ventral surface of centrum:

0: absent

1: present

Character 656: Axis, pneumatic foramina and fossae on each side of the anterior ridge on the neural spine:

0: absent

1: present

Character 657: Axis, neural spine, texture of dorsal region of anterior surface:

0: generally smooth or with subtle texture

1: highly rugose, with series of grooves, ridges, and eminences

Character 658: Axis, dorsal region of neural spine, number of projections on “crown” region:

0: two lateral projections, dorsal surface of spine smoothly concave

1: two lateral projections and one dorsal projection on the midline

Character 659: Axis, supradiapophyseal fossa (fossa posterodorsal to diapophysis), form:

0: absent or shallow

1: deeply excavated and funnel-like

Character 660: Cervical vertebrae, neural spines in middle-posterior cervicals, dorsoventral height:

0: substantially shorter than height of posterior centrum face

1: approximately same length as or longer than height of posterior centrum face

Character 661: Cervical vertebrae, morphology of posterior centrodiapophyseal laminae in anterior-middle cervicals:

0: absent or present as a weak ridge

1: present as a thick, laterally offset lamina that demarcates a deep

infradiapophyseal fossa anteriorly

Character 662: Cervical vertebrae, hypapophysis on anterior region of ventral surface:

0: absent

1: present

Character 663: Cervical vertebrae, position of prezygapophysis in middle cervicals:

0: slightly overhangs centrum laterally

1: strongly overhangs centrum laterally, entire prezygapophyseal facet placed lateral to centrum

Character 664: Cervical vertebrae, orientation of posterior centrodiapophyseal lamina in anterior-middle cervicals:

0: projects posteroventrally, infrapostzygapophyseal fossa located primarily posterior to lamina

1: nearly horizontal, fossa located primarily dorsal to lamina

Character 665: Cervical and dorsal vertebrae, rugose ligament attachment scars in pre- and postspinal fossae: (ORDERED)

0: absent or weakly developed

1: present as prominent, rectangular flanges that extend outside of the fossae and are visible in posterior view, but on the dorsal vertebrae only

2: prominent in dorsals and cervicals

Character 666: Dorsal vertebrae, neural spine, level of posterior termination:

0: at approximately the same level as the posterior centrum face

1: far posterior to the posterior centrum face

Character 667: Dorsal vertebrae, anteroposterior length of middle-posterior dorsal centra compared to dorsoventral height of posterior centrum face:

0: greater

1: less than or equal

Character 668: Dorsal vertebrae, middle-posterior dorsals, position of postzygapophysis relative to prezygapophysis:

0: at same level

1: elevated dorsally

Character 669: Dorsal vertebrae, middle-posterior dorsals, form of anterior and posterior centrodiapophyseal laminae: (ORDERED)

0: discrete laminae absent, or laminae present but do not demarcate a deep infradiapophyseal fossa between them

1: present and make contact on ventral surface of transverse process, demarcating a triangular infradiapophyseal fossa

2: present and do not make contact but roughly parallel each other, infraprezygapophyseal and infradiapophyseal fossa merged into a single fossa

Character 670: Sacral vertebrae, fenestrae between fused neural spines: (ORDERED)

0: neural spines unfused

1: spines fused but fenestrae absent

2: spines fused and fenestrae present

Character 671: Sacral ribs, position of central ribs on sacrum:

0: span two sacrals

1: limited to a single sacral

Character 672: Sacral ribs, position of rib attachment for central ribs on individual sacrals:

0: span centrum and neural arch

1: limited to neural arch only

Character 673: Sacral vertebra five, position of ventral margin of posterior articular face in lateral view:

0: at same level as ventral margin of anterior articular face

1: positioned ventral to ventral margin of anterior articular face

Character 674: Sacral vertebrae, form of hyposphene in posteriormost sacral:

0: absent or present as a single midline structure

1: present and comprised of two parallel-sided sheets

Character 675: Caudal vertebrae, anterior caudals, position of base of neural

spine:

0: anterior to posterior surface of centrum

1: level with or posterior to posterior surface of centrum

Character 676: Caudal vertebrae, anterior caudals, shape of transverse processes in dorsal view:

0: rectangular, with parallel anterior and posterior sides, or slightly ovoid with a gradual expansion in width distally

1: distal end expanded into a spatulate bulb

Character 677: Caudal vertebrae, anterior caudals, two laminae linking prezygapophysis and transverse process, between which is a deep, triangular fossa:

0: absent

1: present

Character 678: Scapula, angle between posterior margin of glenoid and dorsal margin of blade:

0: greater than 90 degrees

1: approximately 90 degrees

Character 679: Scapula, acromion, dorsoventral depth:

0: less than 3.0 times minimum dorsoventral depth of blade

1: greater than 3.0 times minimum dorsoventral depth of blade

Character 680: Scapula, ratio of anteroposterior length of bone to minimum dorsoventral depth of blade:

0: less than 10.0

1: greater than 10.0

Character 681: Scapula and coracoid, glenoid, position relative to posteroventral margin of blade:

0: offset posteroventrally (by a distance equivalent to the width of the neck of the blade to $\frac{1}{2}$ of the width of neck of the blade)

1: offset only slightly posteroventrally (less than 50% the width of the neck of the blade)

Character 682: Coracoid, anteroposterior length at midpoint:

0: approximately 100-150% of the length of the scapular acromion at midheight

1: 200% or greater than the length of the scapular acromion at midheight

Character 683: Coracoid, coracoid foramen:

0: present

1: absent or extremely small

**Character 684: Humerus, apex of deltopectoral crest, location from proximal end:
(ORDERED)**

0: 35-50% of the length of the humerus

1: 25-35% of the length of the humerus

2: less than 25% of the length of the humerus

**Character 685: Humerus, additional muscle attachment tubera at the corner of
the anterior and lateral surfaces distal to the deltopectoral crest:**

0: absent

1: present

**Character 686: Humerus, concave notch between external tuberosity and
deltopectoral crest:**

0: present, two structures clearly separated

1: absent, two structures smoothly confluent

Character 687: Humerus, form of distal condyles:

0: lateral and medial condyles expanded equally (offset from shaft in anterior or posterior view is approximately equal)

1: medial condyle expanded further medially than the lateral condyle is laterally

Character 688: Ulna, shaft axis, form:

0: bowed

1: straight

Character 689: Principal distal carpal, shape:

0: semilunate in lateral view with trochlear proximal surface

1: discoid with flat proximal surface

Character 690: Metacarpal I, medial distal condyle, form:

0: well formed and large

1: rudimentary

Character 691: Metacarpal I, medial margin, shape in proximal view:

0: concave

1: smoothly convex or straight

Character 692: Metacarpals, metacarpal II, mediolateral width at midpoint compared to midpoint width of metacarpal I:

0: equal to or narrower than

1: more robust than

Character 693: Manual phalanx II-1, length compared to that of metacarpal 1:

0: longer

1: subequal to

**Character 694: Ilium, anteroposterior length compared to length of femur:
(ORDERED)**

0: up to 85%

1: 95-105%

2: 105-115% (or greater, in some birds)

Character 695: Ilium, dorsal margin of blade, position relative to sacral neural spines: (UNORDERED)

0: separated by a gap

1: lies against neural spines and opposing iliac blades may make contact above neural spines in some individuals

2: separated by a wide gap

Character 696: Ilium, supraacetabular crest, maximum lateral projection relative to ischial peduncle:

0: significantly greater

1: subequal

Character 697: Ilium, supraacetabular crest, extent on pubic peduncle:

0: extensive, extends along most or all of the edge of the peduncle

1: limited, discretely offset from acetabular edge of pubic peduncle

Character 698: Ilium, pubic and ischial peduncles, anteroposterior lengths at

dorsal base: (ORDERED)

- 0: pubic peduncle substantially longer than ischial peduncle
- 1: both peduncles approximately the same length
- 2: ischial peduncle longer than pubic peduncle

Character 699: Ilium, ventral margin of postacetabular process, shape:

- 0: straight to slightly convex
- 1: highly convex, forming a discrete “lobe”-like flange

Character 700: Ilium, dorsal margin, shape:

- 0: smoothly convex or straight across entire length
- 1: convex anteriorly and straightens out posteriorly

Character 701: Ilium, ratio of anteroposterior length to dorsoventral depth above acetabulum:

- 0: greater than 3.0, ilium is long and low
- 1: less than 2.8, ilium is subovoid in shape

Character 702: Pubis, pubic tubercle: (ORDERED)

- 0: absent
- 1: present as a convexity on the anterior margin of the pubis
- 2: present as a rugose flange that is discretely offset from the anterior margin of the pubis and is bordered posteriorly by heavy rugosities on the lateral surface on the obturator region of the pubis

Character 703: Pubis, pubic tubercle, position:

- 0: distally positioned, located ventral to the level of the obturator notch
- 1: proximally positioned, located level with or dorsal to the obturator notch

Character 704: Pubis, pubic boot, anteroposterior length relative to total long axis length of pubis:

- 0: less than 60%
- 1: greater than 60%

Character 705: Pubis, pubic boot, position of anterior process relative to posterior process:

- 0: displaced dorsally, resulting in a highly convex ventral margin of the boot

1: placed at the same level, ventral margin of the boot essentially straight

Character 706: Pubis, anteroposterior expansion of proximal obturator plate region relative to the anterior edge of the pubis shaft at its midpoint:

0: less than twice the anteroposterior thickness of the shaft at its midpoint

1: greater than twice the anteroposterior thickness of the shaft at its midpoint

Character 707: Pubis, obturator notch, form:

0: discrete structure, demarcated ventrally by extensive obturator flange

1: essentially absent, no ventral flange

Character 708: Ischium, position of medial apron:

0: along posterior margin of shaft

1: along anterior margin of shaft

Character 709: Femur, circular scar on posterior surface of shaft distal to fourth trochanter, position:

0: absent, low, or positioned approximately centrally on the shaft

1: abuts medial edge of shaft

Character 710: Femur, lesser trochanter, height relative to greater trochanter:

0: shorter, terminates further distally

1: subequal or slightly taller, the two structures extend to approximately the same level proximally

Character 711: Femur, proximal margin in anterior view: (ORDERED)

0: approximately straight and perpendicular to the long axis of the shaft

1: approximately straight and oriented at an obtuse angle to the long axis of the shaft (=dorsally or proximally inclined head)

2: concave and oriented at an obtuse angle to the long axis of the shaft, due to head that is proximally inclined and a greater trochanter that is elevated substantially relative to the central portion of the proximal surface of the femur

Character 712: Femur, trochanteric fossa on the posterior surface of the head, lateral to the ligament sulcus (for the capital ligament), form: (ORDERED)

0: absent or shallow

1: deep fossa

2: deep, extensive triangular depression that covers most of the posterior surface of the femur proximally and is demarcated medially and ventrally by a pronounced, curving, swollen ridge

Character 713: Femur, fourth trochanter, position, measurement from proximal margin of head to distal termination of trochanter relative to total length of the femur:

0: 40% or less

1: greater than 40%

Character 714: Femur, lateral condyle, shape in distal view:

0: circular or ovoid

1: ovoid, but with an anterior bulge that is slightly separated from the remainder of the condyle

Character 715: Femur, extensor groove on anterior surface of distal end, form: (ORDERED)

0: absent or extremely shallow, anterior surface flat between the condyles in distal view (extensor groove may be present but does not manifest itself as a groove on the anterior margin in distal view)

1: groove present but shallow, expressed as a broad concave margin in distal view but present as an extensive depression on the anterior surface of the femur

2: groove present and deep, expressed as a deep, U-shaped cleft in distal view and present as an extensive depression on the anterior surface of the femur

Character 716: Femur, mesiodistal crest, form:

0: single structure

1: bifurcates distally to enclose fossa on the medial surface of the medial condyle

Character 717: Tibia, length relative to the femur:

0: 1.05 or greater

1: less than 1.00

Character 718: Tibia, lateral condyle of proximal end, anterior process:

0: absent

1: present

Character 719: Tibia, lateral malleolus, lateral extent:

0: limited, mediolateral measure is less than 40% of mediolateral width of adjacent shaft

1: extensive, mediolateral measure greater than 40% of mediolateral width of adjacent shaft

Character 720: Tibia, lateral malleolus, position relative to medial malleolus:

0: extent to approximately the same level distally

1: lateral malleolus extends substantially further distally than medial malleolus

Character 721: Fibula, iliofibularis tubercle, form:

0: single crest

1: large, rugose, and formed by two crests separated by a depressed fossa (“bipartite” condition)

Character 722: Astragalus, fossa on anterior surface of ascending process, form:

0: shallow concavity that covers most of the ventral region of the ascending process

1: deep, triangular or ovoid fossa immediately above midpoint of condyles, set within a broad fossa that covers most of the ventral region of the ascending process

Character 723: Pes, metatarsal III, form of medial surface in anterior or posterior view:

0: straight or subtly convex

1: with medial convex expansion forming a bulge along the distal part of the shaft

Character 724: Pes, metatarsal III, ventral nonarticular surface (on the flexor surface) immediately proximal to the distal condyles, form:

0: concave

1: raised subtriangular platform

Character 725: Pes, metatarsals II-IV, distal separation when in articulation:

0: metatarsals closely appressed and distance between II-III and III-IV is approximately equal

1: distal ends of II and IV diverge from III, and distance between III-IV greater than that between II-III

Character 726: Pes, metatarsal II, articular scar for metatarsal III on distal portion of lateral surface of shaft, form:

0: subtle or absent

1: enlarged as a rugose fossa that occupies more than half of the proximodistal length of the shaft and expands in anteroposterior width distally

Character 727: Pes, metatarsal II, lateral surface in proximal view, shape: (ORDERED)

0: flat or weakly concave

1: moderately concave

2: strongly concave (deep concave notch is present)

Character 728: Pes, metatarsal IV, distal end, ratio between anteroposterior long axis (measured from midpoint of condyles posteriorly to anterior surface of bone) and mediolateral width (measured at midpoint: (ORDERED))

0: greater than 1.40, distal surface is elongate anteroposteriorly

1: between 1.40 and 1.20

2: less than 1.20, distal surface nearly square shaped with nearly flat anterior surface

Character 729: Pes, proximal pedal phalanges of digits II and III, ratio of length to midshaft width:

0: greater than 3.0

1: less than 3.0

Note; This character is revised to “?” for *Cathayornis*.

Character 730: Pes, pedal unguals, lip overhanging proximal articular surface dorsally (on extensor surface):

0: present

1: absent or reduced to a subtle tuber

Character 731: Maxilla, series of discrete foramina along ventral edge of lateral surface:

0: present

1: absent

Character 732: Lacrimal, prominence on lateral surface of bone:

0: absent

1: present

Character 733: Dentary, morphology of dorsal border in transverse cross section:

0: rounded and lacks “cutting edge”

1: sharp with a “cutting edge”

Character 734: Surangular, foramen on dorsal edge of bone dorsal to mandibular fenestra (anterior surangular foramen):

0: present

1: absent

Character 735: Neck, length compared to that of skull:

0: less than twice skull length

1: greater than twice skull length

Character 736: Coracoid, biceps tubercle, position:

0: positioned close to base of posterior process (closer to coracoid-scapula suture than to anterior edge of coracoid)

1: positioned more anterior than the base of the posterior process (closer to anterior edge of coracoid than to coracoid-scapula suture)

Character 737: Coracoid, position of infraglenoid buttress relative to that of posterior process when bone is seen in dorsal view:

0: two structures extend to same level laterally

1: buttress offset laterally from posterior process

Character 738: Metacarpal II, length compared to metacarpal III:

0: shorter

1: equal to or longer

Character 739: Manual digit I, length of phalanx I-1 compared to metacarpal II:

0: shorter

1: longer

Character 740: Manual unguals, flexor tubercles, position:

- 0: near proximal end
- 1: distal to proximal end

Character 741: Pubis, shape of ventral margin of pubic boot:

- 0: straight or slightly convex
- 1: strongly convex with ventral expansion

Character 742: Pes, pedal digit I:

- 0: present
- 1: absent

Character 743: Pes, phalanx II-2, length:

- 0: more than 60% of length of pedal phalanx II-1
- 1: less than 60% of length of pedal phalanx II-1

Character 744: Pubis, angle between anterior process of pubic boot and shaft:

- 0: greater than 90 degrees
- 1: approximately 90 degrees

Character 745: Pubis, position of anterior edge of anterior process of pubic boot:

- 0: approximately same level as anterior margin of pubic shaft
- 1: markedly anterior to the anterior margin of pubic shaft

Character 746: Pes, pedal unguals, shape:

- 0: curved in lateral view
- 1: straight

Character 747: Premaxillary teeth, size compared to mesial (anterior) maxillary teeth:

- 0: approximately same size, slightly smaller, or larger
- 1: considerably smaller

Character 748: Ischium, form of articulation with ilium on proximal surface of iliac peduncle:

- 0: approximately flat or slightly concave
- 1: deeply concave as a deep socket to receive a peg-like ischial peduncle of the ilium

Character 749: Scapula, acromion process, shape:

0: much deeper dorsoventrally than long anteroposteriorly, generally tapering or triangular in shape

1: approximately as long as or longer anteroposteriorly than deep dorsoventrally, with short reach beyond scapular blade and squared-off profile

Character 750: Basisphenoid, pronounced muscle scars flanking basisphenoid recess:

0: absent

1: present

Character 751: Ilium, form of distal articular surface of pubic peduncle:

0: convex

1: flat or concave (notched)

Character 752: Lacrimal, orientation of ventral ramus relative to the long axis of the alveolar margin of the upper jaw when the articulated skull is seen in lateral view

0: approximately vertical or inclined slightly anteroventrally

1: inclined strongly posteroventrally

Character 753: Exoccipital-opisthotic, position of ventral edge of the base of the paroccipital process:

0: level with or dorsal to the dorsal border of the occipital condyle

1: situated at mid-height of occipital condyle or further ventrally

Character 754: Maxillary teeth, shape: (UNORDERED)

0: mediolaterally thin and recurved

1: lanceolate (as in therizinosauroids)

2: conical (as in alvarezsauroids)

Character 755: Dorsal vertebrae, form of opisthocoely in taxa with opisthocoelous dorsals:

0: some dorsal vertebrae opisthocoelous

1: most or all dorsal vertebrae opisthocoelous

Character 756: Dorsal vertebrae, shape of neural spine in posterior dorsals:

0: approximately square-shaped or slightly rectangular, with a dorsoventral height that is equal to or slightly greater than the anteroposterior length at the base

1: rectangular, much higher dorsoventrally than long anteroposteriorly at the base

Character 757: Dorsal vertebrae, position of parapophysis in posterior dorsals:

0: distinctly ventral to transverse process

1: at approximately same dorsoventral level as transverse process

Character 758: Caudal vertebrae, morphology of anterior caudals:

0: amphiplatyan

1: procoelous

Character 759: Caudal vertebrae, position of transverse process on anterior caudals:

0: approximately centered (in the anteroposterior dimension) on the centrum

1: anteriorly displaced

Character 760: Coracoid, biceps tubercle:

0: absent or subtle

1: present as a discrete, mound-like structure

Character 761: Coracoid, strong lateral ridge on lateral surface, extending posteriorly from biceps tubercle along posteroventral process:

0: absent

1: present

Character 762: Scapula, tubercle on posterior surface of bone dorsal to glenoid:

0: absent

1: present

**Character 763: Humerus, shape of internal tuberosity in anterior view:
(ORDERED)**

0: triangular or rounded, not discretely separated from remainder of humerus

1: rectangular, separated from the humeral head by a small but distinct notch

2: rectangular and hypertrophied, separated from the humeral head by a large notch

Character 764: Ulna, shape of olecranon process:

- 0: transversely broad
- 1: mediolaterally thin and blade-like

Character 765: Ulna, position of distal articular surface:

- 0: limited to distal end
- 1: trochlear articular surface extends onto dorsal surface of ulna, bulbous in shape

Character 766: Metacarpal III, form of proximal articular surface:

- 0: flat or slightly convex
- 1: deeply concave and cup-like

Character 767: Metacarpal III, length:

- 0: considerably longer than length of metacarpal I
- 1: approximately same length as, or slightly longer than, metacarpal I

Character 768: Manual digits, paired flexor processes on proximal portion of ventral surfaces of proximal-most phalanges:

- 0: absent
- 1: present

Character 769: Manus, shape of proximal articular surface of ungual of first digit:

- 0: ovoid, dorsoventrally taller than mediolaterally wide
- 1: approximately square shaped, as mediolaterally wide as dorsoventrally tall

Character 770: Manus, form of lateral groove on ungual of first digit:

- 0: unenclosed or partially enclosed proximally by small flange
- 1: proximal end of grooves passes through foramina on ventral surface of ungual

Character 771: Femur, interaction of head and greater trochanter:

- 0: confluent
- 1: separated by a cleft

Character 772: Femur, shape of lateral distal condyle:

- 0: distally rounded
- 1: distally conical, projecting substantially further distally than medial condyle

Character 773: Tibia, shape of medial posterior condyle of proximal end in

proximal view:

0: posteriorly rounded

1: posteriorly conical, projecting substantially further posteriorly than lateral condyle

Character 774: Fibula, orientation of proximal margin (as seen in lateral view):

0: horizontal or nearly horizontal

1: anterior portion of proximal margin extends substantially further proximally than posterior portion

Character 775: Fibula, shape of proximal surface in proximal view:

0: anterior and posterior portions of surface with nearly equal mediolateral widths

1: anterior portion markedly wider mediolaterally than posterior portion

Character 776: Astragalus, fossa on anterior surface of lateral portion of base of ascending process, sometimes bearing accessory fenestrations:

0: absent

1: present

Character 777: Astragalus, horizontal groove on proximal portion of anterior surface of condyles, separating condyles from ascending process:

0: present

1: absent

Character 778: Pes, phalanges of pedal digit IV, shape:

0: anteroposteriorly long, proximal and distal articular surfaces well separated

1: anteroposteriorly short, with proximal and distal articular surfaces very close together, particularly in distal elements

Character 779: Basisphenoid, inflated basisphenoidal bulla:

0: absent

1: present

Character 780: Braincase, foramen magnum, size (area): (ORDERED)

0: smaller than size of occipital condyle

1: approximately equal in size with occipital condyle

2: larger than size of occipital condyle

Character 781: Ectopterygoid, position:

0: posterior to palatine

1: lateral to palatine

Character 782: Dentary, mediolateral width of symphyseal region of conjoined dentaries:

0: narrower than width of post-symphyseal region

1: broader than width of post-symphyseal region

Character 783: Premaxillary teeth, serrations:

0: present

1: absent

Character 784: Dentary teeth, shape of mesial (anterior) teeth:

0: not conical (i.e., ziphodont or lanceolate)

1: conical

Character 785: Dentary, extent of tooth row:

0: teeth present at anterior (mesial) tip of dentary

1: teeth absent at anterior dentary but present further posteriorly (distally)

Character 786: Cervical vertebrae, length of anterior centra:

0: up to three times longer anteroposteriorly than the minimum transverse centrum width in ventral view (or the height of the anterior articular surface in lateral view, if the centrum cannot be viewed ventrally)

1: hyperelongate, approximately five times longer than wide

Character 787: Cervical vertebrae, morphology of ventral surface of centrum:

0: smoothly flat or convex

1: with distinct depression anteriorly (at the level of the parapophyses)

Character 788: Cervical vertebrae, posterolateral margins of ventral surface of centrum, form:

0: unpronounced

1: developed into prominent crests (ventrally projecting “fins”)

Character 789: Dorsal vertebrae, anterior dorsals, dorsoventral depth of neural

arch compared to that of centrum:

0: depth of region between prezygadiapophyseal lamina and base of neural spine less than or equal to depth of anterior and/or posterior articular surface of centrum

1: depth of region between prezygadiapophyseal lamina and base of neural spine greater than depth of anterior and/or posterior articular surface of centrum (neural arch hypaxially inflated relative to centrum)

Character 790: Dorsal vertebrae, size of parapophyses on anterior dorsals:

0: moderate in size, articular facet of parapophysis less than half dorsoventral depth of anterior articular surface of centrum

1: hypertrophied, articular facet greater than two thirds of the dorsoventral depth of the anterior articular surface of centrum

Character 791: Caudal vertebrae, pneumatic foramina on the centra of anterior caudals:

0: absent

1: present

Character 792: Scapula, dorsal flange on dorsal margin of scapular blade:

0: absent

1: present

Character 793: Humerus, crest on posteromedial surface of humeral shaft:

0: absent

1: present

Character 794: Humerus, tuberosity on anterior surface of distal humerus, proximal to entepicondyle:

0: absent

1: present

Character 795: Humerus, entepicondyle:

0: present and prominent as a spherical, conical, or crest-like structure in cranial view

1: extremely reduced or absent

Character 796: Humerus, mediolateral width of distal end:

0: greater than 2x minimum width of shaft

1: less than 2x minimum width of shaft

Character 797: Humerus, morphology of distal humerus in anterior view:

0: medial aspect of distal humerus unexpanded, entepicondyle situated proximal to ulnar condyle

1: medial aspect of distal humerus expanded and subtriangular in anterior view, entepicondyle located well medial to ulnar condyle

Character 798: Metacarpal I, rectangular buttress on ventrolateral aspect of proximal surface that underlies ventromedial surface of metacarpal II:

0: absent

1: present

Character 799: Manus, ratio of the proximodistal length of metacarpal II to that of the combined proximodistal lengths of phalanges II-1 and II-2:

0: less than or equal to 1.0

1: greater than 1.0 (i.e., metacarpal II longer than combined lengths of phalanges II-1 and II-2)

Character 800: Manus, ligament pits on manual phalanges:

0: strongly developed

1: weakly developed or absent

Character 801: Manus, manual unguals, proximodistal length:

0: shorter to, equal to, or slightly longer than length of penultimate phalanx

1: elongate, twice or more as long as penultimate phalanx

Character 802: Ilium, orientation of ventral portion of preacetabular process:

0: parasagittal, in line with dorsal portion of process

1: laterally deflected, extends nearly perpendicular from sagittal plane of ilium

Character 803: Ilium, size of preacetabular process:

0: moderately developed, anteroposterior length of process subequal with dorsoventral height of ilium directly dorsal to the center of the acetabulum

1: hyperelongate, length of process at least twice the height of ilium above acetabulum

Character 804: Ilium, orientation of blade:

0: parallel or gently inclined relative to dorsoventral plane passing through the pubic and ischial peduncles (the ventral portion of the ilium)

1: angled laterally relative to the ventral portion of the ilium, rising steeply at least a 30 degree angle from the dorsoventral plane passing through the peduncles

Character 805: Ilium, morphology of dorsal surface of postacetabular process in dorsal view: (ORDERED)

0: smooth and non-rugose

1: with rugosity causing transverse expansion of the posterior dorsal margin

2: hyperrugose, with hypertrophied posterior tuberosity

Character 806: Ilium, orientation of pubic peduncle: (ORDERED)

0: straight

1: posteriorly recurved, articular face posteroventrally directed

2: posteriorly recurved, articular face posteriorly directed

Character 807: Ilium, morphology of antitrochanter: (ORDERED)

0: separated from ischial peduncle

1: merged with ischial peduncle, both structures together form enlarged ventrolaterally flattened boss

2: merged with ischial peduncle as a boss, which is hypertrophied and spherical

Character 808: Ischium, position of distally placed dorsal process along posterior edge of shaft: (UNORDERED)

0: entirely proximal to obturator process

1: opposite obturator process

2: extending distal to obturator process

Character 809: Ischium, shape of obturator process in those taxa in which the process contacts the pubis:

0: approximately square-shaped

1: elongate anteroposteriorly, approximately twice as long as dorsoventrally deep

Character 810: Ischium and pubis, morphology of contact surfaces between the

two bones:

0: flat

1: markedly sinuous

Character 811: Pubis, shape of shaft:

0: rod-like

1: mediolaterally flattened

Character 812: Pubis, morphology of distal shaft:

0: distal portion of shaft approximately equal (or less than) in anteroposterior length to proximal portion of shaft

1: distal portion of shaft greatly enlarged, more than twice the anteroposterior length of the proximal portion of shaft

Character 813: Femur, anteroposterior width of region bridging femoral head and greater trochanter in proximal view:

0: smoothly confluent with head and greater trochanter

1: anteroposteriorly constricted relative to head and greater trochanter

Character 814: Femur, hook-like process at distal edge of femoral head, demarcating a notch between the head and the shaft

0: present

1: absent, shaft and head smoothly confluent

Character 815: Tibia, morphology of incisura tibialis (lateral fossa on the tibia in proximal view):

0: deeply inset

1: wide and shallow, nearly absent

Character 816: Tibia, shape of tibia in proximal view:

0: anteroposteriorly longer than mediolaterally wide (measurements taken through midpoint of proximal surface)

1: mediolaterally wider than anteroposteriorly long

Character 817: Tibia, length of fibular crest:

0: short and proximally positioned, extends up to approximately 1/3 of the length of the tibia

1: long and distally extensive, extends to approximately the midshaft of the tibia

Character 818: Tibia, exposure and morphology of the anteromedial region of the distal tibia: (ORDERED)

0: covered anteriorly by the astragalus

1: not covered anteriorly by the astragalus, exposed

2: exposed and developed into an anterior tuberosity

Character 819: Fibula, iliofibularis tubercle, position:

0: proximal to midshaft of fibula

1: approximately at midshaft of fibula

Character 820: Astragalus, ascending process position:

0: lateral edge terminates approximately at the lateral edge of the tibia, or medial to the lateral edge of the tibia

1: lateral edge extends lateral to the tibial shaft to contact and overlap the fibula

Character 821: Astragalus, lateral condyle of distal end, morphology:

0: well developed

1: strongly reduced, lateral tibia exposed on distal and anterior surfaces of tibiotarsal region when tibia and astragalus are in articulation

Character 822: Metatarsus, overall shape:

0: elongate, unit comprised of metatarsals II-IV much longer proximodistally than wide mediolaterally

1: short and broad, unit comprised of metatarsals II-IV less than twice as long as wide

Character 823: Metatarsus, proximodistal length: (ORDERED)

0: greater than 45% length of tibia

1: between 44-38% length of tibia

2: less than 36% length of tibia

Character 824: Metatarsus, orientation of individual metatarsals II-IV:

0: not closely appressed, divergent from each other

1: appressed throughout most of metatarsus

Character 825: Pes, pedal unguals of digits III-IV, proximodistal length:

0: approximately the same length as the penultimate phalanx (ungual may be slightly shorter or longer than the penultimate phalanx)

1: twice as long or more than the penultimate phalanx

Character 826: Premaxilla, anteroposterior length compared to that of maxilla:

0: length of ventral (alveolar) margin greater than 10% total anteroposterior length of maxilla

1: length of ventral (alveolar) margin less than 10% total anteroposterior length of maxilla

Character 827: Supraoccipital, tab-like processes on left and right sides of dorsal margin of bone:

0: absent

1: present

Character 828: Nasal, premaxillary processes (=supranarial processes), extent of their apposition to each other on the midline in dorsal view:

0: apposed for nearly their entire length (may abruptly separate from each other at their tips)

1: not apposed for most of their length, and therefore do not abruptly separate from each other at their tips

Character 829: Dentary, Meckelian groove, position:

0: approximately centered at dorsoventral midheight of dentary

1: positioned ventrally, located closer to the ventral margin than the dorsal margin

Character 830: Dentary, row of foramina on lateral surface paralleling ventral margin:

0: absent or limited to a small series of foramina at the anterior end of the dentary (at the level of the first 1-4 alveoli)

1: present as a distinct row that extends along most of the lateral surface of the dentary (across the entire length of the tooth row at the very least)

Character 831: Splenial, notch along dorsal margin of anterior process, where the splenial contacts the supradentary (if present):

0: absent

1: present

Character 832: Cervical vertebrae, position of prezygapophyses in anterior-middle cervicals:

0: prezygapophyseal facet approximately level with anterior face of centrum

1: prezygapophyseal facet entirely anterior to anterior face of centrum

Character 833: Caudal vertebrae, morphology of dorsal portion of neural spines of anterior caudals:

0: unexpanded

1: expanded anteroposteriorly relative to the remainder of the neural spine (and often mediolaterally as well)

Character 834: Ulna, morphology of distal end:

0: expanded mediolaterally at least 1.5x relative to midshaft mediolateral width

1: expanded less than 1.5x midshaft mediolateral width

Character 835: Ilium, medial surface of preacetabular process, pronounced horizontal shelf continuing from anterior margin of pubic peduncle to demarcate the cuppedicus fossa dorsally:

0: absent

1: present

Character 836: Metatarsal III, mediolateral width of distal end compared to mediolateral widths of distal ends of metatarsals II or IV (whichever of the latter is greater):

0: less than 1.3 times as wide

1: greater than 1.3 times as wide

Character 837: Lacrimal, extent of antorbital fossa on region where anterior and ventral rami meet:

0: extensive, fossa excavates nearly entire region and nearly extends to the posterodorsal corner of the lacrimal (the lacrimal angle), leaving only a thin region of bone at the posterodorsal corner of the lacrimal

1: reduced, fossa stops well short of the posterodorsal corner of the lacrimal

Character 838: Scapula and coracoid, deep fossa on lateral surfaces of both bones in the region of their suture (covering the posterior half of the coracoid and anterior portion of the acromion plate region of the scapula):

0: present

1: absent

Character 839: Scapula and coracoid, contribution of each bone to the glenoid: (UNORDERED)

0: both bones contribute approximately equally in the anteroposterior dimension

1: scapula contribution markedly anteroposteriorly longer than coracoid contribution

2: coracoid contribution markedly anteroposteriorly longer than scapula contribution

Character 840: Femur, shape of anterior margin in proximal view:

0: strongly convex, due to a midline tubercle

1: essentially straight or slightly concave

Character 841: Femur, horizontal ridge on the anterior surface of the head and neck, demarcating a deep fossa ventrally:

0: absent

1: present

Character 842: Femur, extent of crista tibiofibularis in distal view: (ORDERED)

0: projects further posteriorly than medial condyle

1: extends to the same approximate posterior level as medial condyle

2: terminates well short of the posterior level of the medial condyle (medial condyle projects substantially further posteriorly)

Character 843: Tibia, position of medial ridge on posterior surface of distal end: (ORDERED)

0: displaced laterally, positioned lateral to the medial edge of the distal tibia by approximately 25-33% of the mediolateral width of the distal tibia

1: positioned lateral to the medial edge of the distal tibia approximately 10-20% of the mediolateral width of the distal tibia

2: positioned medially, positioned at approximately the posteromedial corner of the distal tibia in distal view

Character 844: Scapula, fossa on lateral surface of bone immediately above glenoid, which is demarcated dorsally by a convex bulge or ridge spanning the scapula-coracoid suture:

0: absent

1: present

Character 845: Humerus, deltopectoral crest, orientation relative to mediolateral long axis of proximal end of humerus in proximal view:

0: straight, approximately perpendicular to long axis of proximal end of humerus

1: curves strongly medially as it continues anteriorly, such that anterior end of crest is oblique to long axis of proximal end of humerus

Character 846: Femur, position of fourth trochanter: (UNORDERED)

0: along posteromedial corner of shaft along its entire length

1: positioned near center of posterior surface of shaft distally and extending proximomedially to become confluent with posteromedial corner of shaft proximally

2: positioned near center of posterior surface of shaft distally and extending proximolaterally to become confluent with the greater trochanter

Character 847: Fibula, anteroposterior width of the minimum point of the midshaft compared to the maximum anteroposterior width of the proximal end:

0: 20% or greater

1: less than 18%, fibula shaft exceptionally gracile

Character 848: Maxillary teeth, posterior (distal) extent of tooth row:

0: extensive, extends posterior to the level of the maxillary ascending ramus and underneath the antorbital fenestra (if present)

1: limited, terminates posteriorly at the level of the maxillary ascending ramus

Character 849: Dentary, shape of ventral margin in lateral view:

0: approximately straight or slightly convex

1: broadly concave

Character 850: Maxilla, posterior extent of the ascending ramus relative to that of the main body (jugal ramus):

0: the two rami extend to approximately the same level posteriorly, distance between posterior tip of ascending ramus and posterior tip of main body no more than 1/3 of the anteroposterior length of the entire maxilla

1: main body extends considerably further posteriorly relative to the ascending ramus, distance between the posterior tips of the two rami is greater than 1/3 of the length of the maxilla

Character 851: Tibia, proximal surface, proximal extent of cnemial crest relative to the proximal extent of the posterior condyles:

0: cnemial crest extends further proximally than condyles

1: cnemial crest and condyles extend to same approximate level proximally

Character 852: Prootic, prominent fossa on the lateral surface of the bone, anterior to the otic recess and posterior to the preotic pendant, that houses the external foramina of the trigeminal and facial nerves and pneumatic openings:

0: absent

1: present

Character 853: Palatine, form of pneumaticity in those taxa with pneumatic palatines:

0: pneumatic fossa on the external surface of the bone

1: large internal chamber that opens externally via a window-like pneumatic opening

5. Character coding of Theropod Working Group matrix used in phylogenetic analysis.

The matrix follows Xu et al.¹ with addition of *Baminornis zhenghensis* (IVPP V33259) and IVPP V33260.

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Rahonavis_ostromi ??
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Mahakala_omnogovae ??????????????101?????????????????????1?00??????0?00
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Buitreraptor_gonzalezorum ?0010????????????????00001011?00????????100?10??1

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Neuquenraptor_Unenlagia ??
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Microraptor_zhaoianus
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Sinornithosaurus_millenii

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Tianyuraptor_ostromi ?001?????????????????0????111???????0?2110?11?????????
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Zhenyuanlong_suni ?001???????????????1000???1110?0??100012110011???01????
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Pyroraptor_olympius ??
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Acheroraptor_temertyorum ?????????????????????2011?????????????????
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Anchiornis_huxleyi
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Xiaotingia_zhengi ?00?????????????????101???111000???0?12?????????10?????
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Aurornis_xui ?001????????????101???1110001?000012100?11?1??0?????
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Jinfengopteryx_elegans ?0????????????????1?01???2110?????2?1??00?0????1???1

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Mei_long ?0????????0????????11010?????0011?002012100001?1010??10
0?????00010010??1?0000?021???01?0011011100011?2110?01???0110222111?1???
??111?11110?0?1?1000001?012111?1??1200302?1110221?[01]?0111100?010100100
0??110011?0?0000??000000?000100?1??001?0000?0?001?0?0000?000001020000?
000????????00?0?0?00?0?01????????0?0000010000[01]0?0????????0100020?0
0?00000?0111000?0?0000000?0000000?000?01?1?0???00000???000000?000000100
00??00000000000?000021?01101000?0???20???1010??101101?1100?10?0000?110
??0??0??????????0?1?0?????01????00??0??????????0?????????1???00?????????
???????1???0?????0????0????0????????????????????????????????0?000??0??
???????0???????0?0000?????????0????????????????01???1?1?0?????????????????
?????????0???????00??00?00?0?????02???0????1?0?000?1001??00?0001?0?010???
01??0?00000000000?000????00??0??00?000000100?????????01?????????0?0??

Sinovenator_changii ?0???0002?000011110110101?1110?011?02??2?0011???1?101
00?????0?000?001?????0000011110?1?????11?10100012110?001000110222?1????
????110111???????100?0??0?211?010112[02]0302?1110221201?11110000??100110
00111??110?000000??000011000100?110001000??1??011??0000?0000[03]??0?00
000000000?000000?00?0?00000?0100[12]00??00000?0010000????????????????2
0000?00?0101?10??00?100000010
0000000000000?0?00?020?0110?00000000020?010?10??1011010??????0000001??
??0000?01?011??00?1?0100010?????0????0?????????0????0?????1???0?????????
?????????????0?????????000???1????????????????????0?????????0??00000?00????0
?????????????????0?00????????????00????0?????00111????????????0000?0??0
?01???????1??0?0??0?0?0??0?0?0??????2?0?0?1?1?0?????100???????0????0?0
01?01?0?0000?00?????0?00?0?0??0000?0000000001?1??10?????0??1??1????000?
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Sinuosonassus_magnodens ?0????????????????1??10101110??11?02?12?????????????
???????0?000?001????????????11?100?????????????????????0?10?011022?02?????
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??1????????0???????00011??010000?1?1001?0000????00?????0000000?0??
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??0?????????00000?0?????02
0?011?0?0????????????????????????00?????????0?1?01?0110000?1?00000
10?????0??0?00?0??00???
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0??????0?2?00????0?0??0????????0?0?0??0?01?0?????????????????
?0?0???00??00101?0?1?????01????????10?????

Sinornithoides_youngi ?0?0????????????1?0?0??1?10????00??2??????1?????
??????00?0010??????000111101?????11?001?????????0011?102121011???1
?00?1?101?0??100000????21?01?02??30???11?0?001??1110????0??1?00??10
001?0??0?0?1?00?0??0??0010?00?00000???0?00?0??00??0?2000000?0????
????????????10????1?00?0000????????[01]0?0??????0?0?20?0?00000?0?
?1000??0?1000??00?0?????????0?010?0000??000000?00?0?000??0000000
0000000020?02100000000????????101?????1??0100??1?000?????????02?011?
????1?????1??????0??
??000?0?0??0
?0?00????????0????????????00?110101?000?000????????????1?????0?????
000??00?0??0??0?02??0??1??0?0????100????0?0??????0??000?000??00??1
0?000????0?00??00000000010????0?1?0?0101????0???0??0

EK_troodontid_IGM_10044 ?????0012????????????????????????????????
?0??????????????1??11??????[01]??1?????0????????????????????
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?001???00?0????0?0?1????????0????????????????????????????
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???2????????????????????0????????1????0?????????0000????????
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Byronosaurus_jaffei ?????101???101?1100110001011?0?????20220????????1?10
0?????0000001??11???000211?01?0?0?????010121????????0?02????????
??1????0?0?0?????21????
????0????0???1?????????01000000?1?00??1?0?0?000?0??000000????
??0????????????0?0???0???0010????????????????????????
????????????????????????????????000????????1????????2

Xixiasaurus_henanensis ??????????????????11000101110??????2?22?????????????
 ??????0?00?001???????000211?01?0?????????????????????????????????
 ?????????????????00?1??0
 ???00?????????????????????0?000000???01?0100????00???????000000??00?????
 ??????????????????0???
 ?????????????????????????0?????0?????????????????????????????????????
 ??0?0????????????????????????????????????00?0??110100??2?01100?0?1?0100010100
 0000??0?0??000??0?????1
 ?????????????????????????????????????010?0?0?????????????????10000?????????
 ???000?????
 ?0?????00?????0?0????????????????0?????????????0100?????????????0?????0?????
 ??????????????1?01???????1????????????00???

Zanabazar_junior ?00101?12?110100?001?000??100000?????2022000?21???0??11100
 ??????100?001???1????000111010100?????????????????1?1000?1020?1?????????
 ?????????????????????????????2????????????????????????011???2???????
 ???00?00???11???????0??0100000001000001???1??00???????00?000?????001??
 0?00?????1?????0000??0?00???????0[01]0?????????????????????????????
 ???00010000??000??2
 ???1??0??00000201001?11???1110?1???????????00??100000??3??11?0?0?1?010
 0010100?000??0?0?0????0?0?0?????????10??000?000?0????????????????????000
 ?00011010????????????????000?00000???0000??000?001??????????0????1000

0????????????????0????????????????????????????????????0????????????00????
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????????????0?00???100110?????????1????200?0?

Archaeopteryx_lithographica ?????????????????100????????????????????????
????????????????????????00020??00????????????????????????02?0?2?1?????
???0?10?1110????10000010??2??????120?????1?1?22121??1111???0?????0?0??0
030?000??00??1??????0???0???01????????????????????0?????300?????????
????????????????????????????????????0?0?0?0?????000002?0?0????????10?00
0?????1??????00000?00?01??????00000?0000000????0?0000000?????????00
000?00?00?000000?????????0?11?????1?1?????0?000?11?000?0????????????
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?00??????100000?0??????0???00?00?00?0???0????0???1?????00??00?000
??0?????00?????????0110??????0????1????0???0????

Confuciusornis_sanctus
10010??????????????1?010?00?000011000??2??0?0??0?01??????000010100?10
20001?1?????????0???1011?20002110?211?01?1??34??111010010??1311100011113
0001101121?1?1?102000?20111022?2101210100011010?0211010030000000000011
02000??00?0100??11?100011?01?????00??0000?123001100120?????????10??00?
?011200??01[12]0111110000001200001001000120000000?0000?0000??112000010?
0002010?0010000000010102101011[01]0100000000000000000000201001000110
00011000?02000000000??2000001101110?001?1100?1000000?110100000????0?0
000?0?01?0?10210?00??????????1??0??0???0000000?0000?01?01???00100000?0
?0??????000?000??000????????????????????????????????????00010??000?000?010?
?0?????????0?0???0001?00000?0???0?00111?001?000?10001?00000?0?01?0?00
????0????0000??00?00?0?1100000?0??1?????1000?00?0?00?000?00010??0???
000000000010?000?100000?0000??0000000100?0?0?10?001??10??0??1?11???

Sapeornis_chaoyangensis
1001?????????????0?010?0?000011000012100000????00?????0??1?0000010??0
02000000200??00000??10???2000??10?211?01?10034??100?????211011110101111
30001101121?000?202000?201[01]002212100??01000110100121111003000000000
0??1?1000?00?0100??01?1?000??01?0?00?00??00100?123000000010[01]???????
?????????????0??0000??00000000110000100?????????00000?0000?00000?1120010
10?0001010?001000001000??001[01]101110000?00010000000000?002020??00110?
1000000000?00000001000?????????001?1110?0?1?110001000010?11?100000?????
??0?0?0001?0?0210?000??0?0001??0?0???000000000000??0??00?0?????0101
0?????????000?000???0000????0???00?????????????????????02000??0000?00?0
?0??0???0?0100??????0001?00000??0?0?000111?1010000?100???00000?0?01?0

?00???0????000??00?00?0??100000?000?1?10?0?0000?0010??000000?00010??
?10?00000?00001??00001?0000?0000????000000100?0?0?10100011101?0??11111??

Jeholornis_prima

10000?????????1???1?010??110000110000121?00?001?00??????000?0000010??0
020001?0200??000?0??????00?0?1?0?11???021010212?11010?0011031110001?01
30001101121?10??102000?20??10221210????10001??100001101003000000000??11
?1000??00?0100??0111000011?1?0?0??00?00100?123001100120?0?????0?????0?
?0??[01]000?0000??0000000000000000?0[01]?001??00000000000?0010001220010
10?0000000?001010001000010000101101000000010000000?0000000100?00100[01
]1000000?00?02000001100?????????011?1110???1?1100?1000000?110?00000??1?0?
?00?0?0001?00?0????00??0?000??0??0???000000000000?01?0200??0?00000
0???????0000??00????0????????????0001????????????????02000??0000??0?0?
0??0???????100??0????0?0?0000??????0?00111?1?10000?10001?00000?0?01?0?0
?????0???0000??00?00?0??100000?0?0?1?10?0?0?00?00?00?000000?00010?????
0?0?0000000?10?0000100000?000???00?0000100?000?1?0?011?10?0??11111??

Yanornis_martini

100???????????????1?010?????0?11???0??2??0?????00?0?????????000?011??002?
??000210??00001??1?0???20?0?????4?1??1???04??111?1100011031110001111300
101?1121?0?1?202000?20111023?210?2?0100?1??110121[23]0000300000??000????
00?0??00?0200??21?1?0???????0?0?0?0??00?000??2300100012?????????10???????1
?????????????00?0010012000?110210?[12]??20100001010?1011?112200111??0101
?0101?10000?0[01]????0?1[01]10131001100011020?100??0?00??????0?0011110[0
1]?1?00??1000?01100?????????01??11???????1100011?0011?11?100?0?0?????????0?
0???????0????0????????????????0?????????0?00?0?????????????????????????
????0??02000?0010??0?0?0?????????0011
00???????0?01?00000??0?0??00111?0010000?100??00000?0?01?0?0?0????0?????0
?0???00?0?0??100000?000?1??0?0?0???00?00?00?00?00?0???100000?0?00000
??10001?00?00?00?000000?00100?0?0?1?00?1110?0??100?1??

Apsaravis_ukhaana ?????????????????????0????????????????????????????

??0002?1?0?0?0????????????????1??11??10200??1??5?1001?1??24?????1?010110
31100001111300??000?1???1?201000?2?011?23?03?12?010?????1??121[23]0100?
00000??20???1?20?0?????0200??21????????????????????????300?10?????????
????????????0?1[01]?????1?0?????????20010?[01]001??21??1????????00000?0?10001
22011111?01011010[12]0111110000101021110?[23]120100?11??20?1[01]0010?11?1
?0?101211211111?0000?1?0?0?1101????????011?????0?1????????0002?????????
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????????????????0?0????????01??0?0??0?0?00111?0010001?1?0?1?0000????01?010?
?????????0000?0000????????????0?0?0?1????????00?00100?????0?????0?0?????0?

???0000000???00000???000???0?000?10???????0?0?11???0?????????

Yixianornis_grabau

100????2?021??1????0?0????0?1?1????????????????0100?????000?010???0?
00?0012?????0?01???1???02000?1?0?4???01?0024???11?1100011031110?0110130
011100021?101?212000020001023?23??210?0??1???1??21[23]0100100000?0000?0
??1000?200?0001???1????????????0?0?0??0?0?1230010?01???????01??1???????
?1???????1?0?????0020011000?11021??[12]?20100001010?11110112200111100?0
110???01?000???0?01021[01]10?312011000100200100?00?0020201?????11110[01
]?0000??1?0?001100?????00011?11?0?????0100?10?0010??1?????????????????
????????????????????????0????????0????????????????????????????0?
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????????0???00?0???0???00111?0???000?100?1??0000???01?0?0???0???000?
??00???0?0?100?00?0??1??????00?00?0?00?0?0?0???0???10?000?0?00?0?00
001000???00???0?0?00100?????1???0?11???0??1?????

Neuquenornis_volans ?????12???????20????????????????????00????00??
????????????????????????????????00?????????????????????1?11011?1
031110?01111000????????????????????????010??????????[01]010030?
?0???0????0?00?????????1????????????????0?????0200????????????
????????????????????0110??????21?????10110??0200?001?001?0??[12]?
?1???0?0???0????[01]????????2???20?1??01????????????10?1???????1?0??
?1011??????0?000???200000110????????????0?0?0????????????????
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????????????????????0111????0????????????????????????0?0?0??00
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Patagopteryx_deferrariisi ?0????????????????????0010?????
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????????0?1????????21101????????????2?010001??100121301001?0
00??????1??????00?02???1????????????0????0????????00?1?
????00??111110000??????010000000??????0??????000????010??1220[01]0
0???[01]?10?0???01000001[01]0001?[12]00???30??????00?2000000?010020?????
000[12]11001100000[01]?0??0?100?1?200??01?0??0?001??????00??0?1?????
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????0?0????0?0?0?110????????????0????????????????0020000
??00????????0?0?00??0001?00000??????00111?00100??????1?0000??????01
00?0?0???0?000???00???0?0????00?0?1?????0?10????????00??010?????
00000000?0????000000???00?1???00000010?????1???0???0???0?1???10?

Cathayornis_yandica ?0????????????1?010????0?1??????0????????????

????00???1???????000210??00?0??????[02]???????3???????4???1?11?0
211031110?011?130000?01111?0????????????22?2??2?????110?0?2???????
???0??00???0???00??0???1?1???????0??0??000???300[01]0?01?????
????????????????0?????0?0?0111??010?0??1??10110?102??0010?01200
0120101?01?01020111100[01]?1?????210120?11?01001000???0?00?001???1?0?0?
1[01]1????????????0?011?????????1?????????1?????????0[01]??11??0?0???
??????0?0?01?0?021?000????????????????????0?00?????????????
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?0????????????0???0??000????00?1?1??0?????001??000?000????0???100?00?
??0??0??1?001?000??00?1??????0??0?0??????????0?????00????

Concornis_lacustris ???
????????????????????????????????????00????????????????????11?02?1031
110?0?1??00?0????????????120?002??11?23??[12]?0???1???1??0?1[012]11??0?30
00?0??0????????????001??1????????????????????2300?????????????
????????????????????????0111???10?20??1?0101100102?0?0010001?0??[01
]201?110?0102?1???10???1[01]1?[12]????????????[01]????????00????0?10
0??1?00??[01]?[01]1??0?????110????????????????1000210??01?????????
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Gobipteryx_minuta ?0????????????1?01010?0?0????????????????
?11?000?0????????1?1????????????????????????????????2???
??11????????
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0????0??0??0??1????????????10????????11??10000?0?10?012000[12]201?1?
0?10??0?0?????????1?121??[012]0?????1?0??1???????000?0??10?001111000?1
?11?0????????????????????????????????00000????????0?1?01??
??0??0?0??
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Vorona_berivotrensis ?????????????????????????????????????
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010?????????0????0????1???1??

Songlingornis_linghensis ??????????????????0?0?????????????????????????????
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???3??0????0??
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0??0????????????1??1????????????????????????????0?????????????????????
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??0?1?????????????????????????0???

Protopteryx

10?????????????1?010??0?00?1???0?1?????0????????????????000001???002?
??0?0200?????00?????1??0?????0?2?1??1?1??24???11?11?0211031111?011?13000
01101?1??????20?0??0?1022?2?0????10??0???0?001?1003000?0???00???00??
?00?0?00???1?1?0011??0?0??0?00????000???30000?012????????????????????
??0?????0?00001?100?0100200?1?010110011100?0?10??1200012010??0100???01?
?00????????1210?2000?01000000???00???001?????????1?0?000?11??[01]00??0
1100????????01??11?0???1?10003110?010?11?1?0??0?????????0?1?01?0??0?0??0
0????????0?????0?????????0??00????????????????????????0???0?????????
????????????????????????????0?000???0?0????0????????????10????????0??1?
000?0??0?0000111?0?1?00??1000?00000?0??1?????????0????000???00?0?0??
000000??00?1??0?0???0??01??0000?????010????1000?00?00??1??1?001?00????
00????00?000100??0?1??00???1???0??1?101??

Pengornis_houi

?00?0?????????????1?010??0?0011????0012??0?????0????????
???0000011??002??000200??0000001??0???2000?0?0?21???1?1???4??111????21
1031110001??1[23]000??0????????????????????2??2???2??100?01010??211?1003
000????00????0??0?00??0???21?1?000??0?0?0?00???00001230000?001?????
????????????????1???0?0????101?001100?0100????????01100?00?0?00?0??1?00
112010?00110??101?[01]???000??1???11[012]20??11010010?????0????00?0???10

0[12]1??1100001011??200??0?100??????0?????000??1000[23]1100?1??110100
000??????0??0?0001?0??0????00????????????0?????????0??000?????2?????
??????????????0?0??0????????????????????????????????0?000?00?0??
00?0?0??????0?0100?0?0?0?0?01?0?0?0?????0?00111?001000??????0000?????
1???0????0????000??00?0?0????000?00?1?0?0??00?001???0?0???010??
??100000?0?0??0??1????0????00?1???0?000100?????1???01?110?0??1000???
Hesperornis ?0????????????????00010100?00?????00021?001???00??00?
???1?000?011???1?0001?021???00??10101110?2100??11?50100??10?24??11??10??
00103111????????????0202100?1??01000??011023?03?12??0001??11?12131100
10??0?00?01?1?0000?000??200??2??1?1111????0??????10000??10?1?10?112120
0110?1010??1110011100??00?0??1010121011000012?0?000100100?0??10?0??0
0012??0????????0??0??0??0????????????????????????20?1100001112120211110
021111122222002?0????00?????0001?0??0?000?0100?11???2??01??00000?????
????0?1?0100??0????00??????0??0??0?????????0?00??????????????00?0?
??????0?0??0??0??0????????????????????????????????0?000??0?????????????
??????000??????0?0??000??????0??01????????????201??000????01????????0
????00?0??0??00?0????00?????1?0?0?0?0??0??????????????0????000?????
???0????0000????00????????001?0?????0???1????????000???

Baptornis_advenus ??
??2??????5??????24????????????????
??212????????????????
????????????2????2????????????????????????????????[12]????????????????110
01??00??1??????????121011000012????012?0????01?10?0??000????0?????????0?
??0??????????01?[01]1[01]????????????20?1100001112120211110021111?2202
0?2??
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Ichthyornis ?????00???????1220????????????????000111???0??????
???000??1?????1000??0210??10??1?01111?2100?1???5?000??1??34???01?100?001
031110?0111300??0102?1??10212000????21023??3?12??10011??11?1213110??0
0?0??20????00????0?00????21?????????0????????????012300[12]0?01??????
???10[01]1?111011101001020??101?1200111?101[12]?211022010100001010?111
1011221011110010110111010000101[01]10112111123120110011?12001[01]0010?1
12120211110021111[12]2?100002?0??011?100?20??0110??1??00?00100?11??02??
01????????????????????????0?00?00????????????????????????????????
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0????????0000?0??????00?0000?0?01?0000?????0?00111?00100?0?10201??000
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01??2?0?00000?00000000????0000????00?111?0?00001????10?1?0?0?11?0?0????
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Iaceornis_marshii ???
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Limenavis_patagonica ???
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Lithornis
100????????????????01010100?00?111??2?02?00?0????????????10000?00???02
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1300???000210101?20200102??1102?????12?01000???11?12130100?????0??200?01
?2010???0?0?0???21???12??????????00??00000??300?11212100?00011111010110
?11[01]1101?1111?01?10121012?0111[12]1211122110100?01011011110112201111
00110001[12]111000010101010111113130110[01]11102[01]0120110?11212020110
002111122110010[01]?000011?1???????011?111?00??????????02???1????????
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Hongshanornis_longicresta

10?????????????????010?????0?1????????????????????????????????????000?01???00??
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11?0112?????20?0?0???111?23?23??2??100?1??1?0?21[23]0100000000??000??1?1
???????0200??21?1?????????0???0????000?12300???012?????????????????????
?????0?????????020?1?00??110210?[12]??1010000101??1010??1220001110??01001
2?0???0???100??????1??3020??000100?0??0?0???0?????102?001100??0?00?0200
??01000?????????01??11??0???11001110?011?11?????0?????????0?????????0???
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Crypturellus_undulatus

10????012?020002?2001010100?00?111?12002100001011100010???1?10000?000??
102?001?1?????????1110111122100?01107?110??12?24??121?110100103110110111
1300???001210001?202201120011023?23?12?01000100110121301?0???010002000
01?20000200?0?001021???120??01?????0???00000103002112121[01]0100011111
010110011011111111100101012101011211211112?1010002101101011111220011
1110110001201100001110101011111031401011111020?120110?1121202021100211
1122210010110?011?1010200000111110000??1100?10??02??11?????????????????
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Gallus_gallus

100???102?021002?2000010100?00?111?120021?0001?1000001????1?10010000000
0021101?1?????????101[01]1111221?0?01007?1201?12?24??1[12]1?1101201031102
001111300???001211111?2?2001120011023?23?12?0100011011??213010010001000
200100?20100200?010???21???121???01???0?00???00000103001102121211111221
101111111111101100011010111210101120111211112110100021011111111122001
11110110001201100001011101011111131401001211021?121111?112120202110021
111322200111?00?0110001020?00011111?000??0010210??02??11????????????????
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Crax_pauxi

1001011?2?021000?001010100?00?111?120021000011100000100??1?1000000000
00021101?1????????1000111122100?111?7?1201?12?24??121?1100201031112101
111300??0002100?1?2?2001120011023?03?12?0100011011?121301001000100020
01?1?20100200?010??21???121??01?????00??0000010300210212121111122110
111111111110110001101011121010112011121111211010002101111111112200111
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Anas_platyrhynchus

100???102?021002?2101001100?00?111?10002??00?1?100010?0??1?10200000100
?021101?1????????101?1111221?0?011?7?11?1?10?2410121?110111103111110111
1300??0012000?1?2?2001120011023?13?12?0100011011?121311?0??010002101?
1?20100?00?010?1021???121?????????00??0000011300210212111111221102111
2111111101100011110111210101020111211113120100101010?1[01]1111122000111
00110001201100001011101111111231401010111021?111110?111120102110021111[
23]2210010210?0011?10?020?00011111?000?0100?11??02??11?????????????????
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Chauna_torquata

000??1012?0210002?101010100?00?111?100021?00010100010100??1?100000000?
?0021101?1????????1011101112100?111?7?11?1?1012412111?10000010311111011
11310??0012101?1?2?200102?011023?23?12?0100011011??213010010000000200
101?20100000?010?1021???121??01?????00??00000123001102121[12]111102211
011112111111011000111101112101210201112111140101001010111110111221021
110011000120110000101110101111231401011111021?111111?1121202021200211
11222200100100001100010200010111110000?11101?11??02??11?????????????????
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Epidexipteryx_hui ?01????????????????????1?????00?????0??2??0011????????????
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0101?010?0?????00?1??????????022?????011?03?0??????????0???011?0?0?10?
000???00??1?1?0???00?0?00???0?0?????????1?2?????0??????2?0?????0?????????
?0????????????????????????000?0???00?0?0??????????????0??0?0?????1???0???
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?0?????0??0???0??
??00200?02?????????0?????????1????????
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?0?????0?0???0?????1??0?????????????????????0??????00?????0???0?????0????????
?0??????????001?00?????????????????????0????
Incisivosaurus_gauthieri ?00?00?01?001??1??100011101001001?010?120000110001
010110101111210100001001?1?000210?00?0????????????????????????????????????
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Citipati_osmolskae ?001001001001??221000101111?01011?00010210001100001000
1000110121120?0100010111?1?????????1011101100101211001??201??002200111?
0111200110100100?11000001000211001??02012020??1011111?2101000000000?0
000000000000000000011020000000?0?001000?000002011???0???[01]000020001220
001000000001102?1??0000?00000010001010?0000020011000[01]0?00?001000010
1020?????0????111000?0?0010000?000000000000?00100?0?0?0???0000000????0
0000?200000000000000000002?000?000000000020?000110??00[01]10?01101100
0000011?1100001???1000001?0?0001?11000?001???1002??0???0?0???000?000??
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00?????10201???2?1?0000000???0????????????????????????????????????10???0
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0?0?00?0???0?00211?????????0?00?000?0?????????0?????0?0000100?0100????10
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Oviraptor_philoceratops ?00?0?????01?1????0?1??111?1011???0???1?0?11???01?
0???0?11?121120?01?00?01?1?1????????????????????????????????0?????????????
?12??1????00???10?00?00?1?0?0????????????????????????????0???0???0?0??
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00?????1100???0???????00????????000?0?00000?????????????????????????
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?0?01???????01???????????????0????0???00?0?0?0?000????00?????????????
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???100???000???????????0???????????????????0?0???????211???????00?????0??
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Microvenator_celer ??
???21?20?0?????????????????????011?0?11000121100???0?1?1002????????????00?
000?11000????0010002???0000????????????1110?0101100?0000010??????0?0
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010?00?000000000000010000????00?????????0???0?000002000000000000?????
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0001?01001?????????????010000?0?????100??????01?01??0000???00?????????
??0?????0???????1????000?10?000???0010?0001????1?????00?000?10?0000000
0?0000?0?00000??????????1?01??11100?001?????

Caudipteryx_zoui
00010?????????????0?111??10?0001?10???21000???0?0????????????21120?0?????
???0?1?0?0????00???0?00???1???0???01????30????0???0?0???01?0???10000
0?000?1?????0201202???1????101?11????0???01000??1?00?0?000000?1102000
??00?0?001000100000?00????0???00?00000?1[01]2000000000?????????0?????0
000????1000???0000?00?0000?0?0????????????20?0?0?000?11?00???????0?0???
00?00???????????1?00000???0000000?00000000?0?0?00???0000000?0?0?2000
000??0?????????01101100??01?110???0?000?10???0000?????0???0?0?0001?00???
??0???????????????0???00???00?0?0?0?0?0????????000?0???????1???0?????
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Ingenia_yanshini ?00?0????????????????1?1????1?????????????????????????
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100000000??000100?000000010?????????0??1?0??00?1???1??

Rinchenia_mongoliensis ?00?0??0?????????0111?1??1?11?00010??00??0000??
??00??1?12112??01000??111?1????????????????1????????????????0????220?????
??2??1??00?0??1?0001000?1????1????????????????1????????0????0?0?0?????
??0??00?001??2?00????????????0????00? ??????00??210?????2??0120?????
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11??0??01???1?????????0???000?000?000??01?00??0?000000?0???????100??
0????0????????????????????????????0????????????????????????????????
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Conchoraptor_gracilis ?0010?????????1??00111?1??1?11?000??21000110?00????
1?0????121120?010?0?0111?1?????????01010110010??1?012?110??10????01?1??
??20011000010??????0010002100010102002020??101101[01]1?11010000?00010
000010?000??000?001102?0?0000?0?0010001000002001??????0?0?0200012????
?000000000????????10??0100100??????000??0?010????????????????????
??00?00??000002000000
000000?0000?002?01?????????0?020?000?0?002?00?????????0011?1?00001???
?1??00?1?0?0?01?11??0??01????02?????????0???0?0?00?0?0?01?00??0?00?00
0?0?0?????100??0??00????????????????10??0? ??????0????????????????
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Chiostenotes_pergracilis ????1?01?01101??0??1?110?0?????????????????
1010?????21120?00000201???1????????????????1101?12????1?12??0?????????
?????101?1?????????00?100021?00101022120201110?111[01]?001??100??00?100
000200000??000?0?1??20?0?000?0?00100????????????????000?????[12]????10
????????001????00????????????01?10??0????0011??00????????????20000?000

00??00000?00?00000?00?0????
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??1000001000??????00200??2?1?000?0000?
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0?00?00000?001?0??1?1?000?01?????1?0??????10????000?0?0????02?1???0110
?1??????000000000?00?0??00?00010?0?0?????1?0?0?0??????0?1??

Avimimus_portentosus ?00?0??10011?00??0??1?1??????1???1????00?11?00100
110??????2?1???00?0?0111??????????011010110101?1?00??100?????????????
?????????0100??????????00?211?01??0201202010?011?0?1000100?0??000111100
20??00?0?0?01?02?000000?0?001000??????0?0??????00?01??0?02001??????
?????????????0?0?0??00?0?0?????????02001000?????????????????????????????0?
??0?0?0010000?000000000?000000000?2?????????[012]0?000?0000020?010000
000000000?00?01?0?0?????0????????????????????????????????1?0?????????????
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??????0?0?????0001000001????????????00001??????101001??0101?0100?0?00
0??001000?000??????0?0?1001??101????0000100000?????1001101102?????1010
10000000????00?000??001000000000010?0????1??01????0?00?1???1??

Falcarius_utahensis ??01?11100001111010?????1????00?????????00?????0000000
?????100?000?0?0?????001010001?1?0001110101210100012000100??0000?????
?000001000100010?0000100?0110010102203010101001000100000000000011000
0000000000?000?10?00?0?000?0?001000??????0?001??00?0?0?0??11?0?000?
?????000?000??0?00?00100?0?00?0000?0010000[01]0?????????0100020000?
00000001110?1?0?0010000?001000000000010000??0100??0000000?0000000002
000000000000?00000000?0000?00000?0?200000?0?0??00000?1100?00000000????
??????????????000?00?00100????0????????????????????????????????0?0????0????
?????????01?00????00?00????????????????????????0000001010010????0?0000000
1???0?????????????0?0?????0001000001000??1000??1010000000100000000000
?0101?010000000001?0000001000?0?00101000010?1?01?11?10001001000000000
11101002?0?101111000000101000100000?0000001000?000000?0?10?10000?01101
1002?00?10?

Beipiaosaurus_inexpectus

0??1??10?10?????????
????1001001?100????1????????????000?0220????????0000?0????0?100000?
0000?001??20220?0?0?0??0?00?0?00?0000?0000?0?0?0?00111??0?0?0
???0010?0?0?????????0?0?????????0?0?0????????????????????????????
???00?0001000????????????00?00????????????????????????????????10000???
???????1?0100??000000??0?0?0?0?????0?????0000000000??0?0?00000????

??????10?????1?1100??0??000?1?0?????0?????????????????????0?????????????????
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?????1??0?00??00??00?1????????10?????0?0????????00??????1?1?0????????1?
?1?????10??000?0?00????????????????????0??0?01000?01010??0?11??10??0?1?0?
??1????????????????????1???

Segnosaurus_galbinensis ???
?????????21??10?0000?000??0100?001????????1?????????1?0?0?????????????????
?0?10?1?00000???0???20011100102020221??0110201101?11001?00?00?11000000
021?0??00?01?1??0?0??00?0?010?00?????????0?????????00??????0????????????
????????????????????0?0???0????????????????????????????????????0?????0????1????1
???0010000?00100000????????????????????????00?00000??10??????00?????00000
0000??21?0????00????????????????????2?????????0????????????????????????????
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?????????0??01??0??1??1????????2??????0??110????????1??????10100??1?11122
21011111112?111201?????????0???1?????????????

Erlikosaurus_andrewsi ?0012???2?0?1?1??1010011100??0001?10000010000100000
00000??11112100100000020001?001001001????????????????????????????????????
????????????????0??0000?0
21?0??00??11??00?0?00?????????????0?00000010010??00000?000?????0?000002000
001???10?0100???0000?0?10000??0000??
???1?0?0010000?0010000000??0
0000000?????????0000?0???000?0???000?0?????????0???01?0001100???1?10000
?0?00?0?100000000??0??0?00?00?0???000001000000?00?0200?00000101000?
00001?000?00?0?00?????????????????00000001101???0???0100100020000000000
0000?????0????????????????????????????????????0?00????????????????????????
?????????????????0000??????00?0?0??0?011????????2??????????????11210?11?????
??1?0?1??????????????????????????1?01001000????01??????????010?0?

Alxasaurus_elesitaiensis ???
?????????210?100????????????1001001?????????0?01010000?1?0101002?0?1?????
?????0?000??0?10?0000120?11??0??1?20?21???11?????????1???0?????????00000?
10000??001?1??00?0?00?0?0??00?0?????????0?????????0?????0?????0?????????
?????????????????????0?00???0?00??[01]0?????????????????0?????????0??11??
01?????0?0???010000????????????10?0100???000000?0?0?0?????????????????
?????????1000000?0?????????0????????????????????000????????????????????
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0??0???1?1??0??0???1??1?100??????0000000??1??0??0?00??11?0????01100?
11?1????1111????1?00??10?1??0??????????1???

Neimongosaurus_yangi ???
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001010000????????????111001?2????????????????????0??00???0?000000021?
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Erliansaurus_bellamanus ???
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Suzhousaurus_megatherioides ???
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Enigmosaurus_mongoliensis ???
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Nanshiungosaurus_bohlini ?????????????????????????????????
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Therizinosaurus_cheloniformis ?????????????????????
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Haplocheirus_sollers ?0010??00010?0?12011011101112001?000020100?0?1010??0
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Alvarezsaurus_calvoi ???
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Patagonykus_puertai ???
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Achillesaurus ???
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Mononykus_olecranus ?????00??????112????????????????????????????10
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Shuvuuia_deserti ?00101002?01011120110001011?01111?10020100001010010010
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?20010?000?010101011?0?0001000?00100000?000???????30000?000?000?000?
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Bonapartenykus_ultimus ???
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Ceratomykus_oculatus ?0010???2??10????????????????11???10?201?0?0?0100??0?
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Linhenykus_monodactylus ???
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Xixianykus_zhangi ???

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Nqwebasaurus_thwazi ?0????????????????02????2010????????0100?00??1????0?0
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Shenzhousaurus_orientalis ???0????????????21000??10?0??1???000??00?000?0?
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Ornithomimus_edmontonicus ?00010?1101101?101021000?01010101100000000000
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Archaeornithomimus_asiaticus ??????????????????????????????????????
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Struthiomimus_altus ?00010?110??0??1010210002011101?1100000000000000010??
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Gallimimus_bullatus ?00010?110110101010210002011?010111000000000000000100
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Pelecanimimus_polydon ?00?????1???????2100?2?1?0000??000000?0000?????
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Harpymimus_okladnikovi ?0?????????????2100?????0?????000000000000??
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Sinornithomimus_dongi ?0001?????1?0?????1?21000??1010001?0000000000000000
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02000000000000000000??00??1100?0000????????000???000000?????????0?0010000
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10000100?11?00???110000000110?000000000???00000000000001000??0?101?011
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Qiupalong_henanensis ???
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Huaxiagnathus_orientalis ?00?0?????????????0001???1???0?????00??0?????????
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Sinosauropteryx_prima
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00?00020?????0100201?000?11?0?1?00?0?000?0?01000000000?011?0000?0000
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Compsognathus_longipes ?00?0????????????00101?1?00??00000??0000??0
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Juravenator_starki

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Sinocalliopteryx_gigas

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Mirischia_asymmetrica ???
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Ornitholestes_hermanni ?0002???0?0?00?1???0?010?01110001?100101?0??1000001
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Coelurus_fragilis ???
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Bicenteneria_argentina ?????????00?1?????0?0?????00?00?0????????00????
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Kileskus_aristotocus ??????????????????0?01120111?????????????????????????????
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Guanlong_wucaii ?00020?000000?010[01]100011201112000?00110000001000000
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1000000000000001000000?0110000000100000?0000000?0001100000100?010010?
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Sinotyrannus_kazuensis ??????????????????0?01???101?????????????????????
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Eotyrannus_lengi ?????????????????000120??12??0???110?????????0???????

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Juratyrant_langhami ???
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Xionguanlong_baimoensis ?0002???00000?????1?000220???0000?001101000?2100
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?????2?000?000000011000011?????????????????????11?001?????0111012?
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Dryptosaurus_acquilunguis ??????????????????????20????????????????
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Appalachiosaurus_montgomeriensi ??????????????0?0?201110?????120????
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Bistahieversor_sealeyi ?1102????????10?2200002?01110000?001201000?21100000
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Albertosaurus_sarcophagus ?1102??000000?100220000220111000000012010000211
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Gorgosaurus_libratus ?11020?000000110022000022011100000001201000021100000
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Daspletosaurus_torosus ?11020?000000?100220000220101000000012010000211000
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201100000000??00000100?00??000010010000??0000000010000?0?0?0?0?0?000
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00101110120011030110021110211110102101201210101[12]1111111111110110102
0000211001011[01]1121121211111100?11101221111110111001101111[01]100111
110111011111111110011122211101112?10012101100011101111021111??????11
1111?211?111?112111??1??111?1??1???2?11????11?12???00000??11000???1??1?
010?1000??000?1000?0?????0?000000000??0011000?0????????????????????
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Tyrannosaurus_rex ?12020?0110001100220000220101000000012010000211000001
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0110000000000000000100000?0000010010000?0000000010000[01]0?0?0?0?0?0
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000001111112001103101[01]0[123]01102111101021112010??10121011111011[01]
1101111021010211001011111211[12]12111111001111212301111111111011011111
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Tarbosaurus_baatar ??2020?011000?100220000220101000000012010000211000001
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021100101111121121211111100011121230111111111110110111111111110110201
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111?1121111110211111112211211111111112211000000010000001011011010?100
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Shri_devi ???
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Fujianvenator ???
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6. Character description of the Mesozoic Avian Phylogeny (MAP) project used in present phylogenetic analysis.

The character description follows Li et al.¹³.

1. Premaxillae in adults: unfused (0); fused only rostrally (1); completely fused (2).
(ordered)

2. Maxillary process of the premaxilla: restricted to its rostral portion (0); subequal or longer than the facial contribution of the maxilla (1).
3. Frontal process of the premaxilla: short (0); relatively long, approaching the rostral border of the antorbital fenestra (1); very long, extending caudally near the level of lacrimals (2). (ordered)
4. Premaxillary teeth: present throughout (0); present but rostral tip edentulous (1); present but restricted to rostral portion (2); absent (3).
5. Caudal margin of naris: far rostral than the rostral border of the antorbital fossa (0); nearly reaching or overlapping the rostral border of the antorbital fossa (1).
6. Naris longitudinal axis: considerably shorter than the long axis of the antorbital fossa (0); subequal or longer (1).
7. Maxillary teeth: present (0); absent (1).
8. Dorsal (ascending) ramus of the maxilla: present with two fenestrae (the promaxillary and maxillary fenestra) (0); present with one fenestra (1); infenestrated (2); ramus absent (3). (ordered)
9. Caudal margin of choana: located rostrally, not overlapping the region of the orbit (0); displaced caudally, at the same level or overlapping the rostral margin of the orbit (1).
10. Rostral margin of the jugal: away from the caudal margin of the naris (0); or very close to (leveled with) the caudal margin of the naris (1).
11. Contact between palatine and maxilla/premaxilla: palatine contact maxilla only (0); contacts premaxilla and maxilla (1).
12. Vomer and pterygoid articulation: present, well developed (0); reduced, narrow process of pterygoid passes dorsally over palatine to contact vomer (1); absent, pterygoid and vomer do not contact (2).
13. Jugal process of palatine: present (0); absent (1).
14. Contact between palatine and pterygoid: long, craniocaudally overlapping contact (0); short, primarily dorsoventral contact (1).
15. Contact between vomer and premaxilla: present (0); absent (1).

16. Ectopterygoid: present (0); absent (1).
17. Postorbital: present (0); absent (1).
18. Contact between postorbital and jugal: present (0); absent (1).
19. Quadratojugal: sutured to the quadrate (0); joined through a ligamentary articulation (1).
20. Lateral, round cotyla on the mandibular process of the quadrate (quadratojugal articulation): absent (0); present (1).
21. Contact between the quadratojugal and squamosal: present (0); absent (1).
22. Squamosal incorporated into the braincase, forming a zygomatic process: absent (0); present (1).
23. Squamosal, ventral or “zygomatic” process: variably elongate, dorsally enclosing otic process of the quadrate and extending cranioventrally along shaft of this bone, dorsal head of quadrate not visible in lateral view (0); short, head of quadrate exposed in lateral view (1).
24. Frontal/parietal suture in adults: open (0); fused (1).
25. Quadrate orbital process (pterygoid ramus): broad (0); sharp and pointed (1).
26. Quadrate pneumaticity: absent (0); present (1).
27. Quadrate: articulating only with the squamosal (0); articulating with both prootic and squamosal (1).
28. Otic articulation of the quadrate: articulates with a single facet (squamosal) (0); articulates with two distinct facets (prootic and squamosal) (1); articulates with two distinct facets and quadrate differentiated into two heads (2). (ordered)
29. Quadrate distal end: with two transversely aligned condyles (0); with a triangular, condylar pattern, usually composed of three distinct condyles (1).
30. Basispterygoid processes: long (0); short (articulation with pterygoid subequal to, or longer than, amount projected from the basisphenoid rostrum) (1).
31. Pterygoid, articular surface for basispterygoid process: concave “socket”, or short groove enclosed by dorsal and ventral flanges (0); flat to convex (1); flat to convex facet, stalked, variably projected (2). (ordered)

32. Eustachian tubes: paired, lateral, and well-separated from each other (0); paired, close to each other and to cranial midline or forming a single cranial opening (1).
33. Osseous interorbital septum (mesethmoid): absent (0); present (1).
34. Dentary teeth: present (0); absent (1).
35. Dentary tooth implantation: teeth in individual sockets (0); teeth in a communal groove (1).
36. Symphyseal portion of dentaries: unfused (0); fused (1).
37. Deeply notched rostral end of the mandibular symphysis: absent (0); present (1).
38. Mandibular symphysis, symphyseal foramina: absent (0); single (1); paired (2).
39. Mandibular symphysis, symphyseal foramen/foramina: opening on caudal edge of symphysis (0); opening on dorsal surface of symphysis (1).
40. Small ossification present at the rostral tip of the mandibular symphysis (intersymphyseal ossification): absent (0); present (1).
41. Caudal margin of dentary strongly forked: unforked, or with a weakly developed dorsal ramus (0); strongly forked with the dorsal and ventral rami approximately equal in caudal extent (1).
42. Mandibular ramus sigmoidal such that the rostral tip is dorsally convex and the caudal end is dorsally concave: absent (0); present (1).
43. Cranial extent of splenial: stops well caudal to mandibular symphysis (0); extending to mandibular symphysis, though non-contacting (1); extending to proximal tip of mandible, contacting on midline (2). (ordered)
44. Meckel's groove (medial side of mandible): not completely covered by splenial, deep and conspicuous medially (0); covered by splenial, not exposed medially (1).
45. Rostral mandibular fenestra: absent (0); present (1).
46. Caudal mandibular fenestra: present (0); absent (1).
47. Articular pneumaticity: absent (0); present (1).
48. Teeth: serrated crowns (0); unserrated crowns (1).
49. Atlantal hemiarches in adults: unfused (0); fused, forming a single arch (1).

50. One or more pneumatic foramina piercing the centra of mid-cranial cervicals, caudal to the level of the parapophysis-diapophysis: present (0); absent (1).
51. Cervical vertebrae: variably dorsoventrally compressed, amphicoelous ("biconcave": flat to concave articular surfaces) (0); cranial surface heterocoelous (i.e., mediolaterally concave, dorsoventrally convex), caudal surface flat or slightly concave (1); heterocoelous cranial (i.e., mediolaterally concave, dorsoventrally convex) and caudal (i.e., mediolaterally convex, dorsoventrally concave) surfaces (2). (ordered)
52. Prominent carotid processes in the intermediate cervicals: absent (0); present (1).
53. Postaxial cervical epiphyses: prominent, projecting further back from the postzygapophysis (0); weak, not projecting further back from the postzygapophysis, or absent (1).
54. Keel-like ventral surface of cervical centra: absent (0); present (1).
55. Prominent (50% or more the height of the centrum's cranial articular surface) ventral processes of the cervicothoracic vertebrae: absent (0); present (1).
56. Thoracic vertebral count: 13-14 (0); 11-12 (1); fewer than 11 (2). (ordered)
57. Thoracic vertebrae: at least part of series with subround, central articular surfaces (e.g., amphicoelous/opisthocoelous) that lack the dorsoventral compression seen in heterocoelous vertebrae (0); series completely heterocoelous (1).
58. Caudal thoracic vertebrae, centra, length and midpoint width: approximately equal in length and midpoint width (0); length markedly greater than midpoint width (1).
59. Wide vertebral foramen in the mid-caudal thoracic vertebrae, vertebral foramen/articular cranial surface ratio (vertical diameter) larger than 0.40: absent (0); present (1).
60. Hyposphene-hypantrum accessory intervertebral articulations in the thoracic vertebrae: present (0); absent (1).
61. Lateral side of the thoracic centra: weakly or not excavated (0); deeply excavated by a groove (1); excavated by a broad fossa (2).

62. Cranial thoracic vertebrae, parapophyses: located in the cranial part of the centra of the thoracic vertebrae (0); located in the central part of the centra of the thoracic vertebrae (1).
63. Notarium: absent (0); present (1).
64. Sacral vertebrae, number ankylosed (synsacrum): less than 7 (0); 7 (1); 8 (2); 9 (3); 10 (4); 11 or more (5); 15 or more (6). (ordered)
65. Synsacrum, procoelous articulation with last thoracic centrum (deeply concave facet of synsacrum receives convex articulation of last thoracic centrum): absent (0); present (1).
66. Cranial vertebral articulation of first sacral vertebra: approximately equal in height and width (0); wider than high (1).
67. Series of short sacral vertebrae with dorsally directed parapophyses just cranial to the acetabulum: absent (0); present, three such vertebrae (1); present, four such vertebrae (2). (ordered)
68. Convex caudal articular surface of the synsacrum: absent (0); present (1).
69. Degree of fusion of distal caudal vertebrae: fusion absent (0); few vertebrae partially ankylosed (intervening elements are well-discernable) (1); vertebrae completely fused into a pygostyle (2). (ordered)
70. Free caudal vertebral count: more than 35 (0); 35-26 (1); 25 - 20 (2); 19-9 (3); 8 or less (4). (ordered)
71. Procoelous caudals: absent (0); present (1).
72. Distal caudal vertebra prezygapophyses: elongate, exceeding the length of the centrum by more than 25% (0); shorter (1); absent (2). (ordered)
73. Free caudals, length of transverse processes: approximately equal to, or greater than, centrum width (0); significantly shorter than centrum width (1).
74. Proximal haemal arches: elongate, at least 3 times longer than wider (0); shorter (1); absent (2). (ordered)
75. Pygostyle: longer than or equal to the combined length of the free caudals (0); shorter (1).
76. Cranial end of pygostyle dorsally forked: absent (0); present (1).

77. Cranial end of pygostyle with a pair of laminar, ventrally projected processes:
absent (0); present (1).
78. Distal constriction of pygostyle: absent (0); present (1).
79. Ossified uncinat processes in adults: absent (0); present and free (1); present and fused (2).
80. Uncinate process, orientation: perpendicular to rib (0); angled dorsally defining an acute angle with the rib (1).
81. Gastralria: present (0); absent (1).
82. Coracoid shape: rectangular to trapezoidal in profile (0); strut-like (1).
83. Coracoid and scapula articulation: pit-shaped scapular cotyla developed on the coracoid, and coracoidal tubercle developed on the scapula (“ball and socket” articulation) (0); scapular articular surface of coracoid convex (1); (2) flat.
84. Scapula: articulated at the shoulder (proximal) end of the coracoid (0); well below it (1).
85. Coracoid, humeral articular (glenoid) facet: dorsal to acrocoracoid process/“biceps tubercle” (0); ventral to acrocoracoid process (1).
86. Humeral articular facets of the coracoid and the scapula: placed in the same plane (0); forming a sharp angle (1).
87. Coracoid, acrocoracoid: straight (0); hooked medially (1).
88. Laterally compressed shoulder end of coracoid, with nearly aligned acrocoracoid process, humeral articular surface, and scapular facet, in dorsal view: absent (0); present (1).
89. Procoracoid process on coracoid: absent (0); present (1).
90. Lateral margin of coracoid: concave (0); nearly concave to straight for most part and the convex portion is restricted at sternal end, which measures less than half the width of sternal end (1); strongly convex, and the convex portion measuring more than half the sternal end (2).
91. Broad, deep fossa on the dorsal surface of the coracoid (dorsal coracoidal fossa): absent (0); present (1).

92. Supracoracoidal nerve foramen of coracoid: centrally located (0); displaced toward (often as an incisure) the medial margin of the coracoid (1); displaced so that it no longer passes through the coracoid (absent) (2). (ordered).
93. Coracoid, medial surface, strongly depressed elongate furrow at the level of the passage of n. supracoracoideus: absent (0); present (1).
94. Supracoracoidal nerve foramen, location relative to dorsal coracoidal fossa: above fossa (0); inside fossa (1).
95. Coracoid, sternolateral corner: unexpanded (0); expanded (1); well-developed squared-off lateral process (sternocoracoidal process) (2); present and with a distinct omal projection (hooked) (3).
96. Scapular shaft: straight, both dorsal and ventral margins straight (0); straight shaft with convex dorsal margin and straight ventral margin (1); the scapular shaft sagittally curved (2).
97. Scapula, length: shorter than humerus (0); as long as or longer than humerus (1).
98. Scapular acromion process: in lateral or costal view, strongly projecting craniodorsally, forming a large angle with the proximal shaft of the scapular (0); nearly parallel to the shaft of the scapular (1).
99. Scapula, acromion process: projected cranially surpassing the articular surface for coracoid (0); projected less cranially than the articular surface for coracoid (1).
100. Scapula, acromion process, in costal or lateral aspect: straight and tapered toward cranial end (0); barely tapered with a blunt end (1); laterally hooked tip (2).
101. Proximal end of scapula, pit between acromion and humeral articular facet (scapular fossa): absent (0); present (1).
102. Costal surface of scapular blade with prominent longitudinal furrow: absent (0); present (1).
103. Scapular caudal end: blunt (may or may not be expanded) (0); sharply tapered (1).
104. Furcular, shape: boomerang-shaped (0); V to Y-shaped (1); U-shaped (2).

105. Furcula interclavicular angle: approximately 90° (0); less than 70° (1). The interclavicular angle is measured as the angle formed between three points, one at the omal end of each rami and the apex located at the clavicular symphysis.
106. Dorsal and ventral margins of the furcula: subequal in width (0); ventral margin distinctly wider than the dorsal margin so that the furcular ramus appears concave laterally (1).
107. Hypocleideum: absent (0); present as a tubercle or short process (1); present as an elongate process approximately 30% rami length (2); hypertrophied, exceeding 50% rami length (3). (ordered)
108. Sternum: unossified (0); partially ossified, coracoidal facets cartilaginous (1); fully ossified (2).
109. Ossified sternum: two flat plates (0); single flat element (1); single element, with slightly raised midline ridge (2); single element, with projected carina (3).
110. Sternal carina: near to, or projecting rostrally from, the cranial border of the sternum (0); not reaching the cranial border of the sternum (1).
111. Sternum, caudal margin, number of paired caudal trabecula: none (0); one (1); two (2).
112. Sternum, outermost trabecula, shape: tips terminate cranial to caudal end of sternum (0); tips terminate at or approaching caudal end of sternum (1); tips extend caudally past the termination of the sternal midline (2).
113. Prominent distal expansion in the outermost trabecula of the sternum: absent (0); present, simple bulb-like (1); fan-shaped expansion (2); triangular expansion with an acute medial angle (3); branched (4).
114. Rostral margin of the sternum broad and rounded: absent (0); present (1).
115. Sternum, coracoidal sulci spacing on cranial edge: widely separated mediolaterally (0); adjacent (1); crossed on midline (2).
116. Costal facets of the sternum: absent (0); present (1).
117. Sternal costal processes: three (0); four (1); five (2); six (3); seven (4); eight (5). (ordered)

118. Sternal midline, caudal end: blunt W-shape (0); V-shape (1); elongate straight projection (xiphoid process) (2); xiphoid process slightly flared mediolaterally (3); xiphoid process distal end strongly flared with prominent medial and lateral projections (4); rounded (5).
119. Sternum, caudal half, paired enclosed fenestra: absent (0); present (1).
120. Sternum, dorsal surface, pneumatic foramen (or foramina): absent (0); present (1).
121. Proximal and distal humeral ends: twisted (0); expanded nearly in the same plane (1).
122. Humeral head: concave cranially and convex caudally (0); globe shaped, craniocaudally convex (1).
123. Proximal margin of the humeral head concave in its central portion, rising ventrally and dorsally: absent (0); present (1).
124. Humerus, proximocranial surface, well-developed circular fossa on midline: absent (0); present (1).
125. Humerus with distinct transverse ligamental groove: absent (0); present (1).
126. Humerus, ventral tubercle projected caudally, separated from humeral head by deep capital incision: absent (0); present (1).
127. Pneumatic fossa in the caudoventral corner of the proximal end of the humerus: absent or rudimentary (0); well developed (1).
128. Humerus, deltopectoral crest: projected dorsally (the plane of the crest is coplanar to the cranial surface of the humerus) (0); projected cranially (1).
129. Humerus, deltopectoral crest: less than shaft width (0); approximately same width (1); prominent and subquadrangular (i.e., subequal length and width) (2).
130. Humerus, deltopectoral crest, perforated by a large fenestra: absent (0); present (1).
131. Humerus, bicipital crest: little or no cranial projection (0); developed as a cranial projection relative to shaft surface in ventral view (1); hypertrophied, rounded tumescence (2).

132. Humerus, distal end of bicipital crest, pit-shaped fossa for muscular attachment: absent (0); craniodistal on bicipital crest (1); directly ventrodistal at tip of bicipital crest (2); caudodistal, variably developed as a fossa (3).
133. Distal end of the humerus very compressed craniocaudally: absent (0); present (1).
134. Humerus, demarcation of muscle origins (e.g., m. extensor metacarpi radialis in Aves) on the dorsal edge of the distal humerus: no indication (0); a pit or a tubercle (1); a variably projected scar-bearing tubercle (dorsal supracondylar process) (2).
135. Well-developed brachial depression on the cranial face of the distal end of the humerus: absent (0); present (1).
136. Well-developed olecranon fossa on the caudal face of the distal end of the humerus: absent (0); present (1).
137. Humerus, distal end, caudal surface, groove for passage of m. scapulotriceps: absent (0); present (1).
138. Humerus, m. humerotricipitalis groove: absent (0); present as a well-developed ventral depression contiguous with the olecranon fossa (1).
139. Humerus, distal margin: approximately perpendicular to long axis of humeral shaft (0); ventrodistal margin projected significantly distal to dorsodistal margin, distal margin angling strongly ventrally (sometimes described as a well-projected flexor process) (1).
140. Humeral distal condyles: mainly located on distal aspect (0); on cranial aspect (1).
141. Humerus, long axis of dorsal condyle: at low angle to humeral axis, proximodistally oriented (0); at high angle to humeral axis, almost transversely oriented (1).
142. Humerus, distal condyles: subround, bulbous (0); weakly defined, “straplike” (1).

143. Humerus, ventral condyle: length of long axis of condyle less than the same measure of the dorsal condyle (0); same or greater (1).
144. Ulna: shorter than humerus (0); nearly equivalent to or longer than humerus (1).
145. Ulnar shaft, radial-shaft/ulnar-shaft ratio: larger than 0.70 (0); smaller than 0.70 (1).
146. Ulna, cotylae: dorsoventrally adjacent (0); widely separated by a deep groove (1).
147. Ulna, dorsal cotyla strongly convex: absent (0); present (1).
148. Ulna, bicipital scar: absent (0); developed as a slightly raised scar (1); developed as a conspicuous tubercle (2).
149. Proximal end of the ulna with a well-defined area for the insertion of m. brachialis anticus: absent (0); present (1).
150. Semilunate ridge on the dorsal condyle of the ulna: absent (0); present (1).
151. Shaft of radius with a long longitudinal groove on its ventrocaudal surface: absent (0); present (1).
152. Ulnare: heart-shaped with little differentiation into short rami (0); U-shaped to V-shaped, well-developed rami (1).
153. Ulnare, ventral ramus: shorter than dorsal ramus (crus brevis) (0); same length as dorsal ramus (1); longer than dorsal ramus (2).
154. Semilunate carpal and proximal ends of metacarpals in adults: unfused (0); semilunate fused to the alular (I) metacarpal (1); semilunate fused to the major (II) and minor (III) metacarpals (2); fusion of semilunate and all metacarpals (3). Any specimen that is inferred to be a juvenile should be scored as a “?” in order to account for the possibility of ontogenetic change.
155. Semilunate carpal, position relative to the alular metacarpal (I): over entire proximal surface (0); over less than one-half proximal surface or no contact present (1).

156. Carpometacarpus, proximal ventral surface: flat (0); raised ventral projection contiguous with minor metacarpal (1); pisiform process forming a distinct peg-like projection (2).
157. Carpometacarpus, ventral surface, supratrochlear fossa deeply excavating proximal surface of pisiform process: absent (0); present (1).
158. Round-shaped alular metacarpal (I): absent (0); present (1).
159. Alular metacarpal (I), extensor process: absent, no cranioproximally projected muscular process (0); present, tip of extensor process just surpassed the distal articular facet for phalanx 1 in cranial extent (1); tip of extensor process conspicuously surpasses articular facet by approximately half the width of facet, producing a pronounced knob (2); tip of extensor process conspicuously surpasses articular facet by approximately the width of facet, producing a pronounced knob (3). (ordered)
160. Alular metacarpal (I), distal articulation with phalanx I: ginglymoid (0); shelf (1); ball-like (2).
161. Metacarpal III, craniocaudal diameter as a percentage of same dimension of metacarpal II: approximately equal or greater than 50% (0); less than 50% (1).
162. Proximal extension of metacarpal III: level with metacarpal II (0); ending distal to proximal surface of metacarpal II (1).
163. Intermetacarpal process or tubercle on metacarpal II: absent (0); present as scar (1); present as tubercle or flange (2).
164. Intermetacarpal space: absent or very narrow (0); at least as wide as the maximum width of minor metacarpal (III) shaft (1).
165. Intermetacarpal space: reaches proximally as far as the distal end of metacarpal I (0); terminates distal to end of metacarpal I (1).
166. Distal end of metacarpals: unfused (0); partially or completely fused (1).
167. Minor metacarpal (III) projecting distally more than the major metacarpal (II): absent (0); present (1).

168. Alular digit (I), phalanx 1, distal extension relative to the major metacarpal (II): beyond the distal end of major metacarpal (0); approximately equal in distal extension (1); shorter than the distal end but beyond half of the major metacarpal (2); terminating less than half of the major metacarpal (3). (ordered)
169. Proximal phalanx of major digit (II): of normal shape (0); flat and craniocaudally expanded (1).
170. Major digit (II), phalanx 1, “internal index process” (Stegmann, 1978) on caudodistal edge: absent (0); present (1).
171. Second phalanx of major digit (II): longer than proximal phalanx (0); shorter than or equivalent to proximal phalanx (1).
172. Ungual phalanx of major digit (II): present (0); absent (1).
173. Ungual phalanx of major digit (II): larger or subequal to other manual unguals (0); smaller than the alular ungual but larger than that of the minor (III) digit, and the ungual of the minor digit may or may not present (1); smaller than the unguals of the alular and minor digits (2).
174. Proximal phalanx of the minor digit (III) much shorter than the remaining non-ungual phalanges of this digit: absent (0); present (1).
175. Ungual phalanx of minor digit (III): present (0); absent (1).
176. Length of manus (semilunate carpal + major metacarpal and digit) relative to humerus: longer (0); subequal (1); shorter (2). (ordered)
177. Intermembral index = (length of humerus + ulna)/(length of femur + tibiotarsus): less than 0.7, flightless (0); between 0.7 and 0.9 (1); between 0.9 and 1.1 (2); greater than 1.1 (3).
178. Pelvic elements in adults, at the level of the acetabulum: unfused or partial fusion (0); completely fused (1).
179. Ilium/ischium, distal co-ossification to completely enclose the ilioischadic fenestra: absent (0); present (1).
180. Preacetabular process of ilium twice as long as postacetabular process: absent (0); present (1).

181. Preacetabular ilium: approach on midline, open, or cartilaginous connection (0); co-ossified, dorsal closure of “iliosynsacral canals” (1).
182. Ilium, m. cuppedicus fossa as broad, mediolaterally oriented surface directly cranioventral to acetabulum: present (0); surface absent, insertion variably marked by a small entirely lateral fossa cranial to acetabulum (1).
183. Preacetabular pectineal process (Baumel and Witmer, 1993): absent (0); present as a small flange (1); present as a well-projected flange (2). (ordered)
184. Small acetabulum, acetabulum/ilium length ratio equal to or smaller than 0.11: absent (0); present (1).
185. Prominent antitrochanter: caudally directed (0); caudodorsally directed (1).
186. Postacetabular process shallow, less than 50% of the depth of the preacetabular wing at the acetabulum: absent (0); present (1).
187. Iliac brevis fossa: present (0); absent (1).
188. Ischium: two-thirds or less the length of the pubis (0); more than two-thirds the length of the pubis (1).
189. Obturator process of ischium: prominent (0); reduced or absent (1).
190. Ischium, caudal demarcation of the obturator foramen: absent (0); present, developed as a small flange or raised scar contacting/fused with pubis and demarcating the obturator foramen distally (1).
191. Ischium with a proximodorsal (or proximocaudal) process: absent (0); present (1).
192. Ischiadic terminal processes forming a symphysis: present (0); absent (1).
193. Orientation of proximal portion of pubis: cranially to subvertically oriented (0); retroverted, separated from the main synsacral axis by an angle ranging between 65° and 45° (1); more or less parallel to the ilium and ischium (2). (ordered)
194. Pubic pedicel: cranioventrally projected (0); ventrally or caudoventrally projected (1).
195. Pubic pedicel of ilium very compressed laterally and hook-like: absent (0), present (1).
196. Pubic shaft laterally compressed throughout its length: absent (0); present (1).

197. Pubic apron: present (0); absent (absence of symphysis) (1).
198. Pubic foot: flaring into simple round shape (0); triangular shape with a pointed caudal tip and caudoventrally directed with respect to the distal pubic shaft (1); the caudal tip recurved caudodorsally with respect to the distal pubic shaft (2); absent (3).
199. Femur with distinct fossa for the capital ligament: absent (0); present (1).
200. Femoral neck: present (0); absent (1).
201. Femoral anterior trochanter: separated from the greater trochanter (0); fused to it, forming a trochanteric crest with a laterally curved edge (1); fused to it, forming a trochanteric crest with a flattened edge (2).
202. Femoral trochanteric crest: projects proximally beyond femoral head (0); equal in proximal projection (1); does not project beyond femoral head (2).
203. Femoral posterior trochanter: present, developed as a slightly projected tubercle or flange (0); hypertrophied, “shelf-like” conformation (1); absent (2).
204. Femur with prominent patellar groove: absent (0); present as a continuous extension onto the distal shaft (1); present and separated from the shaft by a slight ridge, giving it a pocketed appearance (2).
205. Femur: ectocondylar tubercle and lateral condyle separated by deep notch (0); ectocondylar tubercle and lateral condyle contiguous but without developing a tibiofibular crest (1); tibiofibular crest present, defining laterally a fibular trochlea (2). (ordered)
206. Caudal projection of the lateral border of the distal end of the femur, proximal and contiguous to the ectocondylar tubercle/tibiofibular crest: absent (0); present (1).
207. Femoral popliteal fossa distally bounded by a complete transverse ridge: absent (0); present (1).
208. Fossa for the femoral origin of m. tibialis cranialis: absent (0); present (1).
209. Tibia, calcaneum, and astragalus: unfused or poorly co-ossified (sutures still visible) (0); complete fusion of tibia, calcaneum, and astragalus (1).
210. Round proximal articular surface of tibiotarsus: absent (0); present (1).

211. Tibiotarsus, proximal articular surface: flat (0); angled so that the medial margin is elevated with respect to the lateral margin (1).
212. Tibiotarsus, cnemial crests: absent (0); present, one (1); present, two (2).
213. Tibia, caudal extension of articular surface for distal tarsals/tarsometatarsus: absent, articular restricted to distalmost edge of caudal surface (0); well-developed caudal extension, sulcus cartilaginis tibialis of Aves, distinct surface extending up the caudal surface of the tibiotarsus (1); with well-developed, caudally projecting medial and lateral crests (2). (ordered)
214. Extensor canal on tibiotarsus: absent (0); present as an emarginate groove (1); groove bridged by an ossified supratendinal bridge (2). (ordered)
215. Tibia/tarsal-formed condyles: medial condyle projecting farther cranially than lateral condyle (0); equal in cranial projection (1).
216. Tibia/tarsal-formed condyles, mediolateral widths: medial condyle wider (0); approximately equal (1); lateral condyle wider (2). (ordered).
217. Tibia/tarsal-formed condyles: gradual sloping of condyles towards midline of tibiotarsus (0); no tapering of either condyle (1).
218. Proximal end of the fibula: prominently excavated by a medial fossa (0); nearly flat (1).
219. Fibula, tubercle for m. iliofibularis: craniolaterally directed (0); laterally directed (1); caudolaterally or caudally directed (2). (ordered)
220. Fibula, distal end reaching the proximal tarsals: present (0); absent (1).
221. Distal tarsals in adults: free (0); completely fused to the metatarsals (1). Any specimen that is inferred to be a juvenile should be scored as a “?” in order to account for the possibility of ontogenetic change.
222. Metatarsals II-IV, intermetatarsal fusion: absent or minimal co-ossification (0); partial fusion, sutural contacts easily discernible (1); completely or nearly completely fused, sutural contacts absent or poorly demarcated (2). (ordered)
223. Proximal end of metatarsus: plane of articular surface perpendicular to longitudinal axis of metatarsus (0); strongly inclined dorsally (1).

224. Metatarsal V: present (0); absent (1).
225. Proximal end of metatarsal III: in the same plane as metatarsals II and IV (0); plantarly displaced with respect to metatarsals II and IV (1).
226. Tarsometatarsal proximal vascular foramen/foramina: absent (0); one between metatarsals III and IV (1); two (2).
227. Metatarsals, relative mediolateral width: metatarsal IV approximately the same width as metatarsals II and III (0); metatarsal IV narrower than metatarsals II and III (1); metatarsal IV greater in width than either metatarsal II or III (2).
228. Well-developed tarsometatarsal intercotylar eminence: absent (0); present, low and rounded (1); present, high and peaked (2).
229. Tarsometatarsus, projected surface and/or grooves on proximocaudal surface (associated with the passage of tendons of the pes flexors in Aves; hypotarsus): absent (0); developed as caudal projection with flat caudal surface (1); projection, with distinct crests and grooves (2); at least one groove enclosed by bone caudally (3). (ordered)
230. Plantar surface of tarsometatarsus excavated: absent (0); present (1).
231. Tarsometatarsal distal vascular foramen completely enclosed by metatarsals III and IV: absent (0); present (1).
232. Metatarsal I: straight (0); J-shaped, the articulation of the hallux is located on the same plane as the attachment surface of the metatarsal I (1); J-shaped; the articulation of the hallux is perpendicular to the attachment surface (2); the distal half of the metatarsal I is laterally deflected so that the laterodistal surface is concave (3).
233. Metatarsal II tubercle (associated with the insertion of the tendon of the m. tibialis cranialis in Aves): absent (0); present, on approximately the center of the proximodorsal surface of metatarsal II (1); present, developed on lateral surface of metatarsal II, at contact with metatarsal III or on lateral edge of metatarsal III (2). (ordered)

234. Metatarsal II, distal plantar surface, fossa for metatarsal I: absent (0); shallow notch (1); conspicuous ovoid fossa (2). (ordered)
235. Relative position of metatarsal trochleae: trochlea III more distal than trochleae II and IV (0); trochlea III at same level as trochlea IV, both more distal than trochlea II (1); trochlea III at same level as trochleae II and IV (2); distal extent of trochlea III intermediate to trochlea IV and II where trochlea IV projects furthest distally (3).
236. Metatarsal II, distal extent of metatarsal II relative to metatarsal IV: approximately equal in distal extent (0); metatarsal II shorter than metatarsal IV but reaching distally farther than base of metatarsal IV trochlea (1); metatarsal II shorter than metatarsal IV, reaching distally only as far as base of metatarsal IV trochlea (2).
237. Distal tarsometatarsus, trochlea in distal view: aligned in a single plane (0); metatarsal II slightly displaced plantarly with respect to III and IV (1); metatarsal II strongly displaced plantarly in respect to III and IV, such that there is little or no overlap in medial view (2).
238. Trochlea of metatarsal II broader than the trochlea of metatarsal III: absent (0); present (1).
239. Metatarsal III, trochlea in plantar view, proximal extent of lateral and medial edges of trochlea: trochlear edges approximately equal in proximal extent (0); medial edge extends farther (1).
240. Distal end of metatarsal II strongly curved medially: absent (0); present (1).
241. Digit IV phalanges in distal view, medial trochlear rim enlarged with respect to lateral trochlear rim: absent (0); present (1); greatly enlarged with the lateral trochlea reduced to a rounded peg (2).
242. Completely reversed hallux (arch of ungual phalanx of digit I opposing the arch of the unguals of digits II-IV): absent (0); present (1).
243. Size of claw of hallux relative to other pedal claws: shorter, weaker, and smaller (0); similar in size (1); longer, more robust, and larger (2).

244. Alula: absent (0); present (1).
245. Fan-shaped feathered tail composed of more than two elongate rectrices: absent (0); present (1).
246. Sternum, outermost trabecula: mainly parallel to the long axis of the sternum (0); clearly directed laterally (1).
247. Distal end of furcula relative to sternal margin of coracoid: proximal to or level with the sternal margin of the coracoid (0); well beyond the sternal end of the coracoid (1). When coracoid and furcula are not remained in natural position, then their proximodistal lengths are compared.
248. Scapula and coracoid: fused (0); unfused (1).
249. Scapula, acromion process length relative to the length of the humeral articular facet: less than half (0); nearly equivalent (1); longer but less than two times (2); more than two times longer (3); (ordered)
250. Alular digit (I), phalanx 1: longer than the phalanx 1 of digit II (0); shorter than or equivalent to the phalanx 1 of digit II (1).
251. Coracoid, width of the sternal end relative to the length along the shaft: approximately half or greater (0); between half to 1/3 (1); less than 1/3 (2).
252. Coracoid, sternal margin: convex (0); nearly straight (1); concave (2);
253. Humerus, deltopectoral crest, distal end recedes abruptly with the humeral shaft: present (0); absent (1)
254. Tibia/tarsal-formed condyles, intercondylar groove: mediolaterally broad, approximately 1/3 width of anterior surface (0); less than 1/3 width of anterior surface (1).
255. Metatarsal IV, distal extension of the metatarsal IV relative to the metatarsal III: shorter and proximal to the proximal margin of the trochleae III (0); shorter but reaching distally further than the proximal margin of the trochleae III (1); approximately equal or surpassing the trochleae III (2)
256. Reduced claw in digit IV: absent (0); present (1).

257. The length ratio between tibiotarsus and tarsometatarsus: 2 or larger (0); between 2 and 1.6 (1); smaller than 1.6 (2). When distal tarsals are not fused with metatarsals, metatarsal III length is used.
258. Pedal digit, penultimate phalanx, longer than preceding phalanges in each digit: absent (0); present (1).
259. Proximal phalanx of hallux, the longest non-ungual phalanx: absent (0); present (1).
260. Phalanx in digit IV: not as follows (0), the second and the third phalanges reduced and significantly shorter than the fourth phalanx (1), as before but with the proximal phalanx reduced to be nearly equal in length with the second and third phalanx (2).
261. Pedal digit III claw, length relative to the tarsometatarsus: less than 20% the length of tarsometatarsus (0); 20% – 40% (1); extremely elongated and measuring more than 40% the length of tarsometatarsus (2); When metatarsals are not fused with distal tarsals, the length of metatarsal III is used. The length of ungual represents the linear distance between proximal end (position equivalent to flexor process) and tip of the sheath. If the sheath is not preserved or disarticulated with bony ungual, it should be scored as “?”. (ordered)
262. Post-dentary mandible: not as follows (0); dorsal margin concave and ventral margin convex (1); sigmoid (2).
263. Premaxilla, preorbital portion occupying 60% or more the skull length: absent (0); present (1).
264. Pedal digit II: not as follows (0); much robust than the other digits (1)
265. Alular digit (I): long, exceeding the distal end of the major metacarpal (0); subequal (1); short, not surpassing this metacarpal (2). (ordered)
266. Tarsometatarsus, length compared to femur length: 0.6 or fewer (0); 0.8-0.6 (1); 1-0.8 (2); 1 or greater (3).
267. Quadratojugal, shape: without horizontal process posterior to ascending process (reversed “L” shape) (0); with horizontal posterior process (i.e., inverted ‘T’ or ‘Y’ shape) (1).

268. Jugal and quadratojugal, fusion: absent (0); present, the two bones are not distinguishable from one another (1). (ordered)
269. Caudal vertebrae, change in morphology of free caudals along the tail: present, with distinct transition point from shorter centra with long transverse processes proximally to longer centra with small or no transverse processes distally (0); absent, vertebrae homogeneous in shape, without transition point (1).
270. Caudal vertebrae, location of transition point along the tail: begins distal to the 10th caudal vertebra (0); between the 7th and 10th caudal vertebra (1); proximal to the 7th caudal vertebra (2) (ordered).
271. Coracoid and scapula, angle between bones at glenoid: greater than or equivalent to 90° (0); smaller than 90° (1).
272. Ischium, distal end: continuous with the proximal shaft, rendering the cranial margin of the ischium straight or weakly convex (0); directed cranioventrally toward the pubis, rendering the cranial margin concave (1).
273. Ischium, caudal margin with a dorsal process: located proximal to or close to the midpoint of the caudal margin (0); distal to the midpoint of the caudal margin (1).
274. Sternum, cranial margin with a pair of craniolateral processes: absent (0); present (1).
275. Premaxilla corpus: dorsoventral height greater than or equal to craniocaudal length (0); dorsoventral height smaller than craniocaudal length (1).
276. Furcula, omal tip: blunt or expanded (0); tapered (1).
- 277 Alular metacarpal, cranial margin: expanded cranioproximally and craniodistally, and constricted just before flare of articulation with digit (0); broadly convex (1).
278. Alular digit, phalanx 1: straight (0); bowed (1).
279. Major digit, phalanx 2: straight (0); bowed (1).
280. Minor digit: with four phalanges (0); less than four phalanges (1).

7. Character coding used in phylogenetic analysis.

The matrix follows Li et al.¹³. with the addition of *Baminornis zhenghensis* and IVPP V33260.

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??110000?0?0?02??0100?0011?0?00?0?00?001001100001??1?00??01000

Eoconfuciusornis_zhengi

[12]?231?12?0?????0????????????????1?01??000??100???0?0?00??0??1??0241
???0?0?00?0???000000?020???0000?02[12]?????????0?00000?100?0???000??
?01?????0?01??00001?0?0000000210020??0?0?0????????1000[12]?????????0????
??10?????0?000000002?00200?001000???0?000101001000001??1?????101010

Confuciusornis_dui ??23111????????????????0????????1??????0??1????????????
?????[012]????14?10?0??0?0????????????????????????2[12]?0??0???10?0?0?00
021????????????01?????0???1??0[01]00?00?000?0021002????????????????????
???[02]????????1??????10?????0?00???0[12]00?0010?0???0??0?1000011?00[01]
0001?0???1??010

Boluochia ?1[12][02]??
????????????2???????1????????????????????????????[12][12]?[12]?????20????
??110101???02??
????????0??????????0[01]?100100002??3200?0011??1????????2?20?????????1??
??1?????

Concornis ???01?
?11?????????0?01??????111110?02?11?00?1?????1112221222111?20?00111?0[01]0
211?????1????1112????????????0?0?0??30010[01]0122?????????11?1?[12]?00?0
????????1111??????1110?0010?0[01]?0000?001??01131110?0?2??1??022??1?
1??1?0??01

Elsornis ???[01]?10?0

?1?10????????????????11110002121?000001010111[23]22010?11?[12]0?00110
000000[12]0[12]0000111??0100[12]1?1??31????0?[01]?01?????????????????
??1111?121?????????
?????1??0?0???

Eoalulavis ??00111200?
?2?0??????????????0??1111010211100000010?111?312?0?0010?40?00111100102
11001001111111?21?1?????????0??1?01?001????2??0?????1?????????????1?1??
??1??1121111??????????1?????1??0?0?101

Cathayornis
[12]0[12]0??0????????????????????????000???00?????1??1??1??0???11?2????24
0?0?0111???1111?0??20??000001?0111?322122311??20?0011?1?010211[01]01011
111011?????110?31100010?[01]00013001010122000000??11?????100???12????1??
??[01]?????1?1????????????????????????0?111111?????????0?2???1?10?01?1101

Eocathayornis ??0???2??????????????0???0????000???00?????1????????00?
????????????????????11?????02???000000?0???22121311??20??01??1?000??
[01]????11???10??????0?31??0010??0001200100011????????????????????
??0?111111?????????2?????1??01?1101

Eoenantiornis
[01]010??02????????????????0????????00??????????1?????????????[012]????2
4020?????1?011110101?11000?001???11122[123]?2??110?2000?1??1?000?????
?????11?????10?31??0000?000012001010122???0?????????[12]?001????1?????
????????????11??0?10?????0??1?0?1110011[23]1011?[01]?1?0??20?11??1?10?0001
101

Gobipteryx
10[12]3101200021?10????????0???0?1??1?[01]0???10???10?????1????????[012]1
0??[12]401????????1111?010?1???0?0010??111[23]????????????0?????0?????
0????????11???111????????0?0?01?00?????20????????????10?03?????????
10[01]10?011?110010?100??11?0??1?1?????????2??1????????0??????1???1????

Longipteryx ?122111????????????????????????000???00?01?1?1?1011????
?????2????24??0?01?11?01?1110100???000?000?11132[23]?21111??20??0110??0

002??[01]?0?011?1?11?????0?01100000100?0120010001130000????1111011[12]11
001?0?[12]1??0????0????0?1?1?0?1000000001?32000001???1?1211?1?2?2????01?1
1??1?1000101101

Longirostravis

[01]022??1????????????????????????00????00??01?1??1????0????01????24??
0?01110?0111???00?2??000000??0111[123]2[123]?224110?20??01??1??00???[01]?
????????10?????0?31??10?0?[01]01012001??0122??0?????1??10?1?11????0?1????
??1?00?????1?11[01]?10010??0?2?0100?00????0?1??111?1?1????01??1??1?1??010?
???

Neuquenornis ???0??
?11?????????????????????1?1????021111000????1?1111230[12]?1?1????0????11????
?1?01?01????11?1??11??31??10?0?[01]0001????????????????????????????????????111
0???????1?????????10??0?1??1?2?00?011001[12]????1??2[12]0???1?0????0???????1?
???01???

Pengornis

00[01]01101?0??????01?????0?1??????000???0?0?????11?2??1??0?1?10?1????240
?0[12]?11???01?11???00?????0??02???11?[23]????????????001?0100101??[01]?10
0?1???11??????1[02][23]111???0?01001?0010?0?[12]3????????????????????02?01??
?????1??[01]?01[12]11?0100100100101200201?00?????011?100?[01]011?02101?0?
?1?1???10??01

Eopengornis

0000110[012]?0?????????????0?????????00000?000?????1??10?0??00??????????24?
?0?1?????01211101000??000?02?00111321?110?1??10?0010010000??10?0001????
10??????0??1[01]?00?0?010012001010103????????????????000???????0????100?
?????0??0001????1??0101?0012?000111101?1011102?0101??1?1??0101101

Protopteryx

[12]?[12][02]1??[012]????????????????????????00?????00?????1???????10?????01
????14????0??1???1111?0?11?[12]?200?00??0111322111011?[12]10????1????010??
????????????11?????????1??000??[01]0001100000010??00?????11?????????0[12]???
?1?????0????????????00??0010??00??0[01]01?001110011?0100?[01]101101?0000??1

?1000101101

Rapaxavis

[01]022??1[012]????????????????????000??0?0??1?1????1??01??11?1???02
4??0?0?110?01???0?00?[12]?0??001???11?322122411??20??0100??0000??[01]0??
?1111?10??1??0??11?00?010000130011?01230000?0??111101?111?0100???????0
?0[01]?0?11??100?10000??002?0100?0011??0?121011?101102101021??1?100?1011
01

Shanweiniao

[01]?[12][23]??1????????????????????0??00??01?????1?????????????
24?????1?1??01?11???000[12]?000000??011?22[123]?211?[01]??20??1????00??
?????11???11???1????????????????20?11??22?????????1?????1???0?????0??1
?????????110??0000??1?[01][01]?0?0?1[01]?10?12?111?1011?21010[01]??1?1?
?010??01

Vescornis

?0????2????????????????????0000??00[12]001?1??21?1?

?0??1?2??2?????00??01?1??0?02?[12]?000001??011?322120111??20?00110
??0101?1[01]0??111111?????1[02]011010?00[01]0?0130010[01]01220?0?????
????????????????0??[01]?????00??0010?011?[01]201?1011??11121[01]11?
[01]1110?00?021??1?1??0?01101

Qiliania

??

??
??10??00?10101?2?0003?0??11200?00?1
10000?11100?001001?11?[01]?20?0?1[01]?????????1?120021??1?2????00?????
Dunhuangia ??
????????????????????1111?0?02120?02??0??1?11?[23]2[123]?2121???200?0?10??
000????0001?????1?????0?31100000100101200100012????????????????
????????????????????????????????????0?1?1021????????2?????1??0?01
101

Piscivorenantiornis

1??[02]????????????????0?0?0?0??000??00??01011110111?001?[01]1?[12]11
?02?000??01?01111101020110020001?01111222121310??30?001??100001010000

0111110?0?110?2110000010010120010???231000?00?0?01011100?20011?0????
1??0?01001?1100100100102?0020110?1???0112102111?1???0??21??1?1001?0110?

Linyiornis

10101?02?0?????????????0?????????000???0?0??01?1??10?1?2?1?0110101??24??0
20?0???0111110101[12]1?0020001?00111[23]2[123]?[12]?1?????00100??0102110
0???111011110011?012100000010010120010???22000??0010?0101?1100??0012?0?
???1?0?10?001?110010010??0?0?0201?0011??111210211111002100?20??1?100000
?101

Sulcavis

[01]010?0?????????????????0?????????000???0?0?????1?????11?????11?[12]???24
?1010110??01?????0?010[12]?0[01]0001?0?1113[12][123]?????????????01????010??
???????1???11??[01]???0?[02]1??0[01][01]0?00?0120010101120?00?[01]?????????[
12]10?????????????0?00?0?01??110010010??0[123]??0101?0011???11211[12]01111
0012?0110??1?1???01101

Bohaiornis ?0[12]01102?0?????????????0?????????1000??000??0011????1?
120?1?110[0123]???24000?01101?0111110?01020?0[01]0101?0?11122[123]?21311
??30?001??100001?10?0?011???11?????10?0110000010010120010101230000?????
01011[12]?000?0?1???0?0?0?0?0?10?1100100100?01?[01]0101?0?11??101210211
110001210110??1?1000001101

Longusunguis ?0[12]01?02?0?????????????????????000??000??01?1??[12]?
1??20??1110[123]???24?00?0110??01111101020??010001?0111?32[123]???1???[
23]00001??10000??10?00011???11?????10?01??0000100101?00101012200?????????
01011[12]?000?????1?100?0?00?00010?100?1???000?1??010100?1????112102011?
1002210110?01?1000001101

Shenqiornis

[01]0101102?????????0?????0?1?????000??000??1?1???11?0?01??11?????????
0???????01?11?0?01?[12]?010101??011?[23]2[123]?[12][12]3?1??20?01101?000?
???????1???11???????01?001010010120010101130000?????01?111??01?????
???0?0?????????0?1011???0???[01]?0?0?1???[12]111211[12]01??2?0?21011??01?
1000001101

Zhouornis

[01]0101?01?0????????????????????0??1000???000?0??11?[12]?1??20???110?????2
4??0??1?0??011111010101??020101?0111132[123]?2?3110??0?000??10000??10?00
011???11?????10?31??000010010120010101220000????????????[12]?00000??1?1?0
?1?00?0?01??110010010??01??0101?0?11??11121?2011110012?0110??1?1??000110
1

Parabohaiornis

[01]0201102?0????????????????????000???000?0??1???01??200??110[12]01?12
4??0?01101101?1110?01?11?010101?0111132[123]?20311?[345]30?001??10000101
010001110111?????10?01??000010010120010101230000??0?0101011[12]1100000?
?????0?0?00?00010?100010010??01200101?0?11??1112102111100022?0110??1?10
00001101

Fortunguavis ??????0????????????????????????????????00???0???0?110200?
?1?000??02[34]??0??1110?01111101001110020???0111122??2??1???300000??1000
0??1??0001?1??11?????112211000001001012001000?120?????????01011110012?0?
???????1???10???1?110010010000?0?02?100011???11?10?1?11100111?011??1?1??0
??1111

Pterygornis

00201102?0????????????????0?0?0?????000???0000001?111[12]?11??0111110211?12?
000??1101??1?????01021110000001?0?11132[123]1212100?20?00100100001110000
011001110000110?31100000100101200???01221?0?10011??10??1100?10011?0????
1?001?????1?1100100110101?0010110?11??011?1021?1?100??000210?1?10?11011?
1

Cruralispennia

[01]0?0??02????????????????0????????000???0??????1????????0?112???????2??00
????0[01]??1?1??01011??00?001???????2[23]12201???10000110??0001?????????
??10?0?0????[23]1??00???0??0120?0??2200?????????01011110003?????????1??
???????1100?00?00?????????????????1?100221???2???1???2???1?1?101??10?

Monoenantiornis ?0?0??1????????????????0???0???000???00??????1????????0?
??1??11122???????1?0???1??110??1??0?0000010??11??231200000????10100??0001

010????1100011????00????0??0100101200000??12????????????????0000?????
??????1?0111??1?0?10?1???0100?2?0?0?11??1?1?101012000012??110??1?10?0101
101

Archaeorhynchus

1013111[12]??????????????1????????1?00?00100??1???01?0??0??1???1000??[34
]0111????1101011?0010?20?[01]20000?0121002[23]122211?[12]20??1000??010??
?0??0110?100001100?31?000110000021010101030000??0?101100?[12]10001?0?
???1???1?0[12]00????211[01]010100?0?0?0100?00???0010101100000?01[01]002
0?01?10?0110101

Schizoura

0123111[01]????????????????????11?0????10??01??0?[12]1?00?00?1??0[345]?
1??[12][34]?[12]0[12]?000??01011?0?1001??[01]2?00????11012[23]0[12]?011??1??
1?000??0[12]0010[01]0???01?0?10????00?31?0000?001?0[23]001010103?0??1[0
1]1???0101?1?0103????[12]?0????[12]??????111010?00001[01]2?011000010?1?
01?1110?100000010021?01?1??01?0101

Bellulornis ???1?
00?[234]????2?01?11000???1011?0?10?10?020???0?11?12[23]0[12]2211????1100
00?0100100????01???1000???00?3100000000001021010001031???10?1??010?1210
0???0102????1?02?0???1?112010120???02?0200?00?0??001?0011?1010?00??021?
?1?10?1??1101

Vorona ???
??
??101120211?0001
111011111[12]000100011?21000000????????????11????????1????????????

Jianchangornis ?????????????????????????????????00????1?0????1??1????010
1200[234]0????????????0101110010020?0200?0?0121?02[23]031001??[01]0?01
000000100100000001?0111????0???1??01?00000002101010103??01?[01]??????
?[12]?000????2??00??0??0?10??1120?0000????0100?00??01010001110000?0?
10?01????1??1?1100?

Songlingornis ???[01]????????????????????????????000????0????1????????

???2????????????????10????101???2???0???21?02301231[12]?51?????????
??0?????????
??1?10?01????????????????1???1????

Longicrusavis

10[12]01?0????????????????????00???101???11?11?0???20?????????
?????????1011100?0???[12]21100?01210?23?120110?10?110?01?11012021100010
001100???0?31110?00010102100010101??????11?1???[12]?0?????????01?100
22[01]121?1112011100??10100100?0011?0010101000110000???02???1?011?101
Apsaravis ????????????????????1[01]????1?1???1???????021?1?2
01???00?4?0?24?10???????101110000111121102001???[12]30???11?????110010
0010111000011111110121101?311001110110???1???????10001111?111012??113
101[12]?1?0??1???20121??11[12]?111001?1?200100?00?????1??12110??0?????0?1
???1?????0??1

Hongshanornis ?020?10?????????1????????????00???101??0?????????????
??1???????24???????01?0101110010????[01]211?0?0121?12??2201[12]?210?110??
??10???2???0???11???????31?00?0?00?02101010101?????????0??01[12]???
3???????????0?[12]???????1120?0?00?0?0?0200?001111001010210011000010012?
11?1?0110101

Archaeornithura ???
???[23]???0[12]4??1110001?0101110010110?221100?0?2101230[12]?111???????0??
10010??02???0100???????0?[23]1??0[12]?0?000?02100010101?0???????01001[
12]???03???2??0??1?0???2?0?1110?1?01???[01]?0100?001111?0101011?011000
01???1??1?10?0??0101

Parahongshanornis ??1?1?????????
????????????????????1???0?10???[01]211???01210123022011??10??10??1?010?
?0?????01???11???????31?01?0?000102100010101?0?????????10??[12]??003???
???0???000???????1???11?0???1?0100?0011?001?1011?0110000???2???10?0?
10101

Tianyuornis

1020??0????????????????????000???01???1?1????????????????4??????

??11?10??0?10????22?????1210123?22111??10?1100??010??0????01?0?11???
????[23]1??0??0?000102100010101????????????????????????????1??[12]??12??
?111011?01???[01]??01?0?0?11??001?1011?0110000????2??1?1??011?101

Yanornis

10[12]11102?1???????1????????????1000???1?00?01?1??0????01??2003??0?2??
????000??01011100100?0?220001?0121002301121[12]??51011001??010110[01]??
?0100011?0?11?0?31110000000010210101012310100?11?10100?11?003??1??????
1?02?0?0??111011?00[01]1112?0110?0011??0?101001000000000011?11?11?1110
101

Patagopteryx ??????????????1?11110001111????????????0??000?112110110
01100031101??120????????1011100000?0?1210010??????2[12]????10????1001??
1000?0?00000100?000000?0?????????0??1?1?20?00???20?0001000001110121?013?
0??20????1001?0?0111120101001110000?00?0001????10??110100000?0?0??????
0???????

Yixianornis

1121????????????????????0???1?1??0?0???110?????1??1?1??2011?1003??0?24???
1000[12]00101110010010?220001001210?2301121[12]0?51??10??11??0?0?0?11001
?0?100021?0??311101010010102101010102100?1??00?01?111??003??1?2?201?100
2??????11[12]01?0001110?0010?0011?110101011?0000001?0011?11??1?1?10101

Piscivoravis ??????????????????1????111?[01]????????????????????1211??10
111100[34]??0?24?20??0001001011?0??0???[23]20????0121002301121[12]??51?1
10??1?1?0?0?0?????1?0?11????00?31??000110001021010101121000?0????01011[
12]10003?01121?01?10022????1?112011100[01]110?001100001011001?01???00000
00??001?11?11?0?10101

Iteravis

00231102?0????????????????0??????000???1?0??01?1??[12]1????01?12?0[123]???0
24?20110001101011?0?10?10?220????0121002[23]01111[01]??51?11000??01?1?02
????01???11????011312101010001102101010122100?11111?01011110000?010212
0??100[12]?1?00??11211110???100?0110?0011??101?101?0101000000022?11?11?0
110101

Gansus ???121?1?201
111004001024?20210000?1101110010020?320???0012100230210100?10?11001??0
10130?1???010011100111?0?312?01110001?131010001221?0011110101011210003
001[12]?1201?100[12]2?0?0?211201110010102?020000011???001?10110?010000??0
23?11?11?1?10101

Ichthyornis
20231?03100?1??11111110111111?01001???100?101111[01]11012011120?4?0102
401021000??1101111010010?2210110012?002300??1212?011100110010120210110
1000110021101?3121012101001031111???3100010110?11011210113101221201?1
00221110?2112011202101?2102000001?????10101001?1????0?????11?10??100101

Hesperornis
11231101?0021??111111100101111101010???100010101?021001211112004010?130
20210001010?01?00?0010?020???000200?21?0??0011?00??????0?????1000000????
??100012110111001210113102122201110122111
1121120112?21013223220102??????1?01?020?0?0?0???3?11?00??1?????

Parahesperornis
1123??0??0?1??1111111?010111????01????1???????1?02100121111200?????1?????
10001??0?01?0?0010?0????????????2??????1????????????????????????????????
??1021222011101221111???1201
?2?2101?223220002????????????20?0?0?????3????1?????????

Enaliornis ?????????????????????????????11????????????????????????21?0??1???
2??
??1?????1??????2?????10122120111012
21111???1201???1101???0120000????????????02????????????????????????

Baptornis_advenus
1??3????????????11???0??111??????0??1?0?10101?021001?11112004010?13020
?100011?0001?0010010?0?????0?????2[12]????0112??0????????????1000000????0
0000100????????????????????????0100012110111001210113101121201110122111
11211201?2?11013221120001????????????02??????????3????00????????

Baptornis_varneri ???021?01?1??1

??
??10????1???1100?210113?????2201?1012
21111211201?2?1101?221220001????????????2????????????????????????????
Vegavis ??2????????
???[56]????????????????10111001001?0[01]20100?01????????????????1100111?
??0????????????????012?1?022110010031111??12301???1?????01??2?????011
21201?1002?2?1????12011???3?1????1???0???????101011???????????23????1????
00?1
Anas
21230113101111111111111112112111?102100001011?10211012111100060120240
2021000201101111010020?22010000121002311100113401110011110003011111010
0001001110123120132111111031011??123110111110101112101131011212011100
2220111211201120130132102200001011101011210101000100023?11?10?1100??
Gallus
1123111311121111111111111112112111?102000001011?10211012111100160120240
2021000201121111010020?2211000012101231101011220111001111000301111110
0011001110113120132102101131011??1211101121101101112101131011212011100
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Xinghaiornis

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Dingavis

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Yuanchuavis

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Cratonavis

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9. Attributes for Public Domain License images for Figure 3

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Dromaeosaurus albertensis (artwork by Pranav Iyer, CC0 1.0 Universal Public Domain Dedication license) <https://www.phylopic.org/images/925f4b74-6f33-4572-bf8d-be0c6d0f0d12/dromaeosaurus-albertensis>