A new stem caecilian from the Triassic of Colorado sheds light on the origins of Lissamphibia

Supporting Information

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Supporting Information – Appendix Figures and Captions

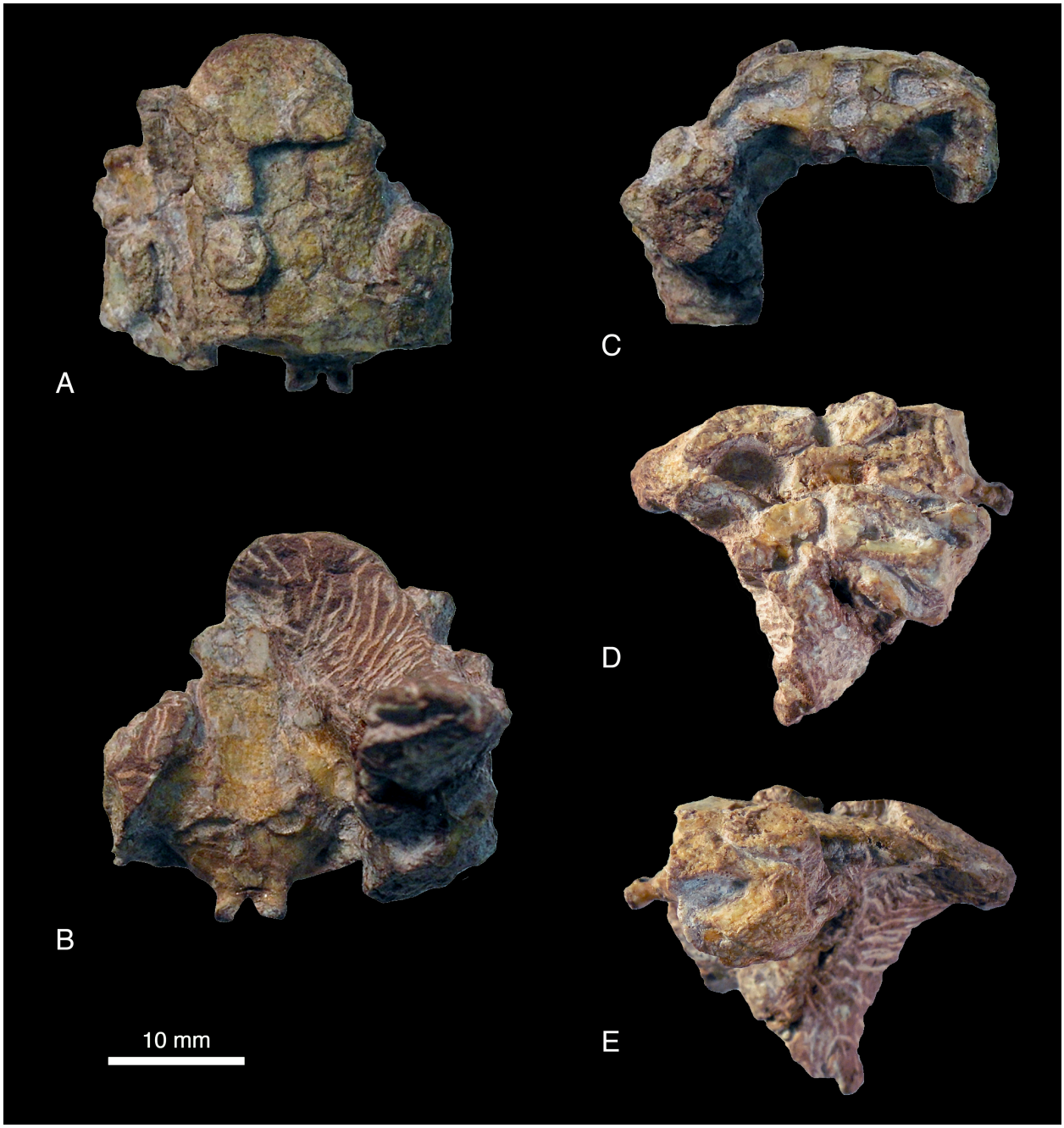

Figure S1. Photograph of *Chinlestegophis jenkinsi* gen. et sp. nov. Holotypic skull (DMNH 56658) in dorsal (*A*), ventral (*B*), occipital (*C*), left lateral (*D*), and right lateral (*E*) views.

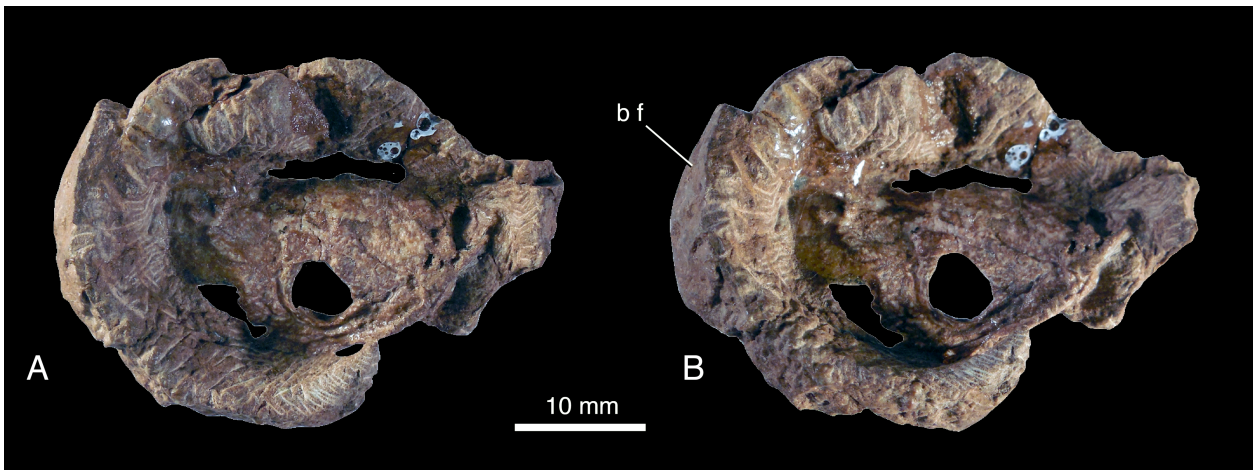

Figure S2. Photograph of *Chinlestegophis jenkinsi* gen. et sp. nov. Referred specimen (DMNH 39033) in burrow shown in dorsal (*A*) and slight oblique dorsolateral (*B*) views. Note that the diameter of the burrow-fill (b f) closely approximates the width of the occupant.

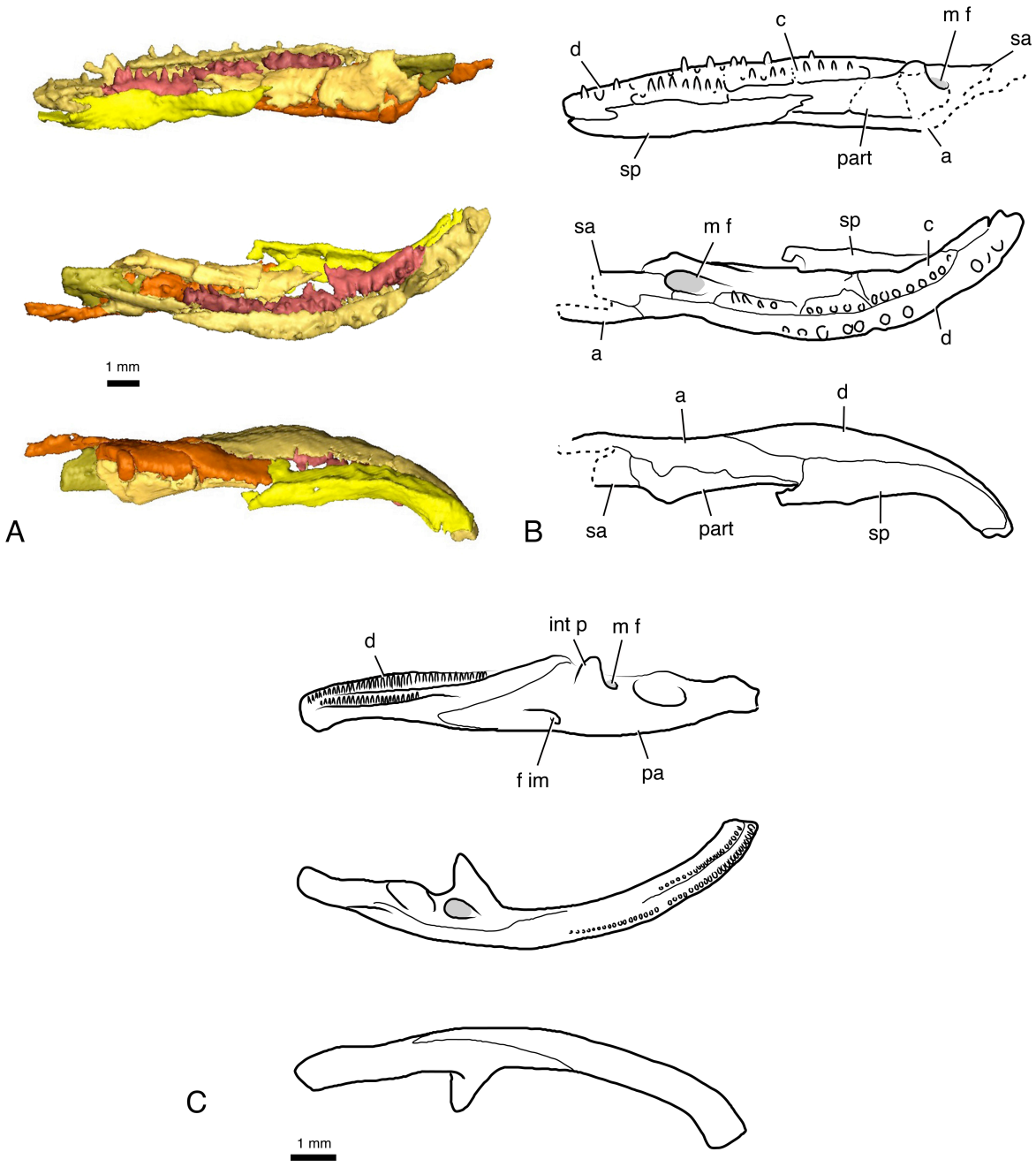

Figure S3. Right lower jaws of *Chinlestegophis* (*A*, *B*) and *Eocaecilia* (*C*) compared. In *A–C* jaws are shown in medial (top), dorsal (middle), and ventral (bottom) views. '*C'* is redrawn from Jenkins et al. (2007). Abbreviations: a, angular; c, coronoid; d, dentary; f im, intramandibular foramen; int p, internal process; m f, mandibular (adductor) fossa; pa, pseudoangular; part, prearticular; sa, surangular; sp, splenial.

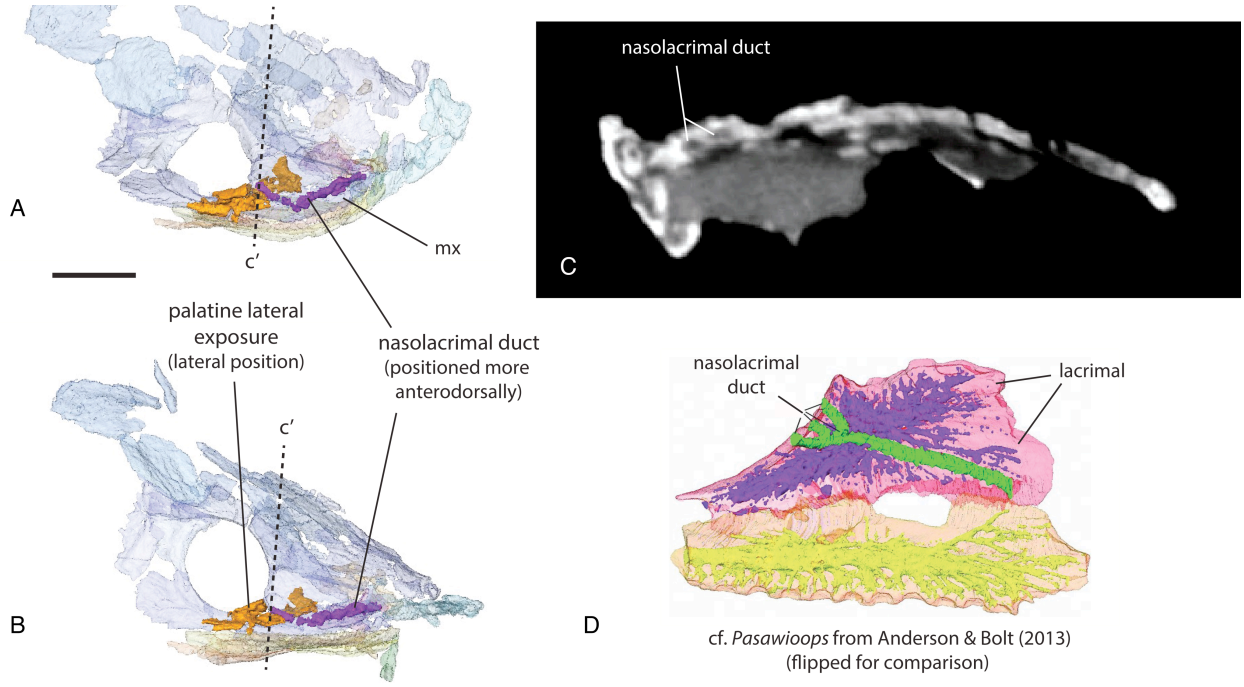

Figure S4. Fate of the lacrimal ossification in *Chinlestegophis*. Position of nasolacrimal duct (purple) and palatine bone (orange) in referred specimen (DMNH 39033) in dorsal (*A*) and lateral (*B*) views, and passage of nasolacrimal duct in maxilla shown in transverse section (*C*). Passage of nasolacrimal duct (green) in lacrimal bone of *Pasawioops mayi* (adapted from Anderson and Bolt, 2013) shown for comparison. Scale is 5 mm in '*A*' and '*B*', dashed line shows approximate position of '*C*', '*C*' and '*D*' not to scale. Abbreviations: mx, maxilla.

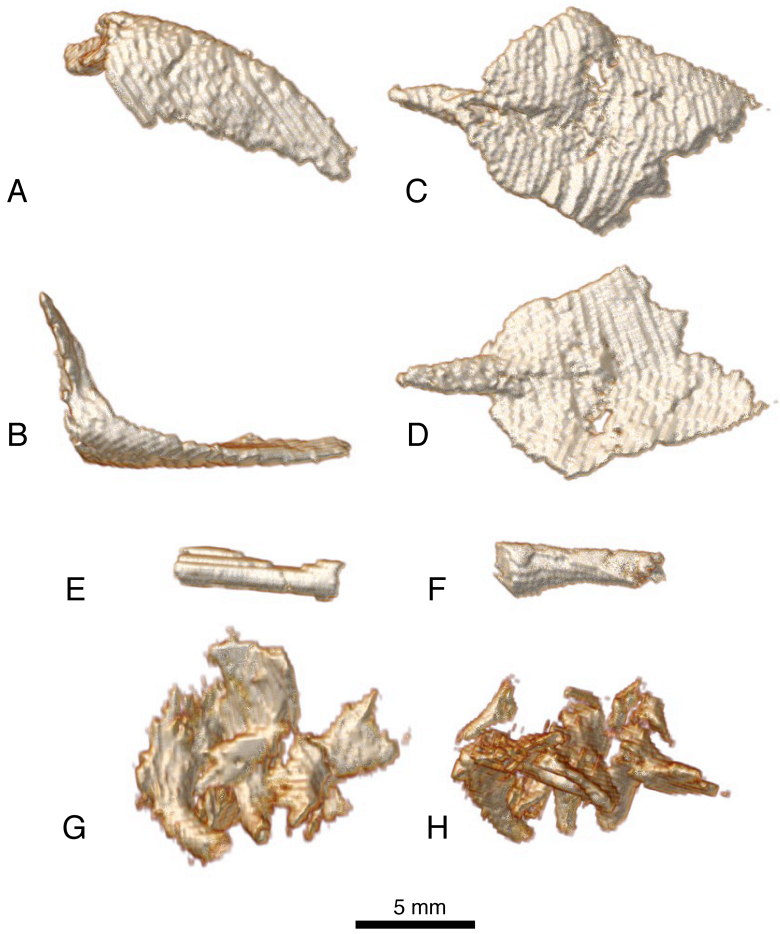

Figure S5. Postcrania of *Chinlestegophis* holotype (DMNH 56658). Right clavicle in ventral (*A*) and lateral (*B*) views (anterior to right). Interclavicle in ventral (*C*) and dorsal (*D*) views. Isolated limb element (ulna?) in lateral (*E*) and medial (*F*) views. Three articulated neural arches lacking their centra in left lateral (*G*) and dorsal (*H*) views (anterior to left).

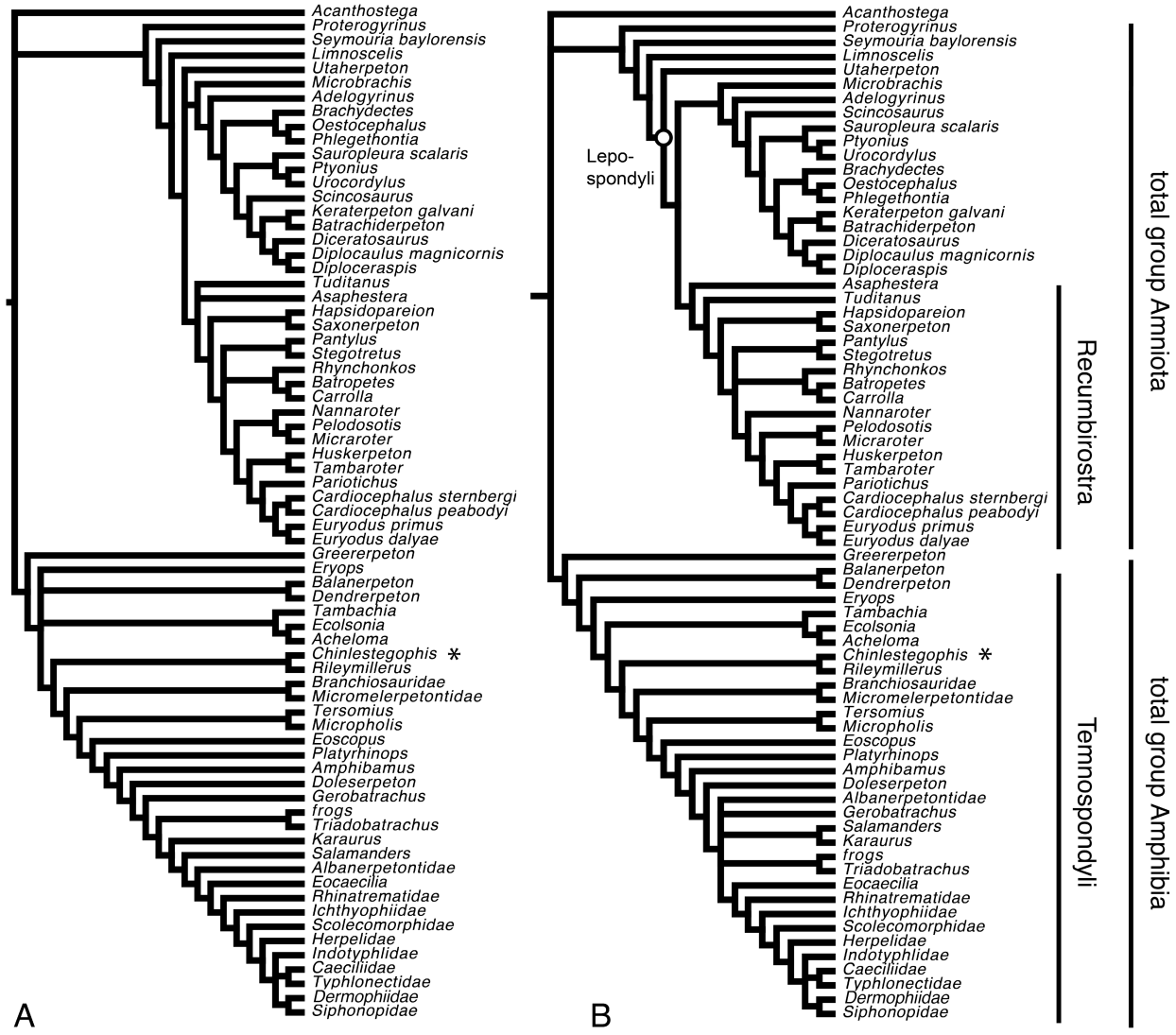

Figure S6. *Chinlestegophis* and *Rileymillerus* added to Maddin et al. data set (no other stereospondyl characters or taxa). Tree topologies from cladistic analysis using the matrix of Maddin (2012b) place *Chinlestegophis* (asterisk) and caecilians outside lepospondyls and within Temnospondyli, but in phylogenetically disparate subclades. Note that no other stereospondyls were included in the original publication, resulting in an undersampling of stereospondyl characters. The two topologies are based on runs using Bayesian (*A*) and parsimony (*B*) analysis in MrBayes and PAUP* 4.0, respectively. Parsimony tree in '*B'* is a strict consensus of 12 equally parsimonious trees (1450 steps).

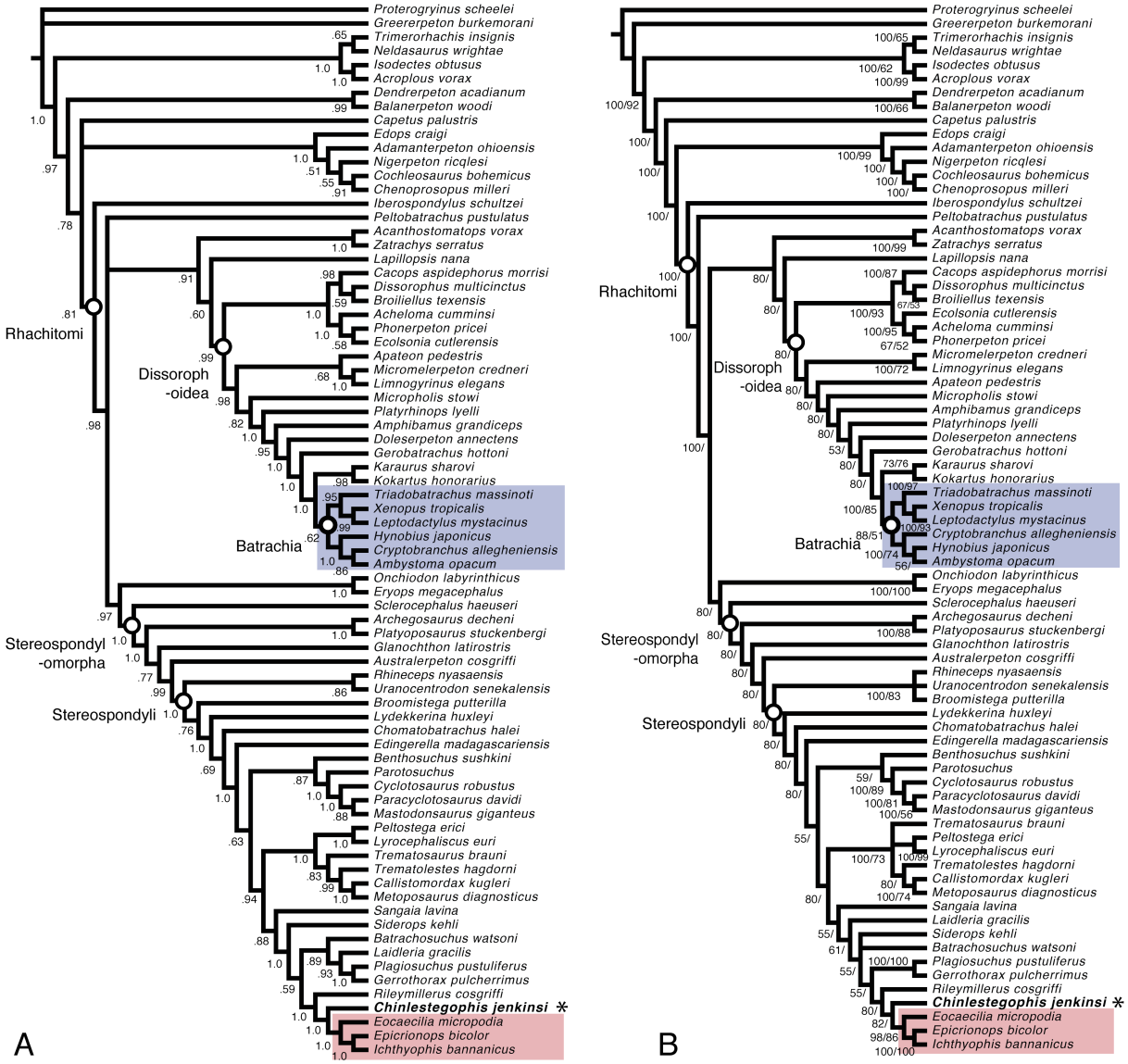

Figure S7. *Chinlestegophis* and *Rileymillerus* added to combined matrix with stereospondyl characters and taxa. Note that analysis combining matrices of Schoch (i.e., with stereospondyls) and Maddin resolve the positions of *Chinlestegophis, Rileymillerus,* and *Eocaecilia* within Stereospondyli. The clade in blue represents early batrachians (frogs and salamanders), whereas that in red represents early caecilian-like stereospondyls, including *Chinlestegophis* as a close sister taxon (asterisk). The two topologies are based on (*A*) Bayesian consensus cladogram from analysis in MrBayes and (*B*) 50% majority rule consensus of 882 equally parsimonious trees (1514 steps) from parsimony analysis in PAUP* 4.0. Bayesian posterior probabilities are shown at nodes in '*A*' and consensus indices (left of virgule) and bootstrap values equal to or greater than 50% (right of virgule) in '*B.*' The complete character list and source matrix is included in Supporting Information Part C & D.

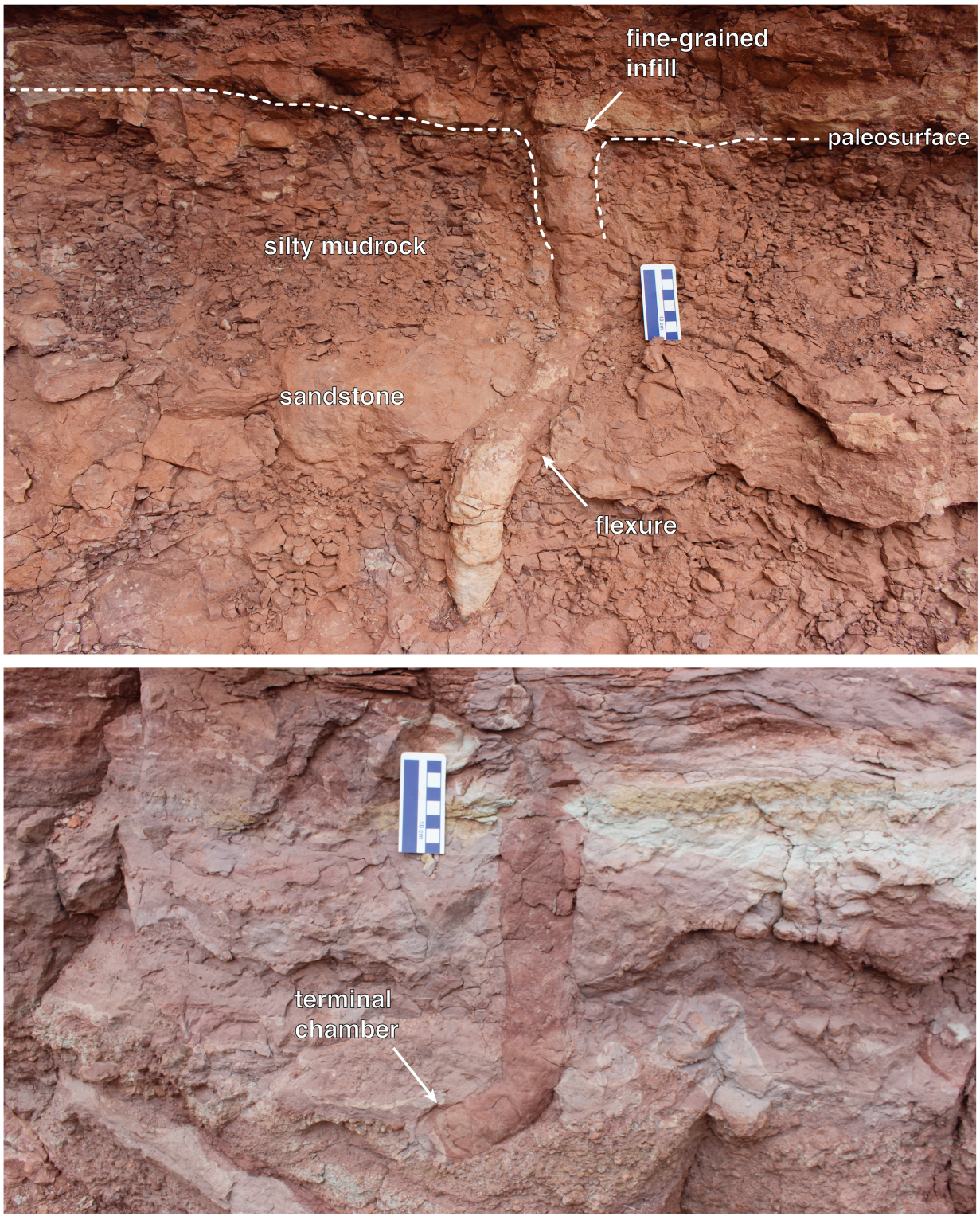

Figure S8. Burrow structures from the Chinle Formation near Derby Junction, Eagle Basin, Colorado.

Appendix – Materials, Methods, Discussion

Part A. Geologic Setting

The specimens (DMNH 56658 and 39033) were collected from the Chinle Formation of the Eagle Basin in northwestern Colorado. The Chinle Formation sediments of Eagle Basin were derived from the Ancestral Rocky Mountains (the Ancestral Front Range and Uncompahgre Uplift), which cut off the Eagle Basin from most of the rest of the Chinle Formation (Stewart et al., 1972; Dubiel, 1992).

The Chinle Formation in the study area consists of steep, bench-forming units composed of complex fluvial sandstones, floodplain mudstones, paleosols, and eolian sands (Dubiel, 1992). The Chinle Formation in the Eagle Basin is divided into two units; the lower Gartra Member, including the Mottled Member of (Stewart et al., 1972), and the informal upper 'red siltstone' member. The Chinle Formation locally sits unconformably on top of the Middle Triassic State Bridge Formation or the Permian Maroon Formation, and is unconformably overlain by the Middle Jurassic Entrada Sandstone (Dubiel, 1992). The temnospondyls of this study were collected from the middle of the informal 'red siltstone' member, in a stratigraphic interval approximately 30–60 meters below the upper contact with the Entrada Sandstone (Small and Martz, 2013).

The holotype (DMNH 56658) was collected by BJS from the Main Elk Creek locality in Garfield County near Newcastle, Colorado. The Main Elk Creek locality is a rich multispecies assemblage of terrestrial vertebrates ranging from isolated elements to disarticulated, associated specimens (Small, 1998, 2001, 2009). The holotype was found in a discrete cluster of small, poorly preserved bones, including ribs and limb elements that are presumed to belong to the holotype. The bones at the Main Elk Creek locality are preserved in a red siltstone/mudstone with small carbonate pebbles probably deposited in an overbank flooding event.

The referred specimen (DMNH 39033) was collected at the Derby Junction locality in Eagle County, Colorado. The Derby Junction locality is a horizon with thin interbedded sandstones, siltstones and mudstones, along with some thicker mudstones, interpreted here as point-bar and flood plain deposits. Fossils here are rare, with shuvosaurid and silesaurid remains, along with some possible isolated phytosaur teeth (Small, 2009).

There are no radioisotopic dates for the Chinle Formation in the Eagle Basin. Direct correlation with members of the Chinle Formation of the Colorado Plateau is not possible due to the isolation of the Eagle Basin by the Uncompahgre Uplift and Ancestral Rocky Mountains. A tentative biostratigraphic correlation with the rest of the Chinle Formation is possible with four taxa recovered from the Eagle Basin.

The dinosauromorph *Dromomeron romeri* (Irmis et al., 2007; Nesbitt et al., 2009) (e.g. DMNH 54826) has been recovered from Main Elk Creek (Small, 2009). The holotype and all referred material of *D. romeri* are from Revueltian age localities in the Petrified Forest Member of the Chinle Formation of New Mexico (Nesbitt et al., 2009).

The leptopleuronine procolophonid *Libognathus sheddi* (Small, 1997) (DMNH 56657) is also known from Main Elk Creek. The holotype and referred material of *L. sheddi* are from Revueltian age localities (possibly upper Adamanian for the holotype) in the Dockum Group of Texas (Small, 1997; Martz, 2008). The other known leptopleuronine procolophonid from the Late Triassic of the western USA is the 'Abajo form' from the Owl Rock Member of the Chinle Formation, also considered Revueltian in age (Fraser et al., 2005).

Numerous bones of a large spiny aetosaur are known from Main Elk Creek (Martz et al., 2003) and are similar to *Rioarribasuchus chamaensis* (Lucas et al., 2006; Parker, 2007). *R. chamaensis* is known from the Revueltian age Petrified Forest Member of the Chinle Formation of New Mexico and Arizona (Parker, 2016).

Small aetosaurs, including *Stenomyti huangae* (Small and Martz, 2013) are also known from the Eagle Basin localities (Small, 1998; Small and Martz, 2013), and are similar to the small aetosaur *Aetosaurus* (Schoch, 2007) and osteoderms of small aetosaurs in the Revueltian age Bull Canyon Formation of New Mexico (Heckert and Lucas, 1998). The shared presence of these taxa suggest that the 'red siltstone' member falls at least partially within the Revueltian land vertebrate faunachron (Nesbitt et al., 2009; Martz, 2008), which is primarily middle–late Norian in age (Parker and Martz 2011).

Part B. Full Description

Tetrapoda Haworth, 1825
Temnospondyli Zittel, 1888
Stereospondyli Zittel, 1887

Chinlestegophis jenkinsi gen. et sp. nov.

Etymology. Jenkins's amphibian-serpent from the Chinle. 'Chinle' for the Triassic Chinle Formation; 'stego-' (Greek) meaning cover or roof, but commonly applied to temnospondyl amphibians and other early tetrapods; '-ophis' (Greek) meaning serpent. Species name honors paleontologist Farish Jenkins whose work on the Jurassic *Eocaecilia* inspired the present study.

Holotype. Denver Museum of Nature & Science **(**DMNH) 56658, partial skull with lower jaw and disarticulated postcrania. Discovered by BJS in 1999 in the Upper Triassic Chinle Formation ('red siltstone' member), Main Elk Creek locality, Garfield County, Colorado (DMNH loc. 1306). The tetrapod assemblage is regarded as middle-late Norian in age (Revueltian land vertebrate faunachron). More specific locality information is on file at DMNH and U. S. Bureau of Land Management.

Referred material. DMNH 39033, anterior skull and partial lower jaw preserved in burrow fill. Also discovered by BJS in 1997 in the Upper Triassic Chinle Formation ('red siltstone' member) of Eagle County, Colorado (DMNH loc. 692).

Diagnosis. Small stereospondyl with a combination of brachyopoid and caecilian characteristics. Unique features: Lateral line sulcus restricted to suborbital margins of jugal and postorbital; parietal-tabular narrowly contact (may be shared with *Compsoceros*); postfrontal anterior process long, forming the majority of the dorsomedial border of the orbit; finger-like process of prefrontal interlocks with notch on postfrontal. Shares with stereospondyls: parasphenoid strongly sutured to pterygoid, supratemporal excluded from otic notch, secondary upper tooth row. Shares with stereospondyls and caecilians: opisthotics fused to exoccipitals. Shares with brachyopoids and caecilians: lacrimal fused to maxilla; two small posterior processes ('horns') on the occipital exposure of the tabular, just posterior to otic notch (as in chigutisaurids). Shares

with *Rileymillerus* and some other small temnospondyls: palatine exposed laterally in ventral margin of the orbit (LEP). Shares with *Rileymillerus* and caecilians: orbits small and laterally directed. Shares with caecilians: double tooth row on mandible; quadrate completely anterior to ear; broad, parallel-sided parasphenoid cultriform process >20% skull width; occipital condyles extend far beyond posterior edge of skull roof; pterygoquadrate. Shares with some other temnospondyls but not caecilians: large, laterally-directed otic notch.

Description

General. The specimens DMNH 56658 and 39033 are semiarticulated skulls with portions of the lower jaw. The holotype, DMNH 56658, also preserves associated postcrania. The restored skull length is approximately 25-30 mm. The skull roof, cheek, and angular portion of the lower jaw bear fine but elaborate sculpturing that is fairly evenly distributed (rather than radiating). The dorsal profile of the skull is narrow and parallel-sided with small, laterally-oriented orbits. The lateral line canals are extremely reduced, limited to the suborbital border, and some circumorbital bones are also highly reduced, particularly the postorbital, which is narrow and falciform. No separate lacrimal is present. The quadratojugal is also either absent or extremely reduced in size and the jaw articulation is in a forward position, well anterior to the occiput. The postorbital region is tall with a steep occiput, producing a wedge-shaped skull in lateral aspect.

Skull roof. The antorbital region in DMNH 39033 is low and bluntly rounded in dorsal view. Lateral line sulci are absent from the anterior skull roof, but are present on the margins of the orbit. The premaxilla is poorly preserved, but can be seen bordering the naris on the right side of the skull. The right external naris preserves its triangular shape and is closely set to the midline. The nasal forms the posterior border of the naris. It is short and broad and bears a sinuous median suture. It is bordered posteriorly by the frontal, laterally by the prefrontal and maxilla, and anteriorly by the naris and premaxilla. The maxilla is missing in the holotype and is incompletely preserved in DMNH 39033 where it is apparently missing the marginal tooth row. The maxilla is preserved as a long, low element that participates in the naris anteriorly and tapers posteriorly to its termination point beneath the palatine and jugal. No details of the maxillary dentition are preserved in either specimen.

The circumorbital bones form a small orbit (< 20% skull length) that is laterally oriented. Anteroventrally, a short, splint-like lateral exposure of the palatine (LEP) is present on the orbital wall. In *Rileymillerus cosgriffi*, a similarly positioned element, also limited to the orbital wall, was interpreted as a LEP by Bolt and Chatterjee (2000) and was reinterpreted as a lacrimal by Schoch (2008) and Martz et al. (2013:fig. 4), although the latter interpretation is less likely given the situation in the closely-related *Chinlestegophis* and new CT scans of *Rileymillerus* by the authors. Although convention would be to recognize these elements as a lacrimal, the bone in *Chinlestegophis* is continuous with a denticulate palatal element and is in the correct location to be an expansion of the dermal palate into the orbital margin (LEP), rather than an ossification that organized around the nasolacrimal canal (lacrimal). Furthermore, the tetrapod lacrimal is characterized by its position between the orbit and naris, where it encloses the nasolacrimal duct. This close relationship between the nasolacrimal duct and the lacrimal is probably inductive, as experiments ablating the nasolacrimal duct placode in hynobiid salamanders appear to prevent formation of the lacrimal bone as well (Medvedeva, 1960). In *Chinlestegophis* the channel likely representing the passage of the nasolacrimal duct is enclosed by the dorsal lamina of the maxilla

(see *SI Appendix* Fig. S4) in similar position to the passage of the nasolacrimal duct in other temnospondyls, such as amphibamids (Anderson and Bolt, 2013). This strongly suggests that the lack of a separate lacrimal is due to fusion of the lacrimal to the maxilla in *Chinlestegophis* (as in caecilians; see Muller, 2006) rather than fusion to the prefrontal (as in salamanders; Lebedkina, 2004) or loss of a lacrimal anlage (as in frogs, Stephenson, 1951).

The jugal forms the entire lateral wall of the orbit and sends a long process to the anterior border of the orbit which sutures to the prefrontal as in brachyopoids. It bears a deep sulcus. Dorsally and medially to the thin LEP, a broad, quadrangular prefrontal forms the anteromedial wall of the orbit. Given the apparent absence of a separate lacrimal, the majority of the anterior margin of the orbit is formed by the prefrontal. As in most temnospondyls, the prefrontal is abbreviated anteriorly and does not contact the external naris. Moreover, the element is at least as broad as it is long, mirroring the condition in *R. cosgriffi*. Posteromedially the prefrontal forms a sutural contact with the postfrontal, forming the orbit's dorsomedial margin and precluding the frontal from contact with the orbit. Most of this margin is formed, however, by the long anterior process of the postfrontal. The postfrontal is also large and quadrangular, but is longer than the prefrontal and extends well posterior to the frontal-parietal suture, nearly to the level of the pineal foramen. Posteriorly, the postfrontal contacts the parietal, supratemporal, and postorbital. The postorbital is a tall, crescent-shaped bone that forms the entire posterior border of the orbit. Its ventrolateral margin bears a slight sulcus that is confluent with that of the jugal, representing the remnants of the circumorbital lateral line canal.

Between the orbits, the frontal is the dominant element. Notably, it is positioned fairly far forward with the frontal-parietal suture located between the orbits rather than at their posterior extent or beyond. The frontal is slightly longer than the nasal, but shorter than the parietal, so that these three elements of the medial series increase slightly in their relative lengths from rostral to caudal. The parietal is long and rectangular with fairly straight sutural connections to communicating bones. The midline suture is also fairly straight. Though slightly damaged in the holotype, a small pineal foramen can be seen on the parietal midline suture about halfway along its length at about the level of the postfrontal-supratemporal contact. The reduced size of the pineal foramen may be reflective of a decreased reliance on light-sensing functions of the pineal organ during the transition to fossoriality (see Supplementary Information Part F, Burrowing in *Chinlestegophis*).

The squamosal is a large, crescentic element that forms the majority of the border of the otic notch. It is bordered anteriorly by the jugal and postorbital, dorsally by the supratemporal and tabular, ventromedially by the pterygoid, and is open posteriorly. The otic notch is large and more laterally directed in comparison to other stereospondyls, located close to the posterior margin of the orbit and is nearly closed-off posteriorly. The dorsal margin of the otic notch is formed by a narrow supratympanic flange that expands posteriorly into a quadrate-directed process. Ventrally, a broad and elongate suture between the squamosal and pterygoid process of the quadrate forms a strongly-developed ridge approximating the semilunar flange of dissorophoids. Unlike many dissorophoids, there is no supratympanic participation of the supratemporal in the otic notch. The supratemporal instead resides dorsally and medially to the otic region, and its circular shape and position are nearly identical to the 'tabular' of *Eocaecilia* (Jenkins et al., 2007). We reinterpret the topologically corresponding element in *Eocaecilia* as a supratemporal, and note its similarly loosely set articulations with surrounding elements (Jenkins et al., 2007:fig. 2). Importantly, Jenkins et al. (2007) note the lack of interdigitating sutures, and

the presence of ventral lappets on the surrounding skull bones that supported this element in *Eocaecilia*, an arrangement also exhibited here in *Chinlestegophis*.

The postparietal and tabular form the rearmost portions of the skull roof. The postparietal is short and broad, roughly rectangular, and is mostly exposed dorsally with only a small occipital flange. It is bordered anteriorly by the parietal, laterally by the tabular, and posteromedially by ascending processes of the exoccipital that bound the foramen magnum. Along with the tabular, it also forms a portion of the roof of the posttemporal fenestra. The tabular is a comparatively broader element that is well exposed both dorsally and laterally. It roofs the rear portion of the otic notch and also forms a portion of its posterior border with a strong semilunate flange. A transverse ridge extends from the postparietal to the tabular, forming an "occipital crest" that delineates the dorsolateral and occipital faces of each element. Posterior to this partition, two modest protuberances project from the occipital face of the tabular. These processes may correspond to a rudimentary tabular horn, but their size and unusual topological relationship to the otic notch makes this homology uncertain. However, it is similar in position to the "tabular horn" of some brachyopoids, particularly *Batrachosuchus* and *Vigilius* (Warren and Marsicano, 2000).

Braincase and occiput. Major portions of the anterior and lateral walls of the braincase are unossified in *Chinlestegophis*. The parabasisphenoid bears a broad basal plate with extensive sutural connections to the pterygoids laterally (forming a strong basicranial girder). Based on the preserved posterior portion in DMNH 56658, the cultriform process is equally broad having a spatulate appearance that is parallel-sided, differing from that of many early stereospondyls where it usually forms an anteriorly tapering wedge. As a result, the interpterygoid vacuities would have been fairly narrow compared to other temnospondyls. The anterior extent of the parasphenoid is not preserved, so that its connection to the vomer cannot be confirmed. There are no denticles on the cultriform process. The sphenethmoid complex is unossified dorsal to the parasphenoid.

The co-ossified exoccipital-opisthotic complex forms the dominant structure of the occiput. These elements appear to be fused ventral to the exoccipital condyles with no obvious midline suture. In general, the left and right portions form a tripartite structure with dorsal, transverse (paroccipital), and anteroventral processes. The dorsal process extends within the synotic tectum where it forms a broad surface dorsal to the foramen magnum and braces against the skull roof (postparietal). The transverse or paroccipital process is a broad, strut-like extension of the crista parotica that extends to the tabular, forming the posterodorsal wall of the stapedial canal. A large posttemporal fenestra is present between the synotic tectum, paroccipital process, and posterior skull roof. The fenestra is relatively large compared to other stereospondyls, approximately double the size of the foramen magnum.

The occipital condyles show the typical stereospondyl condition, formed as paired processes of the exoccipitals having a deeply saddled structure and projecting somewhat posterior to the occiput. The paired articular surfaces appear as flat (rather than convex) facets that are angled somewhat posteromedially.

Palate and splanchnocranium. Few details of the palate of *Chinlestegophis* can be gleaned because the anterior portion of the snout of DMNH 56658 is not preserved and much of the palate is missing in DMNH 39033. However, the posterior portions of both pterygoids are preserved in DMNH 5668 and some elements of the anterior palate can be identified from CT

scans of DMNH 39033. Preserved elements include portions of the vomers, which bear vomerine tusks, palatines, and pterygoids, although the ectopterygoids are absent.

In general, the posterior palate has a strongly vaulted appearance. The pterygoids are preserved in place in the holotype, and resemble most closely brachyopoids (e.g., brachyopids and chigutisaurids). There are no pterygoid teeth or denticles. The palatal rami of the pterygoids are broken on both sides so that their anterior extent and relation to the interpterygoid vacuity cannot be determined. Medially there is an extensive sutural contact with the parabasisphenoid. Dorsally, there is a tall and anteroposteriorly long ascending lamina (dorsal lamina of the quadrate ramus) that contacts a medial flange of the squamosal (visible on both sides in occipital view). On the right side of the holotypic skull, the quadrate ramus maintains its strong posterolateral orientation and preserves a sharp ventral keel. The keel extends well below the floor of the braincase and contributes to the strongly vaulted skull. Notably, the forward position of the pterygoid and its concave posterolateral face suggest a jaw joint that was placed well anterior to the occiput. Moreover, although the cheek is imperfectly preserved in both specimens, CT scans reveal that the posterior ramus of the pterygoid sutures directly to an internal flange of the squamosal on the floor of the otic notch, and is not mediated by contact with a quadratojugal. This condition is suggestive that the quadratojugal was highly reduced or completely absent in *Chinlestegophis*. A separate quadrate is not evident in either side of the skull, but it is likely that the saddle-shaped posterolateral face of the pterygoid represents the articular glenoid, and we hypothesize that this therefore represents a fused pterygoid-quadrate element (pterygoquadrate).

Lower jaw. Large portions of the mandible are preserved in both specimens, including the dentary, splenial, prearticular, portions of the coronoids, angular, and surangular. In general, the size and compliment of bones that make up the mandible (specifically the postdentary bones) are reduced compared to most other Triassic stereospondyls. The dentary is a long, shallow element that is laterally expanded along the region of the tooth row and curves strongly toward the symphysis (resulting in a markedly rounded anterior jaw). Its external surface is relatively smooth-textured with little sculpturing. It is fairly shallow mesially (toward the symphysis) but becomes more deepened distally where it accommodates the postdentary bones on the medial surface. The medial surface, which borders the Meckelian canal, is broadly concave.

On the medial surface of the mandible, a long series of three coronoid elements is preserved in the attributed specimen (disarticulated or absent in the holotype), and bears a row of teeth that are slightly smaller than those in the dentary. The tooth row runs parallel to the marginal dentition resulting in a functional double tooth row as in caecilians (rather than a shagreen of denticles as in most Palaeozoic and Triassic total group amphibians). No postsplenial could be identified ventral to the anterior coronoid in either specimen. The prearticular is extensive, forming the majority of the Meckelian window dorsally, and the splenial forming the ventrolateral portion of the Meckelian canal. Posteriorly, the prearticular broadens toward the coronoid region and its articulation with the surangular, forming the medial border of the mandibular fossa. Though slightly swollen mediolaterally, this region lacks the internal process that is developed in *Eocaecilia*. The angular is situated ventral and lateral to the prearticular and makes up a large portion of the mandible in lateral view. It is deeper than the dentary and bears rugose sculpturing. The dorsal contact with the surangular is difficult to discern, but probably was positioned high on the jaw behind the dentary as in *Rileymillerus* (Bolt and Chatterjee, 2000:fig. 4) and *Callistomordax* (Schoch, 2008:fig. 1). Though poorly preserved, the surangular appears to have been extremely reduced.

Dentition. The present dental description is limited to the lower (mandibular) dentition, as most of the dentigerous elements of the upper jaw are poorly preserved or absent. There are at least 13 dentary teeth and probably more, but the posterior extent of the tooth row is not well preserved. The marginal teeth appear as tiny, isodont cones that are subequal in size. They lack any clear indication of heterodonty or bicuspidity. A dividing zone between pedicel and crown is not evident, but this may be a result of insufficient resolution of the CT data, or presence of a pedicel without a true dividing zone, a distinction which must be made histologically. CT scans of the holotypic jaw show small accessory teeth anteriorly in the dentary that are closely associated with the anteriormost marginals, suggesting the presence of symphysial tusks. Just medial to the marginal dentition, a second tooth row is present on the coronoid elements. The row parallels that of the dentary. The individual teeth are also isodont cones that are similar in size to the marginals but slightly smaller. These formed a complete functional second tooth row, in contrast to the condition observed in most stereospondyls, where the coronoid dentition is restricted to the posteriormost coronoid, or is comprised solely of a denticle shagreen.

Postcrania. A limited amount of postcranial material is preserved in the holotype, including the dermal components of the pectoral girdle, an isolated limb element, several vertebrae, and a number of ribs (*SI Appendix* Fig. S5). The pectoral girdle consists of interclavicle and paired clavicles. The interclavicle is diamond-shaped but narrow, with a short posterior stem. The clavicles have large triangular dermal plates with a narrow stem, as in other temnospondyls. Vertebral arches are present with well-developed transverse processes and a high neural spine. Centra are not preserved.

Part C. Phylogenetic Character List

List of 345 craniodental and postcranial characters used in the complete analysis (with stereospondyls included). Characters 1–212 correspond to those from Schoch (2013), characters 213–309 (A1–A217) correspond to those from Anderson et al. (2008), and characters 310–312 (H220–H227) correspond to those added by Huttenlocker et al. (2013) (with invariant characters removed (e.g., those corresponding to Lepospondyli which were excluded) and redundant characters from 1–212 omitted in all cases). Characters 314–340 (M1–M112) correspond to those added by Maddin et al. (2012a). Characters N2–N5 were added by Maddin et al. (2012b) and N6–N8 are new. Some codings for *Eocaecilia* were modified from Maddin et al. (2012b) due to reinterpretation of "tabular" element as the supratemporal (see included NEXUS script).

Skull roof characters (from Schoch, 2013)

1. Skull (outline). Parabolic (0), or triangular with pointed tip (1).
2. Skull (height). Skull of variable height, but occiput always deeper than snout (0), or extremely flattened to equal height throughout (1).
3. Ornament (elements). Reticulate ridges of various sizes (0), or isolated pustules (1).
4. Ornament (snout). Polygons or short grooves (0), or mostly radial, elongated grooves (1).
5. Ornament (general). Shallow ridges of variable height (0), or high ridges throughout (1).

6. Ornament (intensive growth). Elongated ridges (‘zones of intensive growth’) confined to snout only (0), or prepineal growth zone established on extended anterior parietal and postorbital (1).
7. Ornament (preorbital). Zone of subdued ornament on the medial skull bones adjacent to the midline suture absent (0), or present (1).
8. Spines. Absent (0), or present along lateral flank of quadratojugal (1).
9. Preorbital region (length). Less than twice the length of posterior skull table (0), or more (1).
10. Premaxilla (alary process). Absent (0), or present, forming a posterior hook-like indentation (1).
11. Premaxilla (prenarial portion). Short (0), or very expanded, equalling the length of the frontal (1).
12. Premaxilla (outline). Parabolically rounded (0), or box-like and anteriorly blunt (1).
13. Premaxillary foramen. Premaxilla and nasal completely sutured (0), or medially bearing an opening separating the two alary processes of the premaxilla (1).
14. Premaxillary fontanelle. Premaxillae with or without small opening (0), or encircling large fenestra extending posteriorly between the nasals (1).
15. Snout (internarial distance). Narrower than interorbital distance (0), or wider (1).
16. Nasal (width). Nasal longer than wide (0), or as wide as long (1).
17. Naris (position). At lateral margin of snout, opening laterally (0), or set well medially, opening anteriorly (1).
18. Naris (extension). Naris uniform, with oval shaped margin (0), or posteriorly expanded with distinct anterior and posterior regions giving external overall “key-hole” shape (1).
19. Naris (flange). Ventral (inner) side of prefrontal, lacrimal, and nasal smooth (0), or bearing a complicated bar-like structure (narial flange) permitting contact with the antorbital bar (1).
20. Nasal (lateral margin). Straight (0), or stepped, with lateral excursion anterior to lacrimal (1).
21. Lacrimal. Present (0), or absent (1).
22. Lacrimal (lateral suture). Parallels medial suture (0), or lateral suture posterolaterally expanded to give broader preorbital region (1).
23. Lacrimal (position). Extending anterior to orbit (0), or confined to lateral orbit margin (1).
24. Lacrimal (posterior extension). Restricted to the antorbital region (0), or extending back lateral to orbit (1).
25. Orbit and naris. Well separated (0), or separated only by tiny quadrangular lacrimal (1).
26. Orbit location. Medial, framed by wide jugals laterally (0), or lateral emplacement, framed by very slender jugals (1).
27. Orbit margins. Raised well above skull plain (0), or flush with roof (1).
28. Palpebral ossifications. Ossifications in orbit restricted to sclerotic ring (0), or numerous additional ossicles at medial margin of sclerotic ring (1).
29. Pineal foramen. Present (0), or absent in adults (1).
30. Interorbital distance. Narrower than or equalling orbital width (0), or wider (1).
31. Frontal-nasal (length). Frontal as long or longer than nasal (0), or shorter (1).
32. Frontal-nasal (suture). Level with or anterior to the orbit margin (0), or further posterior (1).

33. Lateral line sulci (adults). Present (0), absent (1).
34. Sulci (skull roof). Throughout skull roof if present (0), or confined to circumorbital region (1).
35. Infraorbital sulcus. With simple curve on lacrimal (0), or with pronounced S-shaped lacrimal flexure (1).
36. Supraorbital sulcus. Passing entirely through nasal (0), or entering prefrontal and lacrimal (1).
37. Maxilla (anterior margin). Straight (0), or laterally convex due to enlarged teeth (1).
38. Maxilla (contact to nasal). Absent, separated by lacrimal (0), or present (1).
39. Prefrontal-frontal. Prefrontal substantially longer than frontal (0), or ending at one level with frontal (1).
40. Prefrontal (anterior end). Pointed (0), or wide and blunt (1).
41. Prefrontal (lateral suture). Straight or concave (0), or with marked medial projection of jugal near the orbit (1).
42. Prefrontal-postfrontal. Sutured (0), or separated by frontal (1).
43. Prefrontal (process). Prefrontal-lacrimal suture simple (0), or prefrontal underlying lacrimal laterally to reach the palatine (1).
44. Prefrontal-jugal. Separated by lacrimal (0), or in contact (1).
45. Prefrontal-maxilla. Separated by lacrimal (0), or in contact (1).
46. Posterior skull table (length). More than 0.6 times the width (0), or less than that (1).
47. Postorbital (shape). Long triangular, wedged deeply between squamosal and supratemporal (0), or short (1).
48. Postorbital (end). Posterior end acutely triangular (0), or with finger-like projection (1).
49. Postorbital. Not wider than orbit (0), or with substantial lateral process projecting into jugal (1).
50. Postorbital, postfrontal. Shorter than supratemporal and parietal (0), or as long or longer (1).
51. Otic notch. Semicircular embayment between squamosal and posterior skull table (0), or straight transverse posterior skull margin without embayment between cheek and table (1).
52. Otic notch (position). Lateral, expanding along entire cheek to form continuous unornamented area up to quadrate (0), or slit-like (1), or small and rounded, confined to dorsomedial part of squamosal (2).
53. Supratemporal. Longer than wide (0), or quadrangular, giving a foreshortened posterior skull table (1).
54. Supratemporal (width). Rectangular, with straight sagittal lateral margin (0), or posterolaterally constricted by expanded otic notch (1).
55. Supratympanic flange. Squamosal continuously ornamented around margin of otic notch (0), or squamosal having dorsally exposed and ornamented area (supratympanic flange) stepping abruptly into steeply aligned, poorly ornamented portion (1).
56. Semilunar flange. Supratemporal without ventral projection into otic notch (0), or supratemporal forming marked ventral flange participating in medial bordering of otic notch (1).
57. Jugal (ventral process). No ventral outgrowth (0), or insula jugalis framing subtemporal window (1).

58. Jugal (anterior extension). Jugal ending at or behind level of anterior orbit margin (0), or extending anteriorly (1).
59. Jugal-lacrimal. In contact (0), or separated by orbit or palate bones (1).
60. Intertemporal. Present (0), absent (1).
61. Intertemporal and postorbital. Postorbital lateral to postfrontal (0), or expanding medially to replace intertemporal, contacting parietal (1).
62. Squamosal-tabular (dorsal). Separated by supratemporal (0), or sutured (1).
63. Tabular and squamosal. Forming either squamosal embayment or straight posterior margin (0), or projecting posteriorly, with tabular extended posterolaterally (1).
64. Squamosal (falciform crest). Posterior rim of squamosal straight (0), or with convex projection, referred to as falciform crest (1).
65. Tabular (horn). Present in some form (0), or entirely absent (1).
66. Tabular (extension). Tabular horn pointing posteriorly if present (0), or aligned laterally (1), or sutured with squamosal posterior to otic notch (cyclotosaur condition) (2).
67. Tabular (ventral crest). Absent (0), or present and shallow (1), or forming a deep ridge that almost doubles the thickness of the tabular in occipital view (2). These character-states were ordered.
68. Quadratojugal (medial process). Absent (0), or present (1).
69. Quadratojugal-maxilla. In contact (0), or separated by jugal (1).
70. Quadrate (dorsal process). Absent (0), or present (1).
71. Posterior skull rim. Quadrate trochlea posterior to tabular horns (0), or at one level or anterior (1).
72. Occipital flange. Descending flange of occipital portion of postparietals forming a bulge (0), or long smooth blades as long as the dermal portion of the postparietal (1).
73. Postparietal-exoccipital. No contact (0), or pillar-like dorsal process of exoccipital firmly sutured to ventral side of postparietal and oblique process of exoccipital sutured with ventral ramus of tabular (1).
74. Postfenestral window. Large opening, having at least double the width of the foramen magnum (0), or reduced to a tiny foramen (1).
75. Quadrate and occipital condyles. Quadrate condyles posterior to occipital ones (0), or at same level (1), or well anterior (2).
76. Epipterygoid. Simple rod-like ascending process (0), or complicated and robust element with up to six processes (1).

Dental characters (from Schoch, 2013)

77. Dentition (marginal). Heterogenous, varying sizes and distances (0), or homogeneous, small teeth, equidistant (1).
78. Dentition (upper jaw). Conical to slightly curved inwards (0), or caniniform (1).
79. Dentition (marginal, tooth bases). Round or oval (0), or forming transversely broadened ovals (1).
80. Palatal tusks (cross-section). Round or oval (0), or laterally compressed and keeled at least on one side (1).
81. Dentition (vomer). Tooth patches present at least in small specimens (0), or dentition entirely restricted to vomerine fangs (1).
82. Pedicely. All teeth formed consisting of a single mineralized conus (0), or at least some teeth with two separate mineralization centres (pedicellate) (1).

83. Bicuspidity. All teeth with single tip (0), or at least some with bicuspid crowns (1).
84. Labyrinthodonty. Teeth with labyrinth infolding of dentine and enamel at base (0), or never labyrinthodont (1).
85. Transverse tooth row (transvomerine). Absent (0), present and transverse (1), V-shaped (2).
86. Additional vomerine fangs. Vomer with a single pair of fangs at the medial margin of choana (0), or with additional fangs/fang pairs posteromedially (1).
87. Parasphenoid (shagreen). Tooth patches present (0), or teeth entirely absent (1).
88. Ectopterygoid (fangs). Present (0), or absent (1).

Palatal and braincase characters (from Schoch, 2013)

89. Interpterygoid vacuities. Slender and slit-like (0), or rounded, oval openings (1).
90. Interpterygoid vacuities, pterygoid. Vacuities rounded bordered by moderately concave pterygoid (0), or laterally greatly extended at mid-level pushing pterygoid to the margin (1).
91. Anterior palatal opening(s). Vomer and premaxilla with continuous suture (0), or perforated to accommodate symphyseal fangs (1).
92. Anterior palatal opening(s). Unpaired if present (0), or paired (1).
93. Vomer. Narrow and small (0), or large plate, widely separating choanae (1).
94. Vomer (paired anterior depressions). Absent (0), or present (1).
95. Anterior palatal depression. Posterior rim round if present (0), or straight transverse (1).
96. Vomerine ridges. Absent (0), or present, radiating from vomerine tusks anteriorly (1).
97. Vomerine pit and fontanelle. Absent (0), or pit present (posterior to mandible) (1), or fenestra within such pit (2).
98. Vomerine septum. Absent (0), or present (1).
99. Choana (lateral). Anterolaterally expanded with triangular outline (0), or oval (1).
100. Choana (medial). Medial margin straight or gently convex (0), or anteromedially expanded giving choana a reniform outline (1).
101. Choana (width). Elongated oval to slit-like (0), or wide round (1).
102. Vomer-pterygoid. Sutured (0), or separated by palatine (1).
103. Vomer (anterior part). Anterior portion shorter than behind anterior level of choana (0), or as long or longer (1).
104. Vomer (extension). Vomer contacts pterygoid lateral to choana (0), or expanding posteriorly (1).
105. Basipterygoid ramus. Pterygoid with short, posteromedially curved basipterygoid process, constricting palatal vacuities posterolaterally (0), or with transversely extended process producing posteriorly wider vacuities (1).
106. Basicranium (contact). Joint between basal plate and pterygoid (0), or sutural contact (1).
107. Basicranium, suture. Suture (if present) much shorter than basal plate, reaching at best 40% its length (0), or suture almost as long as basal plate (1).
108. Parasphenoid. Suturing with exoccipitals (0), or underplating exoccipitals (1).
109. Basicranium (carotids). Internal carotids entered basicranium ventrally near base of cultriform process (0), or at posterolateral corner of bone (1).
110. Parasphenoid plate. Basal plate sagittally rectangular (0), or quadrangular to wider than long (1), or much abbreviated, transversely rectangular (2).

111. Parasphenoid plate (size). Basal plate at level posterior to basicranial joint substantially narrower than parietals (0), or as wide or wider (1).
112. Cultriform process (width). Base not wider than rest, clearly set off from basal plate (0), or merging continuously into plate (1).
113. Cultriform process (structure). Ventrally flat (0), or with ridge emplaced on broader base (1), or knife-edged and keel-shaped (2).
114. Cultriform process (outline). Of similar width throughout (0), or posteriorly expanding abruptly to about twice the width (1).
115. Cultriform process (dentition). Main shaft edentulous except for base (0), or with elongate tooth patch (1).
116. Parasphenoid (posterolateral process). Posterolateral margin straight (0), or with lateral wing (1).
117. Pterygoid (ventral ornament). Palatine ramus of pterygoid smooth (0), or ornamented with reticulate ridges (1).
118. Pterygoid, exoccipital. No contact (0), or sutured lateral to parasphenoid (1).
119. Pterygoid, basioccipital. No contact (0), or sutured lateral to parasphenoid (1).
120. Pterygoid, squamosal. Entirely sutured (0), or with open fissure (1).
121. Pterygoid (flange). Palatine ramus of pterygoid merging continuously into basipterygoid ramus (0), or broadening abruptly to form transverse flange (1).
122. Pterygoid width. Palatine and quadrate regions forming slender rami (0), or broad shelves (1).
123. Pterygoid, ectopterygoid. Palatine ramus exclusively formed by pterygoid (0), or with posteromedial projection of ectopterygoid.
124. Pterygoid-palatine-ectopterygoid. Pterygoid contacting both ectopterygoid and palatine (0), or pterygoid only in contact with ectopterygoid (1).
125. Palatine, ectopterygoid. With simple, transverse suture (0), or palatine with posterolateral process excluding the ectopterygoid from interpterygoid vacuity and contacting pterygoid (1).
126. Palatine, vomer. Suture aligned posterolaterally (0), or with medial wing framing the interpterygoid vacuity anteriorly (1).
127. Palatine (laterally exposed palatine, LEP). Absent (0), or present (1).
128. Palatine, ectopterygoid (ontogeny). Maintain their width (0), or become proportionally wider (1).
129. Palatine, ectopterygoid (width). Much wider than maxilla (0), or as narrow (1).
130. Palatine, ectopterygoid (continuous tooth row). Absent (0), or present (1).
131. Ectopterygoid (length). As long or longer than palatine (0), or markedly shorter (1).
132. Ectopterygoid (laterally exposed ectopterygoid, LEE). Absent (0), or present (1).
133. Ectopterygoid (Y-shaped). Ectopterygoid with continuous maxillary suture (0), or Y-shaped, with posterior half separated from maxilla by a gap (1).
134. Palate structure. In occipital view, pterygoids either sloping continuously ventrolaterally or flat horizontal (0), or vertically curved ventrally at right angle with basicranium (1).
135. Quadrate trochlea. Medial bulge only slightly larger than lateral one (0), or being at least two times longer and twice as wide (1).
136. Occipital condyle. Trilobed, with basioccipital forming ventral part of facet (0), or bilobed exoccipital condyle with reduced basioccipital contribution (1).

137. Exoccipital condyles. Short and broad base, projecting only with their posterior half behind the rim of the skull table (0), or almost the complete element posterior to level of occipital flange (1).
138. Basioccipital (length). Forming a long element posterior to parasphenoid plate (0), or foreshortened to a narrow posterior rim of the palatal bone (1).
139. Dentigerous palatal ossicles. Absent (0), or present within interpterygoid vacuities (1).

Mandibular characters (from Schoch, 2013)

140. Postglenoid area. Absent or present as very faint outgrowth (0), or longer than glenoid facet (1).
141. Postglenoid area (types). Type 1 (0), or type 2 (1).
142. Postglenoid area (dorsal). Plain (0), or with elongated groove (1).
143. Hamate process. Absent (0), or present but lower than postglenoid portion is long (1), or as high as retroarticular process (2).
144. Preglenoid process. Labial side of surangular with straight dorsal margin anterior to glenoid (0), or forming dorsal projection well above the level of the glenoid articulation (1).
145. Meckelian window. Small round or oval opening (0), or elongate window shorter than the adductor fossa (1), or as long or longer than adductor fossa (2).
146. Symphyseal teeth. No accessory teeth posterior to symphyseal tusks (0), or a transverse row of such teeth (1).
147. Posterior coronoid teeth. Present (0), or absent (1).
148. Anterior, middle coronoid teeth. Present (0), or absent (1).
149. Mandibular osteoderms. Throat region naked (0), or covered with a mosaic of ventral osteoderms between mandible and dermal pectoral girdle (1).

Splanchnocranium and suspensorium characters (from Schoch, 2013)

150. Stapes (quadrate process). Absent (0), or present (1).
151. Stapes (ventral process). Absent (0), or present, giving the proximal region two heads (1).
152. Stapes (shape). Robust, tetrahedral bone with substantial quadrate process (0), or rod-like element with elongated stylus (1), or blade-like (2).
153. Stapes (curvature). Stapes with pronounced dorsodistal curvature (0), or abbreviated without such curvature, directed laterally towards vertically aligned otic notch (1).
154. Ceratobranchials. Bony elements absent (0), present in adults (1).
155. Basibranchial. Bony element absent (0), present in adults (1).
156. Hypobranchial elements. Bony elements absent (0), present in adults (1).
157. Branchial denticles. Conical and attached to small ossicles in groups of 2–10 (0), or free and with brush-like end (1).

Postcranial characters (from Schoch, 2013)

158. Presacral count. More than 28 (0), or 23-25 vertebrae (1), or less than 21 (2).
159. Caudal count. Similar to presacral count or higher (0), or much lower (1).
160. Transverse process (orientation). Short, directed posteriorly (0), or distally extended with diapophysis pointing laterally (1).
161. Transverse process (length). Shorter than dorsal spine is high (0), or markedly longer (1).
162. Neural spine (height). As high as distance between zygapophyses (0), or higher (1).

163. Intercentrum (shape). Presacral intercentra form simple wedges (0); or dorsally closed discs (1); or dorsally closed and elongated cylinders (2).
164. Intercentrum (width). Chordal canal wider than intercentrum high (0), narrower (1).
165. Intercentrum (ventral surface). Ventral surface shorter than wide in ventral view, giving transversely rectangular outline (0), or as long as wide, quadrangular (1).
166. Intercentrum anterior surface. Always concave (0), or convex at least in some presacral centra (1).
167. Parapophysis. Segmental (0), or intersegmental (1).
168. Pleurocentrum (presence). Ossified (0), unossified (1).
169. Pleurocentrum (lateral surface). As large as that of intercentrum (0), or smaller (1).
170. Pleurocentrum (ventral extension). Wedged between successive intercentra and not reaching ventral margin of intercentra (0), or pleurocentra ventrally expanded to near each other (1), or ventrally fused to form a single cylindral element (2).
171. Ribs (length). Moderately elongate thoracic ribs curved distoventrally (0), or such ribs foreshortened without distal curvature (1).
172. Ribs (ventral extension). Rib heads (tuberculum and capitulum) confluent (0), or clearly set off and widely separated in mid-trunk region (1).
173. Ribs (uncinate blades). If present, small and spine-like (0), or extensive and blade-like (1).
174. Ribs (uncinate spines). Short (0), or elongated, as long as shaft (1).
175. Cleithrum. With broadened dorsal head region (0), or a simple rod (1).
176. Cleithrum. Head with slightly convex or straight anterior rim (0), or with pronounced anterior projection (1).
177. Cleithrum. Dorsal head region confined to anterior rim of scapula (0), or posteriorly extended to cover dorsal rim of scapula (1).
178. Clavicle (ventral blade). Wide, triangular, overlapping interclavicle broadly (0), or slender, with minor overlap (0).
179. Interclavicle (length). Shorter than posterior skull (0), or substantially longer (1).
180. Interclavicle (ontogeny). Without major proportional change in ontogeny (0), or decreasing proportionally relative to skull length (1).
181. Interclavicle (central ornamented area). Rhomboidal (0), or pentagonal and posteriorly widest (1).
182. Interclavicle (proportions). As long as wide (0), or 1.3 times as long as wide (1), or more than twice as long as wide (2).
183. Interclavicle (posterior margin). With posterior process (0), or transversely straight (1).
184. Interclavicle (anterior margin). Serrated (0), or smooth (1).
185. Interclavicle (anterior stylus). Anterior portion of interclavicle variably shaped but not longer than posterior one, as measured by the centre of ornamentation (0), or substantially longer than posterior one (1).
186. Interclavicle (posterior stylus). Posterior end rounded or blunt (0), or with elongated stylus or parasternal process (1).
187. Interclavicle, clavicles. Clavicles broadly separated by interclavicle ventrally (0), or leaving only narrow strip of interclavicle in between (1), or in contact and excluding anterior part of interclavicle from ventral exposure (2).
188. Scapula (glenoid facet). Ossified (0), or unossified in adults (1).

189. Scapula (height). Maximally two times longer (higher) than wide (0), or dorsally extended and fully ossified, three times higher than wide (1).
190. Humerus (ontogeny). Short cylinder in larvae, elongates at slow rate (0), or with substantial shaft in larvae (1), or very long rod from small stages on (2).
191. Humerus (adult shaft). No shaft proper, humerus blade-like in cross-section (0), or with short shaft oval in cross-section (1), or shaft elongate and slender, comprising more than 50% of the humerus with rounded cross-section (2).
192. Humerus (entepicondylar foramen). Present (0), or absent (1).
193. Humerus (supinator). Present (0), or absent (1).
194. Humerus (condyles). Distal end at least partially ossified with identifiable condyles (0), or unfinished without condyles (1), or with fully established condyles (2).
195. Humerus (torsion). Strong, 70-90° (0), or weak, well below 60° (1).
196. Carpals. All unossified (0), or all at least some ossified (1).
197. Manual digit count. Five (0), or four (1).
198. Ilium (shaft). Shaft of variable length but laterally flattened (0), or very long and slender (1).
199. Ilium (dorsal end). Tip of dorsal end continuous (0), or much broadened (1).
200. Ilium (height). Shaft more than twice the length of the base (0), or shorter (1).
201. Ilium (orientation). Main axis of shaft inclined posterodorsally (0), or vertical (1).
202. Ilium (tip). Dorsal end two-headed (0), or single-headed (1).
203. Pubis. Unossified (0), or ossified (1).
204. Femur. Intercondylar fossa forming deep and elongated trough (0), or reduced to short depression (1).
205. Femur (trochanter). Internal trochanter present as discrete process (0), or reduced to a shallow crest (1), or greatly enlarged to form a massive projection (2).
206. Tarsals. At least some are ossified (0), or all unossified (1).
207. Gastral squamation. Ossified ventral dermal scales (0), or scales absent (1).
208. Squamation. Dermal scales oval to spindle-shaped (0), or broad-oval with “microsaur-type” ornament (1).
209. Osteoderms. Absent (0), or present as single row (1), or more numerous to form a carapace (2).
210. Osteoderms (articulations). Simple set of osteoderms arranged in one layer if present (0), or double set of two layers, the ventral one fused to the tip of the neural arch (1).
211. Osteoderms (width). An intra-dissorophid character: Narrow median osteoderms (0), or transversely extended plates (1).
212. Rib cage. Trunk narrower than skull or as wide (0), or trunk substantially wider than lateral margin of cheeks at about mid-level (1).

Characters sampled from Anderson et al. (2008) A1–A217

213. [A1.] Basal skull length. >70mm (0), 50-70mm (1), 30-50mm (2), <30mm (3).
214. [A2.] Skull to trunk. >=0.45 (0), 0.30-0.45 (1), 0.20-0.29 (2), 0.20 (3).
215. [A3.] Skull proportions. Longer than wide (0), wider than long (1).
216. [A5.] Supratemporal. Present (0), absent (1).
217. [A6.] Supratemporal exposure on occiput. Absent (0), present (1).
218. [A9.] Postfrontal shape. Broadly quadrangular (0), falciform (1).
219. [A14.] Lacrimal-naris contact. Present (0), absent (1).

220. [A15.] Lacrimal contribution to orbit. Absent (0), present (1).
221. [A16.] Lacrimal orbital processes. Only ventral present (0), dorsal and ventral present (1), neither present (2).
222. [A18.] Quadratojugal. Present (0), absent (1).
223. [A21.] Frontals. Paired along midline (0), fused (1).
224. [A22.] Frontal contribution to orbit. No (0), yes (1).
225. [A28.] Septomaxilla. Ossified (0), unossified (1).
226. [A29.] Prefrontal contributes to external naris. Distant from (0), near (1), present (2).
227. [A30.] External naris in dorsal view. Exposed (0), not exposed (1).
228. [A34.] Posterior skull margin. Concave (0), straight (1), convex (2), undulating (3).
229. [A39.] Large otic notch approaching orbit. Absent (0), intermediate (1), close (2).
230. [A45.] Postorbital. Present (0), absent (1).
231. [A48.] Shape of postorbital. Irregular trapezoid (0), triangular, apex caudal (1).
232. [A50.] Parietal-postorbital contact. Absent (0), present (1).
233. [A51.] Parietal-squamosal contact. Absent (0), present (1).
234. [A52.] Parietal-tabular contact. Absent (0), present (1).
235. [A53.] Postparietals. Paired (0), fused (1), absent (2).
236. [A56.] Postparietal-squamosal contact. Absent (0), present (1).
237. [A57.] Postparietal length. Large, quadrangular (0), abbreviated anteroposteriorly, elongate lateral rectangle (1).
238. [A58.] Squamosal-jugal contact. Present (0), absent (1).
239. [A59.] Tabular. Present (0), absent (1).
240. [A68.] Maxilla into external naris. Present (0), absent (1).
241. [A69.] Maxilla forms entire ventral naris. Absent (0), present (1).
242. [A74.] Number of premax teeth. >=10 (0), 5-9 (1), <5 (2).
243. [A75.] Number of max teeth. >=30 (0), 20-29 (1), <20 (2).
244. [A76.] Teeth laterally compressed. No (0), yes (1).
245. [A82.] Occipital profile. Low and wide (0), high and wide (1), high and narrow (2).
246. [A83.] Supraoccipital. Absent (0), present (1).
247. [A86.] Jugular foramen. Between opistotic and exoccipital (0), through exoccipital (1).
248. [A92.] Anterior palatine. Short anteromedial process articulating with vomer at choana (0), long anteromedial process, more medial than lateral (1), palatine absent (2).
249. [A97.] Denticles on pterygoid. Present (0), absent (1).
250. [A98.] Teeth on pterygoid. Absent (0), present (1).
251. [A100.] Denticles on vomers. Present (0), absent (1).
252. [A101.] Denticles on palatines. Present (0), absent (1).
253. [A102.] Denticles on parasphenoid. Present (0), absent (1).
254. [A106.] Cultriform process contact with vomer. Narrow (0), broad (1).
255. [A108.] Stapes. Perforated columella (0), imperforate columella (1), no columella (2).
256. [A113.] Pleurosphenoid. Unossified (0), ossified (1).
257. [A114.] Sphenethmoid. Ossified (0), unossified (1).
258. [A116.] Pterygoids contact anteriorly. Present (0), absent (1).
259. [A120.] Lateral process of pterygoid contribution to posttemporal fossa. Absent (0), present (1).
260. [A124.] Dentary. Long (0), short (1).
261. [A125.] Dentary forms coronoid process. Absent (0), present (1).

262. [A126.] Surangular. Normal (0), reduced (1), absent (2).
263. [A127.] Angular. Narrow (0), deep (1).
264. [A128.] Number of splenials. 2 (0), 1 (1), 0 (2).
265. [A129.] Splenial exposed laterally. Present (0), absent (1).
266. [A130.] Meckelian fossae. 2 or more (0), 1 (1), 0 (2).
267. [A131.] Ventral border of Meckel's fossa. Splenial (0), angular (1).
268. [A133.] Retroarticular process. Straight (0), hooked (1).
269. [A134.] Articulation to tooth row. Above (0), equal (1), below (2).
270. [A135.] Angular extends to (lat view). Posterior tooth row (0), middle of tooth row (1).
271. [A136.] Number of coronoids. 3 (0), 2 (1), 1 (2), 0 (3).
272. [A137.] Coronoid teeth. Present (0), absent (1).
273. [A138.] Coronoid teeth. Larger than marginal (0), equal to marginal (1), smaller than marginal (2).
274. [A139.] Symphysis. Dentary and splenial (0), dentary alone (1).
275. [A140.] Jaw sculpture. Present (0), absent (1).
276. [A141.] Ossified hyoids. Present (0), absent (1).
277. [A143.] Parahyoid. Absent (0), present (1).
278. [A148.] Trunk intercentra. Present (0), absent (1).
279. [A149.] Trunk neural arch to centrum. Loosely articulated (0), sutured (1), fused (2).
280. [A150.] Base of neural spine. Equal to or wider than haemal (0), smaller than haemal spine (1).
281. [A156.] Haemal arches. Present (0), absent (1).
282. [A157.] Haemal arches. Loosely articulated intercentrum (0), fused to mid-length of centrum (1).
283. [A158.] Haemal arches. Longer than or equal to neurals (0), shorter than neurals (1).
284. [A160.] Haemal arch shape. Non-parallel (triangular) (0), parallel (rectangular) (1).
285. [A164.] Spinal nerve foramina. Absent (0), present (1).
286. [A166.] Transverse process. On arch pedicle (0), on centrum (1).
287. [A167.] Atlas-axis intercentra. Present (0), absent (1).
288. [A168.] Atlas anterior centrum. Same size as posterior (0), laterally expanded (1).
289. [A169.] Atlas centrum. Multipartite (0), single notochordal (1), single odontoid (2).
290. [A170.] Atlas neural arch. Loosely articulated (0), sutured to centrum (1), fused to centrum (2).
291. [A171.] Atlas parapophyses. On centrum (0), on transverse process (1), absent (2).
292. [A172.] Atlas neural arch. Paired (0), sutured at midline (1), fused at midline (2).
293. [A174.] Proatlantes. Present (0), absent (1).
294. [A175.] Second cervical arch. Expanded to more posterior (0), equal to more posterior (1), shorter than more posterior (2).
295. [A177.] Cervical rib distal shape. Spatulate (0), pointed (1).
296. [A178.] Ribs anterior to sacrum. Short (0), long (1).
297. [A182.] Sacral parapophysis. On centrum (0), on transverse process (1).
298. [A183.] Number pairs of caudal ribs. 5 or more (0), 4 (1), 3 (2), 2 or fewer (3).
299. [A196.] Supraglenoid foramen. Present (0), absent (1).
300. [A197.] Number coracoid foramina. 0 (0), 1 (1), 2 (2).
301. [A198.] Scapulocoracoid ossification. Both (0), scapula only (1), absent (2).
302. [A201.] Deltopectoral crest. Weak (0), intermediate (1), prominent (2).

303. [A203.] Humerus length. Long (>4 trunk centra) (0), short (1).
304. [A204.] Radius:humerus. >=0.7 (0), 0.5-0.7 (1), <0.5 (2).
305. [A205.] Olecranon process. Unossified (0), ossified (1).
306. [A207.] Basale commune. Absent (0), present (1).
307. [A214.] Femur. Long (0), short (1).
308. [A216.] Elongate tibiale and fibulare. Absent (0), present (1).
309. [A217.] Number of distal tarsals. 6 (0), 5 or fewer (1).

Characters sampled from Huttenlocker et al. (2013) H220–H227

310. [H220.] Dorsal margin of splenial only contacts first coronoid. Absent (0), present (1).
311. [H226.] Parietal anterior waisting. Absent (0), present (1).
312. [H227.] Parietal width relative to frontal. Greater (0), less than or equal to (1).

Characters sampled from Maddin et al. (2012a,b) M1–M112, N1–5

313. [N2.] Skull table. Rectangular (0), T-shaped (1).
314. [M6.] Prefrontals. Present (0), absent (1).
315. [M7.] Postfrontals. Present (0), absent (1).
316. [M8.] Squamosal-frontal contact. Contact (0), no contact (1).
317. [M10.] Zygokrotaphy. Stegokrotaphy including roofing bones like tabulars and supratemporals (0), zygokrotaphy with muscles approaching skull midline (1), stegokrotaphy in the absence of roofing bones such as tabulars and supratemporals (2), zygokrotaphy, but muscle does not extend through temporal fossa (3).
318. [M13.] Quadrate-maxilla separated by. Pterygoid (0), small pterygoid and pterygoid process of quadrate (1), by pterygoid process of quadrate only (pterygoid absent) (2).
319. [M17.] Quadrate-maxillopalatine. contact laterally (0), do not contact laterally (1).
320. [M20.] Ceratobranchials. 3 and 4 fused enclosing larynx (0), not (1).
321. [M26.] Tentacle. Absent (state added here) (0), present adjacent to eye (1), between eye and naris (2), beneath naris (3).
322. [M29.] Splenial teeth. Present (0), absent (1).
323. [M30.] Choanal openings. Small (0), large (1).
324. [M32.] Sphenethmoid. Covered dorsally (0), exposed dorsally (1).
325. [M37.] Larval stage. Present (0), absent, direct development (1).
326. [M51.] Anterior dentary teeth. Bicuspid (0), monocuspid (1).
327. [M79.] Nasal septum ossification. Not ossified (0), 20-35% of the total skull length (1), less than 20% of the total skull length (2).
328. [M81.] Dorsomedial process of the sphenethmoid. Absent (0), 11% or more of the total skull length (1), 10% or less of the total skull length (2).
329. [M82.] Dorsomedial process of the sphenethmoid. Thin and rod-like (0), thick and broad (1).
330. [M83.] Dorsal sutural surface of the sphenethmoid. Narrow or weakly tapered (0), broad and triangular and strongly tapered (1).
331. [M84.] Sola nasi. Absent (0), present and connected to the nasal septum ventrally (1), present, rod-like or tubular (2).
332. [M85.] Length of the lateral walls of the sphenethmoid. 14% or less than the total skull length (0), 15% or greater of the total skull length (1).

333. [M86.] Floor of sphenethmoid. Deeply incised and U-shaped in outline (0), shallowly incised with broad coverage of os basale (1), deeply incised and U-shaped, but with midline extension (2).
334. [M94.] Parasphenoid margins (definition changed here). Absence of lateral constriction posterior to basicranial articulations (0), weak constriction posterior to basicranial articulations present (1), strong constriction posterior to basicranial articulations, reaching to the carotid foramina (2).
335. [M97.] Skull roof exposure of the os basale. Moderate exposure at the dorsal midline (0), little to no exposure near the dorsal midline (1), very wide exposure near the dorsal midline (2).
336. [M100.] Fenestra vestibuli. Large, subcircular (0), anteroposteriorly elongate, oval (1), very small, subcircular (2).
337. [M105.] Canal for palatal ramus of the facial nerve in antotic region. Absent (0), present (1).
338. [M107.] Footplate of stapes. Fills the fenestra vestibule (0), much smaller than the fenestra vestibule (1).
339. [M111.] Columellar process. No ridge present (0), ridge on distal columellar process (1).
340. [M112.] Shape of optic foramen. Large, subcircular opening (0), narrow and slit-like opening (1), oblique anterior margin in the sphenethmoid (2), oblique posterior margin in the os basale (3).
341. [N4.] Anterior wall of sphenethmoid. Unossified (0), ossified, one pair of foramina (1), ossified, two pairs of foramina (dorsal and ventral) (2).
342. [N5.] Anterolateral process of sphenethmoid. Absent (0), present (1).

New characters N6–8

343. [N6.] Parasphenoid cultriform process. Narrow, tapering anteriorly (0), spatulate and parallel-sided (1).
344. [N7.] Dentary marginal dentition. Single row (0), multiple rows (1).
345. [N8.] Dorsolateral osteoderms fused to ribs. Absent (0), present (1).

Part D. NEXUS Scripts

```
#NEXUS
[written Wed Apr 19 09:29:25 PDT 2017 by Mesquite  version 3.10 (build
      765) at usc-secure-wireless-013-081.usc.edu/68.181.13.81]

BEGIN TAXA;
      DIMENSIONS NTAX=76;
      TAXLABELS
            Proterogryinus_scheelei Greererpeton_burkemorani Edops_craigi
      Adamanterpeton_ohioensis Cochleosaurus_bohemicus Nigerpeton_ricqlesi
      Chenoprosopus_milleri Dendrerpeton_acadianum Balanerpeton_woodi
      Trimerorhachis_insignis Neldasaurus_wrightae Isodectes_obtusus
      Acroplous_vorax Capetus_palustris Iberospondylus_schultzei
      Acanthostomatops_vorax Zatrachys_serratus Micromelerpeton_credneri
      Limnogyrinus_elegans Apateon_pedestris Micropholis_stowi
      Platyrhinops_lyelli Amphibamus_grandiceps Doleserpeton_annectens
      Gerobatrachus_hottoni Dissorophus_multicinctus
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      Cacops_aspidephorus_morrisi Broiliellus_texensis Acheloma_cumminsi
      Phonerpeton_pricei Ecolsonia_cutlerensis Onchiodon_labyrinthicus
      Eryops_megacephalus Sclerocephalus_haeuseri Glanochthon_latirostris
      Archegosaurus_decheni Platyoposaurus_stuckenbergi
      Australerpeton_cosgriffi Lapillopsis_nana Peltobatrachus_pustulatus
      Rhineceps_nyasaensis Uranocentrodon_senekalensis
      Broomistega_putterilla Lydekkerina_huxleyi Chomatobatrachus_halei
      Sangaia_lavina Peltostega_erici Laidleria_gracilis Siderops_kehli
      Batrachosuchus_watsoni Plagiosuchus_pustuliferus
      Gerrothorax_pulcherrimus Edingerella_madagascariensis
      Benthosuchus_sushkini Trematosaurus_brauni Trematolestes_hagdorni
      Lyrocephaliscus_euri Callistomordax_kugleri
      Metoposaurus_diagnosticus Parotosuchus Paracyclotosaurus_davidi
      Cyclotosaurus_robustus Mastodonsaurus_giganteus
      Rileymillerus_cosgriffi Chinlestegophis_jenkinsi
      Eocaecilia_micropodia Triadobatrachus_massinoti Karaurus_sharovi
      Kokartus_honorarius Cryptobranchus_allegheniensis Hynobius_japonicus
      Ambystoma_opacum Xenopus_tropicalis Epicrionops_bicolor
      Ichthyophis_bannannicus Leptodactylus_mystacinus
      ;

END;

BEGIN CHARACTERS;
      TITLE  Character_Matrix;
      DIMENSIONS  NCHAR=345;
      FORMAT DATATYPE = STANDARD GAP = - MISSING = ? SYMBOLS = "  0 1 2
      3";
      CHARSTATELABELS
            1 'Skull (outline)' /  Parabolic Triangular_with_pointed_tip,
2 'Skull (Height)' /  'Skull of variable height, but occiput always deeper
than snout' extremely_flattened_to_equal_height_throughout, 3 'Ornament
(elements)' /  Reticulate_ridges_of_various_sizes isolated_pustules
absent, 4 'Ornament (snout)' /  Polygons_or_short_grooves 'mostly radial,
elongated grooves', 5 'Ornament (general)' /
Shallow_ridges_of_variable_height high_ridges_throughout, 6 'Ornament
(intensive growth)' /  'Elongated ridges (''zones of intensive growth'')
confined to snout only'
prepineal_growth_zone_established_on_extended_anterior_parietal_and_postor
bital, 7 'Ornament (preorbital)' /
Zone_of_subdued_ornament_on_medial_skull_bones_adjacent_to_midline_suture_
absent present, 8 Spines /  absent
present_along_lateral_flank_of_quadratojugal, 9 'Preorbital region
(length)' /  Less_than_twice_the_length_of_posterior_skull_table more
equal_in_length, 10 'Premaxilla (alary process)' /  absent 'present,
forming a posterior hook-like indentation', 11 'Premaxilla (prenarial
portion)' /  short 'very expanded, equalling the length of the frontal',
12 'Premaxilla (outline)' /  parabolically_rounded 'box-like and
anteriorly blunt', 13 Premaxillary_foramen /
Premaxilla_and_nasal_completely_sutured
medially_bearing_an_opening_separating_the_two_alary_processes_of_the_prem
axilla, 14 Premaxillary_fontanelle /
Premaxillae_with_or_without_a_small_opening
encircling_large_fenestra_extending_posteriorly_between_the_nasals, 15
'Snout (internarial distance)' /  Narrower_than_interorbital_distance
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wider, 16 'Nasal (width)' / Nasal_longer_than_wide as_wide_as_long, 17 'Naris (position)' / 'At lateral margin of snout, opening laterally' 'set well medially, opening anteriorly', 18 'Naris (extension)' / 'Naris uniform, with oval shaped margin' 'posteriorly expanded with distinct anterior and posterior regions giving external overall "keyhole" shape', 19 'Naris (flange)' / 'Ventral (inner) side of prefrontal, lacrimal, and nasal smooth' 'bearing a complicated bar-like structure (narial flange) permitting contact with antorbital bar', 20 'Nasal (lateral margin)' / straight 'stepped, with lateral excursion anterior to lacrimal', 21 Lacrimal / present absent, 22 'Lacrimal (lateral suture)' / Parallels_medial_suture lateral_suture_posterolaterally_expanded_to_give_broader_preorbital_region, 23 'Lacrimal (position)' / Extending_anterior_to_orbit Confined_to_lateral_orbital_margin, 24 'Lacrimal (posterior extension)' / Restricted_to_the_antorbital_region Extending_back_lateral_to_orbit, 25 Orbit_and_naris / 'Well-separated' Separated_only_by_tiny_quadrangular_lacrimal, 26 Orbit_location / 'medial, framed by wide jugals laterally' 'lateral emplacement, framed by very slender jugals', 27 Orbit_margins / Raised_well_above_skull_plane flush_with_roof, 28 Palpebral_ossifications / ossifications_in_orbit_restricted_to_sclerotic_ring numerous_additional_ossicles_at_medial_margin_of_sclerotic_ring, 29 Pineal_foramen / Present Absent_in_adults, 30 Interorbital_distance / Narrower_than_or_equal_to_orbital_width wider, 31 'Frontal-nasal (length)' / Frontal_as_long_or_longer_than_nasal shorter, 32 'Frontal-nasal (suture). ' / Level_with_or_anterior_to_the_orbit_margin further_posterior, 33 'Lateral line sulci (adults)' / present absent, 34 'Sulci (skull roof)' / Throughout_skull_roof_if_present_ 'confined to circum-orbital region', 35 Infraorbital_sulcus / With_simple_curve_on_lacrimal_ 'with pronounced S-shaped lacrimal flexure', 36 Supraorbital_sulcus / Passing_entirely_through_nasal_ entering_prefrontal_and_lacrimal, 37 'Maxilla (anterior margin)' / Straight laterally_convex_due_to_enlarged_teeth, 38 'Maxilla (contact to nasal)' / 'Absent, separated by lacrimal' present, 39 'Prefrontal-frontal' / Prefrontal_substantially_longer_than_frontal ending_at_one_level_with_frontal, 40 'Prefrontal (anterior end)' / Pointed wide_and_blunt, 41 'Prefrontal (lateral suture)' / straight_or_concave with_marked_medial_projection_of_jugal_near_the_orbit, 42 'Prefrontal-postfrontal' / sutured separated_by_frontal, 43 'Prefrontal (process)' / 'prefrontal-lacrimal suture simple' prefrontal_underlying_lacrimal_laterally_to_reach_palatine, 44 'Prefrontal-jugal' / separated_by_lacrimal in_contact, 45 'Prefrontal-maxilla' / separated_by_lacrimal in_contact, 46 'Posterior skull table (length)' / more_than_.6_times_width less_than_.6_times_width, 47 Postorbital_shape / 'long triangular, wedged between squamosal and supratemporal' short, 48 'Postorbital (end)' / posterior_end_acutely_triangular with_fingerlike_projections, 49 Postorbital / not_wider_than_orbit with_substantial_lateral_process_projecting_into_jugal, 50 'postorbital, postfrontal' / shorter_than_supratemporal_and_parietal asl_long_or_longer, 51 Otic_notch / semicircular_embayment_between_squamosal_and_posterior_skull_table straight_transverse_posterior_skull_margin_without_embayment_between_cheek_and_table, 52 'Otic notch (position)' / 'Lateral, expanding along entire cheek to form continuous unornamented area up to quadrate' slit_like

'small and rounded, confined to dorsomedial part of squamosal', 53
Supratemporal / longer_than_wide 'quadrangular, giving a foreshortened
posterior skull table', 54 'Supratemporal (width)' / 'rectangular, with
straight sagittal lateral margin'
posterolaterally_constricted_by_expanded_otic_notch
small_and_oval_in_shape, 55 Supratemporal_flange /
squamosal_continuously_ornamented_around_margin_of_otic_notch 'squamosal
having dorsally-exposed and ornamented area (supratympanic flange)
stepping abruptly into steeply aligned poorly ornamented portion', 56
Semilunar_flange /
Supratemporal_without_ventral_projection_into_otic_notch
supratemporal_forming_marked_ventral_flange_participating_in_medial_border
ing_of_otic_notch, 57 'Jugal (ventral process)' / no_ventral_outgrowth
insula_jugalis_framing_subtemporal_window, 58 'Jugal (anterior extension)'
/ Jugal_ending_at_or_behind_level_of_anterior_orbit_margin
extending_anteriorly, 59 'Jugal-lacrimal' / in_contact
separated_by_orbit_or_palate_bones, 60 Intertemporal / present absent, 61
Intertemporal_and_postorbital / postorbital_lateral_to_postfrontal
'expanding medially to replace intertemporal, contacting parietal', 62
'Squamosal-tabular (dorsal)' / separated_by_supratemporal sutured, 63
tabular_and_squamosal /
forming_either_squamosal_embayment_or_straight_posterior_margin
'projecting posteriorly, with tabular extended posterolaterally', 64
'Squamosal (falciform crest)' / posterior_rim_of_squamosal_straight 'with
convex projection, referred to as falciform crest', 65 'Tabular (horn)' /
present_in_some_form entirely_absent, 66 Tabular_extension /
tabular_horn_pointing_posteriorly_if_present aligned_laterally
sutured_with_squamosal_posterior_to_otic_notch, 67 'Tabular (ventral
crest)' / absent present_and_shallow
forming_a_deep_ridge_that_almost_doubles_the_thickness_of_the_tabular_in_o
ccipital_view, 68 'quadratojugal (medial process)' / absent present, 69
'Quadratojugal-maxilla' / in_contact separated_by_jugal, 70 'quadrate
(dorsal process)' / absent present, 71 Posterior_skull_rim /
quadrate_trochlea_posterior_to_tabular_horns at_one_level_or_anterior, 72
Occipital_flange /
Descending_flange_of_occipital_portion_of_postparietals_forming_a_bulge
long_smooth_blades_as_long_as_the_dermal_portion_of_the_postparietal, 73
'Postparietal-exoccipital' / no_contact 'pillar-like dorsal process of
exoccipital firmly sutured to ventral side of postparietal and oblique
process of exoccipital sutured with ventral ramus of tabular', 74
Postfenestral_window / 'large opening, having at least double the width
of the foramen magnum' reduced_to_a_tiny_foramen, 75
Quadrate_and_occipital_condyles /
quadrate_condyles_posterior_to_occipital_ones at_the_same_level
well_anterior, 76 Epipterygoid / simple_rodlike_ascending_process
complicated_and_robust_element_with_up_to_six_processes, 77 'Dentition
(marginal)' / 'heterogeneous, varying sizes and distances' 'homogeneous,
small teeth, equidistant', 78 'Dentition (upper jaw)' /
contical_to_slightly_curved_inwards caniniform, 79 'Dentition (marginal,
tooth bases)' / Round_or_oval forming_transversely_broadened_ovals, 80
'Palatal tusks (cross-section)' / round_or_oval
laterally_compressed_and_keeled_at least_on_one_side, 81 'Dentition
(vomer)' / tooth_patches_present_at_least_in_small_specimens
dentition_entirely_restricted_to_vomerine_fangs, 82 Pedicely /
All_teeth_formed_consisting_of_a_single_mineralized_conus

at_least_some_teeth_with_two_separate_mineralization_centres, 83
Bicuspidity / all_teeth_with_single_tip
at_least_some_with_bicuspid_crowns, 84 Labyrinthodonty /
Teeth_with_labyrinthine_infolding_of_dentine_and_enamel_at_base
never_labyrinthodont, 85 'Transverse tooth row (transvomerine)' / absent
present_and_transverse 'V-shaped', 86 Additional_vomerine_fangs /
vomer_with_a_single_pair_of_fangs_at_the_medial_margin_of_choana 'with
additional fangs/fang pairs posteromedially', 87 'Parasphenoid (shagreen)'
/ tooth_patches_present teeth_entirely_absent, 88 'Ectopterygoid (fangs)'
/ present absent, 89 Interpterygoid_vacuities / 'Slender and slit-like'
'rounded, oval openings', 90 'Interpterygoid vacuities, pterygoid' /
vacuities_roundly_bordered_by_moderately_concave_pterygoid 'laterally
greatly extended at mid-level pushing pterygoid to the margin', 91
Anterior_palatal_openings / Vomer_and_premaxilla_with_continuous_suture
perforated_to_accommodate_symphyseal_fangs, 92 Anterior_palatal_openings /
unpaired_if_present paired, 93 Vomer / narrow_and_small 'large plate,
widely separating choanae', 94 'Vomer (paired anterior depressions)' /
absent present, 95 Anterior_palatal_depression /
Posterior_rim_round_if_present straight_transverse, 96 Vomerine_ridges /
absent 'present, radiating from vomerine tusks anteriorly', 97
Vomerine_pit_and_fontanelle / absent 'pit present (posterior to
mandible)' fenestra_within_such_pit, 98 Vomerine_septum / absent present,
99 'Choana (lateral)' / Anterolaterally_expanded_with_triangular_outline
oval, 100 'Choana (medial)' / Medial_margin_straight_or_gently_convex
anteromedially_expanded_giving_choana_a_reniform_outline, 101 Choana_width
/ 'elongated oval to slit-like' wide_round, 102 'Vomer-pterygoid' /
sutured separated_by_palatine, 103 'Vomer (anterior part)' /
anterior_portion_shorter_than_behind_anterior_level_of_choana
as_long_or_longer, 104 'Vomer (extension)' /
vomer_contacts_pterygoid_lateral_to_choana expanding_posteriorly, 105
Basipterygoid_ramus / 'Pterygoid with short, posteromedially curved
basipterygoid process, constricting palatal vacuities posterolaterally
'with_transversely_extended_process_producing_posteriorly_wider_vacuities,
106 'Basicranium (contact)' / Joint_between_basal_plate_and_pterygoid
sutural_contact, 107 Basicranium_suture / ' Suture (if present) much
shorter than basal plate, reaching at best 40% its length'
suture_almost_as_long_as_basal_plate_, 108 parasphenoid /
sutured_or_fused_with_exoccipitals underplating_exoccipitals, 109
'Basicranium (carotids)' /
Internal_carotids_entered_basicranium_ventrally_near_base_of_cultriform_pr
ocess posterolateral_corner_of_bone, 110 Parasphenoid_plate /
Basal_plate_sagittally_rectangular_ quadrangular_to_wider_than_long 'much
abbreviated, transversely rectangular ', 111 'Parasphenoid plate (size)' /
Basal_plate_at_level_posterior_to_basicranial_joint_substantially_narrower
_than_parietals_ as_wide_or_wider, 112 'Cultriform process (width)' /
'Base not wider than rest, clearly set off from basal plate '
merging_continuously_into_plate flaring_anteriorly, 113 'Cultriform
process (structure)' / ventrally_flat with_ridge_emplaced_on_broader_base
'knife-edged or keel-shaped', 114 'Cultriform process (outline)' /
of_similar_width_throughout
posteriorly_expanding_abruptly_to_about_twice_the_width, 115 'Cultriform
process (dentition)' / main_shaft_edentulous_except_for_base
with_elongate_tooth_patch, 116 'Parasphenoid (posterolateral process)' /
posterolateral_margin_straight with_lateral_wing, 117 'Pterygoid (ventral
ornament)' / Palatine_ramus_of_pterygoid_smooth

ornamented_with_reticulate_ridges, 118 'Pterygoid/exoccipital' /
no_contact sutured_lateral_to_parasphenoid, 119 'Pterygoid/basioccipital'
/ no_contact sutured_lateral_to_parasphenoid, 120 'Pterygoid-squamosal' /
entirely_sutured with_open_fissure, 121 Pterygoid_flange /
palatine_ramus_of_pterygoid_merging_continuously_into_pasipterygoid_ramus
broadening_abruptly_to_form_transverse_flange, 122 Pterygoid_width /
palatine_and_quadrate_regions_forming_slender_rami broad_shelves, 123
'Ptergoid-ectopterygoid' / palatine_ramus_exclusively_formed_by_pterygoid
with_posteromedial_projection_of_ectopterygoid, 124 'Pterygoid-palatine-
actopterygoid' / pterygoid_contacting_both_ectopterygoid_and_palatine
pterygoid_contacting_ectopterygoid_only, 125 'Palatine/ectopterygoid' /
with_simple_transverse_suture
palatine_with_posterolateral_process_excluding_the_ectopterygoid_from_inte
rpterygoid_vacuity_and_contacting_pterygoid, 126 'Palatine/vomer' /
suture_aigned_posterolaterally
with_medial_wing_framing_interpterygoid_vacuity_anteriorly, 127 'Palatine
(LEP)' / absent present, 128 'Palatine/ectopterygoid (ontogeny)' /
maintain_their_width become_proportionately_wider, 129
'Palatine/ectopterygoid (width)' / much_wider_than_maxilla as_narrow, 130
'Palatine/ectopterygoid (continuous tooth row)' / absent present, 131
'Ectopterygoid (length)' / as_long_or_longer_than_palatine
markedly_shorter, 132 'Ectopterygoid (LEE)' / Absent present, 133
'Ectopterygoid (Y-shaped)' /
Ectopterygoid_with_continuous_maxillary_suture 'Y-shaped with posterior
half separated from maxilla by gap', 134 Palate_structure / 'in occipital
view, pterygoids either sloping continuously ventrolaterally or flat
horizontal' vertically_curved_ventrally_at_right_angle_with_basicranium,
135 Quadrate_trochlea /
Medial_bulge_only_slightly_larger_than_lateral_one
being_at_least_two_times_longer_and_twice_as_wide, 136 Occipital_condyle /
'Trilobed, with basioccipital forming ventral part of facet'
bilobed_exoccipital_condyle_with_reduced_basioccipital_contribution, 137
Exoccipital_condyles / 'short and broad-based, projecting only with their
posterior half behind rim of skull table'
almost_the_complete_element_posterior_to_level_of_occipital_flange, 138
'Basioccipital (length)' /
Forming_a_long_element_posterior_to_parasphenoid_plate
foreshortened_to_a_narrow_posterior_rim_of_the_palatal_bone, 139
Dentigerous_palatal_ossicles / Absent
present_within_interpterygoid_vacuities, 140 Postglenoid_area /
absent_or_present_as_very_faint_outgrowth longer_than_glenoid_facet, 141
'Postglenoid area (types)' / Type_1 Type_2, 142 'Postglenoid area
(dorsal)' / plain with_elongated_groove, 143 Hamate_process / absent
present_but_lower_than_postglenoid_portion_is_long
as_high_as_retroarticular_process, 144 Preglenoid_process /
labial_side_of_surangular_with_straight_dorsal_margin_anterior_to_glenoid
forming_dorsal_projection_well_above_the_level_of_the_glenoid_articulation
, 145 Meckelian_window / small_round_or_oval_window
elongate_window_shorter_than_the_adductor_fossa as_long_or
longer_than_adductor_fossa, 146 Symphyseal_teeth /
no_accessory_teeth_posterior_to_symphyseal_tusks
transverse_row_of_such_teeth, 147 Posterior_coronoid_teeth / present
absent, 148 'Anterior/middle coronoid teeth' / present absent, 149
Mandibular_osteoderms / throat_region_naked
covered_with_mosaic_of_ventral_osteoderms_between_mandible_and_dermalpecto

ral_girdle, 150 'Stapes (quadrate process)' / absent present, 151 'Stapes (ventral process)' / absent 'present, giving the proximal region two heads', 152 'Stapes (shape)' / robust_tetrahedral_bone_with_substantial_quadrate_process rodlike_element_with_elongated_stylus bladelike, 153 'Stapes (curvature)' / Stapes_with_pronounced_dorsodistal_curvature 'abbreviated without curvature, directed laterally towards vertically aligned otic notch', 154 Ceratobranchials / bony_elements_absent present_in_adults, 155 Basibranchial / bony_elements_absent present_in_adults, 156 Hypobranchial_elements / Bony_elements_absent present_in_adults, 157 Branchial_denticles / 'conical and attached to small ossicles in groups of 2-10' 'free and with brush-like end', 158 Presacral_count / '>28' '23-25' '<21', 159 Caudal_count / ~presacral_count_or_higher much_lower, 160 transverse_process_orientation / 'short, directed posteriorly' distally_extended_with_diapophysis_pointing_laterally, 161 'Transverse process (length)' / shorter_than_dorsal_spine_is_high markedly_longer, 162 Neural_spine_height / as_high_as_distance_between_zygopophyses higher, 163 Intercentrum_shape / presacral_intercentra_form_simple_wedges dorsaly_closed_discs dorsaly_closed_and_elongate_cylinders, 164 'Intercentrum (width)' / chordal_canal_wider_than_intercentrum_high narrower, 165 'Intercentrum (ventral surface)' / ventral_surface_shorter_than_wide_in_ventral_view 'as long as wide, quadrangular', 166 Intercentrum_anterior_surface / always_concave convex_at_least_in_some_presacral_centra, 167 Parapophysis / segmental intersegmental, 168 Pleurocentrum_presence / ossified unossified, 169 Pleurocentrum_lateral_surface / as_large_as_that_of_intercentrum smaller, 170 'Pleurocentrum (ventral extension)' / wedged_between_successive_intercentra_and_not_reaching_ventral_margin_of_intercentra pleurocentra_ventrally_expanded_to_near_each_other ventrally_fused_to_form_single_cylindrical_element, 171 'Ribs (length)' / moderately_elongate_thoracic_ribs_curved_distoventrally such_ribs_foreshortened_without_distal_curvature, 172 'Ribs (ventral extension)' / 'rib heads (tuburculum and capitulum) confluent' 'clearly set off and widely separated in mid-trunk region', 173 'Ribs (uncinate blades)' / 'if present, small and spine like' extensive_and_bladelike, 174 'Ribs (uncinate spines)' / short 'elongated, as long as shaft', 175 Cleithrum / with_broadened_dorsal_head_region simple_rod, 176 Cleithrum / head_with_slightly_convex_or_straight_anterior_rim with_pronounced_anterior_projection, 177 Cleithrum / Dorsal_head_region_confined_to_anterior_rim_of_scapula posteriorly_extended_to_cover_dorsal_rim_of_scapula, 178 'Clavicle (ventral blade)' / 'wide, triangular, overlapping interclavicle broadly' 'slender, with minor overlap', 179 Interclavicle_length / shorter_than_posterior_skull substantially_longer, 180 'Interclavicle (ontogeny)' / without_major_proportional_change_in_ontogeny decreasing_proportionally_relative_to_skull_length, 181 'Interclavicle (central ornamented area)' / rhomboidal pentagonal_and_posteriorly_widest, 182 'Interclavicle (proportions)' / as_long_as_wide 1.3_times_as_long_as_wide more_than_twice_as_long_as_wide, 183 'Interclavicle (posterior margins)' / with_posterior_process transversely_straight, 184 'Interclavicle (anterior margin)' / serrated smooth, 185 'Interclavicle (anterior stylus)' / 'Anterior portion of interclavicle variably shaped but not longer than posterior one, as measured by the centre of ornamentation ' substantially_longer_than_posterior_one_, 186 'Interclavicle (posterior

stylus)' / posterior_end_rounded_or_blunt
with_elongated_stylus_or_parasternal_process, 187 'Interclavicles,
clavicles' / Clavicles_broadly_separated_by_interclavicle_ventrally_
leaving_only_narrow_stripe_of_interclavicle_in_between
in_contact_and_excluding_anterior_part_of_interclavicle_from_ventral_expos
ure, 188 'Scapula (glenoid facet)' / ossified unossified_in_adults, 189
'Scapula (height)' / 'Maximally two times longer (higher) than wide'
'dorsally extended and fully ossified, three times higher than wide', 190
'Humerus (ontogeny)' / 'Short cylinder in larvae, elongates at slow rate
' with_substantial_shaft_in_larvae_ very_long_rod_from_small_stages_on,
191 'Humerus (adult shaft)' / 'No shaft proper, humerus bladelike in
cross-section' 'with short shaft oval in cross-section' 'shaft elongate
and slender, comprising more than 50% of the humerus with rounded cross-
section', 192 'Humerus (entepicondylar foramen)' / present absent, 193
'Humerus (supinator)' / present absent, 194 'Humerus (condyles)' /
Distal_end_at_least_partially_ossified_with_identifiable_condyles
unfinished_without_condyles 'with fully-established condyles', 195
'Humerus (torsion)' / 'strong (70-90deg)' 'weak, well below 60deg', 196
Carpals / all_unossified at_least_some_ossified, 197 Manual_digit_count /
five four_or_less, 198 'Ilium (shaft)' /
shaft_of_variable_length_but_laterally_flattened very_long_and_slender,
199 'Ilium (dorsal end)' / Tip_of_dorsal_end_continuous much_broadened,
200 'Ilium (height)' / shaft_more_than_twice_the_length_of_base shorter,
201 'Ilium (orientation)' / main_axis_of_shaft_inclined_posterodorsally
vertical anterior, 202 'Ilium (tip)' / 'dorsal end two-headed' 'single-
headed', 203 Pubis / unossified ossified, 204 Femur /
intercondylar_fossa_forming_deep_and_elongated_trough
reduced_to_short_depression, 205 'Femur (trochanter)' /
internal_trochanter_present_as_discrete_process reduced_to_shallow_crest
greatly_enlarged_to_form_a_massive_projection, 206 tarsals /
at_least_some_ossified all_unossified, 207 Gastral_squamation /
ossified_ventral_dermal_scales scales_absent, 208 Squamation / 'Dermal
scales oval to spindle-shaped' 'broad oval with "microsaur-type"
ornament', 209 Osteoderms / Absent present_as_single_row 'more numerous,
forming a carapace', 210 'Osteoderms (articulations)' /
simple_set_of_osteoderms_arranged_in_one_layer_if_present 'double set of
two layers, the ventral one fused to tip of neural arch', 211 'Osteoderms
(width)' / narrow_median_osteoderms 'transversely-extended plates', 212
Rib_cage / trunk_narrower_than_skull_or_as_wide
trunk_substantially_wider_than_lateral_margin_of_cheeks_at_about_midlevel,
213 Basal_skull_length / '>70mm' '50-70mm' '30-50 mm' '<30 mm', 214
Skull_to_trunk / '>=.45' '.3-.45' '.2-.29' '<.2', 215 Skull_proportions /
longer_than_wide wider_than_long, 216 Supratemporal / present absent, 217
Supratemporal_exposure_on_occiput / absent present, 218 postfrontal_shape
/ broadly_quadrangular falciform, 219 'Lacrimal-naris contact' / present
absent, 220 Lacrimal_contribution_to_orbit / absent present, 221
Lacrimal_orbital_processes / only_ventral_present
dorsal_and_ventral_present neither_present, 222 Quadratojugal / present
absent, 223 Frontals / paired_along_midline fused, 224
frontal_contribution_to_orbit / no yes, 225 Septomaxilla / ossified
not_ossified, 226 Prefrontal_contributes_to_external_naris / distant_from
near present, 227 External_naris_in_dorsal_view / exposed not_exposed,
228 Posterior_skull_margin / concave straight convex undulating, 229
Large_otic_notch_approaching_orbit / absent intermediate present, 230
Postorbital / present absent, 231 Shape_of_postorbital /

irregular_trapezoid 'triangular, apex caudal', 232 'Parietal-postorbital contact' / absent present, 233 Parietal_squamosal_contact / absent present, 234 'Parietal-tabular contact' / absent present, 235 Postparietals / paired fused absent, 236 'Postparietal-squamosal contact' / absent present, 237 Postparietal_length / large_quadrangular 'abbreviated anteroposteriorly, elongate lateral rectangular', 238 'Squamosal-jugal contact' / present absent, 239 Tabular / present absent, 240 Maxilla_into_external_naris / present absent, 241 Maxilla_forms_entire_ventral_naris / present absent, 242 Number_of_premaxillary_teeth / '>=10' '5-9' '<5', 243 Number_of_maxillary_teeth / '>=30' '20-29' '<20', 244 Teeth_laterally_compressed / no yes, 245 Occipital_profile / low_and_wide high_and_wide high_and_narrow, 246 Supraoccipital / absent present, 247 Jugular_foramen / between_opisthotic_and_exoccipital through_exoccipital, 248 Anterior_palatine / short_anteromedial_process_articulating_with_vomer_at_choana 'long anteromedial process, more medial than lateral' palatine_absent, 249 Denticles_on_pterygoid / present absent, 250 Teeth_on_pterygoid / absent present, 251 Denticles_on_vomers / present absent, 252 Denticles_on_palatines / present absent, 253 Denticles_on_parasphenoid / present absent, 254 Cultriform_process_contact_with_vomer / narrow broad, 255 Stapes / perforated_columella imperforate_columella no_columella, 256 Pleurosphenoid / unossified ossified, 257 Sphenethmoid / ossified unossified, 258 Pterygoids_contact_anteriorly / present absent, 259 Lateral_process_of_pterygoid_contribution_to_posttemporal_fossa / absent present, 260 Dentary / long short, 261 Dentary_forms_coronoid_process / absent present, 262 Surangular / normal reduced absent, 263 Angular / narrow deep, 264 Number_of_splenials / two one none, 265 Splenial_exposed_laterally / present absent, 266 Meckelian_fossae / 2_or_more one none, 267 'Ventral border of meckel''s fossa' / splenial angular, 268 Retroarticular_process / straight hooked, 269 Articulation_to_tooth_row / above equal below, 270 'angular extends to (lat view)' / posterior_tooth_row middle_of_tooth_row, 271 Number_of_coronoids / 3 2 1 0, 272 Coronoid_teeth / present absent, 273 Coronoid_teeth / larger_than_marginals equal_to_marginals smaller_than_marginals, 274 Symphysis / dentary_and_splenial dentary_only, 275 Jaw_sculpture / present absent, 276 Ossified_hyoids / present absent, 277 parahyoid / absent present, 278 Trunk_intercentra / present absent, 279 Trunk_neural_arch_to_centrum / loosely_articulated sutured fused, 280 Base_of_neural_spine / equal_to_or_wider_than_haemal smaller_than_haemal_spine, 281 Haemal_arches / present absent, 282 Haemal_arches / loosely_articulated_to_intercentrum fused_to_midlength_of_centrum, 283 Haemal_arches / longer_than_or_equal_to_neurals shorter_than_neurals, 284 haemal_arch_shape / 'non-parallel (triangular)' 'parallel (rectangular)', 285 Spinal_nerve_foramina / absent present, 286 Transverse_process / on_arch_pedicel on_centrum, 287 'Atlas-axis intercentra' / present absent, 288 Atlas_anterior_centrum / same_size_as_posterior laterally_expanded, 289 Atlas_centrum / multipartite single_notochordal single_odontoid, 290 Atlas_neural_arch / loosely_articulated sutured_to_centrum fused_to_centrum, 291 Atlas_parapophyses / on_centrum on_transverse_processes absent, 292 Atlas_neural_arch / paired sutured_at_midline fused, 293 Proatlantes / present absent, 294 Second_cervical_arch / expanded_to_more_posterior equal_to_more_posterior shorter_than_more_posterior, 295 Cervical_rib_distal_shape / spatulate

pointed, 296 Ribs_anterior_to_sacrum / short long, 297
Sacral_parapophysis / on_centrum on_transverse_process, 298
Number_of_caudal_ribs / 5_or_more 4 3 2_or_fewer, 299
Supraglenoid_foramen / present absent, 300 Number_of_coracoid_foramina /
none one two, 301 Scapulocoracoid_ossification / both scapula_only
absent, 302 Deltapectoral_crest / weak intermediate prominent, 303
Humerus_length / 'long (>4 centra)' short, 304 'Radius:humerus' / '>=.7'
'.5-.7' '<.5', 305 Olecranon_process / unossified ossified, 306
Basale_commune / absent present, 307 Femur / long short, 308
Elongate_tibiale_and_fibulare / absent present, 309
Number_of_distal_tarsals / 6 5_or_fewer, 310
Dorsal_margin_of_splenial_only_contacts_first_coronoid / absent present,
311 Parietal_anterior_waisting / absent present, 312
Parietal_width_relative_to_frontal / greater less_than_or_equal_to, 313
Skull_table / rectangular 'T-shaped', 314 Prefrontals / present absent,
315 Postfrontals / present absent, 316 'Squamosal-frontal contact' /
contact no_contact, 317 Zygokrotaphy /
stegokrotaphy_including_roofing_bones_like_tabulars_and_supratemporals
zygokrotaphy_with_muscles_approaching_skull_midline
stegokrotaphy_in_the_absence_of_roofing_bones_such_as_tabulars_and_suprate
mporals zygokrotaphy_but_muscle_does_not_extend_through_temporal_fossa,
318 'Quadrate-maxilla separated by' / pterygoid
small_pterygoid_and_pterygoid_process_of_quadrate 'by pterygoid process of
quadrate only (pterygoid absent)', 319 'Quadrate-maxillopalatine' /
contact_laterally do_not_contact_laterally, 320 Ceratobranchials /
3_and_4_fused_and_enclosing_larynx not, 321 Tentacle / absent
present_adjacent_to_eye between_eye_and_naris beneath_naris, 322
Splenial_teeth / present absent, 323 Choanal_openings / small large, 324
Sphenethmoid / covered_dorsally exposed_dorsally, 325 Larval_stage /
present 'absent, direct development', 326 Anterior_dentary_teeth /
bicuspid monocuspid, 327 Nasal_septum / not_ossified '20-35% of total
skull length' less_than_20%_of_total_skull_length, 328
Dorsomedial_process_of_the_sphenetmoid / absent
11%_or_more_of_total_skull_length 10%_or_less_of_total_skull_length, 329
Dorsomedial_process_of_the_sphenethmoid / thin_and_rodlike
thick_and_broad, 330 Dorsal_sutural_surface_of_the_sphenethmoid /
narrow_and_weakly_tapered broad_and_triangular_and_strongly_tapered, 331
Sola_nasi / absent present_and_connected_to_the_nasal_septum_ventrally
'present, rodlike or tubular', 332 Lateral_walls_of_the_sphenethmoid /
14%_or_less_than_the_total_skull_length
15%_or_greater_of_the_total_skull_length, 333
Margin_of_the_floor_of_the_anterior_portion_of_the_parasphenoid / narrow
'broad, tapers continuously to a point' rounded_anteriorly 'markedly
tapered, resulting in a bottleneck appearance' 'rod-like distal tip', 334
Parasphenoid_margins /
absence_of_lateral_constriction_posterior_to_basicranial_articulations
weak_constriction_posterior_to_basicranial_articulations_present 'strong
constriction posterior to basicranial articulations, reaching to the
carotid foramina', 335 Skull_roof_exposure_of_the_os_basale /
moderate_exposure_at_the_dorsal_midline
little_to_no_exposure_near_the_dorsal_midline
very_wide_exposure_near_the_dorsal_midline, 336 Fenestra_vestibuli /
'large, subcircular' 'anteroposteriorly elongate, oval' 'very small,
subcircular', 337
Canal_for_palatal_ramus_of_the_facial_nerve_in_antotic_region / absent

present, 338 Footplate_of_stapes / fills_the_fenestra_vestibuli
much_smaller_than_the_fenestra_vestibuli, 339 Columellar_process /
no_ridge_present ridge_on_distal_columellar_process, 340
Shape_of_optic_foramen / large_subcircular_opening 'narrow and slit-like
opening' oblique_anterior_margin_in_the_sphenethmoid
oblique_posterior_margin_in_the_os_basale, 341
Anterior_wall_of_sphenethmoid / unossified 'ossified, one pair of
foramina' 'ossified, two pairs of foramina', 342
Anterolateral_process_of_sphenethmoid / absent present, 343
parasphenoid_cultriform_process / 'narrow, tapering anteriorly'
'spatulate and parallel-sided', 344 Dentary_marginal_dentition /
single_row multiple_rows, 345 Dorsolateral_osteoderms_fused_to_ribs /
absent present ;

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      Balanerpeton_woodi
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      Trimerorhachis_insignis
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      Neldasaurus_wrightae
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      Acroplous_vorax
00000000000001001000000001110010001??000001000000001?000000110000100?01010
2?000010000010101110000000010000000112000000000000010000000000?100000001
11?10????000000000000??000000100000000 10??1?????00011????0?0000110100120
00110100000000100010000000001011?01100000011{0
1}01001?00??00?????????????????????0?11110?10?011000?001?0100?1??????21?????
???100
      Capetus_palustris
00000000010000000000000000?001101?000000000000000000000010000000000100010
0?000000000000100010000000000?000001000000000000000000000000000?1000000???
0?????0?????????????00???????010000000?????????????1????0000000?00000120
00?000001000000000001000?0?????0???1?000000???00????0?????????????????????
???????????????001000?001???0??1??????00?????????00?
      Iberospondylus_schultzei
00000000110000100000000000000000000?000000000000000000010100000000100010
0?0000?00000?0100010000000000?000?0100000000000000000000000?0??000000000
0011000??100000000000000100000?????????????????????1????0000000?00000100
00000000100000000011100 0?00000100?0100001000?0101?100?00001000?????11??
???????????????011000?001?0100?1??????00????????000
```

Acanthostomatops_vorax
0000000111001110000000000000000001101?00001001000110000010000101010000000101010
100000000000000100010002000000001100011000100000000000000000000000101100000000?
01110001011000000000000010000000100000000010111011010110110?0110000000010000100
000000000100000100010000000?0000001??11?????????????????????0000?001000??????0??0
?0???10??000??10100?001?011011??????00????????000
Zatrachys_serratus
0000000111001110000000000000000001101?0000100100011000001000000101000000101010
1?000000000000010001000200000000110001120010000000000000000001000010110000000??
0????00???1?????0?000000000000100
000001000000000010001??000000000001??
??0?0
Micromelerpeton_credneri
000000000100000000010000000110000000000001011001100000000010011000000011?0010
0?00000000101001000100020000100100001100000000011000001000000000??1?000000000
01111001000000000000001000000001000000000010111001010100 11?11010000210001010 0
01100100100000000001??
??0
Limnogyrinus_elegans
0000000001000000000100000000110000000000000001100110000000000?0011000000011?1010
1?00001001000010001000000000100100001100000000010000000?00000000??1?0000000??
011110?1000000???0000?000000001000000000010111?1?010?0011?110100002?00000100
001000000100000000001??
??0
Apateon_pedestris
000000000100100000100000000100000 1?0000110110011000000100?0011000000011?1010
1?10001?00001010001000000000100100002100000000011000001000010100??1?000000011
01111011120000??00000210001001000000000000022111??1010011?110000002110010100
01120100100000000001010 00?1111110?0111 0000?????1?????00000?????00??????????
??0?10020000??10000?0011011001??????00????????000
Micropholis_stowi
0010000000100000000010000000011000010000000101100110000000000000110100000011110 10
10000000000010110001000200101001000021000100001100100101010000101100000 0011
01111011?210000000000011000100100000000000?21100110000100100000000 20?0000120
000?0000?000000010 00??000?000000100011000001110010??100000?????00?0002??100
??1?100110001?11000?001?0?00?1??????00????????000
Platyrhinops_lyelli
000000000100000000010000002110000 1?0000000110011000000010100110000000011100 10
0010000001000000110010000000101001000021200100000100000101010000101100000000 00
011110?1?2?00000000000110001001000000000000022110011010 01?00010000011000?01?0
00100020000000100000000??0?????1??0110000201???0????01002?00?0000102?21?00
?0??0?011000??01000?001?0?00?0??????00????????000
Amphibamus_grandiceps
000000000100000000010000002110000 1?0000010110011000001101001100000000 1110010
0?1000011100011100100010010100100002100010000?1001001010100001 01?000000000
01111011?2?00000000000210001001000000000?0221100110000100?000000031100?0100
000000201000000100000000??0000001001110 00??????0??????1000?00?0000?00?21?00
?00?01010??0??01000??01?0100?1??????00????????000
Doleserpeton_annectens
000000000100100000010000002110000 1?0000010110011000001001001100000000 1110010
0010000011100011100100010010100100002100000000001001001010100001011000000000 10
011110?0?10000000000002100010010000000000000?21120110000 10000?000003?00010100
01?001201000000100000000010000000?001100000000?01002?0100??00??000?1222????
?????????0?0??01000?001?0??0?0??????00???00??0000

```
      Gerobatrachus_hottoni
00000000100?00000100000021?0000???000?1011001100000?00?00110000000011?0010
1??0000?0100??1100100?00?0100100???200?00000000100101010000101?000000???
0????0?0?210000000000?1000100l?????????0??211201????010??0?0000?3111?10120
0101012????0001000000000??1101?????0110??????????1????1??02?????????12??21?01
??????0?11????01100?101?0?0?????????????????????0?0
      Dissorophus_multicinctus
0000000001001000001000000001101001?000001011001100000101100110000000011111010
2000000000000111000100 0?00001001100010000000000100000100000000101?000000000
011100?0?100010000000001000001100000000001?2112011011110000?01110010000010 0
010000100000000100100000000101110100100001??11000????0??00?????00?110?21110
000001011?00??01000?001?0?00?1???1???0????0???0?0
```

Sclerocephalus_haeuseri
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0000000000000010001100000000001000111000000000000000000100000101100000000
0011001001000100000000001000001001000000001100011000010020000000010000100?0
0000000000000000010100000101111?00100011000101000210000000???????????????
?????????????001000?001?0?0011?????000??????0?000
Glanochthon_latirostris
0000000011010010000100000000010000000100000100000000100000101000000010100010
0?000000000000100011000000000001000111000000000000000000100000101100000000
0011001001000100000000001000001001000000100110100100001100?10000000?000010?0
000000001000000000110000000000000?0?1000??????????????1?00?????01?????????0
??0?1111001???01000?001?0?00?1??????00????????0?0
Archegosaurus_decheni
0000000011010010000100000000011000000100000100000000100000101000000010100010
0000000000100010001100000000000000001110000000000000000000100000101100000000
0011001001000100000000001000001001000?1001111101000001100?10000000000000010?0
0000000000000000010000000001010000011000100011110020000000001010000?0?00000
?00200100010010100?001?010011??????00?2?0?100000
Platyoposaurus_stuckenbergi
0000000011010010000000000000000011000000100000100000000100001101000000010100010
0000000000000110001000000000000000011100000000000000000001000000101?000000000
0????0?0?10001000000000001000001001000000010?1111101000011??00000000000000010?0
0010000000000000000100000000010100000110001001111100200????????????????????
?????????????101000?001??100?1?0?1?000?20?0100000
Australerpeton_cosgriffi
0000000011010010000000000000000000000001000001000000001000011010000000101000 10
0?00000000?000101110000000000000000011100000000000000000001000000101?000000000
0????0?0?1000100000000000100000100100000010??10??010??01????00000000000000010?0
00?0000000000000000?0000100011101??1100010000001001?00????????????????????
??????????0??000000?00???100?1???????0????????000
Lapillopsis_nana
00000000010000100?1????00100000001???010101?110100000000 1011?1010000000101010
1?00001000?01010??10000000010011001110000010000001000000000000101?0000000??
0????0????????????????????????00?010??1000?????????????1?????000003?0001???0
01100010000000000001000000000011110??1100100011011002000000?????00?????????
??0?0?????????010000?001???00?1??????00????????000
Peltobatrachus_pustulatus
0010000000100000?0000?0?0000001?010????0000?0000?00?0000??01000000000010?010
??0000?000?00?10??10000000?0011001110001100000000?00000?00000101??0?00????
0????0????0100?00000?00010???0??????????00?11000??0111101???0200?0?0000???0
00?0?0000000000000?????010?00??0??0011?00000?0001????0??000000100?????????0
?002020???0???11000?001????0?????????00?00???0?0?1
Rhineceps_nyasaensis
00000000110000000000000000010011000000010010010000100200001101000100201000 10
000010000001000101110000000000000110011100001000000000000001000000101?000001000
011100?0??01000000000000?0?0?0100101000??????????????1?????000000?00001 0?0
0000000000000010001010001000000 1?00100000000010001?00????????????????????
?????????????001000?001???00?1???????0??????0?100
Uranocentrodon_senekalensis
0000000011000000000000000001001100000001001001000010020000110100010020100010
000010000001000101110000000000000110011100001000000000000001000000101?000001 0??
0111001000010000000000000000000001001010000 0?111110100001 01?00000000?00001 0?0
000000000000000000001???001?????1?00?10????????????????????????????????????
???

Broomistega_putterilla
00000000010000000000000000100110000000100100100001002000011010001002010001 0
0?0010?0001000101110000000?0011001110000100000000000000100000101?00000????
0????0?0???1000000???000?00000100101000?0?110100100001011100000000000000010?0
0000000000000000000111000100000000???100001?01001101?001?00?????01?????????0
??0?11110?10?011000?001??100?1??????00????????000
Lydekkerina_huxleyi
00000000010000000000000000100100001001000000100001002000011010101001010101 0
1010101000100110101000000000100110011100001100000000100001000000101?100001001
011100???1?10000000000000000000001001010000?11000?1010010120000000?000000?0
00?0000000000000000010100011000100100101001000{0
1}01101?001?00?????01?????????0??0102111?10?011000?001??100?1??????00?????
???000
Chomatobatrachus_halei
000000000100000000000000001001000010000000001000010020000110101010010101010
1?1010100010011010100000000010011001110000110000000010000100000101?100001?00
0????0??????????????????????????0??????0???????????????????1?????000000?000000?0
00?0000000100000000001????????????????????000?001101000200?????????????????????
??????????????110000?0????1?0?1????????????????????0?
Sangaia_lavina
1000000001000000000000000011001000 0?10100000010000011?0000?001011010?0?01010
1?10101000?01?1010000000000010011101111000010010000??0001000000101??0?000???
0????0??????????????0????????????0???????????????????????1????1?????000000?10001100
0000000000000000000001000001?00????????10???
????????????????11000?001????0?????????????????????????
Peltostega_erici
1010110001000000000000???0110110000??0????0???0000102000 0???1010100?0?00010
??101?1000????00111000 0010??0011111001000000101 01????0?0??000 0111??????????
??0?0000???0
00?00000000000000????00??
???
Laidleria_gracilis
1110000000100000000000010?00110010000010101000110000 11?0000?0?1011010?0?01011
2?1010100000011101110000000001001110111100001001000101000100000101?1?000????
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0110010000000000000011?00011001110??11100000???010?1?00??00?????0?01???????1
????10110?????01000?001??100?1??????20????????100
Siderops_kehli
0000000001000000110001 0?001100100000101000101100001 1?000010??010100?0001010
20101010000011101010000000000100111011110000110001110100010001 0111?11000000 0
011100???2010000000000?0000000000100101000 10?11111010000111110000000 0?1000????
00?10000000000?0?0?????000111011100011000110 00{0
1}01100200??000000100000202?1?0????101???1???01000?001??10??1??????00?1???
???000
Batrachosuchus_watsoni
0000000001000000110001 0?001100100000101000101100001 1?000010?1010010?0001010
2?101010000001110101000000000100111011110000110101110100010001 0111?11000000 0
001200???????????????????00?00????????????????????????1?????0000?0?1000????
00?1010000000000000001???00111011111??1100000????01021??0????????????????????
???????????????01000?001??10??1??????00????????10?
Plagiosuchus_pustuliferus
0110000000100000011000000000110000100000101010101010100001?10001001010010?0001011
2?101010001011100010000000000100111011110000010001110100010001 0111?110000001
0????1??02110020001 1?000000100101011001 10?1101001000011111001001 0?100?0100

011?0101??000000001??00011001110?1010000000??01021?0000???????????????????
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Gerrothorax_pulcherrimus

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2010101000100110001000000001001110121100001100011101000100000111?110000000
001201110211002000011?000000100101011001 00?11010010111101110020010110011100
010103000000000000001000000111011{0
1}001010000000000111002000000????0011222211?1??????1??????010100?001??10{0
1}?10111?000?1101210000

Edingerella_madagascariensis

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0111000????1000000000000001?000001001010011 0?111110?????1????1000000?10001 0?0
01?000000000000100010000001100010 0?1?1000000010011002001?00?????00?????????
????100??????111000100 1??100?10??????0????????100

Benthosuchus_sushkini

0000000011000000000000000001001000011010000001000010020000110101010010001010
1010101000200110101000000000100111111111000100000000110001000000101?100101000
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00?00000000000000000100000101011 10?0010000000110100010 0??0?????????????????
?????????????011000100 1??100?122111000?1?1?210000

Trematosaurus_brauni

0000110011000000000000000011001000011010000001000000102000010010101001000101 0
1?1010100000001101110000000001001111111112000010001010100010000000101?100112000
01110?????????????????????????01002011 01???????????????1?????0?0000?????????
??
???

Trematolestes_hagdorni

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1?10111000000110111000000000100111111111200001 0?010101000100000101110011 20??
0111011??1010001000000001010000100201101100111110110001111110000000000001120
1010000000000001000110000100011 00?01100000000110100??0000???????????????????
?????????????01010 1001??1???1??????00????????000

Lyrocephaliscus_euri

1000110001000000000000000011001000011011100010000010200001101010100101000 10
10101?10002000000111000000100100111110012000010101110100010000000111?????????
?111??0?000000?0
000000000000000001????001100??1000110??????????????????00?????01???0?0?1??
??????????????01000100 1???0?????????00?1?00???0?0

Callistomordax_kugleri

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1?10111000000110111000000000100111111111200001 0?0111010001000011111?100112010
0????11?00010011110010010100001001011021001101101100011111100000001000011 00
101001000000000100011000010001110?01100101000{0
1}01000200 1?000000100?????????1?1100110 0?10?0010001001??10??10?????00?????
???000

Metoposaurus_diagnosticus

00001100010000000100000010011001000011010000000000000102000010010101001000111 0
2010111000101110111010000000100111011110000110001110100010000111111 00112111
0111001??101101111101001000000010010110210?110110000000111011000000?00001020
0010010000000001000110000101111 10?0?11????????????????????????????????????
??????????????01?????????????????????????????????0

Parotosuchus

0000000011000000000000000000000100001001010001000010020000110101010010001010
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01110?0???????0????0?0???????0??????1????????????????1?????0?0000?00001 0?0
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??????????????11000100 1?0?0??????????20????????0??
Paracyclotosaurus_davidi
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10101010001011101010100000010011101111100001000100110001000001 01?100202 0??
0111000??001100000000100110000010010110110?1111101000011 1?1000000000000010?0
01100000000000000001000001010111 1?0010001100??010???00??000010100?????????0
0?0?12121?10?011000100 1?0100?1?1111020?1?0??1?000
Cyclotosaurus_robustus
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101010100010111010101000001100111011111000110001001100010000010 1?100202101
01110?0????110000000 10???0???01001011011 0?11111??????1?????0?000?????????
??
???
Mastodonsaurus_giganteus
0001000011000000000000000100000001101010001000000020000110101010110001010
11101010001011101110100000010011101111100001000100110001000001 01?101202001
01110?0??001101000001001100000100101101 00?110110?00001111 1?000000000000010?0
01100000000000000001000001010111000010001100100100021 01?0200101 00?????????0
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Rileymillerus_cosgriffi
00000?000?????0????01???011?01?01???011100??10????1??????00???001?????0010
1?1000000000 1110??1??00000010?1110?1?10100011000?1011?010000011 1?0?0?00???
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00?0?10?????0?1?????0000101000 11?0110001 0?????10?0??0????????????????????
??????????????0?000?001???0??1??????0?????????00?
Chinlestegophis_jenkinsi
00000?000?00??0110001???011?010001??011100??1010000012 11??01010?000???1010
2?1?0?100???1?00??????????????0110?0010000011 0?1????1????0?1011?????100100
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00?1012000 01001?0????0001?10??11?01?000101111?10?0110??00??????????????????
?????00????????0100 01001?{0 1}????1??????????1?1??00110
Eocaecilia_micropodia
002????001000000110001???021?11001???011100??10???0??12??00?1???0???0001???
2?100?01111?01100?1??00010110?0{0
1}?0?00100100??1110??00?01????011?011010010001 00?000???10-
0????00200????????????????00?11101????????100??0??0330000????000111?1??1101
0000000000101011010101000??21??01??01?1?002?0100100112?2111013?1021210101?
00000000??1?00?02????11020?0??21110
Triadobatrachus_massinoti ?02----
00?????11?????????121?10?01?????11??????1---?00--1????1---0??????10--
10????????????1111???????????1?1??10-1?21000000000010010?0?101000010100??00?0-
-0001?000-21{0 1}00----10?210??10010????????00-211211?100211110 1-0--01111-
-???1?1???121--1-2--?1?????000110?11?1001000202-??---3--110112-1---
0010122211001-1000010001?-10101110--01?0?-?????1001001????1-0
Karaurus_sharovi
001?0?101100110100010000021?10001???00000?0?01????1?11---
??1??00??????1???1?100??001????11?????????????????10-
???????????00?00???????????????10??0??00????0?????????20110????10?210?????????
??????00?21111010011 1?1111?0??0221 1??01210??101?1??1?2??110??00000?000011?
0?1?0??????????????????0?12???????0?????21100?????2110100??01101?101?0??0?????
???00????????0??0
Kokartus_honorarius
001???10110011?10001????0?1?10001???0??????????1????1?10---

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??1??00??????1???1?100?00011?1?11?010?0?0??????10-
00112000000011O???????????0?10?0???00?00?0??????1???100?1?110?2???????????
????????????????????????????????2????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
??????????????0
      Cryptobranchus_allegheniensis
002????001000000100?1???121?10011???00100???11????1???---
??1??00?????11???1?100?01111?1?100?10?000011-1-00-001120000000111?-?????-
???0011?00??01?0-
10001?111??1110????10?211?????????????????00221111111000101101-0--00111-----
101020301--1-2----0100000021011110001O002-2-2-01-3--1100-
20011011102222111-1????0??0100?-??101110110100000O--002011010-00100
      Hynobius_japonicus              002????0010011111{0
1}00100001210100O1???01100?0?01????1???---
??1??00?????11????2?100?01112?1?1100100000011-1-10-0021200000001110-?????-
???0110?00??01-0-
10001?000?21110????10?211?????????????????00221111111000101101-0--02111--
012101000301--1-2----0100000021011111001O002-2-2--1-3--1100-
20011011102222111-1????0??0100?-??101130110100000O--012010110100100
      Ambystoma_opacum                002----00100110110001---121-10001---
00000---11----1--------1--00-----11--?2-100-01111-1-1100100000011-1-10-
0011200000001110---0------1011?00?-01-0--
0001?000?21110????10?211?????????????????00221111111000101101-0--03111--?--
101020201--1-2----0100000121011111001O002-2-2--2-3--1100-
20011011102222111-1????0??0100?-??101130110100000O--01201010?000100
      Xenopus_tropicalis              002----00100111110011---121-10?11---
0--------?----00--10---1---0-----11---2-100-??11??1?11?0??0????1????10-
10010000000011OO???------0010-00?-0--0--01010000-21110--??10?2----???1---
-----?01-21121111002111101-0---3011-----1110-0221--0-2----00120001{1
2}10??1-10010002-2-2----3--1101?2-1---0010122221??-1-10000000011-?-111?101-
0-?00-00--0130-00100000-0
      Epicrionops_bicolor             000????00{0 1}00000010001---011-
11001???0????-???01?001-----0??1---0-----1-???2-100-010?1-1-000-10---
010111?00?000110100000011OO-1?001---1010?011010010001OO?000-01001----10-
21?????????????????????????????????1?0--03301-----1001-120---0-2---
10112000?0101111110100O1?2-1?01??01?11012001001011122211???-???????????-
010--1310-10000?12111111010100220110
      Ichthyophis_bannannicus         002----02{0 1}00000010001---011-
11001---0?00000??01?001-----0--1---0-----1----2-100-01?11-1-000-10-0-
?10111-00-00011010000001100-1?001---1010-011010010001OO?000?01001----10-
21?????????????????????????????????1?0--03301-0---10001120---?-2----
?11200010101111110100O1?2-1?11??01?11012?????1011122211--?????????????-
010000211?20000?1211111010100220110
      Leptodactylus_mystacinus        102----00100101100011---121-10?01---
00-------?----00--00---1---0---0?11---1-100001112-1-11001000?001111-10-
10210100000011000-00-10---0010-00--0-----00010000-21110----10-2-------10--
------00-21121111002111101-0--02011-----0010-0121--0-2---
10000000111011101001OO02-2-2----3--110112-----0010122211-01-10000000011---
1111301101100-00--0002-00100000-0
;
END;

BEGIN MRBAYES;
      set autoclose=yes nowarn=yes;
      lset nst=6 rates=invgamma;
```

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      unlink statefreq=(all) revmat=(all) shape=(all) pinvar=(all);
      prset applyto=(all) ratepr=variable;
      mcmcp ngen= 10000000 relburnin=yes burninfrac=0.25 printfreq=1000
samplefreq=1000 nchains=4 savebrlens=yes;
      mcmc;
      sumt;
END;
```

Part E. *Chinlestegophis* and 'Lissamphibian Characters'

Prior comparative studies of lissamphibian morphology have identified a series of characters shared among all crown lissamphibian groups. Of these, most are preserved in soft tissue only (e.g. papilla amphibiorum, intrinsic narial musculature, green rods, Leydig cells, dermal body folds, etc., see Trueb and Cloutier, 1991), and thus only a few are thought to be identifiable in fossil relatives of lissamphibians. Of fossilizable characters, two are widely considered to hold strong evidence of lissamphibian origins: pedicellate teeth and tooth crowns with two labiolingually-oriented cusps. Other characters have also been identified as possible synapomorphies with the potential for a fossil record (holospondyly and an opercularis system in the inner ear).

Unfortunately, it is difficult to identify which of these fossilizable characters are held in common between modern lissamphibian orders due to common ancestry and which are held in common due to convergence. Holospondyly in caecilians has already been accepted as a convergence with that of batrachians, as vertebrae in the Jurassic caecilian *Eocaecilia* and the Permian batrachian *Gerobatrachus* are both rhachitomous to some degree (Jenkins et al., 2007; Anderson et al., 2008). In other cases, such as the opercularis system, there is strong evidence from modern taxa that this system was indeed present in the ancestor of all lissamphibians (reversed in caecilians, Maddin and Anderson, 2012) but its distribution amongst fossil lissamphibians is difficult to deduce, as the opercular ossicle is almost always fully cartilaginous.

This uncertainty extends to dental characters as well. In most cases, lissamphibians have 'divided' teeth, in which the tooth (comprised of enamel and tubular dentine) sits on top of a pillar of atubular dentine (the pedicel). 'True' pedicellate teeth are not co-mineralized to the pedicel, but instead are connected by a dental ligament (the 'dividing zone'), which may either implant along the entire circumference of the crown or just the lingual surface. Pedicellate teeth are not seen throughout ontogeny; first generation teeth in caecilians fully lack a pedicel (Wake, 1976), as do early larval teeth in caudates (Davit-Béal et al., 2007). Teeth with a pedicellate morphology, but where the crown is fully mineralized to the orthodentine pedicel, are seen in late premetamorphic caudates (Davit-Béal et al., 2007). In fossil relatives of lissamphibians, pedicelly is recognized only if a clear dividing zone is identified between the crown and implantation tissues. By this definition, pedicelly is present in a handful of dissorophoids (*Amphibamus*, *Platyrhinops*, *Doleserpeton*) but absent in a number of stem (*Kokartus*) and early crown caudates (*Beiyanerpeton*, Gao and Shubin, 2012). Pedicellate morphology, but no clear dividing zone between pedicel and crown, is seen in the batrachian *Gerobatrachus* as well (Anderson et al., 2008). Whether this represents variation in hormonal maturity (either due to preservation of juvenile individuals or neoteny) or lability of the character complex among hormonally mature animals is unclear. Similarly, the wider distribution of a pedicel formed from atubular dentine, as opposed to the presence or absence of a dividing zone, is also unclear.

Bicuspidity is similarly complex. Like pedicelly, bicuspidity appears in caudates at hormonal maturity, but juvenile teeth are strictly unicuspid (Davit-Béal et al., 2007). Young teeth in early-diverging caecilians, like *Typhlonectes*, are unicuspid (Wake, 1976) although first generation teeth in some other caecilians may be ornately multicuspid and assist in the derived behavior of maternal dermatophagy. Bicuspid teeth are known from a handful of dissorophoids (*Amphibamus grandiceps, Platyrhinops lyelli*, *Doleserpeton annectens*, *Tersomius dolesensis*) but are absent from a number of other taxa more closely related to crown Batrachia (e.g. *Gerobatrachus hottoni*) and early caudates (*Kokartus*, *Beiyanerpeton, Pangerpeton*, Wang and Evans, 2006; Gao and Shubin, 2012; Skutchas and Martin, 2011). Although it is tempting to consider distribution of bicuspidity and pedicelly to both reflect hormonal maturity among early fossil lissamphibians, unicuspid pedicellate teeth are known from adults of some early crown salamanders (Jia and Gao, 2016), and the overall distribution of pedicelly and bicuspidity among both modern and fossil lissamphibians suggests that regulation of tooth morphology is more complex than a simple heterochrony.

Our phylogenetic hypothesis strongly supports that bicuspid, pedicellate teeth in lissamphibians had at least two origins; one in batrachians and one in caecilians, as evidenced by well-populated stem groups for both clades that broadly lack bicuspid, pedicellate teeth. This is consistent with high lability of these tooth characters among modern lissamphibians as well as among definitive fossil members of the lissamphibian crown (Gao and Shubin, 2012; Jia and Gao, 2016). This suggests to us one of two possibilities. One is that the ancestral lissamphibian either retained the latent ability to produce teeth with either bicuspid or monocuspid morphology and pedicellate or nonpedicellate implantation, but that most early lissamphibians never produced bicuspid or pedicellate teeth. The other is that bicuspid pedicellate teeth exhibit ‘deep homology’ between modern lissamphibian orders. This could be driven by a shared derived feature of tooth morphogenesis, possibly regulation of the transition from dental cervical loop to Hertwig epithelial root sheath that predisposes a transition from one form of tooth to another. Detailed study of lissamphibian tooth development in both batrachians and caecilians will be necessary to differentiate between these possibilities.

How the dentition of *Chinlestegophis* fits into this complex story is also not clear due to the nature of the material and the limits of the imaging modalities employed here. Teeth of *Chinlestegophis* are clearly unicuspid, but whether they exhibited a clear dividing zone (and therefore pedicelly) cannot be determined from our CT data. More importantly, it is unclear whether a pedicel comprised of atubular dentine is present without a clear dividing zone; this determination would depend on destructive preparation of histological thin-sections of one or both specimens.

Part F. Burrowing in *Chinlestegophis*

During the 1997 field season, an area was found rich in burrows near the Derby Junction locality. Fragments of burrows that had fallen out of the cliff face were collected. Two of these burrows were found to contain bones. A search for the rest of these incomplete burrows was fruitless. Typically, burrows in the ‘red siltstone’ member are associated with floodplain deposits (Dubiel, 1992). One burrow fragment contained the partial skull of DMNH 39033. Unfortunately half of the skull was lost when the burrow broke off from the cliff. It is unknown if there

originally had been any postcranial material in the burrow. The other bone-bearing burrow contained poorly preserved, unidentifiable bone fragments.

The average burrow diameter at the field sites ranges greatly from 23 to 72 mm between different burrows (mean diameter = 45.5 mm). The typical burrow diameter at the Derby Junction site, where DMNH 39033 was collected, is approximately 42 mm. These burrows in question have relatively smooth walls and simple architecture (based upon more complete in situ burrows of similar morphology; see *SI Appendix* Fig. S8). Hasiotis and Mitchell (1989) initially described this morphology as possibly lungfish in origin, but later described a similar morphology as a simple "type III" crayfish burrow (Hasiotis et al., 1993). Although there is both taphonomic and morphological evidence that *Chinlestegophis jenkinsi* may have been fossorial, there remains the possibility that the skull was washed into a burrow or the carcass was carried in for food. Another possibility is that the disparate sizes of burrows locally at Lost Bob and Derby Junction reflect two distinct burrow makers (i.e., decapod and non-decapod, perhaps vertebrate). Indeed, the possibility of a non-decapod burrow-maker of less complex burrows at the Derby Junction locality was suggested by Hasiotis et al. (1993). To test the hypothesis that the burrows were made by two sympatric species, we measured diameters of all available in situ burrows (N = 55) at the two burrow-rich localities and assessed size distributions using Hartigan's test for multimodality. Nevertheless, our results failed to reject the null hypothesis of unimodality at either site (Lost Bob, $D = 0.048$, $p = 0.859$; Derby Junction, $D = 0.083$, $p = 0.177$). This is consistent with the overall similarity of the burrow structures of all sizes, being roughly cylindrical and oriented completely vertically with minor flexures and a J-shaped terminus resembling burrows sometimes interpreted as decapod burrows elsewhere in the Chinle Formation. In summary, we cannot confidently determine whether the simple burrows at our field sites are decapod or vertebrate in origin, or whether they were constructed by more than one species.

There is precedence for Permo-Triassic amphibians as burrowers or secondary burrow occupants. Among known examples are the dvinosaur *Acroplous*, which has been reported in burrows in the Lower Permian Blue Springs Shale of Kansas (McCahon and Miller, 2015), and the dissorophoid *Perryella,* a possible burrow maker from the Lower Permian Wellington Formation of Oklahoma (Carlson, 1987). Among stereospondyls specifically, the small rhinesuchid *Broomistega* has been reported as a secondary inhabitant of a cynodont burrow in the Lower Triassic Normandien Formation of South Africa (Fernandez et al., 2013). Burrow occupancy may have been a latent behavior more common among small temnospondyls than is currently appreciated, in which case caecilian fossoriality may represent part of a continuum of burrowing behaviors present among Permian-Triassic total group amphibians.

Headfirst burrowing is a key aspect of modern caecilian ecology. *Chinlestegophis* exhibits a number of characteristics that were likely requisite for headfirst burrowing. These characteristics fall into several broad categories: consolidation of the cranial bones to resist force of substrate compaction, changes in sensory organ morphology and location, and changes in skull shape to accommodate skull functions in confined spaces. In this regard, *Chinlestegophis* is transitional between the basal amphibian condition and the fossorially-adapted cranial skeleton of later stem caecilians (e.g. *Eocaecilia micropodia*) and crown caecilians. Reduction of ossification centres allows the skull to resist compressive forces by reducing the number of soft tissue connections (sutures) where the skull can fail under compression, and is a well-documented trend in tetrapods employing headfirst burrowing (Gans, 1960). Modern caecilians exemplify this trend by fusing the dermal skull into a small number of compound elements and

by hyperossifying the braincase into robust anterior (sphenethmoid) and posterior (os basale) elements. *Chinlestegophis* exhibits some steps in the direction of the caecilian condition. For example, the lacrimal is fused to the maxilla, forming the beginnings of the maxillopalatine element that dominates the antorbital region of the caecilian skull. The suspensorium was apparently comprised of a single co-ossified element, suggested here to represent a possible pterygoquadrate, which incorporates the pterygoid, quadrate, and epipterygoid. Although *Chinlestegophis* lacks an expanded, convex os basale that incorporates the parasphenoid, pila antotica, and prootic as in *Eocaecilia*, the exoccipitals are fused to each other posteriorly and ventrally to the basioccipital, thereby forming what could be described as an incipient os basale. A number of distinct caecilian compound ossifications are absent in *Chinlestegophis*, however, including a pseudodentary (fusion of coronoid, dentary, and splenial) and pseudangular (fusion of articular, angular, and prearticular), the sphenethmoid, and several compound bones of the dermal skull roof.

Fossoriality is also associated with shifts in sensory adaptation. Fossorial tetrapods typically reduce sensitivity to visual and high-pitched auditory stimuli, as light and high-pitched sounds are negligible underground. In caecilians, the eyes are highly reduced or absent, the pineal organ is reduced, and the tympanic middle ear is lost. Instead, caecilians modify the nasolacrimal duct to form the chemosensory tentacular organ. *Chinlestegophis* shows reduced orbits and pineal foramen, suggesting a reduced reliance on light and visual stimuli. The middle ear, however, still retained impedance-matching capabilities, as evidenced by the retention of a conspicuous otic notch. A tympanic middle ear is lost in *Eocaecilia* and crown caecilians, although sensory epithelia retained by some caecilians indicate that loss of the ability to process high-frequency sounds was not lost immediately following the loss of the tympanic middle ear (Maddin and Anderson, 2012). There is also a well-developed nasolacrimal duct that possibly connects to a sulcus in the rim of the orbit of *Chinlestegophis*, much like *Eocaecilia*. It is unclear whether this represents the insertion of the tentacular apparatus. The above is possible evidence of the stepwise sequence of the acquisition of fossoriality in caecilians, from the use of existing burrows as shelters, or crevice occupiers, to a fully fossorial existence.

Part G. SI Figure List

Figure S1. Photograph of *Chinlestegophis jenkinsi* gen. et sp. nov. Holotypic skull (DMNH 56658) in dorsal (*A*), ventral (*B*), occipital (*C*), left lateral (*D*), and right lateral (*E*) views.

Figure S2. Photograph of *Chinlestegophis jenkinsi* gen. et sp. nov. Referred specimen (DMNH 39033) in burrow shown in dorsal (*A*) and slight oblique dorsolateral (*B*) views. Note that the diameter of the burrow-fill (b f) closely approximates the width of the occupant.

Figure S3. Right lower jaws of *Chinlestegophis* (*A*, *B*) and *Eocaecilia* (*C*) compared. In *A–C* jaws are shown in medial (top), dorsal (middle), and ventral (bottom) views. '*C'* is redrawn from Jenkins et al. (2007). Abbreviations: a, angular; c, coronoid; d, dentary; f im, intramandibular foramen; int p, internal process; m f, mandibular (adductor) fossa; pa, pseudoangular; part, prearticular; sa, surangular; sp, splenial.

Figure S4. Fate of the lacrimal ossification in *Chinlestegophis*. Position of nasolacrimal duct (purple) and palatine bone (orange) in referred specimen (DMNH 39033) in dorsal (*A*) and lateral (*B*) views, and passage of nasolacrimal duct in maxilla shown in transverse section (*C*). Passage of nasolacrimal duct (green) in lacrimal bone of *Pasawioops mayi* (adapted from Anderson and Bolt, 2013) shown for comparison. Scale is 5 mm in '*A*' and '*B'*, dashed line shows approximate position of '*C'*, '*C'* and '*D'* not to scale. Abbreviations: mx, maxilla.

Figure S5. Postcrania of *Chinlestegophis* holotype (DMNH 56658). Right clavicle in ventral (*A*) and lateral (*B*) views (anterior to right). Interclavicle in ventral (*C*) and dorsal (*D*) views. Isolated limb element (ulna?) in lateral (*E*) and medial (*F*) views. Three articulated neural arches lacking their centra in left lateral (*G*) and dorsal (*H*) views (anterior to left).

Figure S6. *Chinlestegophis* and *Rileymillerus* added to Maddin et al. data set (no other stereospondyl characters or taxa). Tree topologies from cladistic analysis using the matrix of Maddin (2012b) place *Chinlestegophis* (asterisk) and caecilians outside lepospondyls and within Temnospondyli, but in phylogenetically disparate subclades. Note that no other stereospondyls were included in the original publication, resulting in an undersampling of stereospondyl characters. The two topologies are based on runs using Bayesian (*A*) and parsimony (*B*) analysis in MrBayes and PAUP* 4.0, respectively. Parsimony tree in '*B'* is a strict consensus of 12 equally parsimonious trees (1450 steps).

Figure S7. *Chinlestegophis* and *Rileymillerus* added to combined matrix with stereospondyl characters and taxa. Note that analysis combining matrices of Schoch (i.e., with stereospondyls) and Maddin resolve the positions of *Chinlestegophis, Rileymillerus,* and *Eocaecilia* within Stereospondyli. The clade in blue represents early batrachians (frogs and salamanders), whereas that in red represents early caecilian-like stereospondyls, including *Chinlestegophis* as a close sister taxon (asterisk). The two topologies are based on (*A*) Bayesian consensus cladogram from analysis in MrBayes and (*B*) 50% majority rule consensus of 882 equally parsimonious trees (1514 steps) from parsimony analysis in PAUP* 4.0. Bayesian posterior probabilities are shown at nodes in '*A*' and consensus indices (left of virgule) and bootstrap values equal to or greater than 50% (right of virgule) in '*B.*' The complete character list and source matrix is included in Supporting Information Part C & D.

Figure S8. Burrow structures from the Chinle Formation near Derby Junction, Eagle Basin, Colorado.

Part H. SI HRXCT Movies

1. 1type_yaw.MPG—3D yaw of holotypic skull (DMNH 56658).

2. 2type_roll.MPG—3D roll of holotypic skull (DMNH 56658).

3. 3type_otic.MPG—3D yaw of otic notch and acoustic canal in holotype (DMNH 56658), showing supraoccipital (green), tabular (magenta), squamosal (red), and pterygoid (orange) bones in articulation.

4. 4type_jaw.MPG—3D roll of mandible in holotype (DMNH 56658).

5. 5paratype_yaw.MPG—3D yaw of referred (burrow) specimen (DMNH 39033).

6. 6paratype_roll.MPG—3D roll of referred (burrow) specimen (DMNH 39033).

7. 7paratype_jaw_roll.MPG—3D roll of referred mandible (DMNH 39033).

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