Supplementary Information for MS 2009-11-14758:

The Evolution of Mammal-like Crocodyliforms in the Cretaceous of Gondwana

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These Supplementary Materials include:

1. Additional geologic context of Galula Formation (Red Sandstone Group, Unit I) exposures preserving specimens of *Pakasuchus kapilimai*.

2. Extended diagnosis, basic metrics, dental formula, and additional anatomy of *Pakasuchus kapilimai*

3. Additional images of *Pakasuchus kapilimai*

4. Phylogenetic analysis protocol, results, and additional discussion

5. Character list

6. Data matrix

7. Comparative taxa used in phylogenetic analysis

8. Details of QuickTime Movie files of holotype (RRBP 08631) and referred (RRBP 05103) specimens to illustrate dental morphology in the context of the toothed elements.

9. Additional References

1. GEOLOGICAL SETTING OF RED SANDSTONE GROUP, GALULA FORMATION (UNIT I), RUKWA RIFT BASIN, SOUTHWESTERN TANZANIA

The Rukwa Rift Basin is located in southwestern Tanzania between Lakes Tanganyika and Nyasa (Malawi) (Supplementary Figure 1a) and developed in an intracontinental transform zone belonging to the East African Rift System (EARS). The Rukwa Rift Basin is roughly 300 km long by 50 km wide and contains up to 11 km of Permian to Recent sedimentary units (Wheeler and Karson, 1994). The Rukwa Rift follows the trend of Precambrian basement foliation, and includes a minimum of three phases of tectonic reactivation with subsequent deposition (e.g., Kilembe and Rosedahl, 1992; Wheeler and Karson, 1994; Van der Beek *et al.,* 1998). The lowermost sequence, tectonically related to the break-up of Pangaea (Van Der Beek *et al.,* 1998), resulted in Karoo-age deposition as seen in other regions of Gondwana (Wopnfer, 2002). The uppermost strata are known as the Lake Beds sequence and resulted from late Tertiary (Pliocene-Pleistocene) rifting (Quenell *et al.,* 1956). However, the Red Sandstone Group strata, in which the fossils reported here were discovered, have been a source of considerable debate (e.g., Tiercelin *et al.,* 1988; Damblon *et al.,* 1998; Morley *et al.,* 1999; Roberts *et al.,* 2004, In Press).

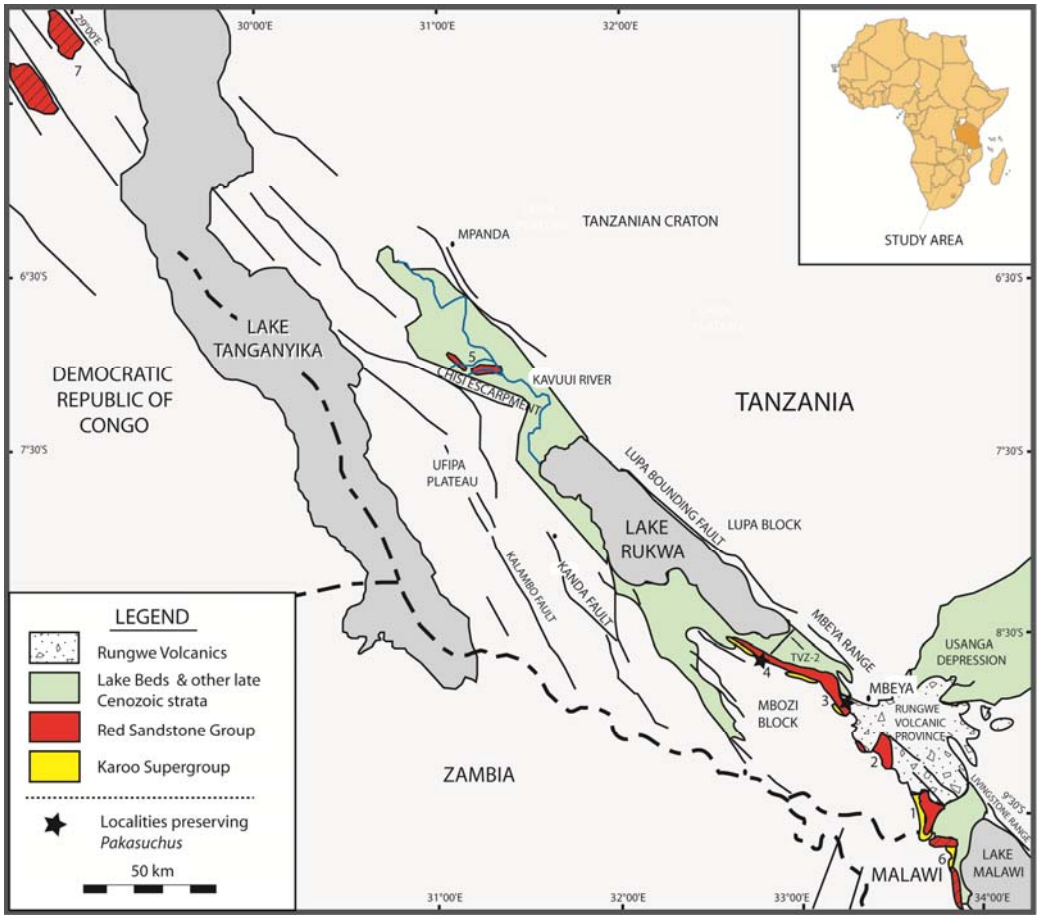


Figure S1a. Regional geological setting of Galula Formation deposits in which specimens of *Pakasuchus kapilimai* have been recovered (black stars indicate localities preserving remains of *Pakasuchus*). Modified from Roberts et al (In Press).

Proposed age estimates for the Red Sandstone Group (RSG) have ranged from Middle Jurassic to late Miocene (see Roberts et al., 2004, [In Press] for a complete discussion). However, recent work by our group has demonstrated the existence of at least two discrete stratigraphic units in the Rukwa Rift Basin: (1) the Cretaceous-age Galula Formation (formerly referred to as Unit I) and (2) the Paleogene (~ Oligocene) age Nsungwe Formation (formerly referred to as Unit II). See Krause et al., 2003; Gottfried et al., 2004; Roberts et al., 2004; O'Connor et al., 2006; Stevens et al., 2005, 2006, 2008, 2009a, 2009b). Specimens of *Pakasuchus* have been recovered from the upper part of the Galula Formation (Supplementary Figure 1b), recently formalized as the Namba Member (Roberts et al., In Press). A combined dating approach, involving biostratigraphy, detrital zircon geochronology and regional correlation, has been used to constrain the age of the Galula Formation. Middle to Late Jurassic populations of detrital zircons (~150-160 Ma) were identified at multiple levels within the sequence, providing a poor, but useful maximum depositional age for the formation. More useful are cross-cutting relationships with a series of carbonatite volcanoes and intrusions dated at between 99-115 Ma, which suggests that deposition of the Namba Member of the Galula Formation occurred contemporaneously with or immediately prior to intrusion and eruption of these volcanics. No volcanic tuffs or ash have yet been observed in the Galula Formation; however the uppermost portion of the sequence is characterized by apparent cross-cutting relationships with carbonatite dikes, as well as intense soft-sediment deformation, including liquefaction features, interpreted as evidence of local seismic activity, as would be expected during intrusion of a magmatic body. In addition, the co-occurrence of osteoglossomorph fish, a group that extends back only as far as the Cretaceous, with *Pakasuchus* in the Galula Formation, coupled with sedimentological and faunal affinities to the Aptian aged Dinosaur Beds of Malawi are consistent with a "Mid" Cretaceous depositional age for the Namba Member, from which all specimens of *Pakasuchus* were derived.

The Galula Formation is at least 500 m thick in outcrop, characterized by a fairly homogenous sequence of multistory red sandstones and thin lenticular pebble conglomerates and mudstones. The entire sequence is characterized by consistent northwesterly paleoflow along the axis of the rift basin, and is interpreted as a braided fluvial system in a semi-arid climate. The sedimentology and fauna preserved in the sequence is generally similar to that recovered from the Dinosaur Beds of Malawi, located less than 150 km to the southeast of the fossiliferous portions of the Red Sandstone Group. Based on this and other unpublished data, the Galula Formation of the Red Sandstone Group is interpreted to represent the downstream equivalent to the Dinosaur Beds, presenting an interesting opportunity to look at regional paleoecology, paleoclimate and paleoenvironments of Central Africa during the "middle" Cretaceous. In addition to the crocodyliform reported here, the Galula Formation preserves a diverse micro- and macrovertebrate assemblage (O'Connor et al., 2006), including small, isolated fish and turtle remains, dinosaur eggshell (Gottfried et al., 2004), and the most complete mammal fossil yet recovered from the Cretaceous of continental Africa (Krause et al., 2003). These deposits also preserve large associated and articulated skeletons of dinosaurs, including as yet unidentified theropods and titanosaurian sauropods currently undergoing preparation and study.

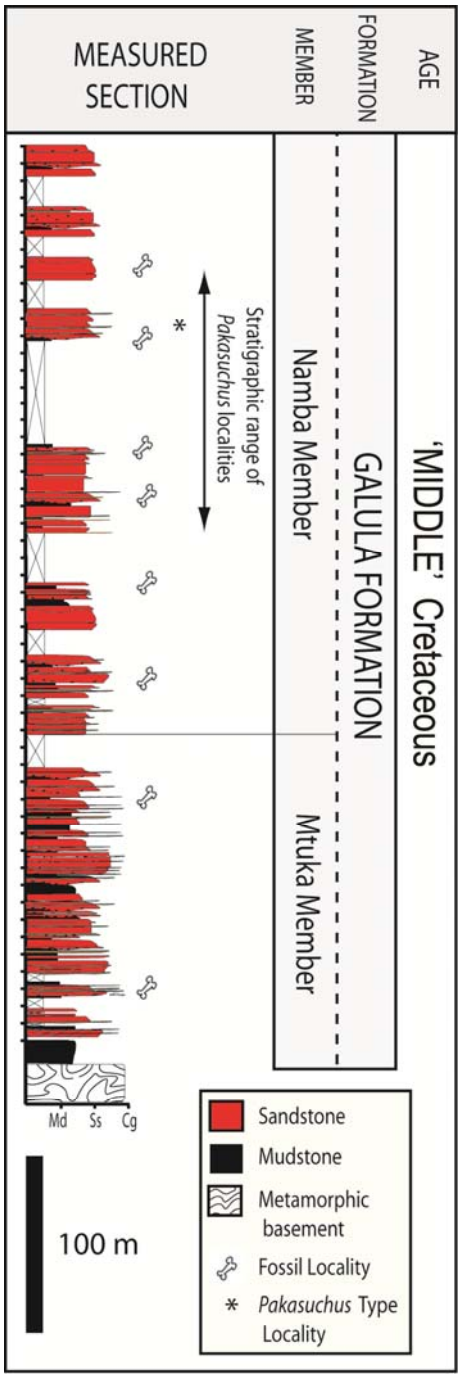


Figure S1b. Type section of the Galula Formation, Red Sandstone Group (mid-Cretaceous), indicating the stratigraphic distribution of *Pakasuchus* specimens and position of the holotype (RRBP 08631) *P. kapilimai*.

2. Extended diagnosis, basic metrics, and additional descriptive anatomy (cranial, dental, postcranial) of *Pakasuchus kapilimai*.

2.a. Extended Diagnosis:

Pakasuchus kapilimai differs from other crocodyliforms in the following features: extreme heterodonty (regionalization) with reduced tooth count (8 in lower quadrant, 5 in upper quadrant); trenchant molariform cheek-teeth with paired rostrocaudally-oriented crests and intervening troughs; upper and lower molariform teeth with complementary occlusal surfaces; rostroventrolaterally projecting pterygoid flanges; squamosal flared dorsally at contact with parietal, forming a shallow longitudinal concavity on the dorsal midline; biplanar articular-quadrate articulation bracketed laterally by dorsally-expanded surangular; extremely reduced osteoderms along the dorsal surface of the thorax, with a normal complement of osteoderms surrounding the tail.

Further differs from other notosuchians, including *Notosuchus* (Woodward, 1896; Andrade and Bertini, 2008b), *Mariliasuchus* (Zaher et al., 2006; Andrade and Bertini, 2008b), *Sphagesaurus* (Pol, 2003; Andrade and Bertini, 2008a) and *Comahuesuchus* (Martinelli, 2003) in lacking expanded ectopterygoids and palatines that exclude the pterygoids from the medial margin of the suborbital fenestrae, and from *Malawisuchus* (Clark et al., 1989; Gomani, 1997) in the absence of an antorbital foramen/fossa, the presence of rostroventrally directed pterygoid flange, ventrocaudally oriented retroarticular process, and complex contact between upper and lower molariform teeth.

2.b. Basic metrics of *Pakasuchus kapilimai*—RRBP 08631 (holotype specimen)

Total Length	55 cm
Snout-Vent (SVL) Length	30 cm
Skull Length	6.1 cm
Maximum Skull Width	3.8 cm
Humerus Length	4.1 cm
Ulna Length	3.4 cm
Femur Length*	5.1 cm
Tibia Length*	4.3 cm

* estimated length due to damage

2.c. Additional anatomical description of the cranio-dental and integumentary skeleton

The small size and state of preservation (i.e., upper and lower jaws recovered in a closed position) prompted the use of high-resolution x-ray micro-computed tomography to elucidate details of morphology related to the teeth and jaws. X-ray micro-computed tomography was conducted at the Ohio University µCT Facility (GE eXplore Locus *in-vivo* micro-CT scanner) using the following protocol: 85 kVp, 400 mA, and a slice thickness of 0.045 mm. VFF and DICOM files were compiled into three-dimensional reconstructions on a Dell Precision 670 3.8 GHz Xeon with 4 GB of memory, and an nVidia Quadro FX 4400 512 MB graphics card, with visualizations obtained using the AMIRA 4.1 Advanced Graphics Package.

2.c.1. Cranio-Dental Anatomy

Remarkable preservation of three specimens (RRBP 08631, RRBP 05103) of *Pakasuchus* with upper and lower dentitions in near-occlusion allows direct assessment of relative tooth size, shape, position, and spacing along the dental series and between tooth rows. Such evidence provides a starting point for highlighting various cranio-dental details and modeling tooth-tooth interactions.

The skull is short and broad with a nearly flat dorsal roof, exhibiting only a slight dorsal elevation of the squamosal near its junction with the parietal. The occipital condyle is directed caudoventrally, rather than caudally as in most aquatic crocodyliforms. The nasals exhibit a flat, dorsally-facing surface and join the unpaired frontals along a transverse suture. The dorsal margin of the laterally-facing orbit was rimmed by two palpebrals: the rostral palpebral is long and narrow, whereas the caudal palpebral is subquadrangular in shape (Fig. 1b). Although the premaxillae and nasals are incomplete rostrally, the external nares were directed rostrally, similar to many small-bodied notosuchians such as *Notosuchus* (Woodward, 1896; Andrade and Bertini, 2008b)*, Mariliasuchus* (Zaher et al., 2006)*, and Malawisuchus* (Clark et al., 1989; Gomani, 1997). Also similar to these forms, a row of distinct foramina is present along the otherwise smooth external alveolar margins of the maxilla and dentary (Fig. 1b). An enlarged mandibular canal is present, paralleling the para-alveolar shelf and passing rostrally to the level of the fourth postcaniniform tooth.

The secondary palate (palatine-pterygoid) is complete being formed rostrally by maxillary palatal processes joined extensively along the midline and caudally by the palatines which form the rostral margin of a deep choanal groove. The choanal groove is bounded caudally by the fused pterygoids, the latter of which have a rostrolaterally directed flange with a distinct ventrally directed caudal margin. The ectopterygoid articulates with the caudoventral end of the maxilla and the medial surface of the jugal in a robust suture, extending caudoventrally to contact the pterygoid flange. The ectopterygoid is mediolaterally restricted, and thus does not extend along the pterygoid flange as in *Notosuchus* (Andrade and Bertini, 2008b)*, Mariliasuchus* (Zaher et al., 2006) and *Sphagesaurus* (Pol, 2003).

Since none of the specimens recovered to date preserves a complete premaxilla, it is not possible to estimate the exact number or morphology of teeth in the rostral part of the upper dental series. Root thickness varies along the tooth row, with thick-walled roots in the anterior dentition and thin-walled, labiolingually compressed roots throughout the molariform series (Fig. 2; Supplementary Videos 1-2). The first alveolus within both the maxilla and dentary is occupied by a hypertrophied caniniform tooth. The medial surface of the upper caniniform is closely aligned with the lateral side of the dentary on each side, thereby restricting any significant transverse movement of the lower jaw. Maxillary tooth two and mandibular teeth two through six are relatively homodont and consist of small, cylindrical ‘premolariforms’ capped with transversely compressed blade-like crowns (Fig. 2a). The occlusal surface of the lower molariform faces rostrodorsally, revealing an asymmetric crown with an apex positioned over the distal half of the tooth. In contrast, the upper molariform has an occlusal surface facing caudoventrally, with its apex positioned near the mesial margin of the crown (Fig. 2c). With jaws closed, the lower molariform was positioned just medial to the upper, resulting in a slight offset of crests and troughs between opposing teeth (Fig. 2j).Whereas the lateral crest of the lower tooth slots into the trough of the upper molariform, the medial crest of the upper tooth occupies the trough of the lower molariform (Fig. 2; also see Supplementary Figure S3).

2.c.2. Integumentary Skeleton—Osteoderms

As noted in the main text, *Pakasuchus* is unique among crocodyliforms in possessing reduced osteodermal structures throughout the trunk region. The identification of these structures as developmentally-truncated osteoderms is based on both topological and

developmental evidence. For example, the ossified structures occupy positions along the epaxial region of the trunk where parasagital, keeled osteoderms typically occur in a variety of diapsid reptiles (Romer, 1956). Moreover, the relative length (craniocaudal dimension) of the individual ossified structures is consistent with that observed in the trunk osteoderms of most crocodyliforms. Finally, the longitudinal arrangement of each structure is consistent with the initial pattern observed during osteoderm osteogenesis in living crocodilians (Vickaryous and Hall, 2008). Specifically, the midline keel of each osteoderm is the first portion of the element to ossify, whereas the broad, flat portion of typical crocodilian osteoderms represents subsequent ossification spreading peripherally from the longitudinal keel.

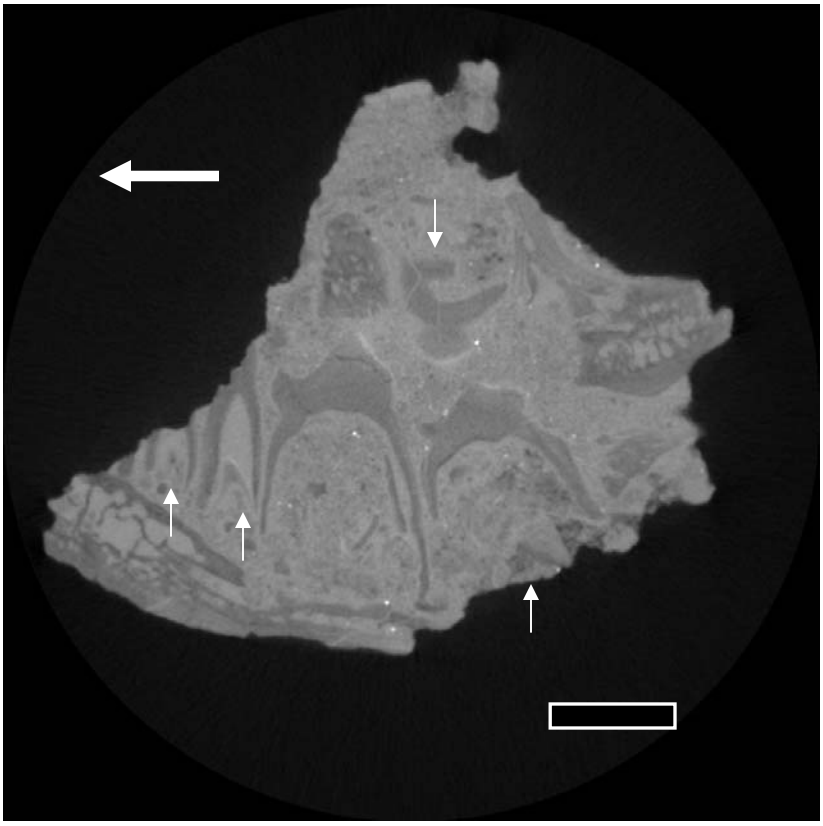
We hypothesize that the longitudinal ossifications observed in *Pakasuchus* result from a truncation in the osteodermal developmental program, whereby only the central primary ossification occurs along the longitudinal axis of the osteoderm. It is possible that the morphology in *Pakasuchus* merely reflects an ontogenetic snapshot in osteodermal development with the caudal region fully ossifying before the thoracic region. However, such a model conflicts with whole-body patterns of osteoderm development in extant crocodilians in which ossification begins in the cervical region and progresses caudally through the thoracic, and finally, caudal regions of the body (Vickaryous and Hall, 2008). The transition between the fully-formed osteoderms of the caudal region and the reduced osteoderms in the thorax is clearly visible at the junction of the tail and the body (Fig. 1e). A reduction in osteoderm size occurs over a 2 to 3 body-segment span centered on the sacral region. Another possibility is that the segmental structures represent ossified tendons associated with epaxial musculature. However, in no cases do the structures attach to the bony axial skeleton (as would be expected in the case of entheses). The possibility that these structures represent ossifications of intramuscular tendons (i.e., that they are not entheses, but contained with the body of muscle itself) of the epaxial musculature is another consideration. However, we view this as unlikely given that the ossifications are also present along the dorsal aspect of the scapula, suggesting a dermal rather than epaxial musculature origin. Finally, remarkable soft-tissue preservation is apparent in the presence of poorly-ossified/cartilaginous intermediate and sternal ribs that are continuous distally with the vertebral rib series (Fig. 1c).

2.d. *Pakasuchus kapilimai*—RRBP (Rukwa Rift Basin Project) 08631

Dental classification (above) of tooth type by position and quadrant-specific (below) dental formula of *P. kapilimai* .

PMX	CN	PRM	MF
inc	cn	prm	mf
?	1	1	3
0	1	5	2

2.e. Replacement teeth and primary crown morphology of molariform teeth



Replacement crowns are present for the post-caniniform tooth series (Supplementary Figure S2, vertical white arrows). Significantly, replacement crowns already possess morphology similar to that of the erupted teeth (Supplementary Figure S3), indicating that postcaniniform crown morphology is primary in nature and does not reflect the result of wear by interaction between opposing teeth. Scale bar equals 0.5 cm.

Figure S2. Sagittal microCT slice section through upper and lower left tooth rows in *Pakasuchus kapilimai* (RRBP 05103) to illustrate the combination of complex occlusal morphology with wide-diameter, single roots. Horizontal white arrow indicated rostral direction, whereas vertical white arrows denote the position of replacement crowns.

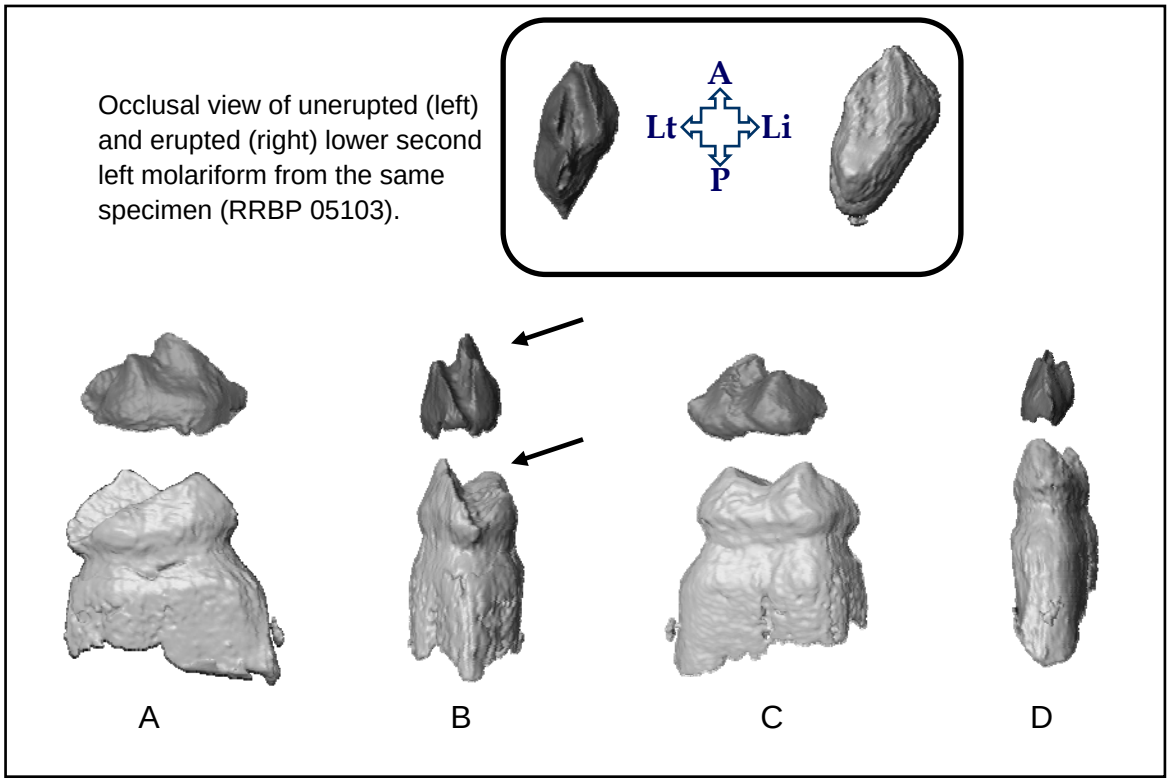


Figure S3. Reconstructed microCT images of erupted and worn left lower second molariform (bottom row) and the unerupted replacement crown for the same tooth (upper row) of *Pakasuchus kapilimai* (RRBP 05103) in lateral (**A**), anterior (**B**), lingual (**C**), and posterior (**D**) views. Inset above includes occlusal views of the two teeth in question. These illustrate the combination of complex occlusal morphology along with wide-diameter, single roots, the distinct constriction between the crown and root, and preferential wear that occurs along the lateral crest (black arrows) of the second lower molariform after it erupts.

3. PHYLOGENETIC ANALYSIS PROTOCOL AND RESULTS:

The analysis described herein represents a phylogenetic sampling strategy focused on notosuchian mesoeucrocodyliforms, including the first formal, large-scale analysis incorporating a number of recently described putative notosuchians (e.g., *Pakasuchus, Adamantinasuchus*). Moreover, this analysis incorporates novel anatomical data from other notosuchians (e.g., *Malawisuchus, Simosuchus*) based on either new specimens, new imaging studies (e.g., MicroCT analysis of *Malawisuchus*), or both.

The 54 taxon, 236 character data matrix was analyzed using equally-weighted maximum parsimony with TNT v.1.1 (Goloboff et al., 2003). Data matrix compilation and editing, and character mapping were conducted in Mesquite v. 2.0 (Maddison and Maddison, 2007). Modified from protocols outlined in Pol and Apesteguía (2005), a heuristic search algorithm was employed using 1000 Wagner tree replicates (random addition sequences: TBR branch swapping with 10 trees held per replicate). Zero-length branches lacking support under any of the most parsimonious tree reconstructions were collapsed (Coddington's rule 1). Two hundred (of 1000 replicates) optimal trees were recovered each with a tree length of 867, Consistency Index (CI) = 0.33, Retention Index (RI) = 0.64, and Rescaled Consistency Index (RC) = 0.21.

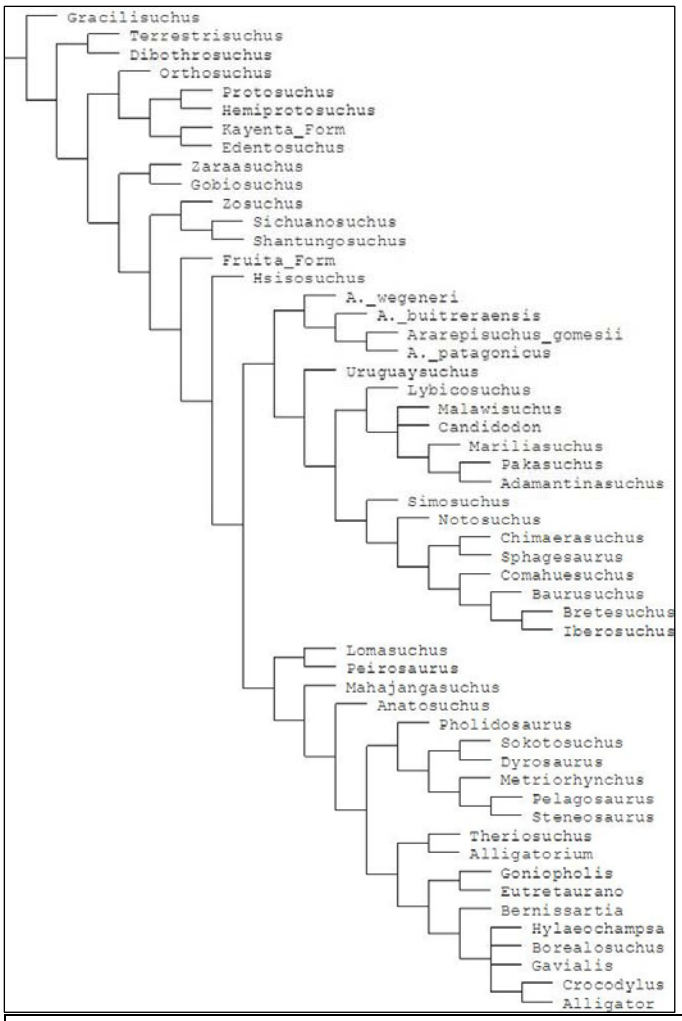


Figure S4. Strict consensus of 200 optimal (out of 1000 replicates) trees: TL, 867; CI =0.33; RI = 0.64.

The strict consensus tree (Figure S4) illustrates that *Pakasuchus kapilimai* nests within both traditional (Gasparini, 1971) and revised (Buckley et al., 2000) definitions of Notosuchia, forming a sister-taxon relationship with *Adamantinasuchus navae*, the small-bodied form from Late Cretaceous (Turonian-Santonian) of Brazil. *Mariliasuchus amarali* (also from the early Late Cretaceous of Brazil) is positioned as the sister taxon to the *Pakasuchus-Adamantinasuchus* clade. *Malawisuchus mwakasyungutiensis* from the ~Aptian Dinosaur Beds of Malawi and *Candidodon itapecuruense* from the late Early Cretaceous of Brazil, together form a trichotomy with the *Paka*-, *Adamantina*-, *Mariliasuchus* cluster. These taxa all represent 'middle' Cretaceous Gondwanan (see main text Figure 3) crocodyliforms characterized by very small body size and extreme heterodonty. *Lybicosuchus*, a very poorly known form from the early Late

Cretaceous of Egypt, is sister to this group. A diverse collection of taxa, including the *Chimaerasuchus*—*Sphagesaurus* clade and a Baurusuchid—*Comahuesuchus* clade, together form the sister taxon to the small-bodied, heterodont notosuchians. *Notosuchus terrestris* (on which the clade name was based) and *Simosuchus clarki* represent successively more distant sister taxa to this varied (e.g., body size, head shape, etc.) group of crocodyliforms. Finally, *Uruguaysuchus* is the sister taxon to the entirety of the notosuchian—sphagesaurid—baurusuchid grouping, with the *Araripesuchus* species cluster occupying the basalmost position within the local topology.

Note: *Comahuesuchus* has previously been interpreted as representing (**a**) a basal mesoeucrocodylian positioned near the notosuchian stem, (**b**) a basal notosuchian, (**c**) a 'notosuchian' crocodyliform allied with the baurusuchids or (**d**) a derived notosuchian allied with *Anatosuchus minor*. One interesting note is that in no reconstruction from this analysis does *Anatosuchus*, a putative notosuchian recovered from mid-Cretaceous deposits in Niger (Sereno et al., 2003; Sereno and Larsson, 2009), demonstrate a relationship with notosuchian crocodyliforms. In fact, in all 200 optimal trees it exhibits affinities with *Mahajangasuchus insignis* (Buckley and Brochu, 1999; Turner and Buckley, 2008), and is positioned near the stem of Neosuchia. Since this represents one of a handful of large-scale analyses to include *Anatosuchus* among a diverse collection of mesoeucrocodylians and basal neosuchians, the hypothesized realignment of this taxon is not unexpected (also see Zaher et al., 2006). More detailed work focused on *Anatosuchus* and other recently discovered mesoeucrocodylians (e.g., Novas et al., 2009; Sereno and Larsson, 2009) will no doubt further clarify relationships in this dynamic portion of the topology.

Character support at the *Malawisuchus* – *Candidodon* – (*Mariliasuchus (Pakasuchus, Adamantinasuchus)*) node includes the presence of: (1) a broad, laterally convex dentary anterior to the mandibular fenestra [Char. 157]; (2) distal end of quadrate that is mediolaterally expanded and anteroposteriorly restricted [Char. 187]; (3) cheek tooth crowns with one main cusp and variably arranged smaller cusps [Char. 183]; (4) a lacrimal that tapers ventroposteriorly and contacts the jugal only slightly, if at all [Char. 224]; (5) an ultimate maxillary tooth that is less than or equal to ½ the size of the penultimate maxillary tooth [Char. 231]; and (6) variably developed cingula at base of tooth crowns [Char. 233]. Characters in support of the *Malawisuchus, Pakasuchus, Candidodon, Adamantinasuchus* grouping includes the presence of: (1) a jugal that does not pass the rostral extent of the orbit [Char. 122], unknown state in *Candidodon*; and (2) molarization of cheekteeth [Char. 232].

The relationships of taxa within the *Pakasuchus, Candidodon, Adamantinasuchus, Malawisuchus* area of the tree is only weakly supported. Although this likely reflects the fragmentary nature of two of the four forms (e.g., *Candidodon* and *Adamantinasuchus* known primarily from fragmentary cranial remains), in all cases the dentitions are preserved in enough detail to place the forms among the notosuchians. Although *Pakasuchus* and *Adamantinasuchus* share a number of potential synapomorphies, additional, better preserved specimens will no doubt add critical character information useful for further resolving ingroup relationships.

4. CHARACTER LIST FOR DATA MATRIX USED IN PHYLOGENETIC ANALYSIS

Characters 1–101 are based on Clark (1994). Characters 102–230 are based on a number of other recent studies and reflect modifications as noted in Pol and Apesteguía (2005). Characters 231–236 are novel to this analysis. Definitions include both the original citation and the character number used in the original work. Similar to recent analyses, Character 5 was excluded from the analysis due to non-independence with the modified definition of Character 6. Characters 6, 12, 37, 45, 69, 73, 104, 105, 149, 190 were coded as additive in this analysis and are indicated by a plus sign (+).

Character 1 (modified from Clark, 1994: char. 1). External surface of dorsal cranial elements: *smooth (0), slightly grooved (1), or heavily ornamented with deep pits and grooves (2).*

Character 2 (modified from Clark, 1994: char. 2). Skull expansion at orbits: *gradual (0), or abrupt (1).*

Character 3 (modified from Clark, 1994: char. 3). Rostrum proportions: *narrow oreinirostral (0), broad oreinirostral (1), nearly tubular (2), or platyrostral (3).*

Character 4 (Clark, 1994: char. 4). Premaxilla participation in internarial bar: *forming at least the ventral half (0), or with little participation (1).*

Character 5 (Clark, 1994: char. 5). Premaxilla anterior to nares: *narrow (0), or broad (1).*

Character 6 (modified from Clark, 1994: char. 6). (+) External nares facing *anterolaterally or anteriorly (0), dorsally, not separated by premaxillary bar from anterior edge of rostrum (1), or dorsally, separated by premaxillary bar (2).*

Character 7 (Clark, 1994: char. 7). Premaxillae, palatal processes: *do not meet posterior to incisive foramen (0), or meet posteriorly along contact with maxillae (1).*

Character 8 (Clark, 1994: char. 8). Premaxilla – maxilla contact: *premaxilla loosely overlies maxilla (0), or sutured together along a butt joint (1).*

Character 9 (modified from Clark, 1994: char. 9). Ventrally directed notch on ventral edge of rostrum at premaxilla – maxilla contact: *absent (0), present as a notch (1), or present as a large fenestra (2).*

Character 10 (Clark, 1994: char. 10). Posterior ends of maxillary palatal processes anterior to palatines: *do not meet (0), or meet (1).*

Character 11 (Clark, 1994: char. 11). Nasal – lacrimal contact: *present (0), or absent (1).*

Character 12 (Clark, 1994: char. 12). Lacrimal contacts nasal *along medial edge only (0), or along medial and anterior edges (1).*

Character 13 (Clark, 1994: char. 13). Nasal contribution to narial border: *yes (0), or no (1).*

Character 14 (Clark, 1994: char. 14). Nasal – premaxilla contact: *present (0), or absent (1).*

Character 15 (modified from Clark, 1994: char. 15). Prefrontal, descending process: *does not contact palate (0), or contacts palate (1).*

Character 16 (Clark, 1994: char. 16). Postorbital – jugal contact: *postorbital anterior to jugal (0), or postorbital medial to jugal (1), or postorbital lateral to jugal (2).*

Character 17 (Clark, 1994: char. 17). Anterior ramus of the jugal with respect to posterior ramus: *as broad (0), or twice as broad (1).*

Character 18 (Clark, 1994: char. 18). Jugal bar beneath infratemporal fenestra: *flattened (0), or rod-shaped (1).*

Character 19 (Clark, 1994: char. 19). Quadratojugal dorsal process: *narrow, contacting only a small part of postorbital (0), or broad, extensively contacting the postorbital (1).*

Character 20 (Clark, 1994: char. 20). Frontal width between orbits: *narrow, as broad as nasals (0), or broad, twice as broad as nasals (1).*

Character 21 (Clark, 1994: char. 21). Frontals: *paired (0), unpaired (1).*

Character 22 (Clark, 1994: char. 22). Dorsal surface of frontal and parietal: *flat (0), or with midline ridge (1).*

Character 23 (modified from Clark, 1994: char. 23 by Buckley and Brochu, 1999: char. 81). Parieto-postorbital suture: *absent from dorsal surface of skull roof and supratemporal fossa (0), absent from dorsal surface of skull roof but broadly present within supratemporal fossa (1), or present within supratemporal fossa and on dorsal surface of skull roof (2).*

Character 24 (Clark, 1994: char. 24). Supratemporal roof, dorsal surface: *complex (0), or flat ‘‘skull table’’ developed, with postorbital and squamosal shelves extending laterally beyond quadrate contact (1).*

Character 25 (modified from Clark, 1994: char. 25). Postorbital bar: *sculpted (if skull sculpted) (0), or smooth (1).*

Character 26 (modified from Clark, 1994: char. 26). Postorbital bar: *transversely flattened (0), or cylindrical (1).*

Character 27 (Clark, 1994: char. 27). Postorbital bar, dorsal end, vascular foramen: *absent (0), or present (1).*

Character 28 (modified from Clark, 1994: char. 28). Postorbital, anterolateral process: *absent or poorly developed (0), or well developed, long, and acute (1).*

Character 29 (Clark, 1994: char. 29). Postorbital, dorsal surface: *with anterior and lateral edges only (0), or with anterolaterally oriented edge (1).*

Character 30 (Clark, 1994: char. 30). Postorbiral bar, dorsal end: *broadens dorsally, continuous with dorsal part of postorbital (0), or dorsal part of the postorbital bar constricted, distinct from the dorsal part of the postorbital (1).*

Character 31 (Clark, 1994: char. 31). Bar between orbit and supratemporal fossa: *broad and solid, with sculpted dorsal surface (0), or bar narrow, sculpting restricted to anterior surface (1).*

Character 32 (modified from Clark, 1994: char. 32). Parietal: *with broad occipital portion (0), or without broad occipital portion (1).*

Character 33 (Clark, 1994: char. 33). Parietal: *with broad sculpted region separating fossae (0), or with sagittal crest between supratemporal fossae (1).*

Character 34 (Clark, 1994: char. 34). Postparietal (dermosupraoccipital): *distinct element (0), or not distinct (fused with parietal?) (1).*

Character 35 (Clark, 1994: char. 35). Squamosal, posterodorsal corner: *squared off, lacking extra ‘‘lobe’’ (0), or with unsculpted ‘‘lobe’’ (1).*

Character 36 (modified from Clark, 1994: char. 36). Squamosal, posterolateral process: *poorly developed and projected horizontally at the same level of the skull (0), elongate, thin, and posteriorly directed, not ventrally deflected (1), or elongated, posterolaterally directed, and ventrally deflected (2).*

Character 37 (Clark, 1994: char. 37). (+) Palatines: without horizontal lamina *(i.e., do not project below the narial passage (0), with restricted horizontal lamina (i.e., form palatal shelves that do not meet on midline) (1), or with horizontal lamina that joins counterpart from the opposite side, forming part of secondary palate (2).*

Character 38 (Clark, 1994: char. 38). Pterygoid: *restricted to palate and suspensorium, joints with quadrate and basisphenoid overlapping (0), or extends dorsally to contact laterosphenoid and form ventrolateral edge of the trigeminal foramen, strongly sutured to quadrate and laterosphenoid (1).*

Character 39 (modified from Clark, 1994: char. 39). Choanal opening: *continuous with pterygoid ventral surface (except for anterior and anterolateral borders) (0), or opens into palate through a deep midline depression (choanal groove) (1).*

Character 40 (Clark, 1994: char. 40). Pterygoid, palatal surface: *smooth (0), or sculpted (1).*

Character 41 (Clark, 1994: char. 41). Pterygoids, posterior to choanae: *separated (0), or fused (1).*

Character 42 (modified from Clark, 1994: char. 42 by Ortega et al., 2000: char. 139). Depression on primary pterygoidean palate posterior to choana: *absent or moderate in size being narrower than palatine bar (0), or wider than palatine bar (1).*

Character 43 (Clark, 1994: char. 43). Pterygoids: *do not enclose choana (0), or enclose choana (1).*

Character 44 (modified from Clark, 1994: char. 44). Choanae, anterior edge: *situated near posterior edge of suborbital fenestra (or anteriorly) (0), or near posterior edge of pterygoid flanges (1).*

Character 45 (Clark, 1994: char. 45). (+) Quadrate: *without fenestrae (0), with single fenestra (1), or with three or more fenestrae on dorsal and posteromedial surfaces (2).*

Character 46 (Clark, 1994: char. 46). Quadrate, posterior edge: *broad medial to tympanum, gently concave (0), or narrow dorsal to otoccipital contact, strongly concave (1).*

Character 47 (Clark, 1994: char. 47). Quadrate, dorsal (primary head) articulates with: *squamosal, otoccipital, and prootic (0), or with prootic and laterosphenoid (1).*

Character 48 (Clark, 1994: char. 48). Otoccipital, ventrolateral contact with quadrate: *very narrow (0), or broad (1).*

Character 49 (Clark, 1994: char. 49). Quadrate, squamosal, and otoccipital: *do not meet to enclose cranioquadrate passage (0), enclose passage near lateral edge of skull (1), or meet broadly lateral to the passage (2).*

Character 50 (Clark, 1994: char. 50). Quadrate, pterygoid ramus: *with flat ventral edge (0), or with deep groove along ventral edge (1).*

Character 51 (Clark, 1994: char. 51). Quadrate, ventromedial portion: *does not contact otoccipital (0), or contacts otoccipital to enclose carotid artery and form passage for cranial nerves IX–XI (1).*

Character 52 (Clark, 1994: char. 52). Eustachian tubes: *not enclosed between basioccipital and basisphenoid (0), or entirely enclosed (1).*

Character 53 (Clark, 1994: char. 53). Basisphenoid rostrum (cultriform process): *slender (0), or dorsoventrally expanded (1).*

Character 54 (Clark, 1994: char. 54). Basipterygoid process: *prominent, forming movable joint with pterygoid (0), or basipterygoid process small or absent, with basisphenoid joint close by suture (1).*

Character 55 (modified from Clark, 1994: char. 55 by Ortega et al., 2000: char. 68). Basisphenoid, ventral surface: *shorter than basioccipital (0), or wide and similar to, or longer in length than basioccipital (1).*

Character 56 (Clark, 1994: char. 56). Basisphenoid: *exposed on ventral surface of braincase (0), or virtually excluded from ventral surface by pterygoid and basioccipital (1).*

Character 57 (Clark, 1994: char. 57). Basioccipital: *without well-developed bilateral tuberosities (0), or with large pendulous tubera (1).*

Character 58 (Clark, 1994: char. 58). Otoccipital, ventral to subcapsular process: *without laterally concave descending flange (0), or with flange (1).*

Character 59 (Clark, 1994: char. 59). Cranial nerves IX–XI: *pass through common large foramen vagi in otoccipital (0), or cranial nerve IX passes medial to nerves X and XI in separate passage (1).*

Character 60 (Clark, 1994: char. 60). Otoccipital: *without large ventrolateral part ventral to paroccipital process (0), or with large ventrolateral part (1).*

Character 61 (Clark, 1994: char. 61). Crista interfenestralis between fenestrae pseudorotunda and ovalis *nearly vertical (0), or horizontal (1).*

Character 62 (Clark, 1994: char. 62). Supraoccipital: *forms dorsal edge of the foramen magnum (0), or otoccipitals meet dorsal to the foramen magnum, separating supraoccipital from foramen (1).*

Character 63 (Clark, 1994: char. 63). Mastoid antrum: *does not extend into supraoccipital (0), or extends through transverse canal in supraoccipitals to connect middle ear regions (1).*

Character 64 (Clark, 1994: char. 64). Posterior surface of supraoccipital: *nearly flat (0), or with bilateral posterior prominences (1).*

Character 65 (modified from Clark, 1994: char. 65). *One small palpebral present in orbit (0), or one large palpebral (1), or two large palpebrals (2).*

Character 66 (Clark, 1994: char. 66). External nares: *divided by a septum (0), or confluent (1).*

Character 67 (modified from Clark, 1994: char. 67). Antorbital fenestra: *as large as orbit (0), between ¼ and ½ diameter of the orbit (1), less than ¼ the size of the orbit (2), or absent (3)*.

Character 68 (modified from Clark, 1994: char. 68 by Ortega et al., 2000: char. 41). Supratemporal fenestrae extension: *relatively large, occupying most of surface of skull roof (0), or relatively short, fenestrae surrounded by a flat and extended skull roof (1).*

Character 69 (modified from Clark, 1994: char. 69). (+) Choanal groove: *undivided (0), partially septated (1), or completely septated (2).*

Character 70 (modified from Clark, 1994: char. 70). Dentary: *extends posteriorly ventral to mandibular fenestra (0), or does not extend ventral to fenestra (1).*

Character 71 (modified from Clark, 1994: char. 71). Retroarticular process: *absent or extremely reduced (0), very short, broad, and robust (1), with an extensive rounded, wide, and flat (or slightly concave) surface projected posteroventrally and facing dorsomedially (2), posteriorly elongated, triangular-shaped and facing dorsally (3), or posteroventrally projecting and paddleshaped (4).*

Character 72 (Clark, 1994: char. 72). Prearticular: *present (0), or absent (1).*

Character 73 (modified from Clark, 1994: char. 73). (+) Articular: *without medial process (0), with short process not contacting braincase (1), or with process articulating with otoccipital and basisphenoid (2).*

Character 74 (Clark, 1994: char. 74). Surangular, dorsal edge: *flat (0), or arched dorsally (1).*

Character 75 (Clark, 1994: char. 75). Mandibular fenestra: *present (0), or absent (1).*

Character 76 (Clark, 1994: char. 76). Insertion area for M. pterygoideous posterior: *does not extend onto lateral surface of angular (0), or extends onto lateral surface of angular (1).*

Character 77 (modified from Clark, 1994: char. 77). Splenial involvement in symphysis, ventral view: *not involved (0), involved slightly (1), or extensively involved (2).*

Character 78 (Clark, 1994: char. 78). Posterior premaxillary teeth: *similar in size to anterior teeth (0), or much longer (1).*

Character 79 (modified from Clark, 1994: char. 79). Maxillary teeth waves: *absent, no tooth size variation (0), one wave of teeth enlarged (1), two waves with enlarged teeth of similar morphology (2), or two waves with enlarged teeth of different morphologies (3).*

Character 80 (Clark, 1994: char. 80). Anterior dentary teeth opposite premaxilla-maxilla contact: *no more than twice the length of other dentary teeth (0), or more than twice the length (1).*

Character 81 (modified from Clark, 1994: char. 81). Dentary teeth posterior to tooth opposite premaxilla-maxilla contact: *equal in size (0), or enlarged dentary teeth opposite to smaller teeth in maxillary toothrow (1).*

Character 82 (modified from Clark, 1994: char. 82 by Ortega et al., 2000: char. 120). Scapula, anterior and posterior edges: *symmetrical in lateral view (0), anterior edge more strongly concave than posterior edge (1), or dorsally narrow with straight edges (2).*

Character 83 (modified from Clark, 1994: char. 83 by Ortega et al., 2000: char. 121). Coracoid length: *up to two-thirds of the scapular length (0), or subequal in length to scapula (1).*

Character 84 (modified from Clark, 1994: char. 84). Ilium, anterior process: *similar in length to posterior process (0), or one-fourth or less of the length of the posterior process (1).*

Character 85 (Clark, 1994: char. 85). Pubis: *rodlike, without expanded distal end (0), or with expanded distal end (1).*

Character 86 (Clark, 1994: char. 86). Pubis: *forms anterior half of ventral edge of acetabulum (0), or at least partially excluded from the acetabulum by the anterior process of the ischium (1).*

Character 87 (Clark, 1994: char. 87). Femur, distal end, fibular facet: *large (0), or small (1).*

Character 88 (Clark, 1994: char. 88). Pedal digit V: *with phalanges (0), or without phalanges (1).*

Character 89 (Clark, 1994: char. 89). Atlas, intercentrum: *broader than long (0), or as long as broad (1).*

Character 90 (modified from Clark, 1994: char. 90). Cervical neural spines: *all anteroposteriorly expanded (0), only posterior ones rodlike (1), or all rodlike (2).*

Character 91 (modified from Clark, 1994: char. 91 by Buscalioni and Sanz, 1988: char. 37 and by Brochu, 1997a: char. 7). Hypapophyses in cervicodorsal vertebrae: *absent (0), present only in cervical vertebrae (1), present in cervical and the first two dorsal vertebrae (2), present up to third dorsal vertebra (3), or present up to the fourth dorsal vertebra (4).*

Character 92 (Clark, 1994: char. 92). Cervical vertebrae: *amphicoelous or amphiplatyan (0), or procoelous (1).*

Character 93 (Clark, 1994: char. 93). Trunk vertebrae: *amphicoelous or amphiplatyan (0), or procoelous (1).*

Character 94 (Clark, 1994: char. 94). Caudal vertebrae: *amphicoelous or amphyplatian (0), first caudal biconvex with other procoelous (1), or procoelous (2).*

Character 95 (Clark, 1994: char. 95). Dorsal osteoderms: *rounded or ovate (0), or rectangular, broader than long (1), or square (2).*

Character 96 (modified from Clark, 1994: char. 96, and Brochu, 1997a: char. 40). Dorsal osteoderms: *without articular anterior process (0), with a discrete convexity on anterior margin (1), or with a well-developed process located anterolaterally in dorsal parasagittal osteoderms (2).*

Character 97 (modified from Clark, 1994: char. 97 by Ortega et al., 2000: chars. 107, 108). Rows of dorsal osteoderms: *two parallel rows (0), more than two (1), or more than four with accessory ranges of osteoderms (sensu Frey, 1988) (2).*

Character 98 (Clark, 1994: char. 98). Osteoderms: *some or all imbricated (0), or sutured to one another (1).*

Character 99 (Clark, 1994: char. 99). Tail osteoderms: *dorsal only (0), or completely surrounded by osteoderms (1).*

Character 100 (Clark, 1994: char. 100). Trunk osteoderms: *absent from ventral part of the trunk (0), or present (1).*

Character 101 (Clark, 1994: char. 101). Osteoderms: *with longitudinal keels on dorsal surfaces (0), or without longitudinal keels (1).*

Character 102 (Wu and Sues, 1996: char. 14). Jugal: *participating in margin of antorbital fossa (0), or separated from it (1).*

Character 103 (modified from Wu and Sues, 1996: char. 17). Mandibular symphysis, lateral view: *shallow and tapering anteriorly (0), deep and tapering anteriorly (1), deep and anteriorly convex (2), or shallow and anteriorly convex (3).*

Character 104 (modified from Wu and Sues, 1996: char. 23). (+) Quadrate condyle, articular facet: *equal in length to the quadrate condyles (0), slightly longer (1), or close to three times the length of the quadrate condyles (2).*

Character 105 (modified from Wu and Sues, 1996: char. 24 and Wu et al., 1997: char. 124). (+) Jaw joint: *at dorsoventral level of basioccipital condyle (0), ventral relative to basioccipital condyle, yet dorsal relative to level of lower toothrow (1), or ventral relative to level of lower toothrow (2).*

Character 106 (modified from Wu and Sues, 1996: char. 27 and Ortega et al., 2000: char. 133). Premaxillary tooth count: *five (0), four (1), three (2), or two (3).*

Character 107 (modified from Wu and Sues, 1996: char. 29). Maxilla, alveolar margin, unsculptured (smooth) region: *absent (0), or present (1).*

Character 108 (Wu and Sues, 1996: char. 30). Maxillary tooth count: *eight or more (0), seven (1), six (2), or five (3).*

Character 109 (Wu and Sues, 1996: char. 33). Coracoid: *without posteromedial or ventromedial process (0), with elongate posteromedial process (1), or distally expanded ventromedial process (2).*

Character 110 (Wu and Sues, 1996: char. 40). Radiale and ulnare: *short and massive (0), or elongate (1).*

Character 111 (modified from Gomani, 1997: char. 4). Prefrontal, anterior to orbit: *elongated, oriented parallel to anteroposterior axis of the skull (0), or short and broad, oriented from posteromedial to anterolateral (1).*

Character 112 (modified from Gomani, 1997: char. 32). Basioccipital and ventral part of otoccipital: *facing posteriorly (0), or posteroventrally (1).*

Character 113 (Buscalioni and Sanz, 1988: char. 35). Vertebral centra: *cylindrical (0), or spool shaped (1).*

Character 114 (modified from Buscalioni and Sanz, 1988: char. 39). Posterior (caudal) dorsal vertebrae, transverse process: *dorsoventrally low and laminar (0), or dorsoventrally expanded (1).*

Character 115 (Buscalioni and Sanz, 1988: char. 44). Sacral vertebral count: *two (0), or more than two (1).*

Character 116 (Buscalioni and Sanz, 1988: char. 49). Ilium, supra-acetabular crest: *present (0), or absent (1).*

Character 117 (Buscalioni and Sanz, 1988: char. 54). Radiale, proximal end: *expanded symmetrically, similarly to the distal end (0), or more expanded proximomedially than proximolaterally (1).*

Character 118 (Ortega et al., 1996: char. 5). Dentary, lateral surface: *without longitudinal depression (0), or with longitudinal depression (1).*

Character 119 (Ortega et al., 1996: char. 9). Splenial, ventral exposure: *absent (0), or present (1).*

Character 120 (Ortega et al., 1996: char. 11, 2000: char. 100). Tooth margins: *with denticulate carinae (0), or without carinae or with smooth or crenulated carinae (1).*

Character 121 (modified from Pol, 1999a: char. 133 and Ortega et al., 2000: char. 145). Jugal, anterior process, lateral surface: *flat or convex (0), or with broad shelf ventral to orbit with triangular depression underneath it (1).*

Character 122 (Pol, 1999a: char. 134). Jugal: *does not exceed the anterior margin of orbit (0), or exceeds margin (1).*

Character 123 (Pol, 1999a: char. 135). Premaxilla, lateral edge with notch for external nares: *absent (0), or present on the dorsal half of the external nares lateral margin (1).*

Character 124 (Pol, 1999a: char. 136). External nares, dorsal border: *formed mostly by the nasals (0), or by both the nasals and premaxilla (1).*

Character 125 (Pol, 1999a: char. 138). Premaxilla, posterodorsal process: *absent (0), or present extending posteriorly to wedge between maxilla and nasals (1).*

Character 126 (Pol, 1999a: char. 139 and Ortega et al., 2000: char. 9). Premaxilla-maxillasuture in palatal view, medial to alveolar region: *anteromedially directed (0), sinusoidal, posteromedially directed on its lateral half and anteromedially directed along its medial region (1), or posteromedially directed (2).*

Character 127 (Pol, 1999a: char. 140). Nasal, lateral border posterior to external nares: *laterally concave (0), or straight (1).*

Character 128 (Pol, 1999a: char. 141). Nasal, lateral edges: *nearly parallel (0), oblique to each other converging anteriorly (1), or oblique to each other diverging anteriorly (2).*

Character 129 (Pol, 1999a: char. 143). Palatine anteromedial margin: *exceeding the anterior margin of the palatal fenestrae extending anteriorly between the maxillae (0), or not exceeding the anterior margin of palatal fenestrae (1).*

Character 130 (Pol, 1999a: char. 144). Jugal, dorsoventral height in antorbital region relative to infraorbital region: *equal or lower (0), or antorbital region more expanded than infraorbital region of jugal (1).*

Character 131 (Pol, 1999a: char. 145). Maxilla-lacrimal contact: *partly included in antorbital fossa (0), or completely included (1).*

Character 132 (Pol, 1999a: char. 146). Lateral Eustachian tube openings: *located posterior to the medial opening (0), or aligned anteroposteriorly and dorsoventrally (1).*

Character 133 (Pol, 1999a: char. 147). Anterior process of ectopterygoid: *developed (0), or reduced–absent (1).*

Character 134 (Pol, 1999a: char. 148). Posterior process of ectopterygoid: *developed (0), or reduced–absent (1).*

Character 135 (Pol, 1999a: char. 149 and Ortega et al., 2000: char. 13). Small foramen located in the premaxillo-maxillary suture in lateral surface (not for big mandibular teeth): *absent (0), or present (1).*

Character 136 (Pol, 1999a: char. 150). Jugal posterior process: *exceeding posteriorly the infratemporal fenestrae (0), or not (1).*

Character 137 (Pol, 1999a: char. 151). Compressed crown of maxillary teeth: *oriented parallel to the longitudinal axis of skull (0), or obliquely disposed (1).*

Character 138 (Pol, 1999a: char. 152). Large and aligned neurovascular foramina on lateral maxilary surface: *absent (0), or present (1).*

Character 139 (modified from Pol, 1999a: char. 153). External surface of maxilla and premaxilla: *with a single plane facing laterally (0), or with ventral region facing laterally and dorsal region facing dorsolaterally (1).*

Character 140 (Pol, 1999a: char. 154 and Ortega et al., 2000: char. 104). Maxillary teeth: *not compressed laterally (0), or compressed laterally (1).*

Character 141 (Pol, 1999a: char. 155). Posteroventral corner of quadratojugal: *reaching the quadrate condyles (0), or not reaching the quadrate condyles (1).*

Character 142 (Pol, 1999a: char. 156). Base of postorbital process of jugal: *directed posterodorsally (0), or dorsally (1).*

Character 143 (Pol, 1999a: char. 157). Postorbital process of jugal: *anteriorly placed (0), in the middle (1), or posteriorly positioned (2).*

Character 144 (Pol, 1999a: char. 158 and Ortega et al., 2000: char. 36). Postorbitalectopterygoid contact: *present (0), or absent (1).*

Character 145 (Pol, 1999a: char. 161). Quadratojugal: *not ornamented (0), or ornamented in the base (1).*

Character 146 (Pol, 1999a: char. 162). Prefrontal-maxillary contact in the inner anteromedial region of orbit: *absent (0), or present (1).*

Character 147 (Pol, 1999a: char. 163). Basisphenoid: *without lateral exposure (0), or with lateral exposure on the braincase (1).*

Character 148 (Pol, 1999a: char. 165). Quadrate process of pterygoids: *well developed (0), or poorly developed (1).*

Character 149 (modified from Pol, 1999a: char. 166 and Ortega et al., 2000: char. 44). (+) Quadrate major axis directed: *posteroventrally (0), ventrally (1), or anteroventrally (2).*

Character 150 (Pol, 1999a: char. 167). Quadrate distal end: *with only one plane facing posteriorly (0), or with two distinct faces in posterior view, a posterior one and a medial one bearing the foramen aereum (1).*

Character 151 (Pol, 1999a: char. 168). Anteroposterior development of neural spine in axis: *well developed covering all the neural arch length (0), or poorly developed, located over the posterior half of the neural arch (1).*

Character 152 (Pol, 1999a: char. 169). Prezygapophyses of axis: *not exceeding anterior edge of neural arch (0), or exceeding the anterior margin of neural arch (1).*

Character 153 (Pol, 1999a: char. 170). Postzygapophyses of axis: *well developed, curved laterally (0), or poorly developed (1).*

Character 154 (modified from Pol, 1999b: char. 212). Shape of dentary symphysis in ventral view: *tapering anteriorly forming an angle (0), U – shaped, smoothly curving anteriorly (1), or lateral edges longitudinally oriented, convex anterolateral corner, and extensive transversely oriented anterior edge (2).*

Character 155 (modified from Pol, 1999b: char. 213). Dentary, sculptured external surface ventral to toothrow: *yes (0), or no (1).*

Character 156 (modified from Ortega et al., 1995: char. 1 and Buckley and Brochu, 1999: char. 107). Dentary, dorsal edge: *slightly concave or straight and subparallel to the longitudinal axis of skull (0), straight with an abrupt dorsal expansion, being straight posteriorly (1), with a single dorsal expansion and concave posterior to this (2), or sinusoidal, with two concave waves (3).*

Character 157 (modified from Ortega et al., 1995: char. 2 and Buckley and Brochu, 1999: char. 108). Dentary compression and lateroventral surface anterior to mandibular fenestra: *compressed and vertical (0), or not compressed and convex (1).*

Character 158 (Ortega et al., 1996: char. 7 and Buckley and Brochu, 1999: char. 110). Splenial: *thin posterior to symphysis (0), or splenial robust dorsally posterior to symphysis (1).*

Character 159 (Ortega et al., 1996: char. 13 and Buckley et al., 2000: char. 117). Cheek teeth: *not constricted at base of crown (0), or constricted (1).*

Character 160 (Ortega et al., 2000: char. 10). Ventral edge of premaxilla located: *at the same height as ventral edge of maxilla (0), or located deeper, with the dorsal contour of anterior part of dentary strongly concave (1).*

Character 161 (modified from Ortega et al., 2000: char. 19). Maxillary dental implantation: *teeth in isolated alveoli (0), or located on a dental groove (1).*

Character 162 (Ortega et al., 2000: char. 24). Caudal tip of nasals: *converge at sagittal plane (0), or caudally separated by anterior sagittal projection of frontals (1).*

Character 163 (Ortega et al., 2000: char. 33). Relative length between squamosal and postorbital: *squamosal is longer (0), or postorbital is longer (1).*

Character 164 (modified from Ortega et al., 2000: char. 34). Jugal portion of postorbital bar: *flushes with lateral surface of jugal (0), anteriorly continuous but posteriorly inset (1), or medially displaced and a ridge separates postorbital bar from lateral surface of jugal (2).*

Character 165 (Ortega et al., 2000: char. 42). Outer surface of squamosal laterodorsally oriented: *extensive (0), or reduced and sculpted (1), or reduced and unsculpted (2).*

Character 166 (Ortega et al., 2000: char. 47). Quadratojugal spine at caudal margin of infratemporal fenestra: *absent (0), or present (1).*

Character 167 (Ortega et al., 2000: char. 53). Quadrate condyles *almost aligned (0), or medial condyle expands ventrally (1).*

Character 168 (Ortega et al., 2000: char. 62). Exposure of supraoccipital in skull roof: *absent (0), or present (1).*

Character 169 (Ortega et al., 2000: char. 75). Anterior opening of temporo-orbital in dorsal view: *exposed (0), or hidden in dorsal view and overlapped by squamosal rim of supratemporal fossa (1).*

Character 170 (modified from Ortega et al., 2000: char. 90). Foramen intramandibularis oralis: absent *or small (0), or large and slotlike (1).*

Character 171 (modified from Ortega et al., 2000: char. 101). Tooth root width with respect to crown: *narrower or equal (0), or wider (1).*

Character 172 (Ortega et al., 2000: char. 109). Gap in cervico-thoracic dorsal armor: *absent (0), or present (1).*

Character 173 (Ortega et al., 2000: char. 130). Lateral contour of snout, dorsal view: *straight (0), or sinusoidal (1).*

Character 174 (Ortega et al., 2000: char. 138). Pterygoidean flanges: *laminar and expanded (0), or barlike (1).*

Character 175 (Ortega et al., 2000: char. 146). Ectopterygoid medial process: *single (0), or forked (1).*

Character 176 (modified from Ortega et al., 2000: char. 157). Skull roof, dorsal view: *rectangular (0), or trapezoidal (1).*

Character 177 (Ortega et al., 2000: char. 30). Prefrontal pillars when integrated in palate: *pillars transversely expanded (0), transversely expanded in their dorsal part and columnar ventrally (1), or longitudinally expanded in their dorsal part and columnar ventrally (2).*

Character 178 (Ortega et al., 2000: char. 21). Maxilla, ventral edge, lateral view: *straight or convex (0), or sinusoidal (1).*

Character 179 (modified from Ortega et al., 2000: char. 156). Position of first enlarged maxillary tooth: *second or third alveoli (0), fourth or fifth (1), or first (2).*

Character 180: Splenial-dentary suture at symphysis on ventral surface: *V-shaped (0), or transversal (1).*

Character 181: Posterior peg at symphysis: *absent (0), or present (1).*

Character 182: Posterior ridge on glenoid fossa of articular: *present (0), or absent (1).*

Character 183 (modified from Gomani, 1997: char. 46 and Buckley et al., 2000: char. 113). Cusps of posterior cheekteeth: *unique cusp (0), one main cusp with smaller cusps arranged in one row (1), one main cusp with variably arranged smaller cusps (2), several cusps of equal size arranged in parallel rows (3), or multiple small cusps along edges of occlusal surface (4).*

Character 184 (modified from Pol and Apesteguia, 2005): Mandibular symphysis, dorsal surface: *flat or slightly concave (0), or strongly concave and narrow, trough-shaped (1).*

Character 185 (modified from Pol and Apesteguia, 2005): Splenial, medial surface posterior to symphysis: *flat or slightly convex (0), or markedly concave (1).*

Character 186: Choanal septum shape: *narrow vertical bony sheet (0), or T-shaped bar expanded ventrally (1).*

Character 187 (Pol and Norell, 2004a: char. 164). Cross section of distal end of quadrate: *mediolaterally wide and anteroposteriorly thin (0), or subquadrangular (1).*

Character 188. Lateral surface of dentaries below alveolar margin, at middle to posterior region of toothrow: *vertically oriented, continuous with rest of lateral surface of the dentaries (0), or flat surface exposed laterodorsally, divided by a ridge from rest of the lateral surface of the dentaries (1).*

Character 189 (Pol and Norell, 2004a: char. 165). Palatine – pterygoid contact on palate: *palatine overlies pterygoid (0), or palatine firmly sutured to pterygoid (1).*

Character 190 (modified from Pol et al., 2004: char. 164). Ectopterygoid, major axis oriented: *laterally or slightly anterorlaterally (0), or anteriorly, subparallel to the skull longitudinal axis (1).*

Character 191 (Wu et al., 1997: char. 103). Squamosal descending process: *absent (0), or present (1).*

Character 192 (modified from Wu et al., 1997: char. 105). (+) Development of distal quadrate body ventral to otoccipital-quadrate contact: *distinct (0), incipiently distinct (1), or indistinct (2).*

Character 193 (Wu et al., 1997: char. 106). Pterygoid flanges: *thin and laminar (0), or dorsoventrally thick, with pneumatic spaces (1).*

Character 194 (Wu et al., 1997: char. 108). Postorbital participation in infratemporal fenestra: *almost or entirely excluded (0), or bordering infratemporal fenestra (1).*

Character 195 (modified from Wu et al., 1997: char. 109). Palatine: *participates in margin of suborbital fenestra (0), or excluded from margin of suborbital fenestra (1).*

Character 196 (Wu et al., 1997: char. 110). Angular posterior to mandibular fenestra: *widely exposed on lateral surface of mandible (0), or shifted to the ventral surface of mandible (1).*

Character 197 (modified from Wu et al., 1997: char. 112). Mandibular ramus, posteroventral edge: *straight or convex (0), or markedly deflected (1).*

Character 198 (modified from Wu et al., 1997: char. 119). Quadrate ramus of pterygoid, ventral view: *narrow (0), or broad (1).*

Character 199 (modified from Wu et al., 1997: char. 121). Pterygoids, anterior to basisphenoid: *not in contact on palate (0), or pterygoids in contact on palate (1).*

Character 200 (Wu et al., 1997: char. 122). Olecranon: *well developed (0), or absent (1).*

Character 201 (Wu et al., 1997: char. 123). Cranial table width respect to ventral portion of skull: *as wide as ventral portion (0), or narrower than ventral portion of skull (1).*

Character 202 (Wu et al., 1997: char. 127). Depression on posterolateral surface of maxilla: *absent (0), or present (1).*

Character 203 (Wu et al., 1997: char. 128). Anterior palatal fenestra: *absent (0), or present (1).*

Character 204 (Pol and Norell, 2004a: char. 179). Paired ridges located medially on ventral surface of basisphenoid: *absent (0), or present (1).*

Character 205 (modified from Pol et al., 2004a: char. 179). Jugal, infratemporal bar, ventral margin: *straight (0), or dorsally arched (1).*

Character 206 (Pol and Norell, 2004a: char. 180). Posterolateral end of quadratojugal: *acute or rounded, tightly overlapping the quadrate (0), or with sinusoidal ventral edge and wide and rounded posterior edge slightly overhanging the lateral surface of the quadrate (1).*

Character 207 (Pol and Norell, 2004a; char. 181). Orientation of quadrate body distal to otoccipital-quadrate contact in posterior view: *ventrally (0), or ventrolaterally (1).*

Character 208 (Gasparini et al., 1993: char. 3). Wedgelike process of the maxilla in lateral surface of premaxilla-maxilla suture: *absent (0), or present (1).*

Character 209 (Pol and Norell, 2004b: char. 181) Palpebrals: *separated from the lateral edge of the frontals (0), or extensively sutured to each other and to the lateral margin of the frontals (1).*

Character 210 (modified from Pol and Norell, 2004b: char. 182) Jugal, ascending process, external surface: *exposed laterally (0), or exposed posterolaterally (1).*

Character 211 (Pol and Norell, 2004b: char. 183) Longitudinal ridge on lateral surface of jugal below infratemporal fenestra: *absent (0), or present (1).*

Character 212 (Pol and Norell, 2004b: char. 184) Dorsal surface of posterolateral region of squamosal: *without ridges (0), or with three curved ridges oriented longitudinally (1).*

Character 213 (Pol and Norell, 2004b: char. 185) Ridge along dorsal section of quadrate-quadratojugal contact: *absent (0), or present (1).*

Character 214 (modified from Pol and Norell, 2004b: char. 186) Angular, sharp ridge along the ventral surface: *absent (0), or present (1).*

Character 215 (Pol and Norell, 2004b: char. 187) Surangular, longitudinal ridge along the dorsolateral surface: *absent (0), or present (1).*

Character 216 (modified from Pol and Norell, 2004b: char. 188) Osteoderms, dorsal surface ornamented with anterolaterally and anteromedially directed ridges (fleur de lys pattern of Osmo´lska et al., 1997): *absent (0), or present (1).*

Character 217 (Pol and Norell, 2004b: char. 189). Cervical region surrounded by lateral and ventral osteoderms sutured to the dorsal elements: *absent (0), or present (1).*

Character 218 (Pol and Norell, 2004b: char. 190). Appendicular osteoderms: *absent (0), or present (1).*

Character 219 (Ortega et al., 2000: char. 72). Supratemporal fenestra: *present (0), or absent (1).*

Character 220: (modified from Pol and Apesteguia, 2005) Internal nares, flat ventral surface of internal narial septum: *anteriorly broad (0), or tapering anteriorly (1).*

Character 221: Perinarial fossa: *restricted extension (0), extensive, with a distinctly concave surface facing anteriorly (1), or large concave surface facing anteriorly, projecting anteroventrally from the external nares opening toward the alveolar margin (2).*

Character 222 (modified from Sereno et al., 2001: char. 67). Premaxillary palate circular paramedian depressions: *absent (0), present located anteriorly on the premaxilla (1), or present located at the premaxilla-maxilla suture (2).*

Character 223. (modified from Pol and Apesteguia, 2005). Posterolateral region of nasals: *flat surface facing dorsally (0), or lateral region deflected ventrally, forming part of the lateral surface of the snout (1).*

Character 224 (Zaher et al., 2006: char. 193). Lacrimal, ventral half: *extending ventroposteriorly, widely contacting the jugal (0), or tapering ventroposteriorly, does not contact or contacts the jugal only slightly (1).*

Character 225 (modified from Zaher et al., 2006: char. 194). Jugal, lateral (external) surface, large foramen near anterior margin: *absent (0), or present (1).*

Character 226 (Zaher et al., 2006: char. 195). Procumbent premaxillary and anterior dentary alveoli *absent (0), or present (1).*

Character 227 (modified from Martinelli, 2003: char. 36 by Zaher et al., 2006: char. 196). Rodlike posterolateral palatine bar: *absent (0), or present (1).*

Character 228 (Zaher et al., 2006: char. 197). Participation of ectopterygoid in palatine bar: *no (0), or yes (1).*

Character 229 (Pol and Norell, 2004a: char. 183). Choanal opening: *opened posteriorly and continuous with pterygoid surface (0), or closed posteriorly by an elevated wall formed by the pterygoids (1).*

Character 230 (Zaher et al., 2006: char. 198). Ectopterygoid projecting medially on ventral surface of pterygoid flanges: *barely extended (0), or widely extended covering approximately the lateral half of the ventral surface of the pterygoid flanges (1).*

Character 231. Ultimate maxillary tooth, size: *greater than ½ of penultimate maxillary tooth (0), or less than or equal to ½ of penultimate maxillary tooth (1).*

Character 232. Molarization of cheek dentition: *absent (0), or present (1).*

Character 233. Pseudo-cingula on postincisiform teeth: *absent (0), or present (1).*

Character 234. Enlarged mental foramen in dentary with rostrocaudally-oriented (paracaniniform) sulcus: *absent (0), or present (1).*

Character 235. Post-caniniform dentition of upper and lower tooth rows with complimentary wear facets: *absent (0), or present (1).*

Character 236. Upper caniniform teeth: *absent (0), present in premaxilla only (1), present in maxilla only (2), or present in both premaxilla and maxilla (3).*

5. DATA MATRIX

Characters enclosed in brackets [ ] indicate polymorphic states preserved in terminal taxa. Characters enclosed in braces { } indicate ambiguity in terminal taxa (i.e., the state is represented among these states, but not among other remaining states). "?" = unknown character state, "-" = non-applicable character state. An electronic version of this data matrix (TNT and nexus versions) is available at: www.oucom.ohiou.edu/dbms-oconnor/.

Gracilisuchus
000000??0? 0000000000 00?0?00000 0000?0??0? 0?00000?00 0???0000?0 ???00000?1
00000?0000 0000?0???0 000?0?0000 013012?00? 0????0?01? 01000??1?0 1???000001
002?0???00 00???0???0 0000?000?? ?000???0?? ???0??????? 0000?00000 ?0?0000000
00?0?0000? 00?0?0??0? 000000

Terrestrisuchus
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011100??00 0001??0??0 ?100000000 00000?000? ?00?0?0010 0001000100 ?0?0000000
00?000000? 0?0000??0? 000?0?

Protosuchus
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1200000111 10??001000 ?010?0000? 0?0000??0? 000?01

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10?0001000 ?0?000?00? 00?0?0??0? 000?0?

Kayenta_Form
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0111?10100 1?01?10000 0000101?1? ?????????? ??00???0?? ??4?000101 12??00011?
?0?010???0 0????????? 000?????0? 0100??

Edentosuchus
201?????[12]? ???0??[01]0?? 1?0100??0? ????02?110 ?00??????? ??????????
????[12]?311? ???10?0101 0????????? [234]????????? ??0???1[23]?? ???????001
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??1????11? ?0??1??000 00??0???0? ??0?????0? ?100??

Zaraasuchus
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1??010???? ?????????? [234]0??1010?? 0????????? ??0??????? ??????????
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Zosuchus
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Fruita_Form
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Notosuchus
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1011?00000 0000000000? 1000001111 000011

Comahuesuchus
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0??0????0? 1?011110?1 00??02

Uruguaysuchus
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Chimaerasuchus
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1000100000 000100?100 1000000010 000000

Sphagesaurus
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Bretesuchus
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Baurusuchus
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Iberosuchus
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Lybicosuchus
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0101?11010 1101000011 100?000000 0000000001 0?00000?10 000???

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A._buitreraensis
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A._wegeneri
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Peirosaurus
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Theriosuchus
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Alligatorium
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Goniopholis
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Eutretauranosuchus
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Bernissartia
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Hylaeochampsa
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Gavialis
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Alligator
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Hsisosuchus
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Pelagosaurus
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?10001200? 3000002000 0110111?00 0000120001 11?01?00?? 10????????1 ?1??????00
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Steneosaurus
[012]02?111111 0011020100 1000000000 0011002l?0 1000?00110 1111001011
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Metriorhynchus
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Sokotosuchus
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Dyrosaurus
002??1?101 ?010?11?00 100011?101 0011012?10 1010011120 11?1011?10 ?10101302?
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Pholidosaurus
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Mariliasuchus
101?00?101 0000111000 1111110001 1001022110 100021?120 11?1000010 ?1?0213110
21000?11?0 0????????? ?????????? ??10111 3?? 11?????010 0110100001 1100111111
10110?0011 ???0101010 1011001 1?0 ??00100001 1020000111 1011000 01? 1010000000
00000???00 1?11111011 101011

Pakasuchus
101??0?101 1???111100 101111?011 0001022110 1000???120 11?1010?10
?1?0[12]?3110 3?01001??1 ?1?111??01 ?0?????11? 0?121?13?? 01?0???011
00????10?? ?000?11101 1011100001 0100101 01? 1001101 0?0 1??0000020 0120000111
1011000010 1000001?00 0000000000? ??010?0000 111112

Adamantinasuchus
001?00??0? 0100??0000 10??1????? 0????????? ?????????? ?????????? ?????13??1
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?02?1????? ????101?10 ?????????? 0?0???001? ???????1?? ?????????? ?0??0?????
1???0????? ??0111???? 110111

Mahajangasuchus
203??[12]?111 1??0111100 1011110011 0001002110 1011011120 11?1010010
1110??2121 1101000011 11?1111?11 40000100?? 01301[01]00?1 0100?01010
010?121100 1000100011 1011100001 ???1010100 0002100100 1?0000110? ?00001001?
1001000011 10?0001 0?0 000000??00 ?000000011 000002

Anatosuchus
103??0?101 1?001?0000 101110??1? 000?022010 10001?0?20 ?1??100??? ?0?0?12111
31000?1010 ?????????? ?????????? ?1001000?? 01?????011 01001?1000 0?100?0010
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7. QuickTime Movie files based on microCT digital reconstructions of holotype and referred specimen of *Pakasuchus kapilimai* to illustrate morphology and position of teeth and jaws in relation to one another.

RRBP 08631—Reconstruction of left side of holotype skull, highlighting the upper and lower dentition and associated skull elements.

RRBP 05103—Reconstruction of fragmentary skull preserving left maxilla, lower jaw and partially-preserved complement of postcaniniform teeth.

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