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# Supporting Online Material for

## A Late Triassic Dinosauromorph Assemblage from New Mexico and the Rise of Dinosaurs

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**This PDF file includes:**

SOM Text
Figs. S1 to S4
Tables S1 to S3
References

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# A LATE TRIASSIC DINOSAUROMORPH ASSEMBLAGE FROM NEW MEXICO AND THE RISE OF DINOSAURS

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## This file includes:

1. Geology and age of the Hayden Quarry (Figures S1, S2).
2. Other Late Triassic occurrences of basal dinosauromorphs in the southwestern U.S.A. (Figure S3).
3. The Hayden Quarry *Silesaurus*-like dinosauriform and *Eucoelophysis baldwini*.
4. Details of phylogenetic analysis (Figure S4, Tables S1, S2).
5. Voucher specimens for Table 1 (Table S3).
6. Supporting Online Material References.

## 1. Geology and age of the Hayden Quarry

The Hayden Quarry (HQ) is located in a series of exposures along the drainage of Arroyo Seco, an intermittently flowing tributary of the Rio Chama. These outcrops consist of variegated mudstones, siltstones and sandstones typical of the Upper Triassic Chinle Formation in this area. The HQ deposits are contained within fossiliferous mudstones, siltstones, and sandy conglomerates that form channel deposits incised into red (10R 3/4) overbank mudstones and siltstones. This facies association is typical of the Petrified Forest Member of the Chinle Formation in the Chama Basin (pers. obs.). The conglomerates are poorly sorted, range in color from brown (5YR 7/6) to yellow (5Y 6/4) and are dominated by intraformational carbonate clasts ranging in size from coarse sand to pebbles. Clasts of permineralized wood and rarer presumed charcoal are commonly found in association with vertebrate remains. Diagenetic gypsum and calcite spar is common. The conglomerates alternate with finer layers of green (5GY 6/1) to pale grey (5Y 5/2) mudstone and siltstone that often include root traces and other organics, but do not show any large-scale evidence of oxidation.

Our preliminary interpretation of these channel deposits is that repeated transient flooding events concentrated vertebrate (bones, carcasses, live animals) and plant material from the landscape surface, possibly in hyperconcentrated flows. These events were separated by periods of standing water and weakly-developed, poorly-drained (hydromorphic) soil formation. The hydromorphic nature of the paleosols is evidenced by the drab matrix colorations, abundance of yellow-brown (goethite) mottles, preservation of organic matter, including local leaf litter, predominance of goethite rhizocretions, and general dearth of other redoximorphic features (Duchaufour 1982, Vepraskas 1992, He et al. 2003, Kraus and Hasiotits 2006). The high density of channel deposits incised into overbank sediments in the Petrified Forest Member indicate that avulsions were common on the Late Triassic landscape of the Chama Basin, and therefore that the Petrified Forest Member fluvial systems were unstable in this area. This large-scale instability in the local base level and resulting incision has also been reported for the Petrified Forest Member in northern Arizona (Kraus and Middleton 1987).

Determining a precise stratigraphic position for the HQ is difficult because laterally continuous outcrops expose less than 10 meters of stratigraphic section with no obvious marker beds. This problem is compounded by the fact that these exposures are fault-bounded to the northwest by a northeast trending fault that prevents direct correlation with the better-exposed stratigraphic sections to the north (Koning et al. 2006). To estimate the stratigraphic position of the HQ, we measured a stratigraphic section to the south of the quarry, where the base of the Petrified Forest Member and top of the Poleo Sandstone are exposed. There is no evidence for faulting between this section and the HQ, and the beds are flat-lying (slight dips mapped by Koning et al. 2006 in the area of the HQ are depositional dips in channel deposits); this allowed us to use elevation data to infer the stratigraphic thickness between the HQ and the top of the Poleo Sandstone. We then correlated this with a stratigraphic section we measured near the Canjilon Quarry to the north using the Petrified Forest Member/Poleo Sandstone contact as a marker. The Canjilon section (Fig. 1) is virtually complete from the top of the Poleo Sandstone through to the unconformable Chinle Formation/Middle Jurassic Entrada Sandstone contact and allowed us to integrate the stratigraphic position of the other Chama Basin quarries. We directly measured the stratigraphic position of the Canjilon Quarry, and placed the Snyder and *Coelophysis* quarries using data from Lucas et al. (2003) that gives the thickness between these quarries and the Chinle/Entrada unconformity.

Determining absolute ages of the Chinle Formation is difficult because of a lack of available radiometric dates and comprehensive paleomagnetic records. The best age estimates come from palynological and vertebrate biostratigraphy. Litwin and his colleagues (1986; Litwin et al. 1991) described Norian-aged palynological assemblages from the approximate level of the Canjilon Quarry, and assemblages from the overlying "upper siltstone" member (which contains the *Coelophysis* Quarry) that are no older than mid-Norian in age.

The HQ assemblage includes several biostratigraphically useful vertebrate taxa: pseudopalatine phytosaurs, and the aetosaurs *Typothorax coccinarum* and *Rioarribasuchus chamaensis* (Fig. S2) (Lucas 1998; Parker 2006). These taxa are only found in sediments with Norian pollen at Petrified Forest National Park (PEFO), Arizona and other Chinle Formation localities (Parker 2006). Furthermore, pseudopalatine phytosaurs and *Typothorax* are found both above and below the Black Forest Tuff at PEFO, a local marker bed that yielded the only published radiometric date in the Chinle Formation. Detrital zircons from the Black Forest Tuff indicate a maximum $^{206}Pb/^{238}U$ age of 213 Ma (Riggs et al. 2003). The association of vertebrate taxa found at this stratigraphic level has a longer range both above and below the Black Forest Tuff (Parker 2006), so it is not clear what part of this range correlates with the HQ assemblage. Nonetheless, a broadly Norian age for the HQ assemblage is justified because both the vertebrates and pollen provide an unambiguous Norian signal, and there is at present no evidence to the contrary. This age assignment is also consistent with preliminary results from magnetostratigraphy in the Chama Basin (Zeigler et al. 2005).

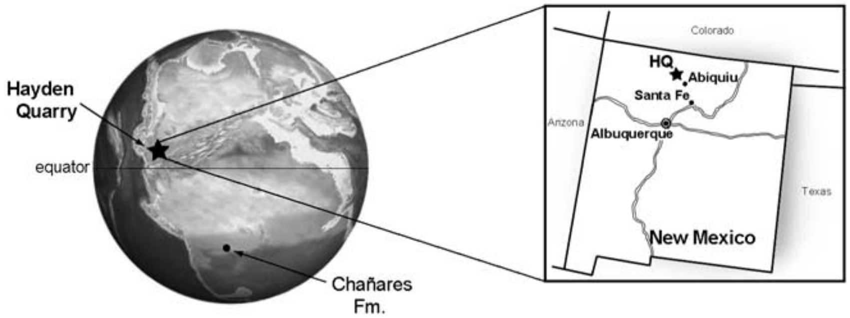



**Fig. S1.** Geographic position of the Hayden Quarry. Paleogeographic globe courtesy of Ron Blakey (2006).

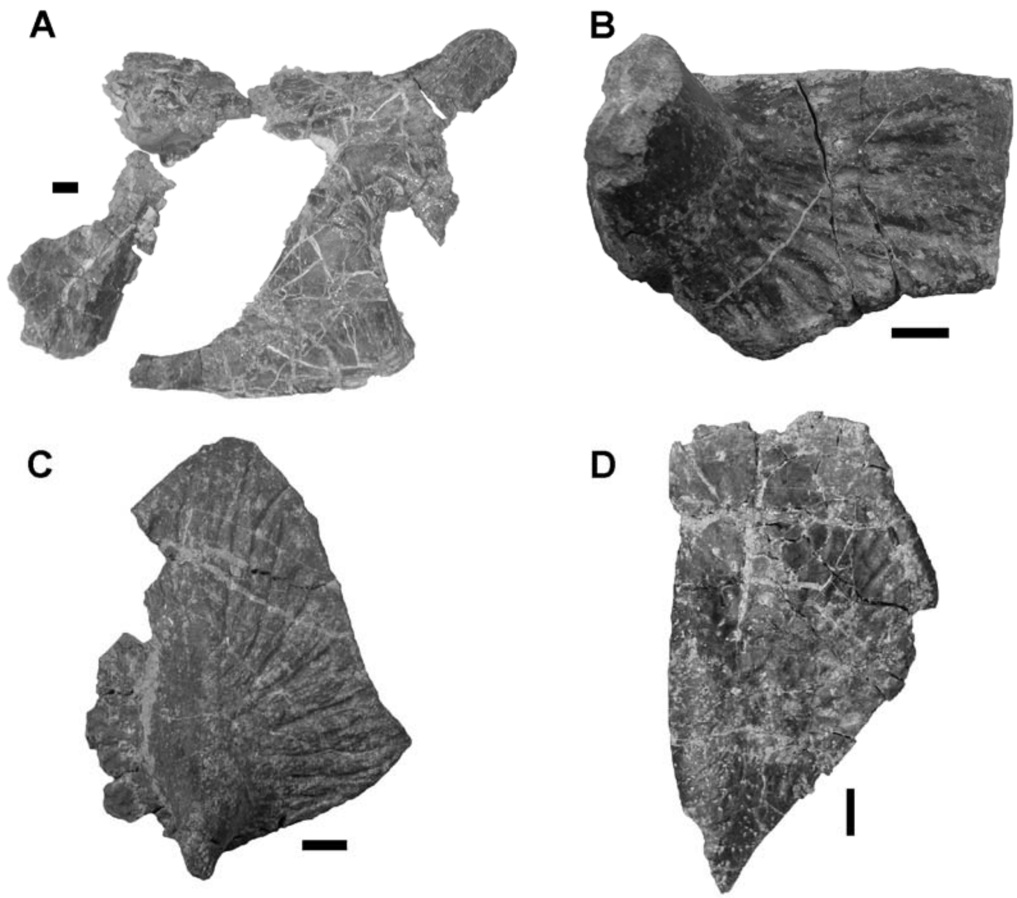



**Fig. S2.** Examples of biostratigraphically significant vertebrate fossils from the Hayden Quarry. (A) Partial posterior skull of a pseudopalatine phytosaur in lateral view (GR 233). (B) Partial paramedian plate of *Rioarribasuchus chamaensis* in dorsal view (GR 193). (C) Caudal lateral plate of *Rioarribasuchus chamaensis* in dorsal view (GR 228). (D) Lateral plate of *Typothorax coccinarum* in dorsal view (GR 229). All scale bars, 1 cm.

## 2. Other Late Triassic occurrences of basal dinosauromorphs in the southwestern U.S.A.

After we discovered the basal dinosauromorph *Dromomeron romeri* at HQ, we analyzed several museum collections in search of other specimens of basal dinosauromorphs from Late Triassic deposits in the southwestern U.S.A. A single distal femur from the *Placerias* Quarry (UCMP loc. A269) in the Chinle Formation of northern Arizona (UCMP 25815) (Fig. S2) shares an enlarged crista tibiofibularis with both *Lagerpeton* and *Dromomeron*. The size of the enlarged crista tibiofibularis is more similar to that of *Dromomeron*. The stratigraphic position of the *Placerias* Quarry is near the base of the Chinle Formation (Long and Murry 1995; Lucas et al. 1997), and the occurrence of this specimen suggests that basal dinosauromorphs were already present in the southwestern U.S.A. at the beginning of Chinle Formation deposition. The *Placerias* Quarry also contains indeterminate basal dinosauriforms and dinosaurs (coelophysoid theropods) (Hunt et al. 1998; Nesbitt et al. in press), further strengthening the coexistence of these taxa. We also identified several *Dromomeron* specimens in the Texas Memorial Museum from the Otis Chalk quarries in the Dockum Group of west Texas (Nesbitt et al. unpublished data). The stratigraphic position of these quarries is traditionally considered to be near the base of the Dockum Group (Long and Murry 1995, Lucas 1998), but see Lehman and Chatterjee (2005) for an alternate interpretation. This locality also includes basal dinosauriforms (Nesbitt et al. unpublished data) and the basal saurischian *Chindesaurus* (Long and Murry 1995, Nesbitt et al. in press). These specimens minimally indicate that basal dinosauriforms and dinosauromorphs were present in low paleolatitude North American faunas from Arizona to west Texas from at least the late Carnian to the middle Norian (15-20 My).

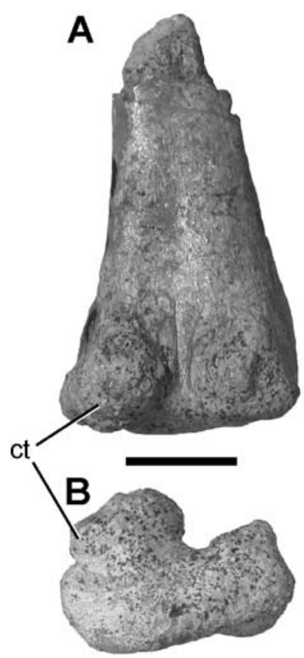


**Fig. S3.** *Dromomeron* distal femur (UCMP 25815) in posterior (A) and distal (B) view from the *Placerias* Quarry in the Chinle Formation near St. Johns, Arizona, U.S.A. Crista tibiofibularis (ct). Scale bar, 1 cm.

**3. The Hayden Quarry *Silesaurus*-like dinosauriform and *Eucoelophysis baldwini***

In this paper, we briefly describe several Hayden Quarry specimens from a *Silesaurus*-like dinosauriform, including a dentary (GR 224), ilium (GR 225), and femur (GR 195). The type locality of *Eucoelophysis* (Sullivan and Lucas 1999) is only a kilometer away from the Hayden Quarry, and from the same stratigraphic unit. Thus, it is possible that the Hayden Quarry material is referable to *Eucoelophysis*. Unfortunately, the only overlapping element is the proximal portion of the femur, and although GR 195 is identical to the femora of the *Eucoelophysis* holotype, they do not share any unique characters absent from *Silesaurus*. Additionally, none of the other HQ material possesses autapomorphies relative to *Silesaurus*. Therefore, we cannot unambiguously refer the Hayden Quarry material to *Eucoelophysis* at this time. We would like to emphasize that *Eucoelophysis* in our phylogenetic analysis was coded only from the holotype, and does not include any Hayden Quarry material. Including the HQ dinosauriform as a separate OTU in the phylogenetic analysis forms a monophyletic clade of *Silesaurus*, *Eucoelophysis*, and the HQ dinosauriform, without affecting the topology of the rest of the tree. In summary, the Hayden Quarry clearly contains a *Silesaurus*-like dinosauriform, but it may or may not be the same taxon as *Eucoelophysis*.

## 4. Details of phylogenetic analysis

The phylogenetic analysis in this paper comprises 26 taxa and 127 characters. At least one of the authors personally observed nearly all of the taxa. *Euparkeria* was constrained as the outgroup, and ingroup taxa included a variety of pseudosuchians, pterosaurs, basal dinosauromorphs, and dinosaurs. *Effigia* was specifically included to test the ability of the dataset to accurately place taxa with many convergences (Nesbitt 2007). Specimen numbers or literature sources for each taxon are reported in Table S1. Characters are mainly derived from Benton (1999) and Langer and Benton (2006), but also include characters from Butler (2005) and several new characters. The character-taxon matrix is presented in Table S2.

The character-taxon matrix was assembled in Mesquite v.1.05 (Maddison and Maddison 2004). We analyzed our dataset using PAUP* 4.0b10 for Macintosh PPC (Swofford 2002). Trees were searched for using the parsimony criterion implemented under the heuristic search option using tree bisection and reconnection (TBR) with 10,000 random addition sequence replicates. All characters were unordered and equally weighted. One most-parsimonious tree was found (Fig. S4). Tree statistics were calculated using PAUP* 4.0b10 for Macintosh PPC (Swofford 2002). Bootstrap proportions were calculated using 10,000 bootstrap replicates with 10 random addition sequence replicates for each bootstrap replicate (Efron 1979, Felsenstein 1985). Bremer support decay indices were calculated using TreeRot v.2 (Sorenson 1999) for Macintosh.

**Table S1:** Specimens and literature sources for the coding of taxa in the phylogenetic analysis. AMNH, American Museum of Natural History, New York; BNMH, The Natural History Museum, London; CM, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania; GPIT, Institut und Museum für Geologie und Paläontologie, Tübingen, Germany; GR, Ghost Ranch Ruth Hall Museum of Paleontology, Ghost Ranch, New Mexico; MCP, Museu de Ciências e Tecnologia, Pontificia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brazil; MNA, Museum of Northern Arizona, Flagstaff, Arizona; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque, New Mexico; PEFO, Petrified Forest National Park, Arizona; PVL, Instituto Miguel Lillo, Tucumán, Argentina; PVSJ, Museo de Ciencias Naturales, San Juan, Argentina; SMNS, Staatliches Museum für Naturkunde, Stuttgart, Germany; TTUP, Texas Tech University, Lubbock, Texas; UCMP, University of California Museum of Paleontology, Berkeley, California; UNLR, Universidad Nacional de La Rioja, La Rioja, Argentina; USNM, National Museum of Natural History, Smithsonian Institution, Washington D.C.; YPM, Yale Peabody Museum, Yale University, New Haven, Connecticut; ZPAL, Instytut Paleobiologii PAN, Warsaw, Poland.

| Taxon | Source |
|---|---|
| *Euparkeria capensis* | Ewer 1965 |
| *Leptosuchus* spp. | UCMP 26699, UCMP 27036, UCMP 27070, UCMP 27200, USNM 18313 |
| *Aetosaurus ferratus* | SMNS 5770 (block of at least 22 specimens), SMNS 5771, SMNS 18554 |
| *Riojasuchus tenuisceps* | PVL 3827 |
| *Effigia okeeffeae* | AMNH FR 30587, AMNH FR 308588, AMNH FR 30859 |
| *Postosuchus kirkpatricki* | TTUP 9000, TTUP 9002, UCMP various (from loc. A269) |
| *Hesperosuchus agilis* | AMNH FR 6758, CM 29894, UCMP 129740 |
| *Protosuchus richardsoni* | AMNH FR 3024, UCMP 36717, UCMP 130860, UCMP 131827 |
| *Eudimorphodon* spp. | Wild 1978, Dalla Vecchia 2003, Wellnhofer 2003 |
| *Dimorphodon macronyx* | BMNH R 1034, BMNH R 1035, BMNH 41212, YPM 350, YPM 9182 |
| *Lagerpeton chanarensis* | UNLR 06, PVL 4619, PVL 4625 |
| *Dromomeron romeri* | see text |
| *Marasuchus lilloensis* | PVL 3870, PVL 3871 |
| *Silesaurus opelensis* | ZPAL Ab III 361, ZPAL Ab III 363, ZPAL Ab III 364, ZPAL various referred material from type locality |
| *Eucoelophysis baldwini* | NMNNH P-22298 |
| *Pisanosaurus mertii* | PVL 2577 |
| *Lesothosaurus diagnosticus* | BMNH RU B.17, BMNH R 8501, BMNH R 11956 |
| *Scutellosaurus lawleri* | MNA V175, MNA V1752, UCMP 130580, UCMP 170829 |
| *Heterodontosaurus tucki* | Crompton and Charig 1962, Santa Luca et al. 1976, Santa Luca 1980 |
| *Herrerasaurus ischigualastensis* | PVL 2566, PVSJ 373, PVSJ 407 |
| *Chindesaurus bryansmalli* | PEFO 10395, GR 226 |
| *Saturnalia tupiniquim* | MCP 3844-PV, MCP 3845-PV, MCP 3846-PV |
| *Efraasia minor* | SMNS 11838, SMNS 12354, SMNS 12667, SMNS 12668, SMNS 12684, SMNS 14881, SMNS 17928 |
| *Plateosaurus engelhardti* | SMNS 13200, GPIT mounted skeletons |
| *Coelophysis bauri* | Various *Coelophysis* Quarry material from AMNH, CM, MNA, and NMMNH |
| *Allosaurus fragilis* | Madsen 1976 |

**Character List**

Skull

1. Skull length:

    (0) – less than 50% of length of the presacral vertebral column
    (1) – equal to or more than 50% of length of the presacral vertebral column
    (Sereno 1991, Benton 1999)

2. Narial fossa:

    (0) – absent or shallow
    (1) – expanded in the rostroventral corner of the naris
    (Sereno 1999, Langer and Benton 2006)

3. Subnarial foramen between premaxilla and maxilla:

    (0) – absent
    (1) – present
    (Benton and Clark 1988, Juul 1994, Benton 1999) modified

4. Caudoventral premaxillary process:

    (0) – extends posteriorly to form the posterior border of the external naris
    (1) – restricted to the ventral border of the naris
    (Langer and Benton 2006)

5. Anterodorsal margin of the maxilla:

    (0) – straight or convex
    (1) – concave with a distinct anteroventral process of the maxilla
    (Gauffre 1993, Langer and Benton 2006)

6. Buccal emargination of the maxilla separated from the ventral margin of the antorbital fossa:

    (0) – absent
    (1) – present
    (Butler 2005, Irmis et al. in press)

7. Buccal emargination of the maxilla:

    (0) – shallow beveling
    (1) –sharp shelf
    (Butler 2005, Irmis et al. in press) modified

8. Relationship of the nasal and antorbital fossa:

    (0) – nasal excluded from the border of the antorbital fossa
    (1) – nasal forms portion of the dorsal border of the antorbital fossa
    (Sereno et al. 1994, Langer and Benton 2006)

9. Lacrimal:
(0) – does not fold over the posterior border of the antorbital fossa
(1) – folds over the posterior border of the antorbital fossa
(Sereno 1999, Langer and Benton 2006)

10. Ventral ramus of the squamosal:
(0) – short and mainly posteriorly inclined
(1) – long, and mainly vertical; 75% or more of maximum pre-orbital skull height, and mainly vertical
(Rauhut 2003, Langer and Benton 2006) modified

11. Jugal-lacrimal articular relation:
(0) – lacrimal overlaps jugal
(1) – jugal overlaps lacrimal
(Sereno and Novas 1993, Benton 1999)

12. Anterior process of the jugal:
(0) – excluded from the posteroventral border of the antorbital fenestra
(1) – enters the posteroventral border of the antorbital fenestra
(Rauhut 2003, Langer and Benton 2006)

13. Jugal posterior process shape:
(0) – tapering
(1) – forked
(Sereno and Novas 1993, Benton 1999)

14. Postfrontal:
(0) – present
(1) – absent
(Gauthier 1986, Benton and Clark 1988, Juul 1994, Bennett 1996, Benton 1999)

15. Lower temporal fenestra shape:
(0) – quadrangular
(1) – triangular and reduced in size
(Benton and Clark 1988, Juul 1994, Benton 1999)

16. Supratemporal fossa
(0) – does not extend onto frontal
(1) – extends onto frontal
(Langer and Benton 2006)

17. Ventral ramus of the squamosal:
(0) – wider than one quarter of its length
(1) – narrower than one quarter of its length

(Yates 2003, Langer and Benton 2006)

18. Squamosal overhanging quadrate and quadratojugal laterally:
(0) – absent
(1) – present
(Benton and Clark 1988, Juul 1994, Benton 1999) Modified

19. Quadrate head in lateral aspect:
(0) – hidden by squamosal
(1) – exposed
(Sereno and Novas 1992, Juul 1994, Benton 1999)

20. Pterygoid-ectopterygoid articular relation:
(0) – ectopterygoid ventral
(1) – ectopterygoid dorsal
(Sereno and Novas 1993, Benton 1999)

21. Size of post-temporal fenestra:
(0) – large
(1) – reduced to a small opening (referred to as a foramen by some authors)
(Sereno and Novas 1992, Juul 1994, Benton 1999) modified

22. Tooth denticles:
(0) – absent or form small, fine knife-like serrations
(1) – enlarged and coarser (lower density)
(Irmis et al. in press)

23. Base of maxillary/dentary tooth crowns:
(0) – unexpanded and confluent with the root
(1) – expanded with markedly constricted roots
(Sereno 1984, Langer and Benton 2006)

24. Tooth shape:
(0) – recurved
(1) – straight
(Sereno 1986, Langer and Benton 2006) Modified

25. Extensive planar wear-facets on the maxillary/dentary teeth:
(0) – absent
(1) – present
(Weishampel and Witmer 1990)

26. Palatal teeth (pterygoid, palatine, vomer):
(0) – present

(1) – absent
(Benton and Clark 1988, Juul 1994, Benton 1999)

27. Predentary bone:
    (0) – absent
    (1) – present
    (Sereno 1986, Sereno 1999, Butler 2005)

28. Dentary symphysis:
    (0) – unexpanded
    (1) – expanded posteriorly both dorsally and ventrally
    (2) – expanded posteriorly only along the ventral border of the bone
    (Langer and Benton 2006)

29. Coronoid process with the anterior margin formed by the dentary:
    (0) – absent
    (1) – present
    (Sereno 1986, Sereno 1999, Butler 2005)

30. Intra-mandibular joint:
    (0) – absent or poorly developed
    (1) – well developed
    (Sereno and Novas 1993, Juul 1994, Benton 1999)

31. External mandibular fenestra:
    (0) – large (anteroposterior length more than maximum depth of dentary ramus)
    (1) – reduced (anteroposterior length less than maximum depth of dentary ramus)
    (2) – absent
    (Butler 2005)

Vertebrae

32. Postaxial anterior cervical vertebrae length:
    (0) – subequal to axis centrum
    (1) – longer than axis centrum
    (Gauthier 1986, Langer and Benton 2006)

33. Centrum shape in presacrals 6-9 (or 10):
    (0) – nearly rectangular
    (1) – parallelogram-shaped where the articular facets are vertically offset in articulation
    (Gauthier 1986, Sereno 1991, Sereno and Arcucci 1994, Benton 1999)

34. Pleurocoels on cervical vertebrae:
    (0) – absent

(1) – present
(Gauthier 1986) Modified

35. Posterior recess between postzygapophysis and neural arch in anterior cervical vertebrae:
(0) – absent
(1) – present
(Langer and Benton 2006)

36. Length of presacral centrum 8 divided by length of presacral centrum 18:
(0) – less than 1.0
(1) – more than 1.0
(Gauthier 1986, Juul 1994, Benton 1999)

37. Cervical ribs:
(0) – slender
(1) – short and stout
(Gauthier 1986, Benton and Clark 1988, Juul 1994, Benton 1999)

38. Hyposphene—hypantrum accessory intervertebral articulations in trunk vertebrae:
(0) – absent
(1) – present
(Gauthier 1986, Juul 1994, Benton 1999)

39. Number of sacral vertebrae:
(0) – two
(1) – three or more
(Gauthier 1986, Juul 1994, Benton 1999)

40. Sacral rib of the primordial first sacral:
(0) – unexpanded and platelike
(1) – dorsally expanded along its anterior margin
(Langer and Benton 2006)

Pectoral girdle
41. Clavicle:
(0) – present
(1) – absent
(Gauthier 1986, Sereno 1991, Benton 1999)

42. Interclavicle:
(0) – present
(1) – absent
(Gauthier 1986, Juul 1994, Benton 1999)

43. Scapulocoracoid notch at anterior junction of scapula and coracoid:
(0) – absent
(1) – present
(Parrish 1993, Benton 1999)

44. Postglenoid process on the coracoid:
(0) – absent
(1) – present but short
(2) – present and elongate (longer than 50% of the coracoid anterior to the glenoid fossa)
(Benton and Clark 1988, Nesbitt et al. 2005)

Forelimb

45. Forelimb-hindlimb length ratio:
(0) – more than 0.55
(1) – less than 0.55
(Gauthier 1986, Sereno 1991, Juul 1994, Sereno and Arcucci 1994, Benton 1999)

46. Deltopectoral crest on humerus:
(0) – rounded or triangular
(1) – subrectangular
(Sereno 1991, Juul 1994, Benton 1999)

47. Apex of deltopectoral crest situated at a point corresponding to:
(0) – less than 30% down the length of the humerus
(1) – more than 30% down the length of the humerus
(Benton 1990, Juul 1994, Benton 1999) Modified

48. Enlarged tab-like medial process on the proximal part of the humerus (extends partway down the shaft):
(0) – absent
(1) – present
New

49. Width of distal end of humerus:
(0) – narrower or equal to 30% of humerus length
(1) – greater than 30% of humerus length
(Langer and Benton 2006)

50. Radius length:
(0) – longer than 80% of humerus length
(1) – shorter than 80% of humerus length
(Langer and Benton 2006)

51. Radiale and ulnare dimensions:
    (0) – short
    (1) – elongate
    (Benton and Clark 1988)

52. Pteroid bone:
    (0) – absent
    (1) – present
    (Bennett 1996)

53. Manual digit I (pollex-thumb):
    (0) – metacarpal I and ungual phalanx similar in size to those of manual digits II-V
    (1) – metacarpal I robust and half or less the length of metacarpal II, first phalanx longer than metacarpal I or any other phalanx in the hand, lingual phalanx I much larger than other unguals
    (Gauthier 1986, Benton 1990, Benton 1999)

54. Distal condyles of metacarpal I:
    (0) – approximately aligned or slightly offset
    (1) – lateral condyle strongly distally expanded relative to medial condyle
    (Bakker and Galton 1974, Langer and Benton 2006) Modified

55. Metacarpal II:
    (0) – shorter than metacarpal III
    (1) – equal to or longer than metacarpal III
    (Gauthier 1986, Langer and Benton 2006)

56. Manual digits I-III:
    (0) – comparatively short with relatively blunt unguals on at least digits II and III
    (1) – long penultimate phalanx with trenchant unguals on digits I-III
    (Gauthier 1986, Juul 1994, Benton 1999)

57. Metacarpal III and IV bases:
    (0) – lie more or less in the same plane as the inner metacarpals
    (1) – lie on palmar surfaces of manual digits III and IV respectively
    (Gauthier 1986, Juul 1994, Benton 1999)

58. Manual digit IV:
    (0) – five phalanges
    (1) – four phalanges
    (2) – fewer than four phalanges
    (Gauthier 1986, Benton and Clark 1988, Sereno 1993, Benton 1999)

59. Manual digit IV length:
(0) – less than 25% of total forelimb length
(1) – more than 50% of total forelimb length
(Bennett 1996) Modified

60. Manual digit V:
(0) – possesses one or more phalanges
(1) – lacks phalanges
(2) – absent
(Bakker and Galton 1974, Langer and Benton 2006) Modified

Pelvic girdle

61. Pre-acetabular process of the ilium:
(0) – short
(1) – extends anteriorly beyond the pubic peduncle
(Galton 1976, Langer and Benton 2006)

62. Supra-acetabular ridge extending dorsally from the acetabular rim of the ilium (supra-acetabular crest of Juul 1994, Nesbitt 2005, 2007, etc):
(0) – absent
(1) – present
(Juul 1994, Benton 1999) modified

63. Brevis shelf on ventral surface of postacetabular part of ilium:
(0) – absent
(1) – present
(Gauthier 1986, Juul 1994)

64. Acetabulum:
(0) – laterally orientated
(1) – ventrally deflected
(Benton and Clark 1988, Juul 1994, Benton 1999)

65. Ventral margin of the acetabulum on the ilium:
(0) concave
(1) straight
(2) convex
(Bakker and Galton 1974, Langer and Benton 2006)

66. Acetabular antitrochanter on ilium:
(0) – absent
(1) – present
(Sereno and Arcucci 1994)

67. Posteroventrally rotated pubis with enlarged prepubic process:
(0) – absent
(1) – present
(Butler 2005)

68. Pubis length:
(0) – shorter than ischium
(1) – longer than ischium
(Benton and Clark 1988, Juul 1994, Benton 1999)

69. Pubis length:
(0) – less than three times width of acetabulum
(1) – more than three times width of acetabulum
(Sereno 1991, Juul 1994, Sereno and Arcucci 1994, Benton 1999)

70. Pubic acetabular margin, posterior portion:
(0) – continuous with anterior portion
(1) – recessed
(Sereno 1991, Benton 1999)

71. Distal pubis mediolateral width:
(0) – nearly as broad as proximal width
(1) – significantly narrower than proximal width
(2) – mediolaterally compressed and not broader than anteroposteriorly deep
(Galton 1976, Sereno 1999, Langer and Benton 2006)

72. Expansion of distal portion of the pubis:
(0) – absent
(1) – slight anteroposterior bulge
(2) – marked anterior and/or posterior expansion forming a pubic boot
(Gauthier 1986, Juul 1994, Benton 1999) Modified

73. Pubic process of the ischium:
(0) – continuous with the acetabular edge of the ilial peduncle
(1) – waisted; separated from the ilial peduncle
New

74. Medioventral lamina of the ischium:
(0) – extends for more than half the length of the bone
(1) – is restricted to the proximal third of the bone
(Novas 1992, Novas 1996, Langer and Benton 2006)

75. Groove on the dorsolateral surface of the proximal part of ischium:

(0) – absent
(1) – present
(Butler 2005)

76. Cross-section of the distal part of the ischium:
(0) – rounded or semi-circular
(1) – sub-triangular
(Sereno 1999, Langer and Benton 2006)

77. Dorsoventral expansion of the distal end of the ischium:
(0) – absent
(1) – present
(Langer and Benton 2006)

Hindlimb

78. Tibia-femur ratio:
(0) – less than or equal to 1.0
(1) – more than 1.0
(Gauthier 1986, Sereno 1991, Juul 1994, Benton 1999) Modified

79. Femoral head in proximal view:
(0) – elliptical or reniform
(1) – sub-triangular
(Nesbitt et al. in press)

80. Femoral head in medial and lateral views:
(0) – rounded
(1) – hook-shaped
(Sereno and Arcucci 1993)

81. Femoral proximal head:
(0) – rounded and not distinctly offset
(1) – subrectangular and slightly offset by a ventral notch
(2) – subrectangular and distinctly offset
(Gauthier 1986, Juul 1994, Benton 1999) Modified

82. Ventral emargination on the anterolateral side of the femoral head:
(0) – absent
(1) – present
(Sereno and Arcucci 1993)

83. Ventral ligament sulcus on the posterior side of the femoral head:
(0) – absent
(1) – present

(Novas 1996)

84. Posteromedial tuber of femoral head:
(0) – small
(1) – enlarged
(2) - absent
(Nesbitt 2005)

85. Lateral tuber of the proximal head of the femur:
(0) – present
(1) – absent
(Sereno and Arcucci 1993) Modified

86. Femoral head articular surface:
(0) – limited extent
(1) – extends under head
(Sereno and Arcucci 1994)

87. Fossa articularis antitrochanterica on femoral head:
(0) – symmetrical extent on anterolateral and posteromedial surfaces
(1) – expanded asymmetrically onto posteromedial surface
(Novas 1996) Modified

88. Femoral fourth trochanter (ridge for attachment of *m. caudifemoralis longus*):
(0) – absent
(1) – present

89. Femoral fourth trochanter shape:
(0) – mound-like
(1) – symmetrical sharp ridge
(2) – asymmetrical, with distal margin forming a steeper angle to the shaft
(3) – asymmetrical, wing-like
(Gauthier 1986, Benton and Clark 1988, Sereno 1991, Sereno and Arcucci 1993, Juul 1994, Bennett 1996, Langer and Benton 2006) Modified

90. Femoral anterior (lesser) trochanter:
(0) – absent
(1) – weakly developed
(2) – spike-like
(3) – crest separated from femoral shaft
(Gauthier 1986, Novas 1992, Juul 1994, Sereno and Arcucci 1994, Langer and Benton 2006) Modified

91. Femoral crista tibiofibularis (fibular condyle of Sereno & Arcucci 1994):

(0) – smaller or equal in size to the tibial condyle
(1) – larger than the tibial condyle
(Sereno and Arcucci 1993) modified

92. Cnemial crest on tibia:
(0) – absent
(1) – present and straight
(2) – present and curved laterally
(Benton and Clark 1988, Juul 1994, Benton 1999) Modified

93. Crista tibiofibularis of the proximal portion of tibia:
(0) – level with the medial condyle at its posterior border
(1) – offset anteriorly from the medial condyle
(Langer and Benton 2006)

94. Distal end of tibia:
(0) – unexpanded, or only slightly expanded, and rounded
(1) – mediolaterally expanded, with a subrectangular or strongly triangular end
(Gauthier 1986, Sereno 1991, Benton 1999)

95. Posteromedial crest on distal portion of tibia:
(0) – absent
(1) – present
(Sereno and Arcucci 1994)

96. Posterolateral flange of the distal portion of the tibia:
(0) – absent
(1) – present and touches fibula
(2) – present and extends posteriorly behind the fibula
(Novas 1992, Juul 1994, Benton 1999, Langer and Benton 2006) Modified

97. Anteromedial margin of the distal end of the tibia:
(0) – rounded obtuse angle
(1) – distinctly acute angle
(Langer and Benton 2006)

98. Posterolateral margin of the distal end of the tibia:
(0) – straight or convex
(1) – concave
New

99. Fibula and calcaneum shape:
(0) – unreduced
(1) – fibula tapering and calcaneum reduced in size

(Gauthier 1986, Juul 1994, Benton 1999)

100. Tibial facet of astragalus:
(0) – concave
(1) – flexed/convex
(Sereno 1991, Juul 1994, Benton 1999)

101. Distinct basin posterior to the ascending process and separated from the tibial facet on the astragalus:
(0) – absent
(1) – present
(Langer and Benton 2006)

102. Anterior ascending process of the astragalus:
(0) – absent
(1) – present
(Benton 1999) Modified

103. Posterior ascending process of the astragalus:
(0) – absent
(1) – present
(Sereno and Arcucci 1994)

104. Astragalus-calcaneum articulation:
(0) – free
(1) – co-ossified
(Sereno and Arcucci 1993)

105. Astragalar anteromedial corner shape:
(0) – obtuse
(1) – acute
(Sereno 1991, Sereno and Arcucci 1993, Juul 1994, Benton 1999)

106. Mediolateral width of the distal articular face of the calcaneum:
(0) – more than 35% of that of the astragalus
(1) – less than 35% of that of the astragalus
(Sereno 1991, Sereno and Arcucci 1993, Juul 1994, Benton 1999)

107. Calcaneal tuber:
(0) – prominent
(1) – reduced but present
(2) – completely absent
(Gauthier 1986, Sereno 1991, Juul 1994, Langer and Benton 2006) Modified

108. Calcaneal tuber orientation:
(0) – lateral
(1) – deflected more than 45° posterolaterally
(Sereno 1991, Juul 1994, Benton 1999)

109. Calcaneal tuber shaft proportions:
(0) – taller than broad
(1) – broader than tall
(Sereno 1991, Juul 1994, Benton 1999)

110. Calcaneal tuber distal end:
(0) – anteroposteriorly compressed
(1) – rounded
(Sereno 1991, Juul 1994, Benton 1999)

111. Calcaneal tuber distal end, with dorsoventrally aligned median depression:
(0) – absent
(1) – present
(Parrish 1993, Juul 1994, Benton 1999)

112. Articular facets for fibula and distal tarsal IV on calcaneum:
(0) – separated by a non-articular surface
(1) – continuous
(Sereno 1991, Juul 1994, Benton 1999)

113. Hemicylindrical calcaneal condyle:
(0) – absent
(1) – present
(Sereno 1991, Juul 1994, Benton 1999)

114. Distal tarsal IV: transverse width:
(0) – broader than distal tarsal 3
(1) – subequal to distal tarsal 3
(Sereno 1991, Juul 1994, Benton 1999)

115. Distal tarsal IV, size of articular facet for metatarsal V:
(0) – more than half of lateral surface of distal tarsal 4
(1) – less than half of lateral surface of distal tarsal 4
(Sereno 1991, Sereno and Arcucci 1993, Benton 1999)

116. Posteromedial prong of distal tarsal IV:
(0) – blunt
(1) – pointed
(Novas 1993, Novas 1996, Langer and Benton 2006)

117. Metatarsus configuration:
(0) – metatarsals diverging from ankle
(1) – compact metatarsus, with metatarsals I-IV tightly bunched
(Benton and Clark 1988, Sereno 1991, Juul 1994, Benton 1999)

118. Metatarsal midshaft diameters:
(0) – I and V subequal or greater than II-IV
(1) – I and V less than II-IV
(Sereno 1991, Sereno and Arcucci 1993, Juul 1994, Benton 1999)

119. Metatarsal I length, relative to length of metatarsal III:
(0) – 50-75%
(1) – 85% or more
(Sereno 1991, Benton 1999)

120. Metatarsals II-IV:
(0) – shorter than 50% of tibial length
(1) – longer than 50% of tibial length
(Sereno 1991, Juul 1994, Benton 1999)

121. Elongate lateral expansion of proximal metatarsal IV anterior to metatarsal V:
(0) – absent
(1) – present
(Sereno 1999, Langer and Benton 2006)

122. Distal articular surface of metatarsal IV:
(0) – broader than deep or equant
(1) – deeper than broad
(Langer and Benton 2006)

123. Metatarsal V, 'hooked' proximal end:
(0) – present
(1) – absent, and articular face for distal tarsal 4 subparallel to shaft axis
(Sereno 1991, Juul 1994, Benton 1999)

124. Phalanges on pedal digit V:
(0) – three
(1) – two or less
(Gauthier 1986, Benton and Clark 1988, Juul 1994, Benton 1999) Modified

Osteoderms

125. Dorsal body osteoderms:
(0) – absent

(1) – present
(Gauthier 1986, Benton and Clark 1988, Sereno 1991, Juul 1994, Benton 1999)
Modified

126. Raised anterior bar (articulation surface) on dorsal surface of osteoderm:
(0) – absent
(1) – present
(Heckert et al. 1996)

127. Anterolateral edge of paramedian dorsal osteoderms
(0) – straight
(1) – with anterior process
(Clark et al. 2000, Olsen et al. 2000, Benton and Walker 2002, Sues et al. 2003, Clark et al. 2004)

**Table S2:** Taxon-character matrix. "P" indicates a polymorphic character and was coded as "(0,1)" in the analysis. "-" indicates the character is inapplicable and were treated as missing data in the parsimony analysis.

| | 10 | 20 | 30 | 40 |
|---|---|---|---|---|
| *Euparkeria* | 000100-000 | 1100001000 | 0000000000 | 0000000000 |
| *Leptosuchus* | 100100-P00 | 0100000000 | 0000010100 | 0000000000 |
| *Aetosaurus* | 000110-000 | ?010100000 | 00PP010000 | 00???0??00 |
| *Riojasuchus* | 000100-000 | 0100000000 | 1000010100 | 0000000010 |
| *Postosuchus* | 0010010000 | 0?00100100 | 0000010100 | 000000?100 |
| *Effigia* | 001110-000 | 0101000000 | ?----10100 | 0?0010?110 |
| *Hesperosuchus* | 000000-000 | ?001110100 | ?000010100 | ?000001000 |
| *Protosuchus* | 001000-010 | 100110010? | 1001010100 | 0000001000 |
| *Dimorphodon* | 100110-101 | ?1?10????? | ?00P010000 | 2?0??????? |
| *Eudimorphodon* | 100110-100 | 01010????? | ?1010?0000 | 200??10?10 |
| *Lagerpeton* | ?????????? | ?????????? | ?????????? | ????????00 |
| *Dromomeron* | ?????????? | ?????????? | ?????????? | ?????????? |
| *Marasuchus* | ?????????? | ?????????? | ?????????? | ?01000?000 |
| *Silesaurus* | 00?000-??? | ?????1???? | 00110100?0 | ?110000011 |
| *Eucoelophysis* | ?????????? | ?????????? | ?????????? | ??10?????? |
| *Pisanosaurus* | ?????11??? | ?????????? | ?1111??010 | 2????????? |
| *Lesothosaurus* | 0000010000 | 01?1010011 | 1111011210 | 11??????1? |
| *Heterodontosaurus* | 0100011000 | 01?101001? | ?101111210 | 1010001?10 |
| *Scutellosaurus* | 00???10??? | ???1?????? | ??110?121? | ?010?0??10 |
| *Herrerasaurus* | 011000-010 | 1?11010011 | 1000110101 | 011011?101 |
| *Chindesaurus* | ?????????? | ?????????? | ?????????? | ???0????01 |
| *Saturnalia* | 0????0-?11 | 1?????10?? | ?0110?0?0? | ??10100101 |
| *Efraasia* | 011110-111 | 11?101101? | 1111010000 | 0?10110111 |
| *Plateosaurus* | 011110-111 | 1111011011 | 1111010000 | 0110110111 |
| *Coelophysis* | 01?110-111 | 1111010011 | ?000010001 | 0111110110 |
| *Allosaurus* | 011110?111 | 1011010011 | 1000010001 | 1?11100110 |

| | 50 | 60 | 70 | 80 |
|---|---|---|---|---|
| *Euparkeria* | 0000000000 | 0000000??? | 0000200000 | 0000000000 |
| *Leptosuchus* | 0011000000 | 0????????? | 0000200000 | 0000000000 |
| *Aetosaurus* | 0001000000 | 0000100?00 | 1000?00101 | 0000000000 |
| *Riojasuchus* | ??01000000 | 0001??0?0? | 0100200?11 | 000????000 |
| *Postosuchus* | 0?11000000 | 0000000100 | 0101200111 | 0110101000 |
| *Effigia* | 0?01?0000? | ?0???00?0? | 1111001111 | 2111000000 |
| *Hesperosuchus* | ?012000000 | 1000000?0? | 110?200??? | 00?????000 |
| *Protosuchus* | 1012000000 | 10??000?00 | ?001000110 | -010000000 |
| *Dimorphodon* | 1?00010100 | 0100?10112 | 1000?10000 | ?00?000100 |
| *Eudimorphodon* | 1?00010100 | 0100010112 | 1000?10010 | ?00?000100 |
| *Lagerpeton* | ?????????? | ?????????? | 1000200000 | 0000000101 |
| *Dromomeron* | ?????????? | ?????????? | ?????????? | ???????101 |
| *Marasuchus* | ??0?110000 | ?????????? | ?000200110 | 0??0000100 |
| *Silesaurus* | ??00000000 | ?????????? | 0010200110 | 0000100010 |
| *Eucoelophysis* | ?????????? | ?????????? | ???0200110 | 000000??10 |
| *Pisanosaurus* | ?????????? | ?????????? | ?????????? | ?????????? |
| *Lesothosaurus* | ????111001 | 0000100?00 | 0010001110 | 2010100100 |
| *Heterodontosaurus* | 1100111001 | 0000100200 | 1000011110 | 2010100100 |
| *Scutellosaurus* | ???0011001 | ?0???00?0? | 10100?1110 | 2?10100100 |
| *Herrerasaurus* | 1101111000 | 0010011201 | 0000010110 | 1211010000 |

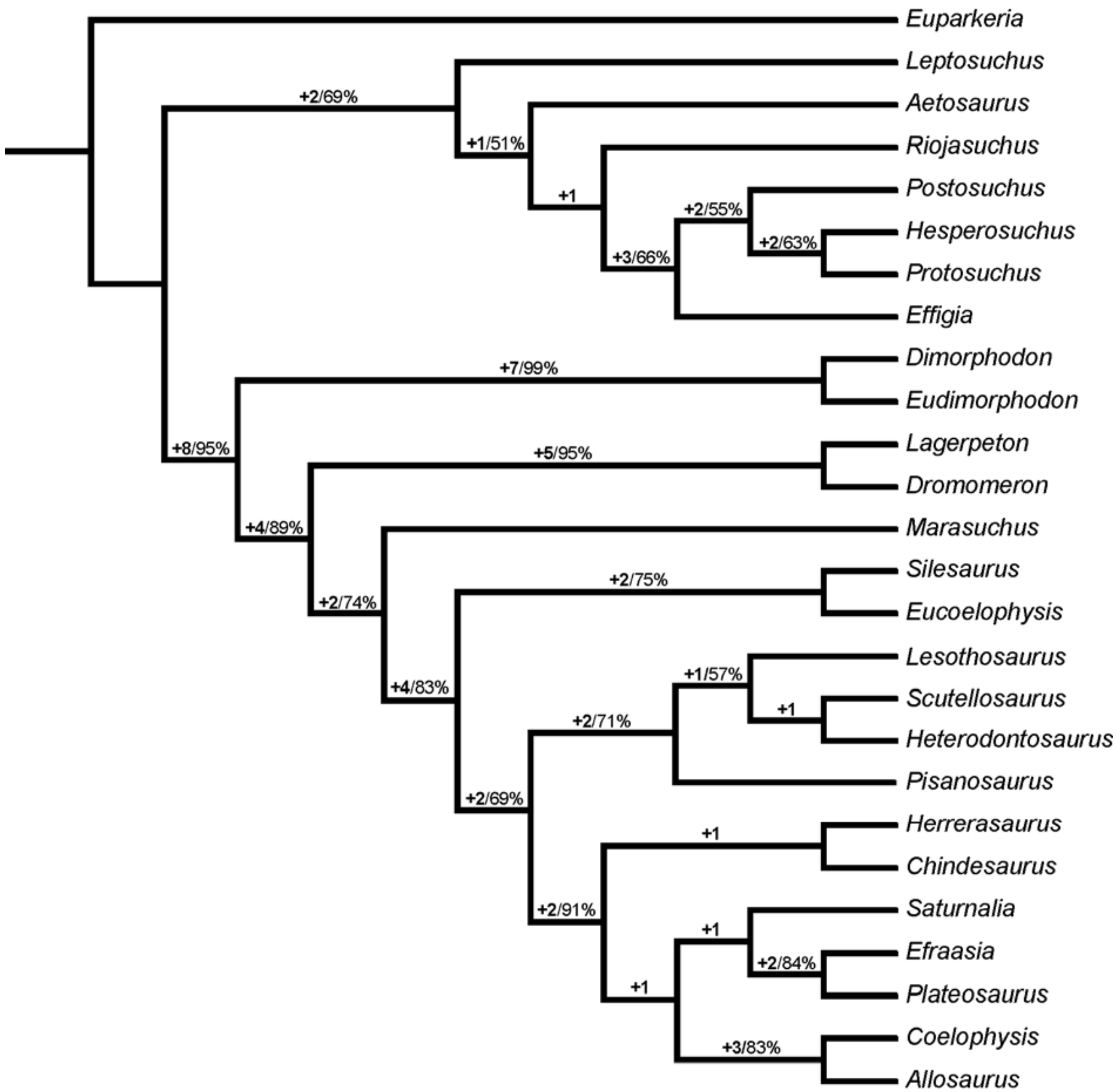
| | | | | |
|---|---|---|---|---|
| *Chindesaurus* | ?????????? | ?????????? | ???00?0?1? | ????????00 |
| *Saturnalia* | ??01?11011 | ?????????? | 0011110010 | 1101111000 |
| *Efraasia* | 1100111011 | 0011?00?0? | 0010010110 | 0?11111000 |
| *Plateosaurus* | 1100111011 | 0011000200 | 0010010110 | 0111111000 |
| *Coelophysis* | 1100111001 | 0011111202 | 1010010110 | 1111001100 |
| *Allosaurus* | 1111111001 | 001111-2-2 | 1010000110 | 1211001000 |

| | 90 | 100 | 110 | 120 |
|---|---|---|---|---|
| *Euparkeria* | 0000000100 | 0000000000 | -000000000 | 0000000000 |
| *Leptosuchus* | 0000000100 | 0000000001 | -000000111 | 001???0??? |
| *Aetosaurus* | 0001000100 | 0000000001 | -000000111 | ?110000000 |
| *Riojasuchus* | 0001000101 | 0000000001 | -000000111 | 0110000000 |
| *Postosuchus* | 0000000100 | 0000000001 | -000000111 | 111???10?0 |
| *Effigia* | 2000100??0 | 0000000001 | -0000001?? | ?110001110 |
| *Hesperosuchus* | 0000000100 | 000000000? | -????????? | ??????1?01 |
| *Protosuchus* | 000?000100 | 0000000001 | -000000111 | 1110001010 |
| *Dimorphodon* | 200?0000-0 | 000000000? | -0010?2--- | -101001010 |
| *Eudimorphodon* | 2????0?0-0 | 00?000??0? | -001002--- | -101001010 |
| *Lagerpeton* | 0101010110 | 1100100011 | 0011012--- | -101101101 |
| *Dromomeron* | 01010100-0 | 11001010?1 | 0111002--- | -10??????? |
| *Marasuchus* | 0000110111 | 0200000010 | 0100011100 | 0101101101 |
| *Silesaurus* | 1000100112 | 0201010010 | 0100012--- | -10??11?0 |
| *Eucoelophysis* | 1000100??2 | 020??????? | ?????????? | ??????1??? |
| *Pisanosaurus* | ?????????? | 0201010010 | ?100012--- | -10???1??1 |
| *Lesothosaurus* | 2012011133 | 021102101? | ?????????? | ??????1101 |
| *Heterodontosaurus* | 2???011133 | 021101??1? | ???1?12--- | -1011?1100 |
| *Scutellosaurus* | 2010011133 | 0211021010 | 0100112--- | -10???11?? |
| *Herrerasaurus* | 2010011122 | 0201010010 | 1100112--- | -101111101 |
| *Chindesaurus* | 2012011122 | 0201010??0 | 11001????? | ?????????? |
| *Saturnalia* | 2010011122 | 0201010110 | 1100112--- | -101111101 |
| *Efraasia* | 2010011122 | 0201011110 | ?10011?--- | -101111100 |
| *Plateosaurus* | 2010011122 | 0201011010 | 1100112--- | -101111100 |
| *Coelophysis* | 2012011112 | 0201021110 | 0101112--- | -101101101 |
| *Allosaurus* | 2012011?23 | 0201021110 | 0100112--- | -101101101 |

| | 127 |
|---|---|
| *Euparkeria* | 00001?0 |
| *Leptosuchus* | ??0?100 |
| *Aetosaurus* | 0001110 |
| *Riojasuchus* | 0001100 |
| *Postosuchus* | 0000101 |
| *Effigia* | 000?0-- |
| *Hesperosuchus* | 00??111 |
| *Protosuchus* | 0001110 |
| *Dimorphodon* | 00010-- |
| *Eudimorphodon* | 00010-- |
| *Lagerpeton* | 00110-- |
| *Dromomeron* | ??????? |
| *Marasuchus* | 00110-- |
| *Silesaurus* | 11110-- |
| *Eucoelophysis* | ?1????? |
| *Pisanosaurus* | 01????? |
| *Lesothosaurus* | 01??0-- |
| *Heterodontosaurus* | ?1??0-- |

| | |
|---|---|
| *Scutellosaurus* | 01??100 |
| *Herrerasaurus* | 11110-- |
| *Chindesaurus* | ??????? |
| *Saturnalia* | 111?0-- |
| *Efraasia* | 11110-- |
| *Plateosaurus* | 11110-- |
| *Coelophysis* | 01110-- |
| *Allosaurus* | 01-10-- |

**Fig. S4.** Single most parsimonious tree with a tree length of 298 steps. Bold numbers on the branches indicate Bremer support indices and percentages indicate bootstrap support when above 50%. Consistency Index (CI) = 0.4799, Homoplasy Index (HI) = 0.5201, Retention Index (RI) = 0.7430, and Rescaled Consistency Index (RC) = 0.3565.



**5. Table S3:** Voucher specimens for Table 1. Data for Canjilon Quarry in part from Nesbitt & Stocker (unpublished data). AMNH, American Museum of Natural History, New York; CM, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania; GR, Ghost Ranch Ruth Hall Museum of Paleontology, Ghost Ranch, New Mexico; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque, New Mexico; PEFO, Petrified Forest National Park, Arizona; UCMP, University of California Museum of Paleontology, Berkeley, California.

| Taxon | Hayden Quarry | Canjilon Quarry | Snyder Quarry | *Coelophysis* Quarry | Petrified Forest N.P. |
|---|---|---|---|---|---|
| Metoposauridae | GR 231 - clavicle | UCMP 122455 - centrum | NMMNH P-29989 - centrum | | PEFO 33977 - skull |
| Drepanosauridae | GR 232 - manual ungual | | | GR 113 - pectoral girdle | |
| *Vancleavea* | GR 230 - ilium | GR 151 - osteoderm | | GR 138 - skeleton | PEFO 33978 - partial skeleton |
| *Pseudopalatus* spp. | GR 233 - partial posterior skull | UCMP 34249 - skull | NMMNH P-31292 - skull | | UCMP 126987 - squamosal |
| *Typothorax coccinarum* | GR 229 - lateral plate | UCMP 34255 - partial skeleton | NMMNH P-35205 - paramedian plate | | UCMP 33979 - partial skeleton |
| *Heliocanthus chamaensis* | GR 193 - paramedian plate GR 228 - lateral plate | | NMMNH P-32793 - paramedian plate | | PEFO 31162 - paramedian plate |
| "Rauisuchia" | GR 186 - maxilla | UCMP 152644 - proximal femur | NMMNH P-36144 - femur | CM 73372 - skeleton | PEFO 33954 - partial skeleton |
| *Shuvosaurus* -like taxon | GR 235 - humerus and radii | | | AMNH FR 30587 - skeleton | PEFO 33953 - partial skeleton |
| Crocodylomorpha | GR 236 - femur | | | CM 29894 - partial skeleton | UCMP 129740 - partial skeleton |
| *Dromomeron romeri* | see text | | NMMNH P-35379 - astragalocalcaneum | | |
| *Silesaurus* -like taxon | see text | | | | |
| *Chindesaurus bryansmalli* | GR 226 - femur | | | | PEFO 33982 - partial skeleton |
| Coelophysoidea | GR 227 - tibia/fibula | UCMP 152645 - partial pes | NMMNH P-30852 - partial skull | AMNH FR 7223 - skeletons | UCMP 129618 - partial skeleton |

## 6. Supporting Online Material References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