APPENDIX: DATA MATRIX AND EMENDATIONS

Sources of additional information for codings in present analysis

Prosauropods: Galton (1984)

Theropoda: Sereno & Novas (1993)

Barapasaurus: McIntosh (1990a)

Omeisaurus: He *et al*. (1988); Tang *et al*. (2001)

Shunosaurus: Chatterjee & Zheng (2002)

Patagosaurus: Bonaparte (1986)

Mamenchisaurus: Ouyang & Ye (2002)

Apatosaurus: Berman & McIntosh (1978)

Barosaurus: Foster (1996)

Brachiosaurus: Janensch (1929b, 1935-1936, 1950, 1961)

Camarasaurus: Madsen *et al*. (1995); McIntosh *et al*. (1996a, b)

Dicraeosaurus: Janensch (1929b, a, 1935-1936, 1961);, pers. obs.

Diplodocus: Osborn (1912); McIntosh & Berman (1975); Berman & McIntosh (1978); Curtice & Stadtman (2001)

Malawisaurus: Gomani (1999)

Alamosaurus: Lawson (1972); Lehman & Coulson (2002)

Rapetosaurus: Curry (2001)

Saltasaurus: Powell (2003)

Characters removed in present analysis

- Rostral process of the prefrontal (U32): Upchurch *et al*. (2004) describe the plesiomorphic state for this character as ‘ (process) present, intervenes between the nasal and lacrimal;’ the

apomorphic state is the loss of this character. However, in no sauropod could a lack of contact between the nasal and lacrimal be observed; although the prefrontal does send a process rostrally, even in the most caudodorsal corner, it never completely separates the nasal and lacrimal in any taxon (including prosauropods). The prefrontal has been poorly described in many sauropods, particularly diplodocoids, owing in part to fusion and its resultant lack of clear sutures, so this character has been removed pending further study.

- Orientation of occipital condyle (U47, S4): For this character, authors regarded the orientation of the occipital condyle as either caudal (or caudoventral) and ventral. These are poor choices for terms because they depend on external referents for determining what is the horizontal against which the angle of the occipital condyle can be measured. This referent has never been specified; it often appears to involve the dentigerous margin of the skull, but may also be compared to a an arbitrarily assumed 'flat' (i.e., horizontal) skull roof (frontals and parietals). Using the dentigerous margin is in itself is problematic, particularly with taxa such as *Diplodocus* in which teeth are present only at the tips of the jaws and in which teeth are procumbent -- using this dentigerous margin as a 'homologue' to the more typical toothed maxilla of other sauropods may be misleading. It is also impossible to discern in taxa for which only the braincase is preserved. Regardless, none of this may have anything to do with the 'true' orientation of the skull *in vivo*. There are also potential errors in reconstructing diagenetically altered skulls (Berman & McIntosh 1978) that may affect the perception of occipital condyle orientation. To avoid the use of arbitrary referents (such as the position with respect to horizontal of the dentigerous skull margin or skull roof), a more concrete referent may, in the future, prove phylogenetically useful. This may be something such as 'Angle between the plane of the nuchal surface (alternatively, the sagittal nuchal crest; i.e., the long

dorsoventral axis of supraoccipital, as proposed by Salgado [1999]) and the occipital condyle,' or 'Angle between the plane of the foramen magnum and the occipital condyle,' or even the 'Angle between the planes of the nuchal surface and foramen magnum,' but such information is not reported in most descriptions, and thus could not be included in the present analysis.

- Presacral bone texture (W77, U309): This character was abandoned in the face of two issues. First, there is a possible size and/or ontogenetic pattern in the development of camerae and camellae (Wedel 2003), as exemplified by an extremely large specimen of *Diplodocus* that possesses camellae in some of its presacral vertebrae, whereas smaller specimens do not (pers. obs.). Second, several intermediate grades can be discerned, demonstrating that internal bone structure is a spectrum rather than a dichotomy (Wedel *et al*. 2000). A multistate character may be useful in future analyses, though drawing lines between discreet categories may prove difficult.
- Caudal corporozygapophyseal lamina on middle and caudal thoracic vertebrae (W95, U143): Wilson (2002) cited the apomorphic state of this character as present only in *Dicraeosaurus* and *Diplodocus*. However, the presence of split laminae in *Dicraeosaurus* could not be confirmed (pers. obs.), so this character was reduced to an autapomorphy of *Diplodocus*. In contrast, Upchurch *et al*. (2004) scored numerous sauropods as possessing the apomorphic state. Clearly, this character needs refinement before it can be included in a phylogenetic analysis, so it has been excluded here.

Most of the characters used in this matrix are either phrased to be self-explanatory or were given detailed explanations either in Upchurch (1995, 1999), Wilson and Sereno (1998), or Wilson (2002); no further explanation is provided here. Explanations are provided for characters that

were (or are) somewhat ambiguous; some have been expanded to include multiple states, either because observed measurements included numbers not covered by existing definitions or because existing definitions left theoretical gaps in coverage. Most comparative measurement characters have been reworded as ratios to facilitate rapid interpretation and calculation.

CHARACTERS AND CHARACTER STATES

1. **Morphology of rostralmost ends of jaws in dorsal view (W65, U1):** triangular, with acute tip (0); broadly rounded rostrally with linear, roughly parallel lateral margins (U-shaped or parabolic) (1); platalean (broadly rounded and convex rostrally but with lateral margins that are sinuous, convex rostrally but becoming concave, producing spoon-shape caudally) (2); rectangular, especially lower jaw (rostral margin linear and at abrupt angle to lateral margins) (3).

   The character states outlined by Upchurch et al. *(2004) do not easily accommodate the distinctive skull morphologies of* Nemegtosaurus *or* Rapetosaurus, *so the category 'platalean' has been added here to describe their distinctive snouts. The otherwise superficially diplodocoid-like morphology of these taxa is almost certainly convergent given the peculiar morphology of the primitive titanosaur* Malawisaurus *(Jacobs et al., 1993) and the* Brachiosaurus*-like titanosaur skulls from the Bajo Barreal Formation of South America (Lamanna et al., 2001).*

2. **Configuration of caudolateral processes of premaxilla and lateral processes of maxilla (W1, U15):** lacking midline contact (0); possessing midline contact and forming marked narial depression (1).

Character 2 of Wilson (2002) is somewhat confusing because it obfuscates important anatomical details; the anatomical relationships Wilson intended to encompass in his character were separated into several distinct characters by Upchurch et al. *(2004). The 'caudolateral process' of the premaxilla is most distinct in taxa (e.g.*, Euhelopus, Omeisaurus, Shunosaurus*) in which the caudal part of the premaxilla bifurcates to house the rostral margin of the external nares. The caudolateral process is the prong or point at the rostroventral most edge of the external nares. By his use of this character, Wilson (2002) clearly accepts that all sauropods retain a 'caudolateral' process, but Upchurch* et al. *(2004) cite as their character 15 the possibility that the process is absent -- indeed, they code it as absent for all sauropods for which this element could be coded except the aforementioned taxa plus* Jobaria. *As a result, the caudal migration of the external nares produced one of two effects: the caudolateral process ceased to exist as a distinct process, or the process fused to the nasal process. Wilson (2002) favors the former interpretation because in the taxa he codes as showing the derived state, there is no distinct process. What occurs instead, however, is that the sutures between the portion of the premaxilla excepting the nasal process (which is the indistinct 'caudolateral process') and the rostromedial portion of the maxilla of the left and right sides meet at the midline within the external narial fossa and/or fenestra. Thus, as used here, this character subsumes character 2 of Wilson (2002) and character 15 of Upchurch* et al. *(2004). Retraction of the nares clearly created a complex set of mutually inclusive states (e.g., characters 3-8, 13, etc.); further discoveries will help determine if they should continue to be coded separately.*

3. **Angle between lateral and medial margins of premaxilla as seen in dorsal view (U12-14):** >20º (0); ≤ 20º (1).

This character has been modified from Upchurch et al. *(2004), which did not specify at point along the midline from which the angle should be measured. The character is clearly intended to describe the unique condition in diplodocoids, induced by the extreme caudal retraction of the external nares (see character 2) and the mediolateral narrowing of the premaxilla. The caudomedial portion of the premaxilla-maxilla suture in non-diplodocoids, however, also closely parallels the midline suture, while it is the rostrolateral part that is at the widely divergent angle, so it is that region that is specified here. The angle is measured between the projection of the line defined by the rostrolateral end of the premaxilla-maxilla suture and the skull midline in dorsal view. The derived character states are probably inextricably linked to the rostrocaudal elongation and mediolateral narrowing of the premaxilla (character 12 of Upchurch* et al. *2004) since any lateral migration of the rostral end of the premaxilla (independent of the nasal process) that creates a wider angle also creates the distinction defined therein; any simultaneous lateral widening of the ascending process maintains the derived low angle.*

4. **Morphology of rostral margin of premaxilla (= region rostral to nasal process) in lateral view (W2, U10):** without 'step' (0); with marked 'step;' rostral margin of skull thus sharply demarcated (= muzzle-like area present).

Another way to phrase this character may be to state that the rostral and dorsal margins of the premaxilla, seen particularly in lateral view, lie in different planes: the dorsal margin approaches horizontal whereas the rostral margin is near vertical. The derived state

appears in sauropods with 'diplodocoid'-type skulls in which the dorsal margin of the skull is more or less linear in lateral view.

5. **Free portion of nasal process of premaxilla in lateral view (U11):** majority projects caudally and divides external nares into right and left halves (0); majority projects dorsally and divides external nares into right and left halves (1); is greatly reduced, reducing or eliminating internarial bar and creating single, confluent external narial opening (2).

Upchurch et al. *(2004) clearly erected this character to distinguish the distinctive, sinuous conjoined nasal processes of the premaxilla that form the internarial bar in taxa such as* Brachiosaurus. *The character has been slightly modified here to specify the 'free' portion of the conjoined processes (the parts that are bordered laterally only by space in the external narial opening), because without that caveat, some of the ascending process bordered laterally by the maxilla could be viewed as having an orientation other than that specified in the coded state*.

6. **Thin, plate-like process (flange) directed rostromedially from edge of maxillary ascending process (U17-18, C14):** absent (0); present but lacking midline contact (1); present and contacting each other at midline (2).

This process was illustrated by Upchurch (1998: fig. 3).

7. **Direction in which subnarial foramen faces (U6):** lateral (0); dorsal (1).
8. **Proportions and size of subnarial foramen (U7):** small and subcircular (0); elongate (at least 2x longer than wide in direction of premaxilla-maxilla suture) (1).
9. **Position of subnarial foramen with respect to narial fossa (U8):** outside (0); within (1).

10. Relative positions of subnarial foramen and rostral maxillary foramen (W5): well distanced from one another (0); separated only by narrow bony isthmus (1).

11. External nares face (U4): laterally or rostrolaterally (0); dorsally or rostrodorsally (1).

12. Shelf-like area or fossa (narial fossa) on premaxilla and maxilla lateral to external nares (W1, U19): absent (0); present (1).

Wilson (2002) included this character as part of what is here character 2, implying that the narial fossa is created solely by the midline contact of the premaxilla and maxilla. However, it is conceivable that such a structure could exist but not be restricted to specific elements -- other cranial openings, such as the supratemporal fenestrae, show different osteological associations throughout sauropodomorph evolution, so there is no a priori reason to make such a restriction. This character is thus retained here separately, following Upchurch (1998) and Upchurch et al. *(2004).*

13. Length of border of external naris formed by maxilla (W3): short (less than 1/4 narial perimeter) (0); long (more than 1/3 narial perimeter) (1).

14. Position of mid-point of osteological external nares (W8, U2-3, C7, S7): rostral to antorbital fenestra (0); dorsal to antorbital fenestra (1); caudal to antorbital fenestra (2).

Wilson (2002) did not specify a specific portion of the external narial opening that acts as a reference for its relative position to the antorbital fenestra. Upchurch et al. *(2004) specified the caudal and rostral margins as two separate characters, but the caudal migration of the nares is more easily perceived as a single entity, so the two separate characters refer to the same evolutionary process. The character is simplified here.*

15. Ratio of maximum diameter of osteological external nares:maximum diameter of orbit (W9, U5): <1.0 (nares shorter) (0); ≥ 1.0 (nares longer) (1).

16. Preantorbital fenestra (W4, U20, S24): absent (0); present (1).

17. Antorbital fossa (W7, U21): present (0); absent (1).

18. Ratio of maximum diameter of antorbital fenestra:maximum diameter of orbit (W6): <0.85 (orbit significantly larger) (0); ≥ 0.85 (diameters subequal) (1).

Wilson (2002) did not specify a dividing point between 'much shorter than' and 'subequal' to, making any assessment in a particular specimen arbitrary. Of course, defining a boundary at a particular numerical value, as has been done here, is equally arbitrary, but has the advantage in that it enhances the testability of the character.

19. Angle subtended by rostral and ventral margins of orbit (W10): obtuse or roughly 90 degrees (0); markedly acute (1).

20. Rostral extent of maxillary process of lacrimal (W11, U16): dorsal to midpoint of antorbital fenestra (0); caudodorsal to midpoint of antorbital fenestra but rostral to caudodorsal corner of antorbital fenestra (1); process absent; maxilla-lacrimal contact at caudodorsal corner of antorbital fenestra (2).

21. Element contacting ectopterygoid laterally (W12, U65): jugal (0); maxilla (1).

22. Contribution by jugal to antorbital fenestra (W13, U22): reduced or absent (0); large (occupying most of caudoventral margin) (1).

23. Size of frontal (= caudal) process of prefrontal (W14): small (does not project far beyond frontal-nasal suture) (0); elongate (approaches parietal) (1).

24. Morphology of frontal process of prefrontal in dorsal view (W15, U33): flat, broadly rounded or square (0); hooked or acute and subtriangular (1).

25. Morphology of jugal (= ventral) process of postorbital (W16, U28): mediolaterally narrow (0); broader mediolaterally than rostrocaudally (1).

26. Jugal (= ventral) process of postorbital (U31): does not contact lacrimal (jugal intervenes) (0); contacts lacrimal (excludes jugal from margin of orbit) (1).

27. Squamosal (= caudal) process of postorbital (W17): present (0); absent (1).

28. Frontal-parietal suture in dorsal view (W18, U34): between supratemporal fenestrae/fossae (frontals contribute to rostral margin of fenestrae/fossae) (0); rostral to supratemporal fenestrae/fossae (frontals excluded from rostral margin of fenestrae/fossae) (1).

29. Midline contact (symphysis) between frontals in adults (W19, U36, C13, S31): sutured (0); fused (1).

30. Ratio of rostrocaudal length:minimum mediolateral width of frontal (W20, U35): ≥ 1.0 (equal or longer than wide) (0); <1.0 (wider than long) (1).

31. Dorsoventral height of occipital process of parietal (W21): short (less than diameter of foramen magnum) (0); deep (nearly twice the diameter of the foramen magnum) (1)

Although the occipital processes of the parietal course ventrolaterally-dorsomedially, the dorsoventral height is measured in the vertical plane by projecting horizontal lines from the dorsal- and ventralmost points of the processes, respectively, and measuring the vertical distance between them.

32. Contribution to posttemporal fenestra by parietal (W22, U42): present (0); absent (1).

The posttemporal fenestra (= posttemporal fossa of Holland 1915), called fenestrae here because they represent actual windows bordered by bones rather than an indentation within a set of bones) is an opening, visible in caudal view, dorsal to the paroccipital processes.

33. Postparietal foramen (W23, U43, S26): absent (0); present (1).

34. Morphology of infratemporal fenestra (C9, S6): subrectangular (0); subtriangular (1); linear (slit-like, crescentic) (2).

35. Position of rostralmost or rostroventralmost end of infratemporal fenestra (W30, U29-30, C8, S32): caudal to orbit (0); rostral to caudal margin of but caudal to or equal with midpoint of orbit (1); rostral to midpoint of orbit (2).

36. Ratio of intraparietal distance separating supratemporal fenestrae:length of long axis of supratemporal fenestrae (W24): <2.0 (0); ≥ 2.0 (1).

37. Supratemporal fossa surrounds supratemporal fenestra (U37): present (0); absent (1).

38. Orientation of long axis of external supratemporal fenestra (W25-26, U40): rostrocaudal (0); mediolateral (1); dorsoventral (axis of fenestra is longer in lateral than dorsal view) (2).

39. Contribution by squamosal to dorsal (dorsomedial) margin of supratemporal fenestra (U44): present (0); absent (excluded by parietal-postorbital contact) (1).

40. Ratio of maximum diameter of supratemporal fenestra:diameter of foramen magnum (W27, U41, C10, S30): >>1.0 (0); ~1.0 (subequal) (1).

41. Ratio of rostrocaudal:mediolateral dimension of temporal bar (supratemporal region) (W28): ≥ 1.0 (longer rostrocaudally) (0); <1.0 (longer mediolaterally) (1).

42. Lateral visibility of supratemporal fenestra (W29, U38-39): not visible (obscured by temporal bar) (0); visible (temporal bar shifted ventrally) (1).

This character is maintained as separate from character 38 because a ventral shift of the temporal bar does not necessary elongate the supratemporal fenestra in the dorsoventral plane; the fenestra may maintain a longer dimension in another plane but still be visible laterally.

43. Maxilla-quadratojugal contact (U24, C11, S2): absent (0); present (1).

44. Squamosal-quadratojugal contact (W31, U45): present (0); absent (1).

45. Ratio of length of rostral (= jugal or maxillary) process of quadratojugal:length of squamosal (= dorsal) process (W32, U23): ≤ 1.0 (0); ≥ 1.0 (1).

46. Rostral process of quadratojugal (U25): tapers to acute tip (0); expands dorsoventrally at tip (0).

47. Orientation of rostral process of quadratojugal in lateral view (U26): straight or curves slightly dorsally at tip (0); angles ventrally at tip (1).

48. Angle between rostral and dorsal processes of the quadratojugal (U27): roughly 90º (0); >>90º (1).

49. Orientation of long axis of quadrate with respect to long axis of skull (U68, C5, S5): perpendicular (0); angled caudodorsally-rostroventrally (1).

50. Quadrate fossa (W33-34, U66-67, C1): absent (0); shallow (1); deeply invaginated (2).

51. Orientation of quadrate fossa (W35): caudal (0); caudolateral (1).

52. Rostral articulation of vomer (W42): with maxilla (0); with premaxilla (1).

53. Morphology of lateral ramus of palatine (W40): plate-like (long maxillary contact) (0); rod-like (narrow maxillary contact) (1).

54. Rostral end of maxillary process of palatine (U57): poorly developed and unexpanded (0); mediolaterally expanded (1).

55. Composition of palatine (= rostral) process of pterygoid (U61): formed from two sheets of bone that project laterally and ventrally (0); formed from single, flat plate (1).

56. Ratio of width of main body of pterygoid:overall length of pterygoid (U62): <0.20 (0); ≥ 0.20 (1).

For a discussion and illustration of this character, see Upchurch (1998: fig.4).

57. Morphology of contact surface on pterygoid for basipterygoid articulation (W36, U63-64): small facet (0); dorsomedially-oriented hook (1); rocker-like surface (2).

58. Rostrocaudal position of ectopterygoid process of pterygoid (W37, U58-59): caudal or ventral to orbit (0); between orbit and antorbital fenestra or ventral to antorbital fenestra (1); rostral to antorbital fenestra (2).

59. Dorsoventral position of ectopterygoid process of pterygoid (U60): projects below ventral margin of skull (usually robust) (0); does not project below ventral margin of skull (usually slender) (1).

60. Size of quadrate flange of pterygoid (W38): large (palatobasal and quadrate articulations well separated) (0); small (palatobasal and quadrate articulations approach) (1).

61. Shape of palatine ramus of pterygoid (W39): straight (at level of dorsal margin of quadrate ramus) (0); stepped (raised above level of quadrate ramus) (1).

62. Epipterygoid (W41): present (0); absent (1).

63. Ratio of dorsoventral height of supraoccipital:height of foramen magnum (W43): ≥ 2 (0); 1.01-1.99 (1); ≤ 1 (2).

64. Sagittal and transverse nuchal crests merge smoothly at dorsal end of supraoccipital forming low tetrahedral process (S29): absent (0); present (1).

65. Distal ends of paroccipital processes (U46): flat or slightly convex laterally (0); markedly convex laterally and expanded suddenly dorsally and ventrally ('tongue-like' process present) (1).

66. Ventral (nonarticular) process of paroccipital process (W44): absent (0); present (1).

67. Morphology of occipital region of skull (W54): concave caudally, with paroccipital processes oriented caudolaterally (0); flat with paroccipital processes oriented mediolaterally (1).

68. Morphology of crista prootica (W45, U49): simple, low crest, either lacking processes or with low, non prominent, craniocaudally compressed process (0); possessing prominent, craniocaudally compressed, 'leaf-shaped' dorsolateral process (1).

69. Ratio of length:maximum basal diameter of basipterygoid processes (W46, U52-53, S27): ≤ 2 (0); 2.01-3.99 (1); ≥ 4.0 (2).

70. Angle of divergence between basipterygoid processes (W47, U54, S28): ≥ 30° (0); <30° (1).

71. Ratio of rostrocaudal depth:dorsoventral height of basal tubercula (W48, U48): ≥ 0.25 (0); <0.25 (sheet-like) (1).

72. Ratio of mediolateral width of paired basal tubercula:mediolateral width of occipital condyle (W49): <1.0 (0); 1.0-1.2 (1); >1.2 (2).

73. Basisphenoid fossa/foramen between foramen magnum and basal tubercula (W50): absent (0); present (1).

Future analysis may benefit from the further division of this character to differentiate between the shallow but large fossae seen in some sauropods and the small but deep foramen in others.

74. Region between basipterygoid processes (W51, U55): shallowly concave (0); deep pit (1).

75. Basisphenoid-quadrate contact (W52): absent (0); present (1).

76. Orientation of basipterygoid processes (W53, U50, C6, S3): roughly perpendicular to skull roof (0); forming markedly acute angle to skull roof (1).

77. Cross-sectional morphology of basipterygoid processes (U51): elliptical or subtriangular (0); subcircular (1).

78. Morphology of parasphenoid rostrum (U56): broadly triangular in lateral view and with groove on dorsal margin (0); slender, spike-like, and lacking dorsal groove (1).

79. Depth of rostral end of dentary ramus (W55, U69): decreases or maintains dorsoventral height rostrally (0); increases in dorsoventral height and robustness rostrally (1).

80. Morphology of rostroventral margin of dentary (W56, U70): gently rounded (0); sharply projecting triangular process ('chin') (1).

81. Angle between dentary symphysis and long axis of jaw ramus (W57, U71): <75° (0); >75° (close to perpendicular) (1).

82. Ratio of length of external mandibular fenestra:length of mandible (W58, U76-77): ≥ 0.10 (0); <0.10 (1); absent (2).

83. Ratio of surangular dorsoventral depth:maximum depth of angular (W59, U75): <2.0 (0); ≥ 2.0 (1).

84. Ridge on surangular separating adductor and articular fossae (W60): absent (0); present (1).

85. Depth of medial wall of adductor fossa (W61): shallow (0); deep, with prearticular expanded dorsoventrally (1).

86. Position of rostral end of splenial relative to mandibular symphysis (U72): caudal to (0); participates in symphysis (1).

87. Position of caudal process of splenial (W62, U74): overlaps angular (0); separating rostral portions of prearticular and angular (1).

88. Caudodorsal process of splenial (W63, U73): present, approaching margin of adductor chamber (0); absent (1).

89. Size of coronoid (W64): extends to dorsal margin of jaw (0); reduced, does not extend to splenial (1); absent (2).

90. Plate of bone lying lateral to teeth on premaxilla, maxilla, and dentary (U9): absent (0); present (1).

91. Position in tooth row of largest teeth (U78): mid-length along maxilla (0); rostral end of jaws (1).

92. Number of dentary teeth (W73, U91): ≥ 18 (0); ≤ 17 (1).

93. Length of tooth rows (W66, U94-95): extends to orbit (0); rostral to orbit but caudal to subnarial foramen (1); restricted rostral to subnarial foramen (2).

94. Occlusal pattern (W67-68): absent (0); interlocking (creating V-shaped facets) (1); planar facets at markedly acute angle to long axis of tooth (high-angled) (2); planar facets at roughly 90° angle to long axis of tooth (low-angled) (3).

95. Orientation of tooth crowns (W69, U80): aligned along jaw axis (crowns do not overlap) (0); aligned slightly rostrolingually (tooth crowns overlap) (1).

'Overlap' in this context means only that, in lateral view, one tooth obscures the view of the next, but does not imply any physical contact between teeth, which is retained as a separate character (96).

96. Contact between adjacent tooth crowns (U81): present (0); absent (1).

97. Ratio of length of worn tooth crown:width of lingual face (= 'slenderness index') (U87-89): ≤ 3.0 (crowns expanded; teeth spatulate) (0); 3.01-3.99 (1); ≥ 4.0 (2).

98. Cross-sectional shape of worn tooth crowns at mid-crown (W70, U84-85, U92, C2, S1): elliptical (convex both labially and lingually) (0); D-shaped (convex labially, flat or concave lingually) (1); circular (spatulate crown wears away leaving facet on root = 'pencil-' or 'peg-like' tooth morphology) (2).

Unlike in its original inclusion by Wilson (2002), the character as used here specifies the worn tooth crowns rather than tooth crowns in general. Some sauropod teeth (particularly those spatulate ones with V-shaped wear facets) do not undergo substantial cross-sectional morphological change as a result of wear, but diplodocoids in particular have newly erupted teeth with somewhat spatulate tips (either elliptical or D-shaped in cross section) that are worn completely away during use, producing the characteristic subcircular cross-sectional morphology.

99. Enamel surface texture (W71, U79): smooth (0); wrinkled (1).

100. Marginal tooth denticles (W72, U82-83, C3): present (0); absent on distal margin only (1); absent on both mesial and distal margins (2).

101. Number of replacement teeth per alveolus (W74, U90): ≤ 2 (0); ≥ 3 (1).

102. Orientation of teeth (W75, U93): perpendicular to jaw margin (0); oriented rostrally with respect to jaw margin (procumbent) (1).

103. Longitudinal grooves on lingual face of tooth (W76): absent (0); present (1).

104. Prominent grooves near mesial and distal margins of labial surface of tooth crowns (U86): absent (0); present (1).

105. Number of cervical vertebrae (W80, U96-100, S25): ≤ 9 (0); 10 (1); 11 (2); 12 (3); 13 (4); 14 (5); ≥ 15 (6).

106. **Shape of occipital facet of atlantal intercentrum (W79, U101):** rectangular in lateral view (dorsal and ventral lengths subequal) (0); wedge-shaped (craniocaudal length of ventral margin greater than that of dorsal margin) (1).

107. **Morphology of articular facets of cervical vertebral bodies (W82, U103):** amphicoelous/amphiplatyan (0); opisthocoelous (1).

108. **Morphology of cervical lateral pneumatic fossae (W78, W83, U110, C15, S33):** absent (0); simple, undivided (1); simple and undivided in cranial cervicals but becoming complex (divided by bony septa) in caudal cervicals, producing numerous, laterally visible foramina (2); complex (with numerous, laterally visible foramina) in all (post-axial) cervicals (3).

109. **Morphology of ventral surface of cervical vertebral bodies (U106-107):** with prominent sagittal keels (0); flat or mildly convex ventrally (1); concave ventrally (longitudinal sulcus present) (2).

110. **Fossae on dorsal surface of costolateral eminences of cervical vertebrae (U109):** absent (0); present and confluent with lateral pneumatic fossa (1); present but separated from lateral pneumatic fossa by ridge (2).

111. **Lamination (especially corporodiapophyseal) of cervical vertebral arches (W81, U115-116):** well developed with well defined lamina and fossae (0); rudimentary; diapophyseal laminae only feebly developed or absent (1).

112. **Ratio of caudal articular surface height:width of cranial cervical vertebral bodies (W84, U108):** <1.25 (0); ≥ 1.25 (1).

113. **Angulation of spinous process on cranial cervical vertebrae (C18):** dorsal (vertical) or craniodorsal (0); caudodorsal (1).

114. Ratio of craniocaudal vertebral body length:dorsoventral height of caudal face of middle cervical vertebral bodies (W86, U102): <4.0 (0); ≥ 4.0 (1).

115. Ratio of dorsoventral height of middle cervical vertebral arches:dorsoventral height of caudal articular facet of vertebral body (W87, U111-112, C16): <1.0 (0); ≥ 1.0 (1).

116. Morphology of cranial corporozygapophyseal lamina on middle and caudal cervical vertebral arches (W88, U113): single (0); divided (= cranial infrazygapophyseal fossae present) (1); consists of two parallel laminae (2).

117. Morphology of articular surfaces of cranial zygapophyses on middle and caudal cervical vertebrae (U114): flat (0); transversely convex (1).

118. Cervical spinous process height (U117): low (height of vertebra subequal to or less than length of vertebral body) (0); high (height of vertebra greater than length of vertebral body) (1).

Upchurch et al. *(2004) code* Dicraeosaurus, Amargasaurus, *and* Limaysaurus *as possessing the apomorphic state*. *However*, *the character is somewhat misleading because the former two taxa possess bifid spines whereas the latter (as well as* Suuwassea*) does not*. *Whether these taxa shared a common ancestor with tall spines that only later became bifid in dicraeosaurids remains to be seen*.

119. Bifurcation of cervical vertebral spines (W85, C17, S34): absent (0); present only on caudal cervicals (1); present on middle cervicals (to C6) (2); present on cranial cervicals (cranial to C6) (3).

120. Morphology of caudal cervical and cranial thoracic spinous processes (W89-90, U118, C17): single (0); bifid but lacking pseudospinous tuberculum (1); bifid with sagittal pseudospinous tuberculum (2).

121. **Orientation of caudal margin of spinous processes on caudal cervical vertebrae with respect to craniocaudal axis of vertebral body (U119):** nearly vertical (0); slopes craniodorsally-caudoventrally (1).

122. **Number of thoracic vertebrae (W91, U122-125):** 15 (0); 14 (1); 13 (2); 12 (3); 11 (4); ≤ 10 (5).

123. **Lateral pneumatic fossae in majority of thoracic vertebral bodies (W78, U128-129, C22):** absent (0); present as deep but simple pits (1); present as deep excavations that ramify into vertebral body and into base of vertebral arch (leaving only thin septum in body midline) (2).

124. **Lateral position of lateral pneumatic foramina on thoracic vertebral bodies (U130):** absent (0); flush with lateral surface (no lateral pneumatic fossa) (1); set within lateral pneumatic fossa (2).

125. **Cranial face of thoracic vertebral arches (U136):** flat or shallowly excavated (0); deeply excavated (1).

126. **Hypantrum-hyposphene articulations on thoracic vertebrae (W106, U145, C23, S15):** absent (0); present on middle and/or caudal thoracics only (1); present on cranial-caudal thoracics (2).

127. **Single midline lamina extending ventrally from hyposphene in thoracic vertebrae (U146):** absent (0); present (1).

128. **Thoracic vertebrae with spinodiapophyseal lamina (W99, U156-157):** none (0); on caudal thoracics only (1); on middle and caudal thoracics (2).

129. **Accessory spinodiapophyseal lamina on thoracic vertebrae with non-bifid spinous processes (U151):** absent (0); present (1).

130. **Postspinal lamina on thoracic vertebrae with non-bifid spinous processes (U149, C27):** absent (0); present (1).

131. **Orientation of transverse processes on thoracic vertebrae (U138, S35):** lateral or slightly dorsal (0); strongly dorsolateral (approximately 45º to horizontal) (1).

132. **Morphology of articular face of cranial thoracic vertebral bodies (W94, U104):** amphicoelous (0); opisthocoelous (1).

133. **Morphology of caudal margins of lateral pneumatic fossae on cranial thoracic vertebrae (U127, C29):** rounded (0); acute (1).

The states in this character may be too subject to (a) individual variation, (b) typical asymmetries created by pneumatic invasion of bone, and/or (c) diagenetic distortion to be phylogenetically useful.

134. **Morphology of ventral surfaces of cranial thoracic vertebral bodies (U126):** ventrally convex (0); flat (1); with sagittal crest (creating two ventrolaterally-facing surfaces) (2); ventrally concave with sagittal crest in resultant sulcus (3).

135. **Cranial corporozygapophyseal lamina on cranial thoracic vertebrae (U134):** consists of single lamina (0); bifurcate toward upper end (= cranial infrazygapophyseal fossa present) (1).

136. **Orientation of spinous processes of cranial thoracic vertebrae (U158):** dorsal or caudodorsal (0); craniodorsal (1).

137. **Ratio of dorsoventral height of vertebral arch:dorsoventral height of thoracic vertebral body (W93, U132, C20, C24, C28, S9):** ≤ 1.0 (0); >1.0 (1).

138. **Morphology of cranial corporozygapophyseal lamina on middle and caudal thoracic vertebral arches (U135):** single (0); bifurcate toward upper end (= cranial infrazygapophyseal fossa present) (1).

139. **Cranial corporoparapophyseal lamina on middle and caudal thoracic vertebral arches (W96, U133):** absent (0); present (1).

140. **Cranial zygaparapophyseal lamina on middle and caudal thoracic vertebral arches (W97):** absent (0); present (1).

141. **Caudal corporoparapophyseal lamina on middle and caudal thoracic vertebral arches (W98, U137):** absent (0); present (1).

142. **Morphology of the distal ends of the transverse processes in thoracic vertebrae (U140):** transitions smoothly and uninterrupted onto dorsal surface of transverse process (0); possesses distinctive, elevated area with its own dorsally-facing surface that is connected to the dorsal surface of the remaining process only by a sloping region (1).

This character is visible in cranial or caudal view, but not lateral view.

143. **Lamination on cranial face of (non-bifid) spinous process of middle and caudal thoracic vertebrae (U148, C26): n**one (0); prespinal lamina present, cranial spinozygapophyseal laminae absent (1); prespinal lamina absent, cranial spinozygapophyseal laminae present (2); both prespinal and cranial spinozygapophyseal laminae present and connected to each other either directly (merging) or via accessory laminae (3); both prespinal and cranial spinozygapophyseal laminae present but unconnected to each other (4).

The following discussion pertains to both prespinal (character 143) and postspinal (character 144) laminae and associated spinozygapophyseal laminae; for the sake of

discussion, the artificial term 'median lamina' is used to denote both prespinal and postspinal laminae and 'spinozygapophyseal laminae' is used to include both cranial and caudal variants. These characters are elaborated from the states listed by Wilson (2002) and Upchurch et al. *(2004) by specifying the nature of any relationship between the median and spinozygapophyseal laminae. In sauropods that lack the a median lamina but possess spinozygapophyseal laminae, the region between the latter generally forms a moderately deep interspinous ligament fossa, as in birds. When the two laminae are connected, it usually manifests by the merging of proximally separate spinozygapophyseal laminae to form a single, median lamina, though the position of the bifurcation varies across taxa. In some cases (e.g.,* Apatosaurus *[Gilmore, 1936: pl. 25, fig. 8]), although the laminae merge distally, the median lamina maintains a separate offshoot proximally between the spinozygapophyseal laminae.* Apatosaurus *is currently unique in possessing at least one vertebra (Gilmore, 1936: pl. 25, fig. 9) with character state 4, although in that specimen the spinozygapophyseal laminae do not persist far distally. To allow the possible evolution of both states 1 and 2 from state 0, this character is unordered. It should be acknowledged that there are serious problems with characters concerning the median laminae and the spinozygapophyseal laminae. As is evident here, many sauropods possess a single midline structure that is superficially like a median lamina that bifurcates toward its proximal end into what would be considered spinozygapophyseal laminae. However, it is impossible to tell in such a configuration whether or not the median lamina is a separate and distinct entity that simply merges with the spinozygapophyseal laminae or whether it is composed entirely of conjoined spinozygapophyseal laminae. This is problematic because it is then impossible to*

ascertain whether or not a median lamina formed only by spinozygapophyseal laminae is homologous to the median lamina of some taxa that is unconnected to the zygapophyses, despite the fact that they receive identical names and codings. Although they are retained here, future analyses will require further analysis and possible restructuring of these characters to address this issue. Conceivably, the fact that different vertebrae within a given individual of some taxa display different states, as well as the frequency of osteological asymmetry that is common in pneumatic features, may render these characters phylogenetically useless.

144. Caudal zygapophyses of middle and caudal thoracic vertebrae supported dorsally by (W100, W101, U147, U150): caudal margin of alaminar spinous process only or no dorsal support (0); separate caudal spinozygapophyseal laminae unconnected to postspinal lamina via accessory laminae (1); separate caudal spinozygapophyseal laminae connected to postspinal lamina at proximal end either directly or via accessory laminae (2).

See notes for character 143.

145. Infradiapophyseal fossa on thoracic vertebral arches (W103, U144): absent (0); present (1).

146. Spinodiapophyseal and caudal spinozygapophyseal laminae on middle and caudal thoracic vertebrae contact each other (W101): absent (0); present (1).

147. Supraneural pneumatic cavity within some or all thoracic vertebral arches (U141): absent (0); present but not open externally (1); present and open externally via foramen (2).

This character was first noticed and discussed by Bonaparte (1986) and elaborated on by Bonaparte (1999: fig. 41).

148. Triangular, aliform processes projecting laterally from distal ends of middle and caudal (= non-bifurcate) thoracic spinous processes (W102, U153-154): absent (0); present but do not project far laterally (not as far as caudal zygapophyses) (1); present and project far laterally (as far as caudal zygapophyses) (2).

149. Orientation of middle and caudal thoracic spinous processes (W104): vertical (0); caudal (distal end approaches level of diapophyses) (1).

150. Morphology of articular face of caudal thoracic vertebral bodies (W105, U105, C25): amphicoelous/amphiplatyan (0); opisthocoelous (1).

151. Cross-sectional morphology of caudal thoracic vertebral bodies (U131): subcircular (0); dorsoventrally compressed (1).

152. Ventral end of caudal corporodiapophyseal lamina of caudal thoracic vertebrae (U142): unexpanded (0); expands and may bifurcate (1).

153. Position of transverse process on caudal thoracic vertebrae (U139): caudal or caudodorsal to costolateral eminence (0); dorsal to costolateral eminence (1).

154. Ratio of mediolateral width:craniocaudal length of caudal (non-bifid) thoracic spinous processes (W92, U152): ≤ 1.0 (longer than wide) (0); >1.0 (wider than long) (1).

155. Morphology of caudal thoracic spinous processes in cranial view (W107, U155): rectangular for most of its length with little or no lateral expansion (except at distal end) (0); progressively expanding mediolaterally through most or all of its length (‘petal’ or ‘paddle’ shaped) (1).

156. Number of sacral vertebrae (W108, U161-163): ≤ 3 (0); 4 (1); 5 (2); ≥ 6 (3).

157. Sacricostal yoke (W109): absent (0); present (1).

Although this is probably a viable character, the condition is figured and described so infrequently in the literature that it is impossible to confirm in most taxa, even with new specimens. It has been included here, but requires better description of the relevant state across taxa.

158. Ratio of maximum mediolateral width across sacral vertebrae and ribs:average length of sacral vertebral body (U164): <4.0 (0); ≥ 4.0 (1).

159. Lateral pneumatic fossae and/or foramina in sacral vertebral bodies (U165): absent (0); present (1).

160. Ratio of proximodistal length of sacral spinous processes:craniocaudal length of vertebral body (W111): <2.0 (0); 2.0-3.49 (1); ≥ 3.50 (2).

161. Dorsoventral length of sacral ribs (W112, U168): low (not projecting beyond dorsal margin of ilium) (0); high (extending to or beyond dorsal margin of ilium) (1).

162. Caudal vertebral bone internal construction (W113): solid (0); spongy (with large internal cells) (1).

163. Number of caudal vertebrae (W114, U170): ≤ 35 (0); 36-60 (1); ≥ 61 (2).

164. Ratio of height of spinous process:dorsoventral height of caudal articular facet of vertebral body in caudal thoracic, sacral and proximal caudal vertebrae (U166-167, C33, S19, S36): <2.0 (0); 2.0-3.0 (1); >3.0 (2).

165. Caudal vertebral transverse processes (ribs) (W115, U193): persist through caudal vertebra 20 or farther distally (0); disappear by caudal 15 (1); disappear by caudal 10 (2).

166. Morphology of articular face of first caudal vertebral body (W116, U171): flat (0); procoelous (1); opisthocoelous (2); biconvex (3).

167. Spinous process of first caudal vertebra (W117): simple and alaminar or single fossa on lateral aspect (0); complex system of laminae, resembling spines of thoracics ('dorsalized') (1).

168. Morphology of articular face of proximal caudal vertebral bodies (excluding first) (W118, U173-174, C30, S16): amphiplatyan or platycoelous (0); weakly procoelous (1); strongly procoelous (2); opisthocoelous (3).

169. Morphology of articular surfaces in proximal caudal vertebral bodies (U172): subcircular (0); dorsoventrally compressed (1); mediolaterally compressed (2).

170. Pneumatopores (lateral pneumatic fossae and/or foramina) on proximal caudal vertebral bodies (W119, U181, C31): absent (0); present (1).

171. Length of caudal vertebral bodies (W120, U178): ~same over first 20 (0); doubling over first 20 (1).

172. Ratio of proximodistal length:dorsoventral height of proximal caudal vertebral body (U177): ≥ 0.6 (0); <0.6 (1).

173. Cranial spinozygapophyseal lamina on proximal caudal vertebral arches (W121, U188): absent (0); present and extending onto lateral aspect of spinous process (1).

174. Cranial and caudal spinozygapophyseal laminae contact on proximal caudal vertebral arches (W122, U188): absent (0); present (1).

In some taxa (e.g., Dicraeosaurus*), 'contact' is loosely defined. In this taxon, the cranial spinozygapophyseal lamina is larger than its caudal counterpart and forms a prominent, laterally-projecting lateral spinal lamina. The caudal spinozygapophyseal lamina, in contrast, weakens progressively to terminate near or at the distal margin of the*

aforementioned lateral lamina. *On some vertebrae*, *the caudal spinozygapophyseal lamina instead merges with the postspinal lamina*.

175. **Prespinal lamina on proximal caudal vertebral arches (W123, U188):** absent (0); present (1).

176. **Postspinal lamina on proximal caudal vertebral arches (W124, U188):** absent (0); present (1).

177. **Postspinal fossa on proximal caudal vertebral arches (W125, U188):** absent (0); present (1).

178. **Hyposphenal ridge on proximal caudal vertebrae (U187):** absent (0); present (1).

179. **Transverse process morphology on proximal caudal vertebrae (W128, U190-192, C32, S11):** simple, flattened processes (0); triangular or aliform process (connected via laminae to vertebral arch) on caudal 1 only (1); triangular or aliform processes through caudal 3 (2); triangular or aliform processes on or beyond caudal 4 (3).

180. **Dorsoventral extent of proximal end of transverse processes on proximal caudal vertebrae (W127):** shallow (on vertebral body only) (0); deep (extending from vertebral body to vertebral arch) (1).

181. **Diapophyseal laminae (= proximal and distal corporodiapophyseal laminae and cranial and caudal zygadiapophyseal laminae) on proximal caudal transverse processes (W129):** absent (0); present (1).

182. **Morphology of proximal corporodiapophyseal lamina on proximal caudal transverse processes (W130):** single (0); divided (1).

183. **Ratio of mediolateral width:proximodistal length of proximal caudal spinous processes (W126, U189):** ≤ 1.0 (longer than wide) (0); >1.0 (wider than long) (1).

184. **Ratio of vertebral body length:height in middle caudal vertebrae (U179):** <2.0 (0); ≥ 2.0 (1).

185. **Sharp ridge on lateral surface of middle caudal vertebral bodies at arch-body junction (U186):** absent (0); present (1).

186. **Morphology of articular surfaces in middle caudal vertebral bodies (W131, U184):** subcircular (0); flat dorsal and ventral surfaces (~ quadrangular) (1).

187. **Ventral longitudinal sulcus on proximal and middle caudal vertebral bodies (W132, U182-183):** absent (0); present (1).

188. **Morphology of proximal articular face of middle and distal caudal vertebral bodies (W134, U175):** amphicoelous/amphiplatyan (0); procoelous (conical) (1); opisthocoelous (2).

189. **Position of vertebral arches over vertebral bodies on middle caudal vertebrae (U185, C35):** straddles midpoint (significant portions located on either side of midpoint) (0); located mostly or entirely over proximal half of body (1).

190. **Orientation of middle caudal spinous processes (W133):** distodorsal (0); vertical (1).

191. **Morphology of distal caudal vertebral bodies (W135):** cylindrical (0); flattened dorsoventrally (at least 2x as wide mediolaterally as tall dorsoventrally) (1).

192. **Number of anarcuate, distal caudal vertebrae (W136, W138, U176):** ≤ 10 (0); ≥ 30 (1).

193. **Morphology of articular surfaces of anarcuate ('whiplash') distal caudal vertebrae (W136, W138, U176):** absent (0); amphiplatyan (1); proximo- or distoplatyan (2); biconvex (3).

194. **Ratio of distalmost caudal vertebral body length:width (W137, U180, C36, S8):** ≤ 4.0 (0); 4.01-4.99 (1); ≥ 5.0 (2).

195. **Angle between tuberculum and capitulum costae of cervical ribs (W139, U121):** **g**reater than 90° (0); less than 90° (rib ventrolateral to vertebral body) (1).

196. **Length of cervical rib bodies (W140, U120):** much longer than vertebral body (overlapping as many as three subsequent vertebrae) (0); slightly longer, equal to, or shorter than vertebral body (little or no overlap) (1).

197. **Proximal pneumatopores on thoracic ribs (W141, U160):** absent (0); present (1).

198. **Morphology of proximal ends of cranial thoracic ribs (U159):** shallowly concave on both cranial and caudal faces (0); strongly convex cranially and deeply concave caudally (1).

199. **Cross-sectional shape of cranial thoracic ribs (W142):** subcircular (0); 'plank'-like (craniocaudal dimension >3x mediolateral dimension) (1).

200. **Haemal arch persistence (W147):** throughout at least 80% of tail (0); disappearing by caudal 30 (1).

201. **Morphology of haemal arches on middle and distal caudal vertebrae (W143-144, U197-198, S17):** simple or curve caudoventrally (forming caudal process) (0); develop small cranial process (1); cranial and caudal processes elongate so arch is proximodistally much longer than tall dorsoventrally ('skid-like') (2).

202. **Ratio of haemal canal dorsoventral height:total haemal arch length (W146, U196):** <0.30 (0); ≥ 0.30 (1).

203. 'Crus' bridging proximal margin of haemal canal (W145, U194-195, C34, S18): present in proximal through distal haemal arches (0); present in proximal arches but absent in middle and distal arches (1); absent in proximal through distal arches (2).

204. Distal ends of distal haemal arches (W148, U199, C37): fused (0); unfused (open) (1).

205. Ratio of forelimb:hindlimb length (W149, U214-215): ≤ 0.6 (0); 0.6-0.74 (1); ≥ 0.75 (2).

206. Ratio of humerus:femur proximodistal length (W172, U216, C48, S12): <0.60 (0); 0.60-0.89 (1); ≥ 0.90 (2).

207. Position of dorsalmost point of acromion process of scapula: closer to level of glenoid fossa than to level of midpoint of scapular body (0); equidistant between or closer to level of midpoint of scapular body than to level of glenoid fossa (1).

208. Size of scapular acromion (W150, U200): small and narrow (0); broad (dorsoventral width more than 150% minimum width of scapular body) (1).

209. Deltoid crest (= crest of acromion process) (U201): absent (0); present (1).

210. Morphology of portion of acromion caudal to deltoid crest (U202): flat or convex and decreases in mediolateral thickness toward caudal margin (0); forms distinct fossa (1).

211. Orientation of scapular body with respect to coracoid articulation (W151): roughly perpendicular (0); roughly 45° angle (1).

212. Morphology of scapular body (W152, U206, C38, S19): acromial (dorsal) edge not expanded (parallels long axis of body) (0); acromial edge with rounded dorsal expansion caudal to acromion but cranial to distal end (1); distal end racquet-shaped (dorsoventrally expanded) (2).

213. **Orientation of scapular glenoid fossa (W153, U203):** flat or facing laterally (0); strongly bevelled medially (1).

214. **Cross-sectional shape of proximal end of scapular body (W154):** flat or rectangular (0); D-shaped (1).

215. **Dorsal ridge on medial surface of scapular body (U204):** absent (0); present (1).

216. **Ventral ridge on medial surface of scapular body (U205):** absent (0); present (1).

217. **Ratio of craniocaudal length of coracoid:maximum length of scapula-coracoid articulation (W155):** <1.5 (articular surface longer) (0); ≥ 1.5 (craniocaudal length longer) (1).

218. **Morphology of craniodorsal margin of coracoid (W156, U208):** rounded (cranial and dorsal margins grade into one another) (0); rectangular (meet at abrupt angle) (1).

219. **Position of dorsal margin of coracoid with respect to dorsal margin of scapula (U207):** equal or dorsal to acromion (0); ventral to acromion and separated from it by V-shaped notch (1).

220. **Infraglenoid lip of coracoid (W157):** absent (0); present (1).

This unusual elaboration of the coracoid glenoid fossa is well illustrated in Saltasaurus *by Powell (1992: fig. 29).*

221. **Morphology of sternal plate (W158, U210, C39):** ovoid (0); triangular due to presence of acute craniolateral projection (1); elliptical with concave lateral margin (2).

222. **Ratio of maximum length of sternal plate:length of humerus (U209):** <0.75 (0); ≥ 0.75 (1).

223. **Ridge on ventral surface of sternal plate (U213):** absent (0); present (1).

224. Prominent caudolateral expansion of sternal plate producing reniform profile in dorsal view (U211): absent (0); present (1).

225. Prominent proximolateral process on humerus (W159, U218): present (proximal end of humerus markedly convex in cranial view) (0); absent (proximal end of humerus flat or gently sinusoidal in cranial view) (1).

Both Upchurch et al. *(2004) and Wilson (2002) diagnose this character by noting the 'abrupt' or 'square' angle of the proximodistal corner of some sauropods. However, in numerous sauropods coded as lacking this feature actually have a roughly 90° angle at the proximolateral corner of the humerus that technically falls under the heading of 'square' and could easily be construed as 'abrupt.' The real difference between the taxa coded by both authors as possessing it is that the apomorphic state lacks the prominent, pointed, laterally-projecting process at the proximolateral corner that overhangs the main body of the humerus by a substantial margin. Thus, in derived sauropods, such as* Saltasaurus *and* Opisthocoelicaudia *(Upchurch, 1998: fig. 12), the proximolateral margin, in cranial view, parallels the long axis of the element rather than lying at an angle to it. This process seems to be universally accompanied by the marked convexity of the proximal end of the humerus, and the loss of the proximolateral process is connected to the flattening of the proximal end, but these may need to be separated out as discreet characters in the future.*

226. Supracoracoideus tuberculum on proximolateral portion of humerus (U217): absent (0); present (1).

227. Development of humeral deltopectoral crest (W160, U219): prominent (0); reduced to low crest or ridge (1).

228. **Position of deltopectoral crest (U220):** restricted to lateral edge of humerus (0); expanded medially across cranial face of humerus (1).

229. **Morphology of humeral deltopectoral crest (W161):** relatively narrow throughout length (0); markedly expanded distally (1).

230. **Cross-sectional shape of humerus at mid-shaft (W162):** circular (0); elliptical with long axis oriented transversely (1).

231. **Extent of distal articular surface of humerus (W163, U222):** restricted to distal end (articular surface flat) (0); exposed on cranial and caudal portions of humeral shaft (forming convex articular surface) (1).

232. **Distocaudal surface of humerus (U221):** shallowly concave (0); deeply concave, bounded between prominent vertical ridges (1).

233. **Morphology of distal humeral articular surface (W164):** divided (0); flat (separate condyles indistinct) (1).

234. **Morphology of proximal ulna (W165, U223):** subtriangular (0); triradiate with deep radial fossa (1).

235. **Morphology of articular surface of craniomedial process of ulna in cranial view (U224):** flat (0); strongly concave on proximal surface (1).

236. **Relative length of proximal ulnar condylar processes (W166):** subequal (0); unequal (with cranial process longer) (1).

237. **Development of ulnar olecranon process (W167):** prominent (projecting beyond proximal articular surface) (0); rudimentary (level with proximal articular surface) (1).

238. **Ratio of proximodistal length:proximal breadth of ulna (W168):** gracile (0); stout (1).

239. **Ratio of maximum diameter of proximal end of radius:radius length (U225):** <0.30 (0); ≥ 0.30 (1).

240. **Morphology of distal condyle of radius (W169, U226):** round (0); subrectangular (flattened caudally and articulating on cranial side of ulna) (1).

241. **Ratio of distal:midshaft breadth of radius (W170):** <1.50 (0); 1.50-1.90 (1); >1.90 (2).

242. **Orientation of distal radial condyle with respect to long axis of shaft (W171):** perpendicular (0); bevelled approximately 20° proximolaterally (1).

243. **Number of ossified carpal bones (W173, U228-230):** ≥ 3 (0); 2 (1); 1 (2); none (3).

244. **Morphology of carpal bones (W174, U227):** round (0); blocky (with flattened proximal and distal articular surfaces) (1).

245. **Morphology of metacarpus (W175, U235):** spreading (0); bound (with subparallel shafts and articular surfaces extending half their length) (1).

246. **Morphology of proximal surface of metacarpals in articulation (W176):** gently curving to form 90° arc (0); U-shaped (subtending arc of 270°) (1).

247. **Triangular, striated areas for ligament attachment on proximal parts of metacarpal shafts (U236):** absent (0); present (1).

248. **Ratio of length of longest metacarpal:length of radius (W177, U233, C49):** <0.35 (0); 0.35-0.45 (1); >0.45 (2).

249. **Ratio of length of metacarpal I:lengths of metacarpal II or III (whichever is longest) (U232):** ≤ 1.0 (0); >1.0 (McI is longest metacarpal) (1).

250. **Ratio of length of metacarpal I:length of metacarpal IV (W178, U231):** <1.0 (0); ≥ 1.0 (1).

251. **Morphology of distal condyle of metacarpal I (W179):** divided (0); undivided (1).

252. **Ratio of length of metacarpal V:length of longest metacarpal (U234):** <0.90 (0); ≥ 0.90 (1).

253. **Orientation of mediolateral axis of metacarpal I distal condyle with respect to axis of shaft (W180):** bevelled ~20° proximodistally (0); perpendicular (1).

254. **Manual phalangeal formula (W181, U238-239, U241):** 2-3-4-3-2 or more (0); reduced to 2-2-2-2-2 or fewer (1); completely absent or unossified (2).

255. **Morphology of manual phalanx I-1 (W182):** rectangular (0); wedge-shaped (1).

256. **Ratio of proximodistal length:mediolateral width of manual nonungual phalanges (W183, U237):** >1.0 (longer than wide) (0); <1.0 (wider than long) (1).

257. **Size of ungual on manual digit I (U240):** large (at least 50% length of metacarpal I) (0); reduced (<25% length of metacarpal I) or absent (1).

258. **Cranial mediolateral dimension of pelvis (W184):** narrow (ilia longer craniocaudally than distance separating preacetabular processes) (0); wide (distance between preacetabular processes exceeds craniocaudal dimension of ilia) (1).

This is the maximum distance between the cranialmost points on the preacetabular alae of the ilia.

259. **Morphology of dorsal margin of ilium body (in lateral view) (W186, U247):** flat, sigmoid, or gently convex (0); semicircular (markedly convex) (1).

260. **Position of dorsalmost point on ilium (U245):** caudal or dorsal to base of pubic process (0); cranial to base of pubic process (1).

261. **In lateral view, the cranioventralmost point on the iliac preacetabular process (W188, U244, C40):** is also the cranialmost point (preacetabular process is pointed) (0);

is caudal to the cranialmost part of process (process is semicircular with caudoventral excursion of cartilage cap) (1).

262. **Orientation of preacetabular ala of ilium with respect to axis of body (W187, U242-243):** cranial in vertical plane (0); craniolateral in vertical plane (1); craniolateral and cranial edge curls laterally into horizontal plane (2).

263. **Size of ischiadic peduncle of ilium (W185, U248):** large and prominent (long axis of ilium roughly horizontal) (0); low and rounded (long axis of ilium oriented craniodorsally-caudoventrally) (1).

264. **Projected line (chord) connecting articular surfaces of ischiadic and pubic processes of ilium (U249):** passes ventral to ventral margin of postacetabular portion of ilium (0); passes through or dorsal to ventral edge of postacetabular portion of ilium (1).

265. **Brevis fossa on postacetabular ala of ilium (U246):** present (0); absent (1).

266. **Development of ambiens process of pubis (W189, U250, C42, S20):** absent or small, striated area confluent with cranial margin of pubis (0); prominent and projecting cranial to cranial margin of pubis ('hook-like') (1).

267. **Morphology of pubic 'apron' (W190, U252):** flat (with straight symphysis, proximal end in parasagittal plane but middle and distal ends in mediolateral plane) (0); canted craniomedially (middle and distal ends in same plane as proximal end; gently sigmoid symphysis and V-shaped in cross section at body midlength) (1).

268. **Ratio of length of puboischiadic contact:proximodistal length of pubis (W191, U253, C41):** <0.40 (0); ≥ 0.40 (1).

269. **Ratio of proximodistal length of ischium body:length of pubis body (W192, U251, C45):** <0.90 (0); ≥ 0.90 (1).

270. **Tuberosity on lateral surface of iliac process of ischium (U255):** absent (0); present (1).

271. **Projected line (chord) of long axis of ischium body in articulation with ilium (U259):** passes through lower part of acetabulum or upper part of pubic articular surface (long axis of ischium ~60º to horizontal) (0); passes through upper part of acetabular margin or approaches rim of iliac articulation (long axis of ischium ~80º to horizontal) (1).

272. **Morphology of ischium body distal to pubic process (W193, U254, C46):** emarginate (sagittal notch) (0); not emarginated (1).

273. **Morphology of distal shaft of ischium (W194, U260):** craniocaudal depth increases medially but not laterally (0); blade-like (craniocaudal depths on both medial and lateral sides subequal) (1).

274. **Ratio of mediolateral width of distal end of ischium:proximodistal length of ischium (U256):** ≤ 0.15 (0); >0.15 (1).

275. **Ratio of mediolateral width:craniocaudal thickness of distal end of ischium body (U260):** <2.0 (0); ≥ 2.0 (1).

276. **Cross-sectional morphology of articulated distal ischial bodies (W195, U258, C43, S22):** V-shaped (forming marked angle to one another) (0); flat (nearly coplanar) (1).

277. **Expansion of distal end of ischium body (U257, C44, S21):** slight (0); strong dorsoventrally (1).

278. **Morphology of cranial face of femoral body in lateral view (U266):** convex (0); straight (1).

279. **Orientation of femoral caput in cranial view (U263):** medial or ventromedial (0); dorsomedial (1).

280. **Position of fourth trochanter on femoral body (U268):** on caudal surface, near midline (0); on caudomedial margin (1).

281. **Development of fourth trochanter of femur (W196, U269):** prominent and blade-like (0);reduced to low crest or ridge (1).

282. **Position of distal tip of fourth trochanter (U267):** lies above midshaft height (0); lies at or below midshaft height (1).

283. **Morphology of lesser trochanter of femur (W197, U261-262):** well-developed ridge or plate (0); weakly developed ridge or plate (1); absent (2).

284. **Ratio of mediolateral:craniocaudal diameter of femur at midshaft (W198, U270):** <1.25 (~1.0) (0); 1.25-1.50 (1); ≥ 1.85 (2).

285. **Morphology of lateral margin of femoral shaft in cranial or caudal view (W199, U265, C47):** straight (0); proximal 1/3 deflected medially (1).

286. **Morphology of middle and distal portion of femoral body in cranial view (U264):** sigmoid (0); straight (1).

287. **Relative mediolateral breadth of distal femoral condyles (W200, U271):** subequal (0); tibial condyle much broader than fibular condyle (1).

288. **Orientation of femoral distal condyles with respect to femoral shaft (W201):** perpendicular or slightly bevelled dorsolaterally (0); bevelled dorsomedially ~10° (1).

289. **Morphology of articular surface of femoral distal condyles (W202, U272):** restricted to distal portion of femur (0); expanded onto cranial and caudal portion of femoral shaft (surfaces visible in cranial and caudal views) (1).

290. **Ratio of tibia:femur length (U273):** ≥ 0.70 (0); <0.70 (1).

291. Morphology of tibial proximal condyle (W203, U274): longer craniocaudally than mediolaterally by at least 15% (0); expanded mediolaterally (craniocaudal and mediolateral dimensions <15% each other) (1).

Wilson and Sereno (1998) correctly discuss the fact that in sauropod outgroups, the tibia is mediolaterally compressed and that in derived sauropods it is 'subcircular.' Upchurch et al. *(2004) attempted to quantify the vague term 'subcircular' by arbitrarily setting the boundary of 'subcircular' as when both craniocaudal and mediolateral dimensions are within 15% of each other. There are two problems with this character that indicate it requires revision in future analyses. First, there is little consistency in orienting the tibia such that the craniocaudal and mediolateral dimensions can be consistently measured; certainly, it seems that the longest dimension of the proximal tibia is usually (but not always) in the direction in which the cnemial crest points (see character 291), but this is not necessarily either purely craniocaudal or mediolateral. Some sauropod tibiae display torsion between the proximal and distal ends, making it difficult to pick the 'true' cranial and lateral directions. Second, highlighting the dangers of using percentages or ratios in phylogenetic characters, the tibia of* Suuwassea *is 19% wider than long, which is technically greater than the 15% specified by Upchurch* et al. *(2004). However, it is substantially different than the plesiomorphic, mediolaterally compressed tibia; in fact, it lies toward the* opposite *extreme of the potential ratio spectrum. It has been coded here as possessing the derived state because it seems to be 'in the spirit' of the original, intended reading, but future work may require further subdivision of this character into multiple states to accommodate interspecific variation more accurately. Finally, further*

work is required on the individual variation of the tibial proximal condyle within a species to better clarify the phylogenetic utility of this character.

292. Tibial cnemial crest (U275): prominent (0); reduced to low ridge (1).

293. Orientation of tibial cnemial crest (W204, U276): projects cranially (fibula entirely visible in cranial view) (0); projects craniolaterally or laterally (obscures part of fibula in cranial view) (1).

As with character 291, potential exists for slight variations in interpretation of what is truly craniocaudal and mediolateral for an in vivo sauropod tibia. Slight rotations about the tibial long axis can obscure (to varying degrees) the fibula in 'cranial' view, the defining symptom of this character (Wilson and Sereno 1998), but still have the fibula exposed laterally (the 'normal' condition). This is not to say that a valid phylogenetic character cannot be ascertained in the orientation of the cnemial crest, but that future work may need to find a less subjective and less external referent for cnemial crest orientation than one utilizing the entire leg.

294. Ratio of distal mediolateral dimension of tibia:midshaft mediolateral dimension (W205): <2.0 (0); ≥ 2.0 (1).

295. Size of distal caudoventral process of tibia (W206, U278): broad mediolaterally (covering caudal fossa of astragalus) (0); shortened mediolaterally (caudal fossa of astragalus visible caudally) (1).

296. Distal end of tibia (U277): wider mediolaterally than craniocaudally (0); roughly equal mediolateral and craniocaudal dimensions (1).

297. Development of proximal tibial scar on fibula (W207, U279): not well marked (0); well marked and widening craniocaudally toward proximal end (1).

298. **Morphology of M. flexor digitorum longus sulcus and tuberculum of fibula (W208, U281):** absent (0); present and ovoid (tuberculum angled) (1); present, fossa bounded by two vertically elongate, parallel ridges (tuberculum linear) (2).

299. **Size of distal condyle of fibula (W209):** subequal to shaft (0); expanded mediolaterally (>2x midshaft mediolateral dimension) (1).

300. **Morphology of astragalus (W210, U284):** rectangular (0); wedge-shaped (with reduced craniomedial corner) (1).

301. **Craniocaudal dimension of astragalus as seen in dorsal view (U285):** widens medially (0); narrows medially (1).

302. **Morphology of ventral surface of astragalus (U282):** flat or slightly concave mediolaterally (0); convex mediolaterally (1).

303. **Vascular foramina at base of ascending process of astragalus (W211, U286):** present (0); absent (1).

304. **Extent of ascending process of astragalus (W212, U283):** terminates cranial to caudal edge (0); extending to caudal margin (1).

305. **Morphology of caudal fossa of astragalus (W213, U287):** undivided (0); divided by vertical, caudomedially-oriented crest (1).

306. **Ratio of mediolateral width:maximum craniocaudal length of astragalus (W214):** ≤ 1.25 (dimensions subequal) (0); >1.25 (1).

307. **Ossified calcaneum (W215, U288):** present (0); absent or unossified (1).

308. **Ossified distal tarsals 3 and 4 (W216, U289):** present (0); absent (1).

309. **Posture of metatarsus (W217, U291):** bound (0); spreading (1).

310. **Angle between long axis of body of metatarsal I and plane of proximal articular surface as seen in cranial view (W218):** perpendicular (0); angled ventromedially (1).

311. **Angle between long axis of body of metatarsal I and plane of distal articular surface as seen in cranial view (W219):** perpendicular (0); angled dorsomedially (1).

312. **Caudolateral projection of distal condyle of metatarsal I (W220, U293, S23):** absent (0); present (1).

313. **Size of metatarsal I (W221, U292):** slender, reduced, or absent (0); robust (ratio of length:mediolateral width of proximal end ≤ 1.5) (1).

314. **Rugosities on distal parts of dorsolateral portions of bodies of metatarsals I-III (U294):** absent (0); present (1).

315. **Size of proximal condyles of metatarsals I and V compared to metatarsals II, III, and IV (W222, U296):** smaller than (0); subequal to (1).

316. **Ratio of length of metatarsal III:length of tibia (W223, U290, U295):** ≥ 0.40 (0); 0.26-0.39 (1); ≤ 0.25 (2).

317. **Ratio of minimum mediolateral shaft diameters of metatarsals III and IV:minimum mediolateral shaft diameters of metatarsals I or II (W224, U297):** ≥ 0.65 (0); <0.65 (1).

318. **Ratio of length of metatarsal V:length of metatarsal IV (W225, U298):** <0.70 (usually <<0.70) (0); ≥ 0.70 (1).

319. **Relationship of plantar to proximal surface of pedal phalanx I-1 (U301):** meet at ~90° angle (0); meet at acute angle (area drawn into thin plate that projects caudal to distal condyles of metatarsal I) (1).

320. **Collateral ligament foveae on non-ungual pedal phalanges (U302):** present (0); absent (1).

321. **Ratio of maximum proximodistal:mediolateral dimensions of pedal nonungual phalanges (W226, U304):** >1.0 (longer than wide) (0); ≤ 1.0 (wider than long) (1).

322. **Development of penultimate phalanges of pedal digits II-IV (W227, U305):** subequal in size to more proximal phalanges (0); rudimentary or absent (1).

323. **Morphology of pedal phalanx II-2 (U303):** square or rectangular in dorsal view (0); reduced craniocaudally, irregular in shape, and semicircular in dorsal view (1).

324. **Number of phalanges on pedal digit IV (U299-300):** ≥ 4 (0); 3 (1); ≤ 2 (2).

325. **Orientation of pedal unguals with respect to digit axis (W228, U306):** aligned (point forward) (0); deflected ventrolaterally (1).

326. **Length of pedal ungual I relative to pedal digit II ungual (W229):** subequal (0); 25% larger than (1).

327. **Ratio of length of pedal digit I ungual:length of metatarsal I (W230, U307):** <1.0 90); ≥ 1.0 (1).

328. **Ratio of mediolateral width:dorsoventral height of pedal digit I ungual (W231):** >1.0 (wider than tall) (0); ≤ 1.0 (sickle-shaped, much taller than wide) (1).

329. **Morphology of pedal unguals II-III (W232, U308):** broader mediolaterally than dorsoventrally (0); sickle-shaped (much deeper dorsoventrally than broad mediolaterally) (1).

330. **Development of pedal digit IV ungual (W233):** subequal in size to unguals of pedal digits II and III (0); rudimentary or absent (1).

331. **Osteoderms (W234):** absent (0); present (1).

DATA MATRIX

To preserve monospaced formatting, the following abbreviations are used in the data matrix for multistate characters: A = 0+1; B = 0+2; C = 1+2; D= 2+3; E = 3+4; F = 0/1; G = 1/2.

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Theropoda	0000000000	00000A0000	0000000000	000A000000	0000000000
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Barapasaurus	??????????	??????????	??????????	??????????	??????????
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Shunosaurus	0011000000	0010001002	0000000001	??01101010	1100110002
Patagosaurus	11???G0000	0110?01???	??????????	??????????	??????????
Mamenchisaurus	1101?G???-	??11101002	0000??0101	000110?110	?1?01????2
Apatosaurus	3010221101	1012011112	?111100101	1101211210	1111110111
Barosaurus	??????????	??????????	??????????	??????????	??????????
Brachiosaurus	1101121010	011111101?	1000110101	1001201110	1111110002
Camarasaurus	1101121010	0110111012	1000110101	1001211110	1110110002
Dicraeosaurus	3010?21101	?????????2	??101?0011	101??11210	11????????
Diplodocus	3010221101	1012011112	1111100101	1101211210	1111110111
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Amargasaurus	??????????	??????????	??001?0-11	1012210211	11????????
Euhelopus	1101010000	0111?01?12	?0??1?0?01	???1??1?1?	????110002
Jobaria	11010?1010	0110111012	1000100101	1001101110	11?01100?2
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Nigersaurus	30?0???00	??12011?0?	??001?1-00	1????-?-?-	--??1????2
Limaysaurus	??????????	???2????0?	??000?1-01	100??-1---	--?0????12
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Alamosaurus	??????????	??????????	??????????	??????????	??????????
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Losillasaurus	??????????	??????????	??????????	??????????	??????????
Suuwassea	3?10??????	??????????	??????000?	101???1210	?1????????1

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Shunosaurus	0011?01100	0110001000	01?0000?10	000?1?00?1	0011111110
Patagosaurus	?1????????	??????????	????????10	0????????1	???11?0112
Mamenchisaurus	011?10?100	?101101070	?10?0???10	0101100111	?111110111
Apatosaurus	0011110210	????101020	0100010??	?????????1	1?230?2212
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Camarasaurus	0111101100	1110001010	0100000010	0211111111	1111110112
Dicraeosaurus	?0????1??0	?101010121	0001010?11	0????0???1	?123??2212
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Losillasaurus	??????????	?????????0	???1??????	??????????	??????????
Suuwassea	0?????????	??11101070	0110?1????	??????????	????????12

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Shunosaurus	?001401000	1100100000	120?01?00?	10?000100?	0000100000
Patagosaurus	?001??1001	0?00100000	1?11110200	1100001011	0021102000
Mamenchisaurus	010160100?	0101110011	130?1201?0	01?0??1?11	001110?101
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Brachiosaurus	0001401322	0001110000	1321120101	0112001111	1031100201
Camarasaurus	1013013120	0001000311	3211202000	1100011110	0211012011
Dicraeosaurus	?1003?110C	00A01A0132	1300120211	110B001010	001C1A0000
Diplodocus	1100611322	00011C1032	1521121201	0100101111	10EC101000
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Euhelopus	01016?101?	1101110012	111????1?1	?1???11111	1???10?111
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Limaysaurus	??1???13??	0010100100	1312?00201	1100?01???	?012?0?000
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Saltasaurus	??????111?	0000120000	1?1210?101	1111001111?	111110?111
Isisaurus	??????11??	1000100000	1?1?1?0201	011?001111	100110?011
Losillasaurus	??????1101	00???10?00	??1???0??1	1100?01???	0??110?200
Suuwassea	1?00?1121C	0010?10121	??221?????	?1???01???	?0?????????

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Omeisaurus	000021 0?0	1?10100A00	0100000111	000000?000	0??0100??0
Shunosaurus	0000010001	1011100000	0100000111	000000?000	00000?0001
Patagosaurus	000102??01	???0???000	?1?????101	??0000?000	0???1?0?0?
Mamenchisaurus	0000021?A1	1?10110220	0100000111	000000?000	000?10000?
Apatosaurus	0001021112	1021110100	0111110121	1111000000	0132110001
Barosaurus	0??102????	?021110101	1?11110131	11110?1001	0??2110?0?
Brachiosaurus	1000021111	1010100010	0100110111	0000000010	0???10111?
Camarasaurus	0000021111	1010100000	0100110111	0000000000	0000100 1?1
Dicraeosaurus	0001121102	10?2111A00	011A110131	0011000000	00D111010?
Diplodocus	0001021112	1021110101	1111110131	1111001001	0132110001
Haplocanthosaurus	0010021111	10?0100000	0100110111	0000100000	????1?010?
Amargasaurus	01?112???2	????2?0???0	??????????	???????0??	????????0?
Euhelopus	010003?1??	1??0??????	??????????	??????????	????101?1?
Jobaria	?0?1021???	1010100?0	0?00110??1	0000?00000	000?100?01
Malawisaurus	01??131???	???01??200	0000111011	0000101010	0??010 10??
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Limaysaurus	???11?????	?012100000	0100110001	0011?00000	??C2110???
Rebbachisaurus	0?111?????	??????????	??????????	??????????	??????????
Alamosaurus	???113????	?000231200	0000110011	0001111110	1?????0?01
Nemegtosaurus	??????????	??????????	??????????	??????????	??????????
Opisthocoelicaudia	111-03110?	1?00221300	0100110111	0010111010	0030???11
Rapetosaurus	1?11131?10	01101??200	0000111???	0001?10110	0???101?01
Saltasaurus	111103110?	11?0???210	?000111111	0011?11110	1?001????
Isisaurus	0?11?3110?	???0???200	0000110001	0000101110	0???1???1?
Losillasaurus	0?1?1???0?	???0???1?0	?000000031	0?0???????	??????????
Suuwassea	??????????	?0?????100	?0????????1	??? 100000?0?11?1000?	

OTU	21 0	22 0	23 0	24 0	25 0
Prosauropoda	00000000??	0000000000	0000000001	00001-0000	0000000001
Theropoda	00000001??	0000000000	0000000001	A0001-0000	0000000100
Vulcanodon	?00?2??0??	??????????	??????1001	00?1111001	00????10??
Barapasaurus	2?00??01??	0000??00?0	????0?1?01	0?11?110?1	00????????
Omeisaurus	200121010?	000?000010	0000001001	0011001001	C021001100
Shunosaurus	2021110000	0000000010	0000001001	0011001001	1001001000
Patagosaurus	?00???011?	0?0???0010	????001001	0?11011001	00????????
Mamenchisaurus	2001211???	0?????00??	0???0?1?01	0?11?110?1	101101?1?0
Apatosaurus	2011110111	0011000110	1?00001001	0011001001	1021111100
Barosaurus	2?11??1?11	????00?01?	?????0?0??	?0????????	??????????
Brachiosaurus	?020220111	0101100110	2000001001	0011011001	2011111201
Camarasaurus	1020210111	0101000110	0000001001	0011011001	C011111101
Dicraeosaurus	201111?11?	?001000?0	????001001	0011011001	10????????
Diplodocus	2011111111	0001000010	1000001001	0011011001	?0????????
Haplocanthosaurus	?02????111	00010?00?0	2?00??????	??????????	??????????
Amargasaurus	????11??1?	?0?1??????	????001001	0?1100100?	?0????????
Euhelopus	??????0110	0010??00?0	????1?1001	011???????	??????????
Jobaria	1??0210117	0101??0000	????0?1?01	0?11?11001	?00111?1?0
Malawisaurus	0120??????	??????00?0	2??11?1?01	0?11100001	10??1???11
Nigersaurus	??????11??	020??00???	??????????	??????????	??????????
Limaysaurus	?02?111111	020???0110	2??1101?00	0?11011001	?0?????00?
Rebbachisaurus	??????11??	0201??????	??????1??0	??????????	??????????
Alamosaurus	0121??0110	1211?11100	21?1101111	1101010011	213-111211
Nemegtosaurus	??????????	??????????	??????????	??????????	??????????
Opisthocoelicaudia	0120210110	0011111101	2111111111	1101010111	213-111211
Rapetosaurus	?12021?111	1010??1000	20?11?1?01	1?01000001	20??11?200
Saltasaurus	0120??0111	1010??1101	2??1111111	1?01110111	11????????
Isisaurus	0120??01??	1010??10??	????111101	111101011?	??????????
Losillasaurus	??????????	??????????	00000??001	00????????	2?????1???
Suuwassea	??F???0111	0001100010	????011001	001???????	??????????

OTU	26 0	27 0	28 0	29 0	30 0
Prosauropoda	000000000?	0000000000	000000000A	0000000000	0000000000
Theropoda	0000000000	0000000000	0000000000	0000000000	0000000000
Vulcanodon	?1???????0	??1??00010	0010100101	011101???1	0100??0000
Barapasaurus	???????01?	0110?01010	0010?00011?	112101100?	0?10111?1?
Omeisaurus	0101110010	0010101010	0010100110	1121010001	0110101??0
Shunosaurus	0111010010	0010101010	00?0100110	1121010001	?1101???00
Patagosaurus	????????10	0110101010	0010100110	1121010001	01001?????
Mamenchisaurus	0?01???10	001010??10	0010100110	112101100?	11?01???10
Apatosaurus	0101110110	0111111010	0000101111	1121011001	1110111101
Barosaurus	?????????0	???1111010	0010101111	?1???1???1	11???1????
Brachiosaurus	1111011111	1111101110	1010110111	1121111001	1110111111
Camarasaurus	0101110110	0111101110	0010110111	1121011001	1110111101
Dicraeosaurus	???????110	0011111010	0000101111	1121011001	1110111101
Diplodocus	???????110	0111111010	0000101111	1121011001	1110111101
Haplocanthosaurus	???????110	0111101010	0010110111	1121011001	??????????
Amargasaurus	????????11	1111??????	???????111	11?101?001	?1????????
Euhelopus	???????110	121??01110	001?110???	1??11?100?	111011?101
Jobaria	0101110110	0111?01???	0010?1?11?	11?1011001	1?101?1101
Malawisaurus	1?1???????	?????????1	0111110???	???11?????	1??11?1?0?
Nigersaurus	??????????	??????????	???????00?	??????????	??????????
Limaysaurus	?1???????1?	?01??01010	0010110111	1?2101?001	?11????1?1
Rebbachisaurus	??????????	??????????	?01??1????	??????????	??????????
Alamosaurus	1112--1?11	1211?????0	0111110?01	111?1?1?1?	??11??0?1?
Nemegtosaurus	??????????	??????????	??????????	??????????	??????????
Opisthocoelicaudia	1112--1111	?211101001	0111110111	1122111111	1111101201
Rapetosaurus	110????111	1111?0100?	0111?10111	1?10111010	110????10?
Saltasaurus	???????111	1211101100	0111110111	1122111111	?11110?20?
Isisaurus	???????111	1211101100	0111111???	??????????	??????????
Losillasaurus	?????????0	00???010??	?1????????	??????????	??????????
Suuwassea	??????????	??????????	??????????	??????????	111???110?

OTU	3 1 0	3 2 0	3 3 0	
Prosauropoda	0000000000	0000000000	0000000000	0
Theropoda	0000000000	--00000000	0000000000	0
Vulcanodon	101000010?	1000110100	000?100100	0
Barapasaurus	??1?1????0	10????????	????1??11?	0
Omeisaurus	0010101111	1110121101	1101111111	0
Shunosaurus	0010?00111	1?10120101	1101?11111	0
Patagosaurus	?????????0	10??1?????	??????????	0
Mamenchisaurus	00111??11?	1010?2?101	11?11??1??	0
Apatosaurus	1111101111	1111121111	A112111111	0
Barosaurus	111???????	??11????1?	??????????	0
Brachiosaurus	1111100111	101012?101	110?1?111?	0
Camarasaurus	1111100111	1010121101	1102111111	0
Dicraeosaurus	111111??11	111?1?11?1	??????11??	0
Diplodocus	11111?0111	1111121111	11121?1111	0
Haplocanthosaurus	??????????	??????????	??????????	0
Amargasaurus	??????????	??????????	??????????	0
Euhelopus	1111??0?11	1010121??1	1???11111?	0
Jobaria	??111?0111	10??1111??	??????????	0
Malawisaurus	??????????	??????????	1????1?11?	1
Nigersaurus	??????????	??????????	??????????	?
Limaysaurus	11??????0?	?10001?121	1?????????	?
Rebbachisaurus	??????????	??????????	??????????	0
Alamosaurus	??????????	??????????	??????????	0
Nemegtosaurus	101201????	??????????	??????????	?
Opisthocoelicaudia	1111111111	1010121101	1102101111	0
Rapetosaurus	????????10	0?1?1210??	??????????	1
Saltasaurus	??????????	??1???????	??????????	1
Isisaurus	??????????	??????????	??????????	?
Losillasaurus	??????????	??????????	??????????	?
Suuwassea	??????0?11	11111?1?11	1???10111?	0