**SUPPLEMENTARY MATERIAL**

The evolution of the tetrapod humerus: morphometrics, disparity, and evolutionary rates

Marcello Ruta, Jonathan Krieger, Kenneth D. Angielczyk and Matthew A. Wills

**Contents**

**1. Time-calibrated supertree.** The phylogeny with temporally scaled branches is reproduced as an object of class “phylo”. The file can be opened and manipulated in various phylogenetic R packages. Taxon name abbreviations are reported in Supplementary Table 1.

**2. Literature sources.** The published sources that were consulted for images of humeri are listed in the order in which taxa appear in the time-calibrated supertree. An asterisk next to a taxon name indicates that direct observations of either original specimens or casts were carried out.

**3. Supplementary figure captions.** The captions that refer to Supplementary Figures 1–7 are reported below.

**4. Supplementary table captions.** The captions that refer to Supplementary Tables 1–3 are reported below.

**1. Time-calibrated supertree**

#NEXUS

BEGIN TAXA;

 DIMENSIONS NTAX = 135;

 TAXLABELS

 saur

 bara

 rhiz

 stre

 gogo

 ster

 eust

 cabo

 mand

 pand

 tikt

 cats

 acan

 icht

 tule

 hortone

 ossi

 pede

 what

 cras

 horttwo

 dora

 gree

 eucr

 baph

 edop

 coch

 glau

 eryo

 scle

 chel

 glan

 arcg

 aust

 bala

 dend

 neld

 trim

 acro

 dvin

 acat

 ache

 mrxd

 broi

 diss

 scap

 caco

 perr

 ters

 mpho

 plat

 dole

 eoca

 celt

 kara

 sine

 chun

 irid

 beyi

 vald

 tria

 czat

 pros

 vier

 mmel

 tung

 mele

 apko

 apca

 apdr

 silv

 eohe

 call

 prot

 arch

 chro

 geph

 disc

 seym

 west

 utah

 bracone

 bractwo

 scin

 dipl

 sapl

 ptyo

 uroc

 micr

 hylo

 asap

 tudi

 saxo

 ricn

 pant

 rhyn

 pelo

 trih

 elfr

 leio

 eury

 card

 casi

 sole

 limn

 orob

 diad

 dias

 ophi

 oeda

 casa

 case

 coty

 ange

 aero

 vara

 wato

 edap

 hapt

 sphe

 dime

 mros

 brba

 embr

 anth

 proc

 thur

 prus

 capt

 labi

 pale

 ptts

 spin

 petr

 arae

 ;

END;

BEGIN TREES;

 TRANSLATE

 1 saur,

 2 bara,

 3 rhiz,

 4 stre,

 5 gogo,

 6 ster,

 7 eust,

 8 cabo,

 9 mand,

 10 pand,

 11 tikt,

 12 cats,

 13 acan,

 14 icht,

 15 tule,

 16 hortone,

 17 ossi,

 18 pede,

 19 what,

 20 cras,

 21 horttwo,

 22 dora,

 23 gree,

 24 eucr,

 25 baph,

 26 edop,

 27 coch,

 28 glau,

 29 eryo,

 30 scle,

 31 chel,

 32 glan,

 33 arcg,

 34 aust,

 35 bala,

 36 dend,

 37 neld,

 38 trim,

 39 acro,

 40 dvin,

 41 acat,

 42 ache,

 43 mrxd,

 44 broi,

 45 diss,

 46 scap,

 47 caco,

 48 perr,

 49 ters,

 50 mpho,

 51 plat,

 52 dole,

 53 eoca,

 54 celt,

 55 kara,

 56 sine,

 57 chun,

 58 irid,

 59 beyi,

 60 vald,

 61 tria,

 62 czat,

 63 pros,

 64 vier,

 65 mmel,

 66 tung,

 67 mele,

 68 apko,

 69 apca,

 70 apdr,

 71 silv,

 72 eohe,

 73 call,

 74 prot,

 75 arch,

 76 chro,

 77 geph,

 78 disc,

 79 seym,

 80 west,

 81 utah,

 82 bracone,

 83 bractwo,

 84 scin,

 85 dipl,

 86 sapl,

 87 ptyo,

 88 uroc,

 89 micr,

 90 hylo,

 91 asap,

 92 tudi,

 93 saxo,

 94 ricn,

 95 pant,

 96 rhyn,

 97 pelo,

 98 trih,

 99 elfr,

 100 leio,

 101 eury,

 102 card,

 103 casi,

 104 sole,

 105 limn,

 106 orob,

 107 diad,

 108 dias,

 109 ophi,

 110 oeda,

 111 casa,

 112 case,

 113 coty,

 114 ange,

 115 aero,

 116 vara,

 117 wato,

 118 edap,

 119 hapt,

 120 sphe,

 121 dime,

 122 mros,

 123 brba,

 124 embr,

 125 anth,

 126 proc,

 127 thur,

 128 prus,

 129 capt,

 130 labi,

 131 pale,

 132 ptts,

 133 spin,

 134 petr,

 135 arae

 ;

 TREE \* UNTITLED = [&R] ((1:24.1,(2:20.1,(3:14.225,4:17.775):14.225):20.1):24.1,((5:1.65,6:24.55):18.15,((7:5.5,(8:7.9,9:7.9):7.9):5.5,(10:5.5,(11:4.4,(12:20.36666667,(13:6.933333333,(14:3.466666667,((15:4.322222222,(16:6.161111111,(17:20.77407407,(18:2.387037037,19:14.83703704):2.387037037):2.387037037):6.161111111):4.322222222,(20:33.48333333,((21:4.161111111,(22:12.58055556,23:15.58055556):12.58055556):4.161111111,((24:2.5,25:21.5):18.2047619,(((26:21.18,27:13.5):17.5,(((28:10,29:17.8):10,(30:13.25,(31:15.33333333,(32:5.416666667,(33:2.708333333,34:33.10833333):2.708333333):5.416666667):5.416666667):13.25):13,((35:1,36:17.8):1,((37:4.55,(38:6.475,(39:3.2375,40:35.2375):3.2375):6.475):28.71666667,(41:28.73333333,(((42:35.83333333,43:4.833333333):4.833333333,((44:6.255555556,45:28.15555556):6.255555556,(46:10.45555556,47:25.85555556):10.45555556):6.255555556):4.833333333,(((48:11.75,(49:9.625,50:35.525):9.625):19,(51:3.625,(52:17.3125,(53:92.984375,((54:42.6,(55:45.68,(56:59.16,((57:8.1,58:3.9):24.94,(59:10.52,60:41.42):10.52):10.52):10.52):10.52):63.65625,(61:10.528125,(62:5.7640625,(63:33.08203125,64:45.48203125):33.08203125):5.7640625):10.528125):10.528125):10.528125):17.3125):3.625):3.625,(65:19.92916667,(66:60.78333333,(67:12.8375,(68:9.891666667,(69:2.945833333,70:4.345833333):2.945833333):2.945833333):2.945833333):2.945833333):2.945833333):3.625):4.833333333):4.833333333):4.833333333):1):1):14.08730159,((71:2.5,(72:4.25,(73:12.63333333,(74:2.416666667,75:37.91666667):2.416666667):2.416666667):4.25):12.96984127,((76:65.53333333,(77:10.66666667,(78:12.43333333,79:10.08333333):10.08333333):10.66666667):18.51904762,((80:2.5,(81:8.15,(((82:21.55,83:21.55):22.35,((84:4.6,85:35.6):5.2,(86:9.6,(87:9.4,88:0.2):0.2):0.2):0.2):8.5625,((89:5.1,90:5.1):10.675,(91:2.7875,(92:12.35625,((93:16.45,94:4.6):7.125,((95:15.65,96:27.45):17.54375,((97:34.3,98:5.9):7.1625,(99:0.63125,(100:0.315625,(101:20.2578125,102:20.2578125):20.2578125):0.315625):0.63125):0.63125):0.63125):0.63125):0.63125):2.7875):2.7875):2.7875):8.15):7.734920635,(103:2.617460317,(104:31.1292517,((105:8.45,(106:22.43333333,(107:5.616666667,108:2.816666667):2.816666667):2.816666667):25.89104308,((109:31.38333333,((110:4.65,((111:9.783333333,112:8.033333333):8.033333333,(113:9.558333333,114:10.85833333):9.558333333):8.033333333):13.71666667,((115:3.25,(116:10.3,117:20.45):10.3):10.05,(118:18.08333333,(119:2.266666667,(120:7.908333333,121:18.20833333):7.908333333):2.266666667):2.266666667):2.266666667):2.266666667):16.21950113,((122:52.76,((123:25.73,(124:10.44,125:19.39):10.44):10.44,126:46.22):10.44):20.90462585,((127:16.75,(128:10.35,(129:5.175,130:11.825):5.175):10.35):23.72641723,(131:3.488208617,(132:1.744104308,(133:13.52940287,(134:5.114701436,135:28.51470144):5.114701436):5.114701436):1.744104308):3.488208617):3.488208617):3.488208617):3.488208617):3.488208617):3.488208617):2.617460317):2.617460317):2.617460317):2.617460317):2.617460317):2.617460317):4.161111111):4.161111111):4.322222222):3.466666667):6.933333333):6.933333333):4.4):5.5):5.5):5.5):1;

END;

**2. Literature sources**

*\*Sauripterus taylori –* Davis, M. C., Shubin, N. & Daeschler, E. B. 2004. A new specimen of *Sauripterus taylori* (Sarcopterygii, Osteichthyes) from the Famennian Catskill Formation of North America. *Journal of Vertebrate Paleontology* **24,** 26–40.

*Barameda decipiens –* Garvey, J. M., Johanson, Z. & Warren, A. 2005. Redescription of the pectoral fin and vertebral column of the rhizodontid fish *Barameda decipiens* from the Lower Carboniferous of Australia. *Journal of Vertebrate Paleontology* **25,** 8–18.

*Rhizodus hibberti* – Jeffery, J. E. 2001. Pectoral fins of rhizodontids and the evolution of pectoral appendages in the tetrapod stem-group. *Biological Journal of the Linnean Society* **74,** 217–36.

*Strepsodus sauroides –* Jeffery, J. E. 2001. Pectoral fins of rhizodontids and the evolution of pectoral appendages in the tetrapod stem-group. *Biological Journal of the Linnean Society* **74,** 217–36.

*Gogonasus andrewsae –* Holland, T. & Long, J. A. 2009. On the phylogenetic position of *Gogonasus andrewsae* Long 1985, within the Tetrapodomorpha. *Acta Zoologica* **90,** 285–96.

*Sterropterygion brandei –* Rackoff, J. S. 1980. The origin of the tetrapod limb and the ancestry of tetrapods. *In* Panchen, A. L. (ed.) *The Terrestrial Environment and the Origin of Land Vertebrates*, 255–92. New York: Academic Press. 633 pp.

*\*Eusthenopteron foordi –* Sanchez, S., Tafforeau, P. & Ahlberg, P. E. 2014. The humerus of *Eusthenopteron*: a puzzling organization presaging the establishment of tetrapod limb bone marrow. *Proceedings of the Royal Society of London B: Biological Sciences* **281 (e20140299),** 1–10.

*Cabonnichthys burnsi –* Ahlberg, P. E. & Johanson, Z. 1997. Second tristichopterid (Sarcopterygii, Osteolepiformes) from the Upper Devonian of Canowindra, New South Wales, Australia, and the phylogeny of the Tristichopteridae. *Journal of Vertebrate Paleontology* **17,** 653–73.

*Mandageria fairfaxi –* Johanson, Z. & Ahlberg, P. E. 1997. A new tristichopterid (Osteolepiformes: Sarcopterygii) from the Mandagery Sandstone (Late Devonian, Famennian) near Canowindra, NSW, Australia. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **88,** 39–68.

*Panderichthys rhombolepis –* Boisvert, C. A. 2009. The humerus of *Panderichthys* in three dimensions and its significance in the context of the fish-tetrapod transition. *Acta Zoologica* **90,** 297–305.

*\*Tiktaalik roseae* – Shubin, N. H., Daeschler, E. B. & Jenkins, F. A. Jr. 2006. The pectoral fin of *Tiktaalik roseae* and the origin of the tetrapod limb. *Nature* **440,** 764–71.

\*Catskill humerus *–* Shubin, N. H., Daeschler, E. B. & Coates, M. I. 2004. The early evolution of the tetrapod humerus. *Science* **304,** 90–3.

*\*Acanthostega gunnari –* Callier, V., Clack, J. A. & Ahlberg, P. E. 2009. Contrasting ontogenetic trajectories in the earliest known tetrapod forelimbs. *Science* **324,** 364–7.

*\*Ichthyostega stensioei –* Callier, V., Clack, J. A. & Ahlberg, P. E. 2009. Contrasting ontogenetic trajectories in the earliest known tetrapod forelimbs. *Science* **324,** 364–7.

*\*Tulerpeton curtum –* Lebedev, O. A. & Coates, M. I. 1995. The postcranial skeleton of the Devonian tetrapod *Tulerpeton curtum* Lebedev. *Zoological Journal of the Linnean Society*. **114,** 307–48.

Horton Bluff humerus 1 – Anderson, J. S., Smithson, T., Mansky, C. F., Meyer, T. & Clack, J. A. 2015. A diverse tetrapod fauna at the base of ‘Romer’s Gap’. *PLoS ONE* **10 (e0125446),** 1–27. [illustrated in figure 5A–F of that paper]

*Ossinodus pueri* – Bishop, P. J. 2014. The humerus of *Ossinodus pueri*, a stem tetrapod from the Carboniferous of Gondwana, and the early evolution of the tetrapod forelimb. *Alcheringa* **38,** 209–38.

*\*Pederpes finneyae* – Clack, J. A. & Finney, S. M. 2005. *Pederpes finneyae*, an articulated tetrapod from the Tournaisian of Western Scotland. *Journal of Systematic Palaeontology* **2,** 311–46.

# *\*Whatcheeria deltae –* Lombard, R. E. & Bolt, J. R. 1995. A new primitive tetrapod, *Whatcheeria deltae*, from the Lower Carboniferous of Iowa. *Palaeontology* **38,** 471–94.

*\*Crassigyrinus scoticus* – Panchen, A. L. 1965. On the amphibian *Crassigyrinus scoticus* Watson from the Carboniferous of Scotland. *Philosophical Transactions of the Royal Society of London B* **309,** 505–68.

Horton Bluff humerus 2 – Anderson, J. S., Smithson, T., Mansky, C. F., Meyer, T. & Clack, J. A. 2015. A diverse tetrapod fauna at the base of ‘Romer’s Gap’. *PLoS ONE* **10 (e0125446),** 1–27. [illustrated in figure 6C–D of that paper]

# *\*Doragnathus woodi* – Smithson, T. R. & Clack, J. A. 2013. Tetrapod appendicular skeletal elements from the Early Carboniferous of Scotland. *Comptes Rendus Palevol* **12,** 405–17.

*\*Greererpeton burkemorani –* Godfrey, S. J. 1989. The postcranial skeletal anatomy of the Carboniferous tetrapod *Greererpeton burkemorani* Romer, 1969 *Philosophical Transactions of the Royal Society of London B* **323,** 75–133.

*\*Eucritta melanolimnetes –* Clack, J. A. 2001. *Eucritta melanolimnetes* from the Early Carboniferous of Scotland, a stem tetrapod showing a mosaic of characteristics. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **92,** 75–95.

*\*Baphetes* cf*.* *kirkbyi* – Milner, A. C. & Lindsay, W. A. 1998. Postcranial remains of *Baphetes* and their bearing on the relationships of the Baphetidae (= Loxommatidae). *Zoological Journal of the Linnean Society* **122,** 211–35.

*\*Edops craigi* – Romer, A. S. & Witter, R. V. 1942. *Edops*, a primitive rhachitomous amphibian from the Texas Red Beds. *The Journal of Geology* **50,** 925–60.

# *\*Cochleosaurus bohemicus* – Sequeira, S. E. K. 2009. The postcranium of*Cochleosaurus bohemicus* Frič, a primitive Upper Carboniferous temnospondyl from the Czech Republic. *Special Papers in Palaeontology* **81,** 137–54.

*Glaukerpeton avinoffi* – Werneburg, R. & Berman, D. S. 2012. Revision of the aquatic eryopid temnospondyl *Glaukerpeton avinoffi* Romer, 1952, from the Upper Pennsylvanian of North America. *Annals of Carnegie Museum* **81,** 33–60.

*\*Eryops megacephalus* – Pawley, K. & Warren, A. 2006. The appendicular skeleton of Eryops megacephalus (Temnospondyli: Eryopoidea) from the Lower Permian of North America. Journal of Paleontology **80,** 561–80.

*\*Sclerocephalus haeuseri* – Schoch, R. R. & Witzmann, F. 2009. Osteology and relationships of the temnospondyl genus *Sclerocephalus*. *Zoological Journal of the Linnean Society* **157,** 135–68.

*\*Cheliderpeton vranyi –* Werneburg, R. & Steyer, J. S. 2002. Revision of *Cheliderpeton vranyi* Fritsch, 1877 (Amphibia, Temnospondyli) from the Lower Permian of Bohemia (Czech Republic). *Paläontologische Zeitschrift* **76,** 149–62.

*\*Glanochthon latirostre –* Schoch, R. R. & Witzmann, F. 2009. The temnospondyl *Glanochthon* from the Permian Meisenheim Formation of Germany. *Special Papers in Palaeontology* **81,** 121–36.

*\*Archegosaurus decheni –* Witzmann, F. & Schoch, R. R. 2006. The postcranium of Archegosaurus decheni, and a phylogenetic analysis of temnospondyl postcrania. *Palaeontology* **49,** 1211–35.

*Australerpeton cosgriffi –* Dias, E. V. & Schultz, C. L. 2003. The first Paleozoic temnospondyl postcranial skeleton from South America. *Revista Brasileira de Paleontologia* **6,** 29–42.

*\*Balanerpeton woodi –* Milner, A. R. & Sequeira, S. E. K. 1994. The temnospondyl amphibians from the Viséan of East Kirkton, West Lothian, Scotland. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **84,** 331–61.

*\*Dendrerpeton acadianum –* Holmes, R. B., Carroll, R. L. & Reisz, R. R. 1998. The first articulated skeleton of *Dendrerpeton acadianum* (Temnospondyli, Dendrerpetontidae) from the lower Pennsylvanian locality of Joggins, Nova Scotia, and a review of its relationships. *Journal of Vertebrate Paleontology* **18,** 64–79.

*\*Neldasaurus wrightae –* Chase, J. N. 1965. Neldasaurus wrightae, a new rhachitomous labyrinthodont from the Texas Lower Permian. *Bulletin of the Museum of Comparative Zoology* **133,** 153–225.

*\*Trimerorhachis insignis –* Pawley, K. 2007. The postcranial skeleton of *Trimerorhachis insignis* Cope, 1878 (Temnospondyli: Trimerorhachidae): a plesiomorphic temnospondyl from the Lower Permian of North America. *Journal of Paleontology* **81,** 873–94.

*\*Acroplous vorax –* Coldiron, R. W. 1978. *Acroplous vorax* Hotton (Amphibia: Saurerpetontidae) restudied in light of new material. *American Museum Novitates* **2662,** 1–27.

*Dvinosaurus egregius –* Nikitin, V.B. 1995. Morphology of the postcranial skeleton of *Dvinosaurus* (Amphibia, Temnospondyli). 1. The structural diversity of the anterior limbs. *Paleontological Journal* **29,** 96–106.

*Acanthostomatops vorax –* Witzmann, F. & Schoch, R. R. 2005. Skeletal development of the temnospondyl *Acanthostomatops vorax* from the Lower Permian Döhlen Basin of Saxony. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **96,** 365–85.

# *Acheloma dunni –* Polley, B. P. & Reisz, R. R. 2011. A new Lower Permian trematopid (Temnospondyli: Dissorophoidea) from Richards Spur, Oklahoma. *Zoological Journal of the Linnean Society* **161,** 789 -815.

*Mordex laticeps –* Milner, A. R. & Sequeira, S. E. K. 2003. Revision of the amphibian genus *Limnerpeton* (Temnospondyli) from the Upper Carboniferous of the Czech Republic. *Acta Palaeontologica Polonica* **48,** 123–41.

*\*Broliliellus brevis –* Carroll, R. L. 1964. Early evolution of the dissorophid amphibians. *Bulletin of the Museum of Comparative Zoology, Harvard University* **131,** 161–250.

*\*Dissorophus multicinctus –* DeMar, R. 1968. The Permian labyrinthodont amphibian *Dissorophus multicinctus*, and adaptations and phylogeny of the family Dissorophidae. *Journal of Paleontology* **42,** 1210–42.

*\*Scapanops neglecta –* Schoch, R. R. & Sues, H.-D. 2013. A new dissorophid temnospondyl from the Lower Permian of north-central Texas. *Comptes Rendus Palevol* **12,** 437–45.

*\*Cacops aspidephorus –* Williston, S. W. 1910. *Cacops*, *Desmospondylus*; new genera of Permian vertebrates. *Geological Society of America Bulletin* **21,** 249–84.

# *\*Perryella olsoni –* Ruta, M. & Bolt, J. R. 2006. A reassessment of the temnospondyl amphibian *Perryella olsoni* from the Lower Permian of Oklahoma. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **97,** 113–65*.*

*\*Tersomius mosesi –* Daly, E. 1994. The Amphibamidae (Amphibia: Temnospondyli), with a description of a new genus from the Upper Pennsylvanian of Kansas. *University of Kansas Museum of Natural History, Miscellaneous Publications* **85,** 1–59.

*\*Micropholis stowi –* Schoch, R. R. & Rubidge, B. S. 2005. The amphibamid *Micropholis* from the *Lystrosaurus* Assemblage Zone of South Africa. *Journal of Vertebrate Paleontology* **25,** 502–22.

*\*Platyrhinops lyelli –* Clack. J. A. & Milner, A. R. 2009. Morphology and systematics of the Pennsylvanian amphibian *Platyrhinops lyelli* (Amphibia: Temnospondyli). *Transactions of the Royal Society of Edinburgh, Earth Sciences* **100,** 275–95.

*\*Doleserpeton annectens –* Sigurdsen, T. & Bolt, J. R. 2010. The Lower Permian amphibamid *Doleserpeton* (Temnospondyli: Dissorophoidea), the interrelationships of amphibamids, and the origin of modern amphibians. *Journal of Vertebrate Paleontology* **30,** 1360–77.

*Eocaecilia micropodia –* Jenkins Jr., F. A., Walsh, D. M. & Carroll, R. L. 2007. Anatomy of *Eocaecilia micropodia*, a limbed caecilian of the Early Jurassic. *Bulletin of the Museum of Comparative Zoology* **158,** 285–365.

*Celtedens ibericus –* McGowan, G. J. 2002. Albanerpetontid amphibians from the Lower Cretaceous of Spain and Italy: a description and reconsideration of their systematics. *Zoological Journal of the Linnean Society* **135,** 1–32.

*\*Karaurus sharovi –* Ivachnenko, M. F. 1978. Urodelans from the Triassic and Jurassic of Soviet Central Asia. *Paleontological Journal* **12,** 362–8.

*Sinerpeton fengshanensis –* Gao, K.-Q. & Shubin, N. H. 2001. Late Jurassic salamanders from northern China. *Nature* **410,** 574–7.

*Chunerpeton tianyiensis –* Gao, K.-Q. & Shubin, N. H. 2003. Earliest known crown-group salamanders. *Nature* **422,** 424–8.

*Iridotriton hechti –* Evans, S. E., Lally, C., Chure, D. J., Elder, A. & Maisano, J. A. 2005. A Late Jurassic salamander (Amphibia: Caudata) from the Morrison Formation of North America. *Zoological Journal of the Linnean Society* **143,** 599–616.

*Beiyanerpeton jianpingensis –* Gao, K.-Q. & Shubin, N. H. 2012. Late Jurassic salamandroid from western Liaoning, China. *Proceedings of the National Academy of Sciences of the United States of America* **109,** 5767–72.

*Valdotriton gracilis –* Evans, S. E. & Milner, A. R. 1996. A metamorphosed salamander from the Early Cretaceous of Las Hoyas, Spain. *Philosophical Transactions of the Royal Society of London B* **351,** 627–46.

# *\*Triadobatrachus massinoti –* Ascarrunz, E., Rage, J.-C., Legreneur, P. & Laurin, M. 2016. *Triadobatrachus massinoti*, the earliest known lissamphibian (Vertebrata: Tetrapoda) re-examined bum CT scan, and the evolution of trunk length in batrachians. *Contributions to Zoology* **85,** 201–34.

*Czatkobatrachus polonicus –* Evans, S. E. & Borsuk-Białinicka, M. 2009. The Early Triassic stem-frog *Czatkobatrachus* from Poland. *Palaeontologica Polonica* **65,** 79–105.

*Prosalirus bitis –* Jenkins Jr., F. A. & Shubin, N. H. 1998. *Prosalirus bitis* and the anuran caudopelvic mechanism. *Journal of Vertebrate Paleontology* **18,** 495–510.

*Vieraella herbsti –* Estes, R. & Reig, O. A. 1973. The early fossil record of frogs: a review of the evidence. *In* Vial, J. L. (ed.) *Evolutionary Biology of the Anurans: Contemporary Research on Major Problems*, 11–63. Columbia: University of Missouri Press. 470 pp.

*\*Micromelerpeton credneri –* Boy, J. A. 1995. Über die Micromelerpetontidae (Amphibia: Temnospondyli). 1. Morphologie und Paläoökologie des *Micromelerpeton credneri* (Unter-Perm; SW-Deutschland). *Paläontologische Zeitschrift* **69,** 429–57.

*Tungussogyrinus bergi –* Werneburg, R. 2009. The Permotriassic branchiosaurid *Tungussogyrinus* Efremov, 1939 (Temnospondyli, Dissorophoidea) from Siberia restudied. *Fossil Record* **12,** 105–20.

*Melanerpeton eisfeldi –* Werneburg, R. 1988. Die Stegocephalen der Goldlauterer Schichten (Unterrotliegendes, Unterperm) des Thüringer Waldes, Teil II: *Apateon kontheri* n. sp., *Melanerpeton eisfeldi* n. sp. und andere. *Freiberger Forschungsheft, Hefte C* **427,** 7–29.

*Apateon kontheri* *–* Werneburg, R. 1988. Die Stegocephalen der Goldlauterer Schichten (Unterrotliegendes, Unterperm) des Thüringer Waldes, Teil II: *Apateon kontheri* n. sp., *Melanerpeton eisfeldi* n. sp. und andere. *Freiberger Forschungsheft, Hefte C* **427,** 7–29.

*Apateon caducus –* Fröbisch, N. B. & Schoch, R. R. 2009. The largest specimen of Apateon and the life history pathway of neoteny in the Paleozoic temnospondyl family Branchiosauridae. *Fossil Record* **12,** 83–90.

*Apateon dracyiensis –* Werneburg, R. 2012 Dissorophoide Amphibien aus dem Asturian (Ober-Karbon) von Nyrany in Bohmen (Tschechische Republik) - der Schlussel zum Verstandnis der fruhen "Branchiosaurier". *Veröffentlichungen des Naturhistorischen Museums Schleusingen* **27,** 3–50.

*\*Silvanerpeton miripedes –* Ruta, M. and Clack, J. A. 2006. A review of *Silvanerpeton miripedes*, a stem amniote from the Lower Carboniferous of East Kirkton, West Lothian, Scotland. *Transactions of the Royal Society of Edinburgh,* *Earth Sciences* **97,** 31–63.

*\*Eoherpeton watsoni –* Smithson, T. R. 1985. The morphology and relationships of the Carboniferous amphibian Eoherpeton watsoni Panchen. *Zoological Journal of the Linnean Society* **85,** 317–410.

*Calligenethlon watsoni –* Carroll, R. L. 1967. Labyrinthodonts from the Joggins Formation. *Journal of Paleontology* **41,** 111–42.

*\*Proterogyrinus scheelei –* Holmes, R. 1984. The Carboniferous amphibian *Proterogyrinus scheelei* Romer, and the early evolution of tetrapods. *Philosophical Transactions of the Royal Society of London B* **306,** 431–524.

# *\*Archeria crassidisca –* Romer, A. S. 1957. The appendicular skeleton of the Permian embolomerous amphibian *Archeria*. *Contributions from the Museum of Paleontology, University of Michigan* **13,** 103–59.

# *\*Chroniosaurus dongusensis –* Clack, J. A. & Klembara, J. 2009. An articulated specimen of *Chroniosaurus dongusensis* and the morphology and relationships of the chroniosuchids. *Special Papers in Paleontology* **81,** 15–42.

*\*Gephyrostegus bohemicus –* Carroll, R. L. 1970. The ancestry of reptiles. *Philosophical Transactions of the Royal Society of London B* **257,** 267–308.

*\*Discosauriscus austriacus –* Klembara, J. & Bartik, I.1999. The postcranial skeleton of *Discosauriscus* Kuhn, a seymouriamorph tetrapod from the Lower Permian of the Boskovice Furrow (Czech Republic). *Transactions of the Royal Society of Edinburgh, Earth Sciences* **90,** 287–316.

*\*Seymouria baylorensis –* White, T. E. 1939. Osteology of *Seymouria baylorensis* Broili. *Bulletin of the Museum of Comparative Zoology* 85, 325-409.

*\*Westlothiana lizziae –* Smithson, T. R., Carroll, R. L., Panchen, A. L. & Andrews, S. M. 1994. *Westlothiana lizziae* from the from the Viséan of East Kirkton, West Lothian, Scotland, and the amniote stem. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **84,** 383–412.

*Utaherpeton franklini –* Carroll, R. L. Bybee, P. & Tidwell, W. D. 1991. The oldest microsaur (Amphibia). *Journal of Paleontology* **65,** 314–32.

*Brachydectes elongatus* humerus 1 *–* Wellstead, C. F. 1991. Taxonomic revision of the Lysorophia, Permo-Carboniferous lepospondyl amphibians. *Bulletin of the American Museum of Natural History* **209,** 1–90. [illustrated in figure 21A of that paper]

*Brachydectes elongatus* humerus 2 *–* Wellstead, C. F. 1991. Taxonomic revision of the Lysorophia, Permo-Carboniferous lepospondyl amphibians. *Bulletin of the American Museum of Natural History* **209,** 1–90. [illustrated in figure 21E of that paper]

# *\*Scincosaurus crassus –* Milner, A. C. & Ruta, M. 2009. A revision of *Scincosaurus* (Tetrapoda, Nectridea) from the Moscovian of Nýřany, Czech Republic, and the phylogeny and interrelationships of nectrideans. *Special Papers in Palaeontology* **81,** 71–89.

# *Diplocaulus magnicornis –* Williston, S. W. 1909. The skull and extremities of *Diplocaulus*. *Transactions of the Kansas Academy of Sciences* **22,** 122–32.

# *\*Sauropleura scalaris –* Carroll, R. L., Bossy, K. A., Milner, A. C., Andrews, S. M. & Wellstead, C. F. 1998. *Handbook of Paleoherpetology, Part 1: Lepospondyli*. München: Verlag Dr. Friedrich Pfeil. 216 pp.

# *\*Ptyonius marshii –* Carroll, R. L., Bossy, K. A., Milner, A. C., Andrews, S. M. & Wellstead, C. F. 1998. *Handbook of Paleoherpetology, Part 1: Lepospondyli*. München: Verlag Dr. Friedrich Pfeil. 216 pp.

# *\*Urocordylus wandesfordii –* Carroll, R. L., Bossy, K. A., Milner, A. C., Andrews, S. M. & Wellstead, C. F. 1998. *Handbook of Paleoherpetology, Part 1: Lepospondyli*. München: Verlag Dr. Friedrich Pfeil. 216 pp.

# *\*Microbrachis pelikani* – Carroll, R. L. & Gaskill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *\*Hyloplesion longicostatum* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Asaphestera intermedia* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Tuditanus punctulatus* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *\*Saxonerpeton geinitzi* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Ricnodon copei* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *\*Pantylus cordatus* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *\*Rhynchonkos stovalli* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Pelodosotis elongatum* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Trihecaton howardinus* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Elfridia bulbidens* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Leiocephalikon problematicum* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Euryodus* cf*. primus* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

# *Cardiocephalus peabodyi* – Carroll, R. L. & Gakill, P. 1978. The Order Microsauria. *Memoirs of the American Philosophical Society* **126,** 1–211.

*\*Casineria kiddi* – Paton, R. L., Smithson, T. R. & Clack, J. A. 1999. An amniote-like skeleton from the Early Carboniferous of Scotland. *Nature* **398,** 508–13.

*\*Solenodonsaurus janenschi* – Laurin, M. & Reisz, R. R. 1999. A new study of *Solenodonsaurus janenschi*, and a reconsideration of amniote origins and stegocephalian evolution. *Canadian Journal of Earth Sciences* **36,** 1239–55.

*Limnoscelis paludis* – Kennedy, N. K. 2010. Redescription of the postcranial skeleton of *Limnoscelis paludis* Williston (Diadectomorpha: Limnoscelidae) from the Upper Pennsylvanian of El Cobre Canyon, northern New Mexico. *Bulletin of the New Mexico Museum of Natural History and Science* **49,** 211–20.

*Orobates pabsti –* Berman, D. S., Henrici, A. C., Kissel, R., Sumida, S. S. & Martens, T. S. 2004. A new diadectid (Diadectomorpha), *Orobates pabsti*, from the Early Permian of Central Germany. *Bulletin of the Carnegie Museum of Natural History* **35,** 1–37.

*Diadectes* sp. – Case, E. C. 1911. A revision of the Cotylosauria of North America. *Carnegie Institution of Washington Publication* **145,** 1–122.

*Diasparactus zenos* – Case, E. C., Williston, S. W. & Mehl, M. G. 1913. Permo-Carboniferous vertebrates from New Mexico. *Carnegie Institution of Washington Publication* **181,** 1–81.

*\*Ophiacodon retroversus* – Brinkman, D. 1988. Size-independent criteria for estimating relative age in *Ophiacodon* and *Dimetrodon* (Reptilia, Pelycosauria) from the Admiral and lower Belle Plains formations of west-central Texas. *Journal of Vertebrate Paleontology* **8,** 172–80.

*Oedaleops campi –* Sumida, S. S., Pelletier, V. & Berman, D. S. 2004. New information on the basal pelycosaurian-grade synapsid *Oedaleops*. *In* Kammerer, C. F., Angielczyk, K. D. & Fröbisch, J. (eds) *Early Evolutionary History of the Synapsida*, 7–23. New York: Academic Press. 337 pp.

*\*Casea broili –* Olson, E. C. 1968. The family Caseidae. *Fieldiana, Geology* **17,** 225–349.

*\*Caseoides sanangelensis –* Olson, E. C. & Beerbower, J. R. 1953. The San Angelo Formation, Permian of Texas, and its vertebrates. *The Journal of Geology* **61,** 389–423.

*\*Cotylorhynchus hancocki –* Olson, E. C. 1968. The family Caseidae. *Fieldiana, Geology* **17,** 225–349.

*\*Angelosaurus dolani –* Olson, E. C. & Beerbower, J. R. 1953. The San Angelo Formation, Permian of Texas, and its vertebrates. *The Journal of Geology* **61,** 389–423.

# *Aerosaurus wellesi –* Pelletier, V. 2014. Postcranial description and reconstruction of the varanodontine varanopid *Aerosaurus wellesi* (Synapsida: Eupelycosauria). *In* Kammerer, C. F., Angielczyk, K. D. & Fröbisch, J. (eds) *Early Evolutionary History of the Synapsida*, 53–68. New York: Academic Press. 337 pp.

*Varanops brevirostris –* Campione, N. E. & Reisz, R. R. 2010. *Varanops brevirostris* (Eupelycosauria: Varanopidae) from the Lower Permian of Texas, with discussion of varanopid morphology and interrelationships. *Journal of Vertebrate Paleontology* **30,** 724–46.

*Watongia meieri –* Reisz, R. R. & Laurin, M. 2004. A reevaluation of the enigmatic Permian synapsid *Watongia* and of its stratigraphic significance. *Canadian Journal of Earth Sciences* **41,** 377–86.

*\*Edaphosaurus* sp. *–* Case, E. C., 1913, A description of Edaphosaurus Cope. Carnegie Institution of Washington Publication **181,** 71–81.

*Haptodus garnettensis –* Laurin, M. 1993. Anatomy and relationships of *Haptodus garnettensis*, a Pennsylvanian synapsid from Kansas. *Journal of Vertebrate Paleontology* **13,** 200–29.

*Sphenacodon ferocior –* Lucas, S. G., Harris, S. K., Spielmann, J. A., Berman, D. S., Henrici, A. C., Heckert, A. B., Zeigler, K. E. & Rinehart, L. F. 2005. Early Permian vertebrate biostratigraphy at Arroyo Del Agua, Rio Arriba County, New Mexico. *New Mexico Museum of Natural History and Science Bulletin* **31,** 163–9.

*\*Dimetrodon* sp*.* – Brinkman, D. 1988. Size-independent criteria for estimating relative age in *Ophiacodon* and *Dimetrodon* (Reptilia, Pelycosauria) from the Admiral and lower Belle Plains formations of west-central Texas. *Journal of Vertebrate Paleontology* **8,** 172–80.

*Millerosaurus ornatus* –Watson, D. M. S. 1957. On *Millerosaurus* and the early history of the sauropsid reptiles. *Philosophical Transactions of the Royal Society of London B* **240,** 325–400.

*Bradysaurus baini –* Boonstra, L. D. 1932. Pareiasaurian studies. Part VIII. The osteology and mycology of the locomotor apparatus B. Fore Limb. *Annals of the South African Museum* **28,** 436–503.

*Embrithosaurus alexanderi –* Boonstra, L. D. 1932. Pareiasaurian studies. Part VIII. The osteology and mycology of the locomotor apparatus B. Fore Limb. *Annals of the South African Museum* **28,** 436–503.

*Anthodon serrarius –* Boonstra, L. D. 1932. Pareiasaurian studies. Part VIII. The osteology and mycology of the locomotor apparatus B. Fore Limb. *Annals of the South African Museum* **28,** 436–503.

*\*Procolophon trigoniceps –* deBraga, M. 2003. The postcranial skeleton, phylogenetic position, and probable lifestyle of the Early Triassic reptile *Procolophon trigoniceps*. *Canadian Journal of Earth Sciences* **40,** 527–56.

*Thuringothyris mahlendorffae –* Müller, J., Berman, D. S., Henrici, A. C., Martens, T. & Sumida, S. S. 2006. The basal reptile *Thuringothyris mahlendorffae* (Amniota: Eureptilia) from the Lower Permian of Germany. *Journal of Paleontology* **80,** 726–39.

*Protocaptorhinus pricei –* Clark, J. & Carroll, R. L. 1973. Romeriid reptiles from the Lower Permian. *Bulletin of the Museum of Comparative Zoology* **144,** 353–407.

*\*Captorhinus aguti –* Fox, R. C. & Bowman, M. C. 1966. Osteology and relationships of *Captorhinus aguti* (Cope) (Reptilia: Captorhinomorpha). *The University of Kansas Paleontological Contributions* **11,** 1–79.

*\*Labidosaurus hamatus –* Sumida, S. S. 1989. The appendicular skeleton of the Early Permian genus *Labidosaurus* (Reptilia, Captorhinomorpha, Captorhinidae) and the hind limb musculature of captorhinid reptiles. *Journal of Vertebrate Paleontology* **9,** 295–313.

*\*Paleothyris acadiana –* Carroll, R. L. 1969. A Middle Pennsylvanian captorhinomorph, and the interrelationships of primitive reptiles. *Journal of Paleontology* **43,** 151–70.

*\*Protorothyris archeri –* Clark, J. & Carroll, R. L. 1973. Romeriid reptiles from the Lower Permian. *Bulletin of the Museum of Comparative Zoology* **144,** 353–407.

*Spinoaequalis schultzei –* deBraga, M. & Reisz, R. R. 1995. A new diapsid reptile from the uppermost Carboniferous (Stephanian) of Kansas. *Palaeontology* **38,** 199–212.

*Petrolacosaurus kansensis –* Reisz, R. R. 1981. A diapsid reptile from the Pennsylvanian of Kansas. *University of Kansas Museum of Natural History, Special Publication* **7,** 1–74.

*Araeoscelis gracilis –* Williston, S. W. 2010. New Permian reptiles: rhachitomous vertebrae. *The Journal of Geology* **18,** 585–600.

**3. Supplementary figure captions**

**Supplementary Figure 1** Supertree used in this paper with branches scaled in proportion to their durations in millions of years; for taxon name abbreviations, see Supplementary Table 1. Colour codes for the branches are as follows: fish, blue; stem tetrapods, green; stem amphibians, magenta; crown amphibians, red; stem amniotes, grey-blue; crown amniotes, brown; lepospondyls, black.

**Supplementary Figure 2** Plots of Ripley’s *K* function for the distribution of humeri in the three-dimensional space delimited by the first three eigenaxes; in each plot, the solid black line represents Ripley’s *K* for the observed data; the grey area is the 95% confidence envelope obtained via 1000 simulations of complete spatial random distributions for a number of data points equal to that of the observed data; the dashed red line is the median distribution obtained from those random simulations. Abbreviations at the top of the plots are as follows: (A) EALL, total sample; (B) EFISH, fin-bearing tetrapodomorphs (fish); (C) ESTTET, limb-bearing tetrapodomorphs (stem tetrapods); (D) ESTAMP, stem-group amphibians; (E) ECAMP, crown-group amphibians; (F) ESAMN, stem-group amniotes; (G) ECAMN, crown-group amniotes; (H) ELEPOS, lepospondyls.

**Supplementary Figure 3** Distribution of evolutionary rate shifts for the scores on the first eigenaxis, plotted as coloured branches on the supertree (see also Supplementary Table 3).

**Supplementary Figure 4** Distribution of evolutionary rate shifts for the scores on the second eigenaxis, plotted as coloured branches on the supertree (see Supplementary Table 3).

**Supplementary Figure 5** Distribution of evolutionary rate shifts for the scores on the third eigenaxis, plotted as coloured branches on the supertree (see Supplementary Table 3).

**Supplementary Figure 6** Distribution of evolutionary rate shifts for the scores on the first three eigenaxes, plotted as coloured branches on the supertree (see Supplementary Table 3).

**Supplementary Figure 7** Distribution of evolutionary rate shifts for the scores on the first ten eigenaxes, plotted as coloured branches on the supertree (see Supplementary Table 3).

**Supplementary Figure 8** Labelled plot of the distribution of humeri in the two-dimensional space delimited by eigenaxes ES1-2 (x-y).

**Supplementary Figure 9** Labelled plot of the distribution of humeri in the two-dimensional space delimited by eigenaxes ES1-3 (x-z).

**Supplementary Figure 10** Labelled plot of the distribution of humeri in the two-dimensional space delimited by eigenaxes ES2-3 (y-z).

**4. Supplementary table captions**

**Supplementary Table 1** The left part of the table shows the sample of taxa used in this study arranged in the order in which they appear in the time-calibrated supertree, the acronyms for the taxon names, first stratigraphic appearance data in millions of years, and the ln-transformed humerus lengths originally expressed in mm. The right part of the table shows the results of the Coordinate Point Eigenshape analysis, with the first 40 eigenaxes accompanied by the value of the variance they explain (eigenvalue), also expressed as a percentage of the total variance. The cumulative variance column reports, in percentage, the amount of variance of all eigenaxes that precede any given eigenaxis, and including the latter.

**Supplementary Table 2** The table shows the results of two statistical tests of group separation in morphospace based on the first 40 eigenaxes, specifically an analysis of similarity and a permutational multivariate analysis of variance. For each pair-wise comparison, the test statistic values are reported above the diagonal, and the associated p-values are shown below (uncorrected to the left of the forward slash, Bonferroni-corrected to the right).

**Supplementary Table 3** The left part of the table shows the results of evolutionary model fitting for various sets of eigenscores, as well as two analyses of evolutionary rates and shifts. The middle part of the table shows the results of pair-wise comparisons between group-specific posterior evolutionary rates. The right part of the table shows the results of the Phylogenetic Generalized Least Square correlations between humeral size and shape, ith shape represented by scores on each of the first three eigenaxes.