**1. List of the institutions visited in this study:**

American Museum of Natural History, New York, USA;

Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, San Miguel de Tucumán, Argentina;

Field Museum of Natural History, Chicago, USA;

Florida Museum of Natural History and Science, Gainesville, Florida, USA;

Museo Argentino de Ciencias Naturales “Bernadino Rivadavia”, Buenos Aires, Argentina;

Museo de La Plata, La Plata, Argentina;

Museo Egidio Feruglio, Trelew, Argentina;

Museo Geológico Nacional Jose Royo y Gomez, Servicio Geológico Colombiano (formerly

INGEOMINAS, Instituto Colombiano de Geología y Minería), Bogotá, Colombia;

Museu de Ciências da Terra, Rio de Janeiro, Brazil;

Museu Nacional, Rio de Janeiro, Brazil;

Muséum National d'Histoire Naturelle, Paris, France;

Museum of Paleontology, University of California, Berkeley, California, USA;

Natural History Museum of Los Angeles County, California, USA;

Natural History Museum, London, England;

Smithsonian Institution, Washington D.C., USA.

**2. List of characters coded in this phylogenetic analysis**

CH01 – Dental Enamel having horizontal Hunter-Schreger Bands (HSB) (0); or bands are vertical and thick (1); or bands are vertical, thin and branched (2);

CH02 – Three lower incisors (0); or two lower incisors or lower incisors are absent (1);

CH03 – Upper incisors are present (0); or absent (1);

CH04 - First lower incisors are equal in size or smaller than second lower incisors (0), or first lower incisors are well developed, the largest lower incisors (1);

CH05 - Three upper incisors (0); or two (1); or one (2); or upper incisors are absent (3);

CH06 - Procumbent posterior lower incisors are absent (0); or present (1);

CH07 - Incisor arcade is transverse (0); or U-shaped (1); or sharply angled at the level of first incisors (V-shaped) or parallel-sided (2);

CH08 – Well-developed lower canines, sabertooth-like, but with closed roots and determined growth (0); or lower canines are not well-developed, not protruded from cheek teeth (1); or lower canines are absent (2); or lower canines are not well-developed, but protrude from cheek teeth (3); or welldeveloped lower canines, tusk-like, ever-growing teeth, tending to close roots in the elderly (4);

CH09 – Lower canines with parallel and vertical crowns, perpendicular to mandibular axis (0); or lower canines oblique-labially implanted, non-parallel crowns, in a 45° angle to mandibular axis (1);

or lower canines oblique-labially implanted, non-parallel crowns, forming an angle of about 0° in relation to mandibular axis (2); or lower canines forwarded implanted following mandible axis and with parallel crowns (3);

CH10 – Cross-section of lower canines is oval (0); or circular (1); or asymmetrical – lingual facet is relatively flat, and labial facet is concave (2);

CH11 – Upper canines with determined growth (0); or ever-growing upper canines (1);

CH12 – Large upper canines (0); or reduced (1); or upper canines absent (2);

CH13 – Four lower premolars (0); or three (1); or two (2); or one (3); or five (4);

CH14 – Paraconid absent on p3 (0); or present (1);

CH15 – Plesioconulid absent or indistinguishable from the paracristid on p3 and p4 (0); or present and separated from the paracristid (1);

CH16 – Metaconid absent on p3 (0); or present and less-developed than protoconid (1); or present and equal in size with protoconid (2);

CH17 – Protocristid absent on p3 (0); or present and low, with metaconid and protoconid evident (1);

or present and high, forming a protolophid (2);

CH18 – Cristida obliqua absent on p3 (0); or present and long, lingually connected to the valid wall, at the base of metaconid (1); or present and short, connected to valid wall at the base of protoconid (2);

CH19 – Paraconid absent on p4 (0); or present (1);

CH20 – Metaconid absent on p4 (0); or present, but less-developed than protoconid (1); or present, and equal in size with protoconid (2);

CH21 – Metaconid aligned to protoconid on p4 (0); or metaconid more distal than protoconid on p4 (1);

CH22 – Metaconid of p4 great in size and isolated from the protoconid (0); or small to medium-sized and compressed against the protoconid (perhaps fused to it) (1);

CH23 – Protocristid absent on p4 (0); or present, but low, metaconid and protoconid evident (1); or present, but high, forming a protolophid (2);

CH24 – Cristida obliqua absent on p4 (0); or present and long, lingually connected to the valid wall, at the base of metaconid (1); or present and short, connected to the valid wall, at the base of protoconid, internally, leaving a marked ectoflexid (2); or present and short, connected at the base of protoconid, externally, leaving no ectoflexid (3);

CH25 – p4 and m1/m2 with similar size (0); or p4 smaller than half size of m1/m2 (1);

CH26 – Four upper premolars (0); or three (1); or two (2); or one (3); or five (4);

CH27 – P2 with a main cusp, possibly the paracone, and a distal cingular cusp, in a very lower level, but mesio-distally aligned to it (0); or distal cusp absent (1);

CH28 – Protocone absent on P2 (0); or protocone present, mesio-lingually positioned (1); or protocone present, disto-lingually positioned (2);

CH29 – Continuous and incipient cingulum on P2 (0); or lingual cingulum continuous and labially

absent (1); or distal-lingual cingulum only and labial cingulum is incipient, but continuous (2);

CH30 – Protocone on P3 is absent (0); or present, but smaller than the paracone (1); or present, equal in size to paracone (2);

CH31 – Preprotocrista on P3 is absent (0); or present, but low (1); or present and high (2);

CH32 – Postprotocrista on P3 is absent (0); or present, but low (1); or present and high (2);

CH33 – Preparaconular crista on P3 is absent (0); or present, but low (1); or present and high (2);

CH34 – Postparaconular crista on P3 is absent (0); or present (1);

CH35 – Metacone on P3 is absent (0); or metacone present, and very close or fused to paracone (1); or paracone and metacone distant and separated (2);

CH36 – Centrocrista (premetacrista + postparacrista) on P3 is absent (0); or present (1)

CH37 – Metastyle on P3 is present, but restricted to an accessory cingular cusp (0); or absent (1);

CH38 – Protocone on P4 is present, but smaller than paracone (0); or present, equal in size to paracone (1);

CH39 – Preprotocrista on P4 is absent (0); or present, and low (1); or present and high (2);

CH40 – Postprotocrista on P4 is absent (0); or present, and low (1); or present and high (2);

CH41 – Preparaconular crista on P4 is absent (0); or present, and low (1);

CH42 – Postparaconular crista on P4 is absent (0); or present and low (1); or present and high (2);

CH43 – Metacone on P4 is absent (0); or metacone present, and very close to or fused to paracone (1); or paracone and metacone distant and separated (2);

CH44 – Centrocrista on P4 (premetacrista + postparacrista) is absent (0); or present and low (1); or present and high, forming part of the ectoloph (2);

CH45 – Parastyle present on P4, as an accessory cingular cusp (0); or absent (1); or present, high and columnar, associated to a fold between paracone and parastyle (2);

CH46 – Ectoflexus present on P4 (0); or absent (1);

CH47 – Metastyle present on P4, as an accessory cingular cusp (0); or absent (1);

CH48 – Diastema posterior to first upper premolar is absent (0); or present (1);

CH49 – Number of roots in first lower premolar is one (0); or two (1);

CH50 – Ultimate lower premolar anterolingual cingulid is present (0); or absent (1);

CH51 – Paraconid on m1 and m2 is present(0); or absent (1);

CH52 – Paracristid on m1 and m2 is present and low(0); or absent (1); or present and high (paralophid), closing mesially the trigonid (2);

CH53 – Trigonid is equal in size or greater than talonid (0); or reduced (1);

CH54 – Metaconid adjacent to protoconid on m1 and m2 (0); or metaconid more distal than the protoconid on m1 and m2 (1);

CH55 – Protocristida present and low, making metaconid and protoconid well-evident on m1 or m2 (0); or protocristida absent (1); or present and high, forming a protolophid (2);

CH56 – Long cristid oblique, connected to the base of metaconid on m1 and m2 (0); or cristid absent (1); or short cristid, connected mesially to valid wall at the base of protoconid, associated to a marked ectoflexid (2); or short cristid connected labially to valid wall at the base of protoconid, but not forming a ectoflexid (3);

CH57 – Entoconid and hipoconulid closer, individualized and the latter is more disto-lingually positioned on m1 and m2 (0); or relatively separated and the hipoconulid is more disto-medial (1); or relatively separated; the hipoconulid is more disto-labial and it closer or fused to hipoconid (2); or relatively separated and entoconid incorporated to entocristid (3);

CH58 – Entoconid disto-lingually in the talonid of m1 and m2 (0); or medio-lingually (1); or mediomesially (2); or labio-mesially, closer to postcristid (3);

CH59 – Big and conical hipoconid, reaching talonid´s basin (0); or relatively small and totally incorporated to hipocristid (1);

CH60 – Mesoconid on m1 and m2 is absent (0); or present and isolated (1); or present and nonisolated (2);

CH61 – Entoconid associated to hipoconulid by a postcristid (not isolated) on m3 (0); or isolated (1); or entoconid isolated from postcristid, and incorporated to entocristid (2);

CH62 – Preprotocrista on M1 and M2 is present and low, connecting the base of paraconule (0); or absent (1); or present and high (2);

CH63 – Postprotocrista on M1 and M2 is present but low, connecting at the base of metaconule (when it is present) (0); or absent (1); or present and high (2);

CH64 – Paraconule on M1 and M2 is present, conical and comparatively smaller than the main cusps (0); or present on M1 and M2 – conical and comparatively of the same size of main cusps (1); or absent or incorporated to paraloph (2);

CH65 – Preparaconular crista on M1 and M2 is present but low (0); or absent (1);

CH66 – Secondary Crista of ectoloph on M1 and M2 is absent (0); or present and short, not closing the medial fossete (1); or present and long, closing medial fossete (2);

CH67 – Centrocrista (premetacrista + postparacrista) on M1 and M2 is absent (0); or present and low (1); or present and high, forming part of ectoloph (2);

CH68 – Parastyle on M1 and M2 is present, as an accessory cingular cusp (0); or absent (1); or present, inflated, high and columnar, associated to a fold between paracone and parastyle (2); or present, not-inflated, high and columnar, associated to a fold between paracone and parastyle (3);

CH69 – Hipocone isolated from all crista on M1 and M2 (0); or connected to metaconule by a crista (1);

CH70 – Hipocone on M3 is absent(0); or present (1);

CH71 – Hipocone on M3 aligned to protocone (0); or hipocone positioned lingually in relation to (1);

CH72 – Postmetaconular crista on upper molars is absent (0); or present and direcioned to metacone (1);

CH73 – Size (area) of M1 vs M3 is subequal (80%<>120%) (0); or much larger (>120%)(1); or much smaller (80%<)(2);

CH74 – Upper molar is much wider than long (length less than 75% of the width) (0); or wider than long (length more than 75% but less than 99%of the width) (1); or as long as wide (2);

CH75 – M1 parastylar lobe is anterolabial to paracone (0); or anterior to paracone (1) (if parastylar lobe is absent, scored as non-applicable);

CH76 – Metacone linguallly positioned to paracone (0); or approximately at the same level (1); or labial (2);

CH77 – Postmetacrista is absent or weak (0); salient (expanded posterolabially) (1); or prominent from side of metacone to metastyle (2);

CH78 – Metaconule is prominent, closer to protocone (0); or prominent, mid-way or closer to metacone (1); or prominent, distolingually positioned, not close to metacone or protocone, faking hypocone (2); or absent or weak (3);

CH79 – Labial edge of the precingulum labial to paraconule (= reaching labially past the paraconule or paraconule position) (0); or absent or weak (1); or labial edge of the precingulum, lingual to paraconule; (2);

CH80 – Labial edge of the postcingulum labial to metaconule (0); or labial edge of the postcingulum lingual to metaconule (1); or postcingulum extending to labial margin; (2); or absent or weak (3);

CH81 – M1–M2 metaconular hypocone is absent (0); or present (1);

CH82 – Crochet is absent (0); or present (1);

CH83 – Hypoconulid of last lower molar is tall and sharply recurved (0); or posteriorly procumbent (1); or short and erect (2); or absent (3); or spur-like (4);

CH84 – Hypolophid (loph joining hypoconid to hypoconulid) is absent (0); or present (1);

CH85 – Labial postcingulid is present (0); or absent (1);

CH86 – Position of hypoconulid on M1 and M2 is medial (0); or lingual (1); or labial (2);

CH87 – Postmetaconular crista is absent or, when present, is disto-labially positioned (0); or present and distally (1);

CH88 – Mesostyle is absent (0); or present (1):

CH89 – More distal re-entrant grooves on the molars are absent (0); or present (1);

CH90 – Molars transverse lophs are absent (0); or present (1);

CH91 – Short symphysis, extending until the level of p2 (0); or long symphysis, extending until the level of p3 (1); or very long symphysis, extending until the level of p4 (2); or extremely long symphysis, extending until molar level (3);

CH92 – Diastema between canines and premolars is absent (0); or long diastema with well-marked crest (1);

CH93 – Well-developed angle between mandible and angular process, with small area of muscle insertion (0); or well-developed angle between mandible and angular process with large area of muscle insertion (1); or mandibular angle without angular process (2);

CH94 – Proximal border of coronoid process higher than condylar process with large muscle externus temporalis insertion area (0); or both at the same level with large muscle externus temporalis insertion area (1); or higher with a narrow area for the muscle externus temporalis insertion area (2);

CH95 – Ventral border of dentary bone is not medial-posteriorly flat (0); or is flat (1);

CH96 – Dentary body is slender and long (0); or deep and short (1);

CH97 – Angle between anterior border of coronoid process and horizontal alveolar border of cheek teeth is obtuse (anterior border of coronoid process strongly oblique posteriorly) (0); or slightly obtuse or perpendicular (anterior border of coronoid process slightly oblique posteriorly or subvertical) (1); or acute angle (anterior border of coronoid process shifted anteriorly) (2);

CH98 – Anterior extension of masseteric fossa on the dentary body, below the last molars, is absent (0); or present (1);

CH99 – Condyloid crest is present (0); or absent (1);

CH100 – Posteroventral shelf of the masseteric fossa is absent (0); or present (1);

CH101 – Angular process shape (in lateral view) is hook-like with base width subequal to (or wider than) length (0); or hook-like with base width smaller than length (1); or plate-like (no hook distinct), more or less rounded or sub rectangular (2); or triangular (3);

CH102 – Angular process apex vertical position is lower or below the level of the alveolar border (0); or in the same level or above the alveolar border (1);

CH103 – Condyle shape is wider than long (ovoid) (0); or wider than long (cylindrical) (1); or as long as wide or longer (anteroposteriorly elongate) (2);

CH104 – Condyle position relative to teeth row is above by approximately one molar length (0); or above by two molars length or more (1); or approximately at the same level or slightly above (2);

CH105 – Symphysis is tapered (0); or deep (1);

CH106 – Retromolar space in adults (when ultimate molar exhibits wear process) is absent (0); or present (1);

CH107 – Diastema between upper canines and premolars is absent (0); or present (1);

CH108 – Dental substitution delay is absent (0); or present (1);

CH109 – Hipocone shelf absent (0); or present and very narrow (1); or present and narrow (2); or present and large (3).

**3. Morphological Phylogenetic Matrix**

Data matrix used in this study, with 109 morphological characters and 44 taxa, all from Paleogene. Some characters were coded as polymorphic.

xread

'sudamericungulata'

109 44

Protungulatum

?0?000?00?0000000000??0000000000000?0000000?000?00000????????0?0000000?0000000000000000000?000000000000000000

Tribosphenomys\_minutus

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Purgatorius

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Cambaytherium\_thewissi

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Hyrachyus

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Diacodexis

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Hyopsodus

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Phenacodus

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Pyrotherium

11001?22???221022002002001110220012011200220101??1111021300022121001110122?101[01]200?10000013?111111102?0000?03

Propyrotherium\_saxeum

11?01??????221022012002002???220012011200220101??1111021300022121001110122?101[01]200?1000001?????1?????????0?03

Carodnia\_vieirai

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Eoastrapostylops\_riolorense

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Trigonostylops\_wortmani

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Tetragonostylops\_apthomasi

20103104111000122202102200012211101101111021200100101122111012120013?1100110210000211000000111001010210001103

Albertogaudrya\_unica

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Maddenia\_lapidaria

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Astraponotus

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Parastrapotherium

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Phosphatherium\_escuilliei

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Ocepeia\_daouiensis

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Numidotherium\_koholense

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Moeritherium\_trigodon

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Titanohyrax\_andrewsi

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Seggeurius\_amourensis

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Eotheroides

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Protosiren\_fraasi

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Eritherium\_azzouzorum

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Abdounodus\_hamdii

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Daouitherium\_rebouli

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Stylolophus\_minor

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Dilambdogale\_gheerbranti

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Widanelfarasia

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Palaeoamasia\_kansui

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Didolodus\_multicuspis

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Paulacoutoia\_protocenica

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Lamegoia\_conodonta

0?????????0????????2?0??0????100000?10011010111??100000?110110010001011021?0012300??100010?????????????????02

Protolipterna\_ellipsodontoides

0?????????000??????2?0??00100000000?0000001011011100000011110001000000?001?11123001010001010???01010301100?02

Paranisolambda\_prodromus

0?????????0????????2?0??0????????????0000010110???000000?1?11001000000?001?1012300?010011011???01???????0??02

Henricosbornia

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Notostylops

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Microhyrax\_lavocati

????????????0100021211011????????????????????????1001110110110100000?0?10201022310401011001???001???????01?13

Chambius\_kasserinensis

?0?0?0?100??01000211111100???100001010110010001?0000000001001000001010?01111011300200000000???00????????00?12

Herodotius\_pattersoni

?0?0?01100??0102121111110????????????0110010001??010000001001000000010?011110113002000000000??00????????00?12

Behemotops

?0?0?00031??0002020200010???????????????????????0011001100011?????????????????????1010??000011011000??1001?13;

**4. List of Synapomorphies of some resulted clades from implied weighting phylogenetic analysis. Numbers outside parentheses indicate characters and numbers inside indicate the characters states (see List of characters above):**

**Clade → Synapomorphies**

Astrapotheria **→ 3(1)**, **8(4)**, **9(1)**, **10(1)**, **14(0)**, **18(2)**, **24(2)**, **29(2)**, **36(1), 50(0), 67(1), 76(0),** **77(2),** **80(0)**, **96(0)**;

Notoungulata **→ 24(2)**, **37(1)**, **43(1)**, **67(2)**, **74(1)**, **77(1)**, **82(1)**;

Pyrotheria **→ 1(1)**, **2(1)**, **5(1)**, **12(2)**, **13(2)**, **18(0), 21(0)**, **24(0)**, **31(2)**, **34(1),** **35(2),** **37(1)**, **39(2)**, **41(0)**, **42(2)**, **43(2)**, **45(1)**, **47(1)**, **50(1),** **51(1)**, **52(1)**, **57(3), 58(0)**, **61(2)**;

Xenungulata\* **→ 6(1)**, **8(3), 9(0), 16(1), 17(1)**, **23(1)**, **24(1)**, **30(1), 33(1), 38(0)**, **46(1),** **50(0),** **97(2),** **105(1)**;  
Sudamericungulata **→ 16(2)**, **17(2)**, **23(2)**, **35(1),** **45(2)**, **53(1), 56(2), 57(1),** **62(2)**, **75(1),** **78(1)**, **81(0)**, **84(1)**, **88(0),** **108(0)**;

Sudamericungulata + Hyracoidea **→ 8(2)**, **21(1)**, **28(1)**, **44(1), 46(0)**, **54(1), 99(1)**;

Hyracoidea **→ 83(4), 87(1);**

Proboscidea + Embrithopoda → **1(1)**, **29(1), 32(1), 65(1), 90(1)**;

Proboscidea + Embrithopoda + Desmostylia **→** **21(0)**, **54(0), 91(0), 96(1)**;

Paenungulata **→ 9(3)**, **70(0)**, **74(2), 78(2), 84(0), 93(1)**, **109(3)**;

Paenungulatomorpha **→ 35(0)**, **46(1)**, **47(0)**, **78(0),** **81(1),** **88(1)**, **91(1)**, **106(1)**;

Afrotheria **→ 14(1)**, **79(2), 80(3)**, **89(0),** **108(1)**;

Litopterna **→ 40(0)**, **41(0)**, **49(1)**, **91(1)**, **97(1), 101(3)**;

“Didolodontidae” + Litopterna **→ 37(1)**, **38(0)**, **43(1)**, **64(1), 68(1)**, **71(1)**, **79(2)**, **80(3);**

Panameriungulata **→ 23(1)**, **27(1)**, **46(1)**, **50(1)**, **61(1)**.

\*The apomorphies of this clade are the autapomorphies for *Carodnia vieirai*.