

Supplementary Information

A Spanish saltasauroid titanosaur reveals Europe as a melting pot of endemic and immigrant sauropods in the Late Cretaceous.

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Supplementary Note 1: Abbreviations and extended description

1.1. Institutional abbreviations

HUE, Lo Hueco collection, housed at the Museo Paleontológico de Castilla-La Mancha (MUPA) in Cuenca, Spain; **MCNA**, Museo de Ciencias Naturales de Álava/Arabako Natur Zientzien Museoa, Vitoria-Gasteiz, Spain; **MMS/VBN**, Musée Moulin Seigneurial/Velaux-La Bastide Neuve, Bouches-du-Rhône, France; **MOZ-Pv**, Museo Provincial de Ciencias Naturales ‘Prof. Dr. Juan A. Olsacher’, Zapala, Argentina; **MPCA**, Museo Provincial ‘Carlos Ameghino’, Cipolletti, Río Negro Province, Argentina; **MUGEO**, Museu Geológico Valdemar Lefèvre, São Paulo, Brasil; **NHMUK**, Natural History Museum, London, U.K.; **PVL**, Instituto ‘Miguel Lillo’, Tucumán, Argentina.

1.2. Anatomical abbreviations

*, diagnostic features; **acdl**, anterior centrodiapophyseal lamina; **acf**, anterior chevron facet; **acet**, acetabulum; **acf**, anterior chevron facet; **acpl**, anterior centroparapophyseal lamina; **Cd**, caudal vertebra; **cdf**, centrodiapophyseal fossa; **cg**, cingulum; **cpaf**, centroparapophyseal fossa; **cpof**, centropostzygapophyseal fossa; **cpol**, centropostzygapophyseal lamina; **cpvf**, centroprezygapophyseal fossa; **cri**, caudal rib; **di**, diapophysis; **Dv**, dorsal vertebra; **ep**, epiphysis (its presence is considered diagnostic of *Qunkasaura pintiquiniestra*); **fs**, flat surface; **lt**, lateral trochanter; **pa**, parapophysis; **pacdf**, parapophyseal centrodiapophyseal fossa; **pacpvf**, parapophyseal centroprezygapophyseal fossa; **pcdl**, posterior centrodiapophyseal lamina; **pcf**, posterior chevron facet; **pcpl**, posterior parapophyseal lamina; **pf**, pneumatic foramen; **podf**, postzygapophyseal centrodiapophyseal fossa; **podl**, postzygodiapophyseal lamina; **posdf**, postzygapophyseal spinodiapophyseal fossa; **posl**, postspinal lamina; **poz**, postzygapophysis (the concave morphology in the posterior cervical

and anterior dorsal neural spines is diagnostic of *Qunkasaura pintiquirestra*); **ppdl**, paradiapophyseal lamina; **prdl**, prezygodiapophyseal lamina; **prpadf**, prezygapophyseal paradiapophyseal fossa; **prsd**, prezygapophyseal spinodiapophyseal fossa; **prsl**, prespinal lamina; **prsl-f**, prespinal lamina fossa; **prsl pr**, prespinal lamina process; **prz**, prezygapophysis; **ri**, ridge; **spdl**, spinodiapophyseal lamina; **spof**, spinopostzygapophyseal fossa; **spol**, spinopostzygapophyseal lamina; **sprf**, spinoprezygapophyseal fossa; **sprl**, spinoprezygapophyseal lamina; **tap**, triangular aliform process; **tprl**, intraprezygapophyseal lamina; **tprl pr**, intraprezygapophyseal lamina process; **vh**, ventral hollow

1.3. Extended description

“Romerian” terms¹ are used for the anatomical structures (e.g., “centrum”) and their orientation (e.g., “anterior”). Landmark-based terminology of Wilson^{2,3} and Wilson et al.⁴ is used for vertebral laminae and fossae. The position used for caudal vertebrae was based on Díez Díaz et al.⁵, Mannion et al.⁶ and Tschopp et al.⁷. The holotype specimen of *Qunkasaura pintiquiniestra* gen et sp nov. described in this paper is housed at the Museo de Paleontología de Castilla-La Mancha (MUPA) in Cuenca, Spain.

Only one partially and badly preserved posterior neural spine of a cervical vertebra was recovered, preserving a laterally expanded neural spine (Supplementary Fig. 1A and B) as occur in the referred posterior cervical vertebrae of *Garrigatitan meridionalis*⁸ and some members of Lognkosauria⁹. The postzygapophyseal facet is strongly concave. The neural spine is markedly posteriorly deflected and preserves a round and rudimentary epiphyses (Supplementary Fig. 1A and B), differing from the posterior cervical neural spines of *Garrigatitan meridionalis*, *Atsinganosaurus velauciensis* and *Ampelosaurus atacis*^{8,10,11}. The presence of epiphyses in the cervical vertebrae is considered part of the diagnosis of *Qunkasaura pintiquiniestra*. The epiphyseal process is absent in most titanosaurs^{6,9}, which contrasts with the developed epiphyses of some non-titanosaurian somphospondylans, such as *Euhelopus zdanskyi*¹², however, in *Qunkasaura pintiquiniestra* this process is just rudimentary developed. The holotype of *Qunkasaura pintiquiniestra* preserves an articulated-to-associated series of ten dorsal vertebrae (Supplementary Figure 1C-K and Supplementary Table 1), with some sectors found in almost full-articulation, corresponding to an uninterrupted series from the first to tenth dorsal vertebrae (Fig. 2A-E). This suggests for the presence of 11 or less dorsal vertebrae, condition that is shared by several lithostrotian titanosaurs, including *Overosaurus paradasorum*^{13,14}, and some diplodocoids^{6,15}. The dorsal centra are opisthocoelous, i.e., the anterior articular surface is convex, and the posterior surface is concave, as in most macronarian sauropods¹⁵⁻¹⁷. They are markedly convex in the anterior and posterior dorsal vertebrae. The

anterior articular surface of the centrum is badly preserved in the middle dorsal vertebrae, but they seem to be less strongly convex than on the anterior and posterior dorsal vertebrae (Fig. 2E). This condition differs from the progressive loss of a strongly convex anterior articular surface of the mid-posterior dorsal centra that characterizes some brachiosaurids^{18,19} and the lithostrotians *Lohuecotitan pandafilandi* and *Paludititan nalatzensis* (pers. observ. PM 2014-2020), some middle to posterior dorsal vertebrae of *Lirainosaurus astibiae* (MCNA 8551 and 13859; pers. observ. PM 2016) and *Tapuiasaurus macedoi*²⁰. The ratio of mediolateral width to the dorsoventral height of the posterior articular surface in the anterior dorsal centra is greater than 1.3 as in *Abditosaurus kuehnei*²¹ and *Opisthocoelicaudia skarzynskii*²², differing from the more subcircular centra of lirainosaurines such as *Lohuecotitan pandafilandi*²³ and *Lirainosaurus astibiae*⁵.

Measurements (mm)	HUE-2981				HUE-2979					HUE-2980
	Dv1	Dv2	Dv3	Dv4	Dv5	Dv6	Dv7	Dv8	Dv9	Dv10
Anteroposterior width of the centrum with condyle	219	226	?	232	?	?	?	280	≈ 200.0	167.57
Anteroposterior width of the centrum without condyle	179.0	168.0	156.0	200.0	?	200.0*	211.0	210.0	165.0	126.6
Dorsoventral width of the anterior articular surface of the centrum	75.9	65.0	?	76.0	?	?	?	?	?	131.2
Mediolateral width of the anterior articular surface of the centrum	168.0	163.0	169.0	132.0	?	?	?	?	?	147.4
Dorsoventral width of the posterior articular surface of the centrum	137.0	88.0*	100.0	99.0	?	?	?	?	138.0	?
Mediolateral width of the posterior articular surface of the centrum	192.0*	186.0	169.0	169.0	?	?	?	?	?	172.3
Dorsoventral width of the neural arch (up to the dorsalmost point of the postzygapophysis)	?	62.0	?	?	?	?	?	?	?	88.2
Dorsoventral width of the neural arch (up to the ventralmost point of the postzygapophysis)	?	37.5	35.7	?	?	?	?	?	?	65.35
Total height of the vertebra	?	?	?	?	?	?	?	?	?	>500.0

Supplementary table 1. Measurements (in mm) for the dorsal vertebrae of *Qunkasaura pintiquiniestra*.

*Estimated.

The lateral surface is characterized by dorsoventrally compressed and eye-shaped pneumatic fossa, which is set within a fossa as in many somphospondylans¹⁷ (Fig 2D, Supplementary Fig. 1D, G and K) including all Ibero-Armorican titanosaurs^{10,11,21,23} and *Igai semkhu*²⁴. The anterior pneumatic fossae preserve an acute posterior edge as occurs in

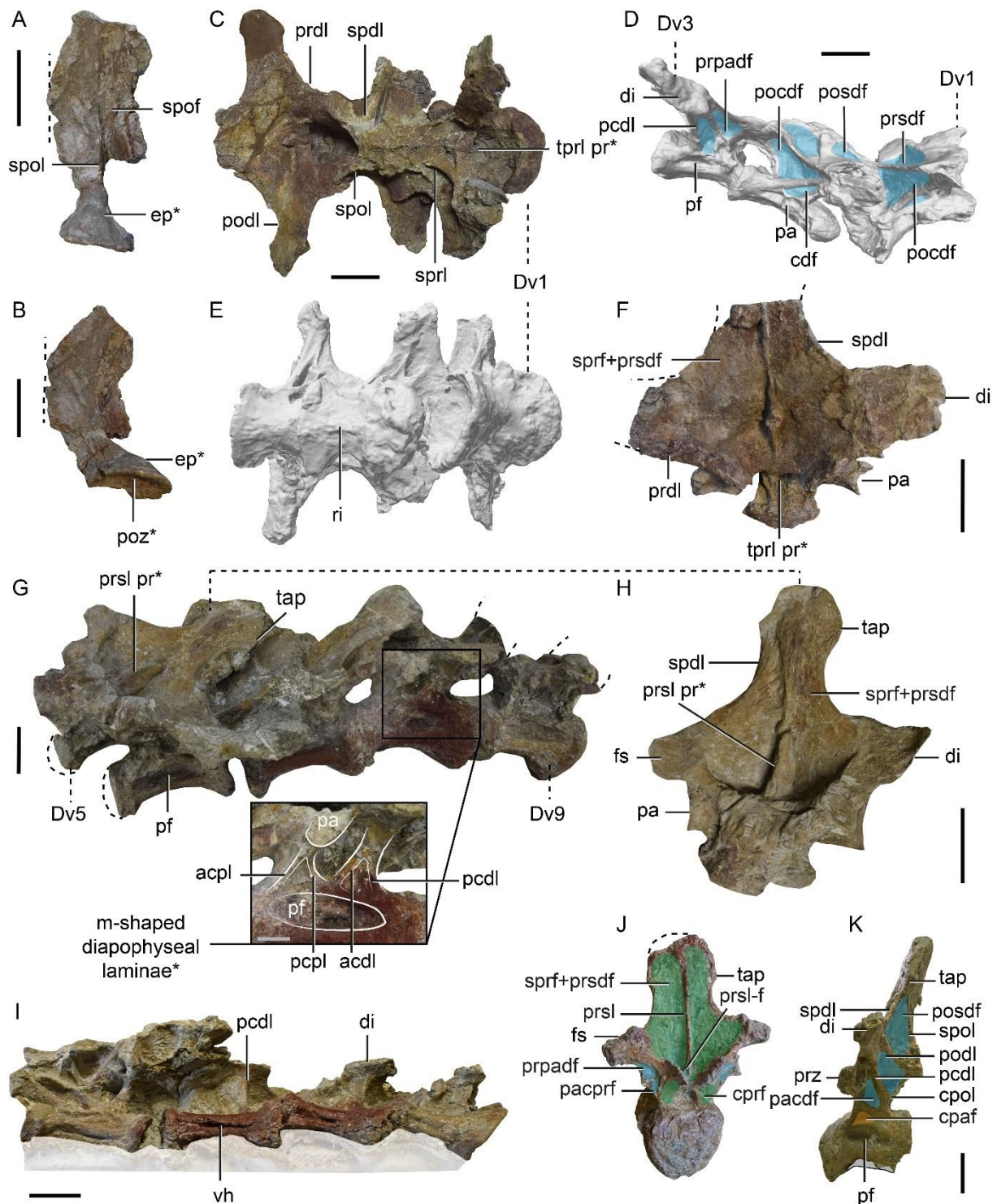
macronarians^{6,17,25}. Some dorsal vertebrae present subvertical struts within the pneumatic fossa as in *Lirainosaurus astibiae*⁵, *Mansourasaurus shahinae*²⁶, *Trigonasaurus pricei*²⁷ (considered as a junior synonym of *Baurutitan britoi*²⁸) and some dorsal vertebrae of *Opisthocoelicaudia skarzynskii*²². A developed ventral keel is only present in the second dorsal vertebrae (being incipient in the first one; Fig. 2B, Supplementary Fig. 1E). The presence of a ventral keel in anterior dorsal vertebrae is shared by *Lohuecotitan pandafilandi*²³, and *Lirainosaurus astibiae* (MCNA 3159, 7445), being absent in *Abditosaurus kuehnei*, and *Ampelosaurus atacis*²¹. The ventral surface in the last anterior and posterior dorsal vertebrae is transversely convex but become smoothly transversely concave in the middle dorsal vertebrae (Supplementary Fig. 1D), resembling the condition of *Abditosaurus kuehnei*²¹. The ventral surface is also transversely concave in *Lohuecotitan pandafilandi*²³, *Atsinganosaurus velauciensis*²⁹ and possibly *Ampelosaurus atacis*¹⁰, and *Opisthocoelicaudia skarzynskii*²². The middle and posterior dorsal vertebrae of *Lirainosaurus astibiae* are marked by a transversely convex ventral surface with an associated ventral keel (pers. observ. PM 2016; ²¹); and in *Igai semkhu*²⁴, *Overosaurus paradasorum*, *Punatitan coughlini*, *Bravasaurus arreirosorum* and *Gondwanatitan faustoi*²⁸, the ventral surface is just transversely convex to flat. Cervical and dorsal vertebrae have an internal camellate bone tissue as in titanosauriforms^{17,30-32} as all Ibero-Armorican titanosaurs^{5,8,10,11,21,23}, *Mansourasaurus shahinae*²⁶, and *Igai semkhu*²⁴.

The neural arches are placed at midpoint of the length of the centrum length in the anterior and middle dorsal vertebrae and they do not reach the anterior and posterior articular surfaces, condition considered here as an autapomorphy of *Qunkasaura pintiquiniestra* (Fig. 2C-D, Supplementary Fig. 1D and G). The parapophyses migrates rapidly from an anteroventral position in the centrum in the first dorsal to a full-placed position in the neural arch of the third dorsal (Fig. 2D). The lateral side of the dorsal neural arch preserves a unique configuration of laminae, which is markedly affected in the anterior dorsal series due the migration of the parapophysis, which captures the anterior centrodiapophyseal lamina (acd1) becoming the

paradiapophyseal lamina (ppdl), and by the appearance of the anterior centroparapophyseal (acpl) and posterior parapophyseal (pcpl) laminae. The parapophyses are supported by the acpl and a single pcpl as in *Igai semkhu*²⁴, differing from the double pcpl present in some sauropods such as the saltasauroids *Lohuecotitan pandafilandi*²³, *Paludititan natalzensis* (pers. observ. PM 2018), *Saltasaurus loricatus* and *Opisthocoelicaudia skarzynskii*^{6,13}. This lamina is absent in *Abditosaurus kuehnei*²¹ and *Alamosaurus sanjuanensis*⁶. The diapophysis is ventrally supported by the acdl and posterior centrodiaepophyseal laminae (pcdl), which bordered a subtriangular centrodiaepophyseal fossa (cdf). The acdl is absent in *Atsinganosaurus velauciensis*¹¹. The acpl, pcpl, acdl and pcdl have a similar extension and give place to M-shaped laminar structure well-visible in lateral the view from the last anterior and to ninth dorsal vertebra (Fig. 2C, Supplementary Fig. 1G). This structure is absent in all European titanosaurs^{5,10,21,23,29,33} *Igai semkhu*²⁴ and *Opisthocoelicaudia skarzynskii*²², being considered as an autapomorphy of *Qunkasaura pintiquiniestra*.

The transverse processes are laterally projected throughout the dorsal series differing from the middle-posterior transverse processes of *Lirainosaurus astibiae*⁵, *Atsinganosaurus velauciensis*^{11,29} and *Igai semkhu*²⁴, which are dorsolaterally projected. Laterally projected transverse processes are observed in many macronarians, including *Abditosaurus kuehnei*, *Lohuecotitan pandafilandi*, saltasaurines and aeolosaurines^{21,23,28}. They are laterally well-developed in anterior and middle dorsal vertebrae. In the middle-posterior dorsal vertebrae there are a distinct flat surface near the diapophyses that is well-visible in anterior view (Fig. 2F). This flat surface was recovered as a synapomorphy of Euhelopodidae and Lithostrotia or ‘Titanosauroidea’, depending on the preformed analyses of Mannion et al.⁶ and Euhelopodidae + (*Chubutisaurus* + Titanosauria) by D’Emic³². The aeolosaurines *Punatitan coughlini* and *Bravasaurus arreirosorum* and the possible aeolosaurine *Overasaurus paradasorum* are characterized by the absence of this flat surface^{14,28}. Diapophyses are dorsoventrally narrow and anteriorly connected to the prezygapophysis through the prezygodiaepophyseal lamina

(prdl) and posteriorly connected to the postzygapophysis through the postzygodiapophyseal lamina (podl) in anterior dorsal vertebrae, and through the spinodiapophyseal lamina (spdl) in the middle and posterior dorsal vertebrae. The podl becomes absent in the middle and posterior section of the dorsal series as occur in some saltosaurids such as *Lohuecotitan pandafilandi*, *Paludititan nalatzensis*, *Igai semkhu*, *Opisthocoelicaudia skarzynskii* and *Alamosaurus sanjuanensis*^{12,13,23,24,33} (pers. observ. PM 2014-2020), but in *Qunkasaura pintiquiniestra* the podl reappears in the last dorsal vertebrae (Fig. 2E, Supplementary Fig. 1K). The anterior surface of the neural arch is marked by a shallow and flat centroprezygapophyseal fossa (cprf) in middle and posterior dorsal vertebrae as in *Abditosaurus kuehnei*²¹ (both were scored as present in our dataset), *Igai semkhu*²⁴, *Punatitan coughlini* and *Bravasaurus arreirosorum*²⁸. The posterior surface of the neural arch is marked by a well-developed and single centropostzygapophyseal lamina (cpol). The neural canal is sub-circular, and dorsoventrally compressed. The centropostzygapophyseal fossa (cpof) is rudimentary to absent. The prezygapophyses and postzygapophyses are dorsoventrally elongated, with an elliptical outline, and face dorsomedially, but become more medially inclined posteriorly in the series (more than 30° to the horizontal in posterior dorsal vertebrae as in other European titanosaurs). However, in the anterior and middle dorsal, the zygapophyseal facets are inclined less than 30° as *Abditosaurus kuehnei*²¹ and differing from saltosaurines³⁴, lirainosaurines (pers. observ. PM 2014-2020) and most aelosaurines²⁸. The prezygapophyses are medially connected by an intraprezygapophyseal lamina (tprl), which presents a triangular and anteriorly projected process in anterior dorsal vertebrae (autapomorphy of *Qunkasaura pintiquiniestra*, Fig. 2A, Supplementary Fig. 1 C and F). The postzygapophyses are concave in the anterior vertebrae, considered as autapomorphic of *Qunkasaura pintiquiniestra*, differing from the condition present in other Ibero-Armorican titanosaurs^{8,11} (pers. observ. PM 2014-2020) and *Igai semkhu*²⁴.



Supplementary Figure 1. Presacral vertebrae of *Qunkasaura pintiquiniestra* gen. et sp. nov. Posterior cervical vertebrae (HUE-2981) in posterior (A) and posterolateral (B) views. Anterior dorsal vertebrae (Dv1-Dv3, HUE-2981) in dorsal (C, anterior towards right side), right lateral (D), and ventral (E, anterior towards right side) views. Middle dorsal vertebra (Dv4, HUE-2981) in dorsal view (F). Middle-to-posterior dorsal vertebrae (Dv5-Dv9, HUE-2979) in left lateral (G), and ventrolateral (I) views; and anterodorsal view for the Dv5 (H). Posterior dorsal

vertebra (Dv10, HUE-2980) in anterior (J), and left lateral (K) views. D and E correspond to a 3D digital model. Black dashed line: broken borders. Diapophyseal fossae are in blue, parapophyseal fossae are in orange, and prezygapophyseal fossae are in green. *Abbreviations*: *, diagnostic features; **acdl**, anterior centrodiapophyseal lamina; **acet**, acetabulum; **acf**, anterior chevron facet; **acpl**, anterior centroparapophyseal lamina; **cdf**, centrodiapophyseal fossa; **cpaf**, centroparapophyseal fossa; **cpol**, centropostzygapophyseal lamina; **cprf**, centroprezygapophyseal fossa; **di**, diapophysis; **Dv**, dorsal vertebra; **ep**, epiphysis (its presence is considered diagnostic of *Qunkasaura pintiquirestria*); **fs**, flat surface; **pa**, parapophysis; **pacdf**, parapophyseal centrodiapophyseal fossa; **pacprf**, parapophyseal centroprezygapophyseal fossa; **pcdl**, posterior centrodiapophyseal lamina; **pcpl**, posterior parapophyseal lamina; **pf**, pneumatic foramen; **podf**, postzygapophyseal centrodiapophyseal fossa; **podl**, postzygodiapophyseal lamina; **posdf**, postzygapophyseal spinodiapophyseal fossa; **poz**, postzygapophysis (the concave morphology in the posterior cervical and anterior dorsal neural spines is diagnostic of *Qunkasaura pintiquirestria*); **prdl**, prezygodiapophyseal lamina; **prpadf**, prezygapophyseal paradiapophyseal fossa; **prsd**, prezygapophyseal spinodiapophyseal fossa; **prsl**, prespinal lamina; **prsl-f**, prespinal lamina fossa; **prsl pr**, prespinal lamina process; **prz**, prezygapophysis; **ri**, ridge; **spdl**, spinodiapophyseal lamina; **spof**, spinopostzygapophyseal fossa; **spol**, spinopostzygapophyseal lamina; **sprf**, spinoprezygapophyseal fossa; **spri** spinoprezygapophyseal lamina; **tap**, triangular aliform process; **tpri pr**, intraprezygapophyseal lamina process; **vh**, ventral hollow. Black scale bar equals 100 mm, gray scale bar equals 50 mm.

The neural spine of the anterior up to the first posterior dorsal vertebra is markedly inclined posteriorly. In the last preserved posterior vertebrae, the neural spine becomes subvertical, resulting in a dramatic change in the inclination of the neural spine in the posterior section of the dorsal series (Fig. 2C, E). The neural spine is not bifurcated, in contrast to *Opisthocoelicaudia skarzynskii*²², and markedly compressed anteroposteriorly (the mediolateral width is six times the anteroposterior length, which is considered autapomorphic for *Qunkasaura pintiquirestria*). Such distinctly anteroposteriorly compressed neural spines are absent in *Lohuecotitan pandafilandi*²³, *Lirainosaurus astibiae*⁵, *Ampelosaurus atacis*¹⁰ and other saltasaurids^{35,36} but is more similar to the condition observed in some colossosaurs^{37,38} and *Abditosaurus kuehnei*²¹. The anterior surface of the neural spine is marked by the presence

of the spinoprezygapophyseal lamina (sprl) in the anterior dorsal vertebrae, which converge to the prespinal lamina (prsl; it becomes rudimentary to absent in middle and posterior dorsal vertebrae). In the middle and posterior dorsal vertebrae, the anterior surface of the neural spine is delimited by the prdl, diapophyses and spdl. These laminae delimit a wide spinoprezygapophyseal + prezygapophyseal spinodiapophyseal (sprf+prsd) (Fig. 2F). The prsl is medially restricted and well-developed, and the ventral section of the prsl is anteroposteriorly project, autapomorphy of *Qunkasaura pintiquirestria* (Supplementary Fig. 1G and H). No accessory spdl is present. The posterior face is delimited by a dorsoventrally short and single spinopostzygapophyseal lamina (spol). The postspinal lamina (posl) is well-developed and medially restricted in the ventral half of the spine. The spdl and spol contact with an anteroposteriorly compressed triangular aliform process. The neural spine is transversely expanded and has a rounded dorsal edge. The height of the posteriormost dorsal neural spine is two times the height of the posterior articular surface of the centrum (characteristic of *Qunkasaura pintiquirestria*). This ratio is not available for the other preserved middle and posterior dorsal vertebrae.

Six sacral vertebrae are identified (Fig. 2K). They are fully fused, as occur in titanosaurs and some deeply nested non-titanosaurian somphospondylans such as the euhelopodids^{6,12,32}. The anterior articular surface of the centrum of the first sacral vertebra is strongly convex. The posterior surface of the last centrum is concave, unlike *Lohuecotitan pandafilandi*, which is convex (pers. observ. PM 2014-2020). *Atsinganosaurus velauciensis* only preserves the first five sacral vertebrae²⁹). The ventral surface of the fourth to sixth sacral centra preserves a ventral keel (Fig. 2K), differing from *Atsinganosaurus velauciensis*¹¹ and *Garrigatitan meridionalis*⁸, which present a keel in the third-to-fifth sacral vertebrae. In addition, there is a ventral groove from the first to third sacral (Fig. 2K), an autapomorphy of *Qunkasaura pintiquirestria*. All the six sacral ribs are preserved and attached to the centra and ilium. The second, third, and fourth sacral ribs are contributing to the acetabular surface. The dorsal surface

of the sacral plates is anteroposteriorly expanded resulting in a flat surface, which narrows significantly near the dorsal surface of the ilium, as occurs in *Lohuecotitan pandafilandi* (pers. observ. PM 2014-2020), but not in *Garrigatitan meridionalis*⁸. The dorsal processes of these plates are projected dorsomedially resulting in a hooked process in posterior view, an autapomorphy of *Qunkasaura pintiquiniestra*. The sacral vertebrae preserved an internal camellate tissue bone, like that of *Lohuecotitan pandafilandi* and differing from *Garrigatitan meridionalis*. The neural spines are completely fused and preserve a well-developed supraspinous rod (Fig. 2H) as occurs in *Lohuecotitan pandafilandi* and *Atsinganosaurus velauciensis*, which is considered as rudimentary to absent in *Garrigatitan meridionalis*^{8,11,23}. This feature was considered as a possible synapomorphy of Titanosauria^{39,40}.

Measurements (mm)	HUE-2957											HUE-2959
	Cd1	Cd 2	Cd3	Cd4	Cd5	Cd6	Cd7	Cd8	Cd9	Cd10	Cd11	middle
Anteroposterior width of the centrum with condyle	140	120	136	120	?	127	130	?	?	128	127	93.2
Anteroposterior width of the centrum without condyle	53	85	101	100	99	102	97	100	100	109	110	85.1
Dorsoventral width of the anterior articulation	138	127	122	110	119	113	115	98	100	103	88	47.2
Mediolateral width of the anterior articulation	144	124	112	98	95	82	84	81	82	79.8	?	54.5
Dorsoventral width of the posterior articulation	?	107	?	103	104	103	101	104	103	92.9	88	44.9
Mediolateral width of the posterior articulation	128	85	86	81	79	77	80	82	77	81.9	74	59.1
Total height of the vertebra	?	?	?	?	?	?	?	?	?	?	?	63.1

Supplementary Table 2. Measurements (in mm) for the caudal vertebrae of *Qunkasaura pintiquiniestra*. The measurements of the first eleven caudal vertebrae (Cd1-to-Cd11) were based on its 3D models. *Estimated.

Eleven articulated anterior caudal vertebrae were recovered in association with a partially complete sacrum and one isolated middle caudal vertebra (Fig. 2K, Supplementary Fig. 2; see measurements in Supplementary Table 2). The centra are transversely compressed, probably due deformation. The centrum of the first caudal vertebra is a biconvex with a strongly convex anterior articular surface (Fig. 2J), which is not recorded in other Ibero-Armorican forms^{5,23} but present in some titanosaurs such as *Dreadnoughtus schrani*⁴¹ and the saltasauroids

*Alamosaurus sanjuanensis*⁴², *Opisthocoelicaudia skarzynskii*²² and *Baurutitan britoi*⁴³. The first caudal of aeolosaurines is characterized by a concave anterior articular surface of the centrum^{14,28}. The remaining caudal vertebrae are strongly procoelous (Fig. 2L-P) which is shared with lithostrotians and some mamenchisaurids and turiasaurs^{44,45}. The posterior condyle is constricted, and the apex of this convexity is dorsally displaced as occur in *Lohuecotitan pandafilandi* (pers. observ. PM 2014-2020), *Trigonosaurus pricei*²⁷ and some aeolosaurines²⁸. In lateral view, the anterior articular surface is markedly inclined anteriorly unlike the subvertical orientation (Fig. 2M, O) of *Lohuecotitan pandafilandi*²³, sharing this condition with aeolosaurines⁴⁶ (see Supplementary Note 4), and considered as characteristic of *Qunkasaura pintiquiniestra*. The ventral surface of the centrum preserves a ventral hollow bordered by ventrolateral ridges as occurs in many titanosaurs^{30,32}. This ventral hollow generally appears in the anterior sector of tail, after the first caudal vertebrae, and might be developed up to the middle or even posterior region of the caudal series. The presence of this feature in anterior caudal vertebrae is shared by several titanosaurs^{35,41,47-50}. The presence of this feature in the middle caudal vertebrae has a more restricted distribution within Titanosauria [e.g. *Andesaurus delgadoi*⁴⁹, *Alamosaurus sanjuanensis*, *Isisaurus coberti*⁵¹, *Malawisaurus dixeyi*⁴⁷, *Neuquensaurus australis*³⁶, *Opisthocoelicaudia skarzynskii*²², *Punatitan coughlini*⁵², *Rapetosaurus krausei*⁴⁸, *Saltasaurus loricatus*³⁵)

The caudal ribs are posterolaterally projected in dorsal view and extend beyond the lateral edge of posterior articular surface (Supplementary Fig. 2G and H). The neural arch is markedly displaced anteriorly in all preserved caudal vertebrae, as occur in titanosauriforms and some non-neosauropod eusauropods^{13,45,53}. The neural arch in the anteriormost caudal vertebrae of *Qunkasaura pintiquiniestra* are pneumatized internally as in lirainosaurines¹¹ (pers. observ, PM 2014-2020), differing from the solid internal bone tissue that characterizes the neural arches of the aeolosaurines *Punatitan coughlini*, *Arrudatitan maximus* and *Uberabatitan ribeiroi*^{28,52,54}. The prezygapophyses are markedly projected anterodorsally,

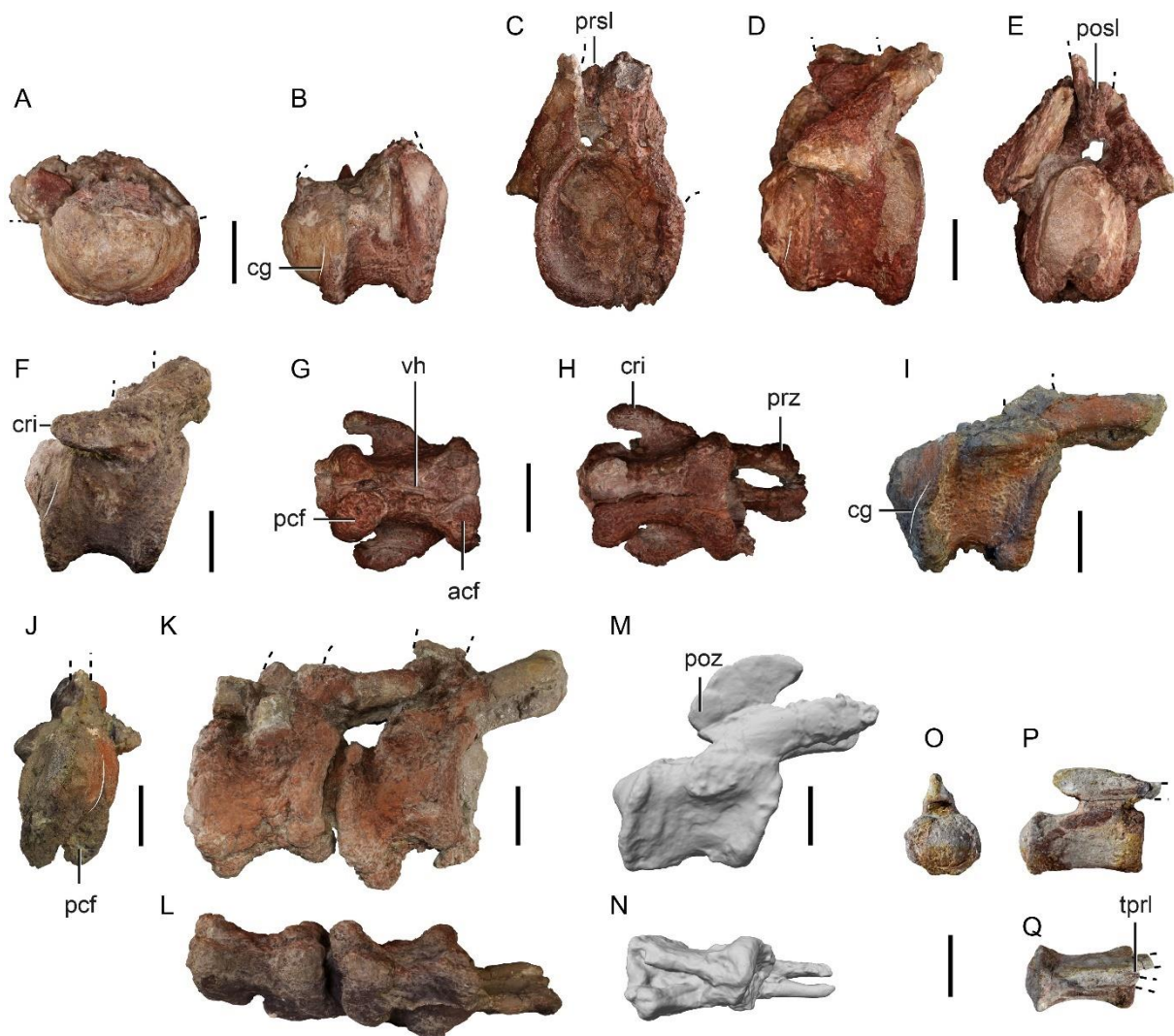
reaching 92% of the total length of the centrum, which is considered characteristic of *Qunkasaura pintiquiniestra* and drastically differs from *Lohuecotitan pandafilandi*, *Lirainosaurus astibiae* and *Atsinganosaurus velauciensis*^{5,11,23}. The comparison of the caudal vertebral morphology between *Qunkasaura pintiquiniestra* and *Magyarosaurus dacus*, *Atsinganosaurus velauciensis*, and *Ampelosaurus atacis* is problematic. The morphological variability observed in these three taxa, especially, on the anterior caudal vertebrae is highly variable^{11,55} (pers. observ. FO 2011), including significant differences in the orientation of neural spine, orientation of the prezygapophyseal processes and the anterior articular surface of the centrum, or in the morphology of the dorsal edge of the sprl. The morphological variability of some of these characters is difficult to explain by intra-specific variability based on other taxa represented by more than one individual (e.g. *Saltasaurus loricatus*). In the referred anterior caudal vertebrae of *Atsinganosaurus velauciensis*, two of the figured elements, which are not probably separated by more than five sequential caudal vertebrae, show a difference of more than 60° in inclination of the neural spine (see MMS/VBN.93.31a and MMS/VBN. 02.110 in ¹¹). In *Magyarosaurus dacus*, some referred specimens showing a similar tail position (NHMUK R.4898, see also ⁵⁵) show differences of more than 30° in the neural spine orientation. This variation in the neural spine orientation have not been recorded in several partially complete series belonging to titanosaurian sauropods (see Supplementary Table 4). We believe that more than one taxon can be present in these associations. The postzygapophyses are in the anterior half of the centrum near the anterior edge of the articular surface (also characteristic of *Qunkasaura pintiquiniestra*; Supplementary Fig. 2M), differing from *Lohuecotitan pandafilandi* and the caudal vertebrae referred to *Lirainosaurus astibiae* (pers. observ. PM 2014-2020). Some of the anterior caudal vertebrae referred to *Ampelosaurus atacis* also present a posteriorly located postzygapophyses while other do not. A full description of the referred caudal vertebrae of *Ampelosaurus atacis* is necessary to understand the caudal morphology of this taxon and its phylogenetic relationships. The detailed description of *Atsinganosaurus*

velauciensis have been provided by Díez Díaz et al. ¹¹, and, in future approaches, we believe that it will be important to provide a detailed comparison and full figuration of all caudal vertebrae of this taxon and provide a better characterization of the morphological variability present in these elements, for example, in the morphological characterization of the ventral surface. The neural spine is anteriorly directed, differing from other preserved caudal series found at Lo Hueco and from those of other Ibero-Armorican taxa (some anterior caudal vertebrae of *Atsinganosaurus velauciensis* preserve posteriorly inclined neural spines, but some might preserve an anterior orientation)^{5,11}. The marked anterior projection of the anterior caudal neural spines (Fig. 2O; Supplementary Fig. 2M) is part of the diagnosis of *Qunkasaura pintiquiniestra*, being shared by the aeolosaurines *Aeolosaurus rionegrinus*^{34,56}, *Arrudatitan maximus*⁴⁶, *Gondwanatitan faustoi*⁵⁷ and *Punatitan coughlini*⁵².

Two ilia were found (only the left one is complete) articulated with the sacrum, as well as the right and left pubes and ischia (Fig. 2G-H). The preacetabular process is anterolaterally projected (not laterally projected as in *Lohuecotitan pandafilandi*²³ and *Garrigatitan meridionalis*⁸) and twisted and oriented at an oblique-to-subvertical plane (it never reaches the subhorizontal position as in *Lohuecotitan pandafilandi*²³). The dorsal edge of this process is smoothly round. The ventral edge of the preacetabular process bears a rough ventral process (Fig. 2G), which may be homologous to the ventral kink observed in several titanosauriform ilia (e.g. *Giraffatitan brancai*⁵⁸, *Saltasaurus loricatus*³⁵, *Dreadnoughtus schrani*⁴¹ or *Lohuecotitan pandafilandi*²³). The articular surface of the pubic peduncle has an arched outline. Above the base of the pubic peduncle, there is a flat to slightly concave triangular surface, distinct from the described circular fossa of the referred ilium of *Garrigatitan meridionalis* (not visible or described for the holotype specimen). This fossa is well-developed in the lithostrotians *Lirainosaurus astibiae*⁵⁹, *Lohuecotitan pandafilandi* (pers. observ. PM 2014-2020) and *Dreadnoughtus schrani*⁴¹ and is also present in some diplodocoids⁷. The maximum dorsoventral height of the iliac blade is located above the pubic peduncle (autapomorphic for

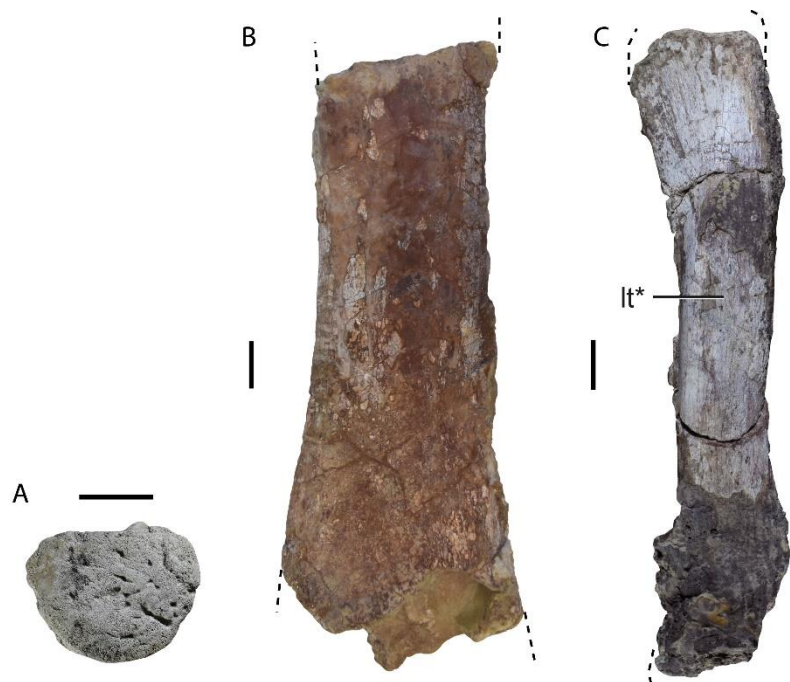
Qunkasaura pintiquirestria) differing from the ilium of *Lohuecotitan pandafilandi*²³ and *Garrigatitan meridionalis*⁸, which preserve their maximum height anteriorly to the base of the pubic peduncle. The postacetabular process is short and mediolaterally thicker, and oriented posterodorsally, preserving a tuberosity in the lateral surface as occur in *Lohuecotitan pandafilandi* (pers. observ. PM 2014), *Opisthocoelicaudia skarzynskii*²² and *Rapetosaurus krausei*⁴⁸. The two pubes of *Qunkasaura pintiquirestria* are preserved and are in full articulation with the ilia and ischia. The obturator foramen is present and located below the iliac articulation. The foramen is dorsoventrally elongated in lateral view. A longitudinal and well-developed ridge can be observed on the lateral surface of the pubis as seen in many deeply nested titanosaurs⁴⁰ and slightly developed in *Igai semkhu*²⁴. The distal end of the pubic blade is coplanar, and the distolateral edge of the pubis is slightly expanded, producing an anteriorly expanded boot not as pronounced as in some macronarians⁶⁰. The proximodistal length ratio between ischium to pubis is lower than 0.8 as in many somphospondylans⁶. However, in *Qunkasaura pintiquirestria*, the ischium is extremely reduced (the ratio of ischium to pubis length is 0.57, a feature only shared with a few somphospondylans such *Opisthocoelicaudia skarzynskii*²², *Rapetosaurus krausei*⁴⁸ and *Savannasaurus elliotorum*⁶¹. Considering the preserved portion of the pubis and ischium of *Paludititan natalzensis*, it is also possible to predict a relatively low ratio of ischium to pubis length, around 0.60, but the distal end of both elements is not completely preserved (pers. observ. PM 2018). The pubis corresponds to 118 % of the ilium, differing from many other titanosaurs (e.g. *Dreadnoughtus schrani*, 105%; *Rapetosaurus krausei*, 107%; *Rocasaurus muniozi*, 84%), and considered an autapomorphy of *Qunkasaura*. The acetabulum is widely concave in lateral view as in some titanosaurs¹³ and the acetabular surface is mediolaterally constricted at midpoint as in some rebbachisaurids^{13,62}, and diagnostic of *Qunkasaura pintiquirestria*. The distal end is twisted and reaches a coplanar position as in macronarians¹⁶. The proximal plate is shorter anteroposteriorly than the proximodistally length of the pubic peduncle, as in most titanosauriforms^{13,40,50}. The ridge for

attachment of *M. flexor tibialis internus III* is visible in the lateral face and no associated depression is present (Fig. 2H) as is common in titanosauriforms³².



Supplementary Figure 2. Caudal vertebrae of *Qunkasaura pintiquirestra* gen. et sp. nov. First caudal vertebra (Cd1) in posterior (A) and right lateral (B) views. Second caudal vertebra (Cd2) in anterior (C), right lateral (D), and posterior (E) views. Third caudal vertebra (Cd3) in right lateral view (F). Fifth (Cd5, G) and fourth (Cd4, H) caudal vertebrae in ventral view (anterior towards right side). Seventh caudal vertebra (Cd7) in right lateral (I) and posterior (J) views. Articulated eighth (Cd8) and ninth (Cd9) caudal vertebrae in right lateral (K) and ventral (L, anterior towards right side) views. Eleventh caudal vertebra (Cd11) in right lateral (M) and ventral (N, anterior towards right side) views. Middle caudal vertebra (HUE-2959) in posterior (O), right lateral (P) and dorsal (Q, anterior towards right side) views. M and N correspond to a 3D digital model. Black dashed line: broken borders. *Abbreviations:* **acf**, anterior chevron facet; **cd**, caudal vertebra; **cg**, cingulum; **cri**, caudal rib; **pcf**, posterior chevron facet; **posl**, postspinal lamina; **poz**, postzygapophysis; **prsl**, prespinal lamina; **prz**, prezygapophysis; **tprl**, intraprezygapophyseal lamina; **vh**, ventral hollow. Black scale bar equals 50 mm.

The elements of the forelimbs and hindlimb are scarce, incomplete and some of them are still unprepared (e.g. femur), but some information can be provided about the morphology of these elements (Supplementary Fig. 3). Only the distal end of the ulna is preserved (Supplementary Fig. 3A), which does not have a comma-shaped outline, being semi-circular and bearing a reduced anteromedial fossa. The right fibula is not complete (the proximal and distal ends are missing) but is interpreted as being a relatively robust element (Fig. 2I; Supplementary Fig. 3C), differing from the morphology of *Lirainosaurus astibiae* and *Lohuecotitan pandafilandi*^{23,59}. The proximal end preserves a well-developed anteromedially directed crest, anteriorly directed, and not laterally bordered by a groove, unlike *Lohuecotitan pandafilandi*, *Lirainosaurus astibiae* and *Abditosaurus kuehnei*^{21,23,59}. The lateral trochanter is oval as in other Ibero-Armorican forms^{21,23,59}, but the surface is flat, which is considered as diagnostic for *Qunkasaura pintiquiniestra*; and shared with the non-neosauropod eusauropod *Turiasaurus riodevensis*⁶³. The shaft is straight in lateral view as in *Igai semkhu*²⁴, not sharing the sigmoidal profile present in several somphospondylans and most saltasauroids^{13,21,35,64,65}.



Supplementary Figure 3. Appendicular bones of *Qunkasaura pintiquiestra* gen. et sp. nov. Partial right ulna in distal view (A); femur in anterior/posterior (?) view (B); and right fibula in lateral view (C). Black dashed line: broken borders. *Abbreviations:* *, diagnostic features; **lt**, lateral trochanter. Black scale bar equals 50 mm.

Supplementary Note 2. **Phylogenetic analyses**

2.1. Dataset choice and modifications

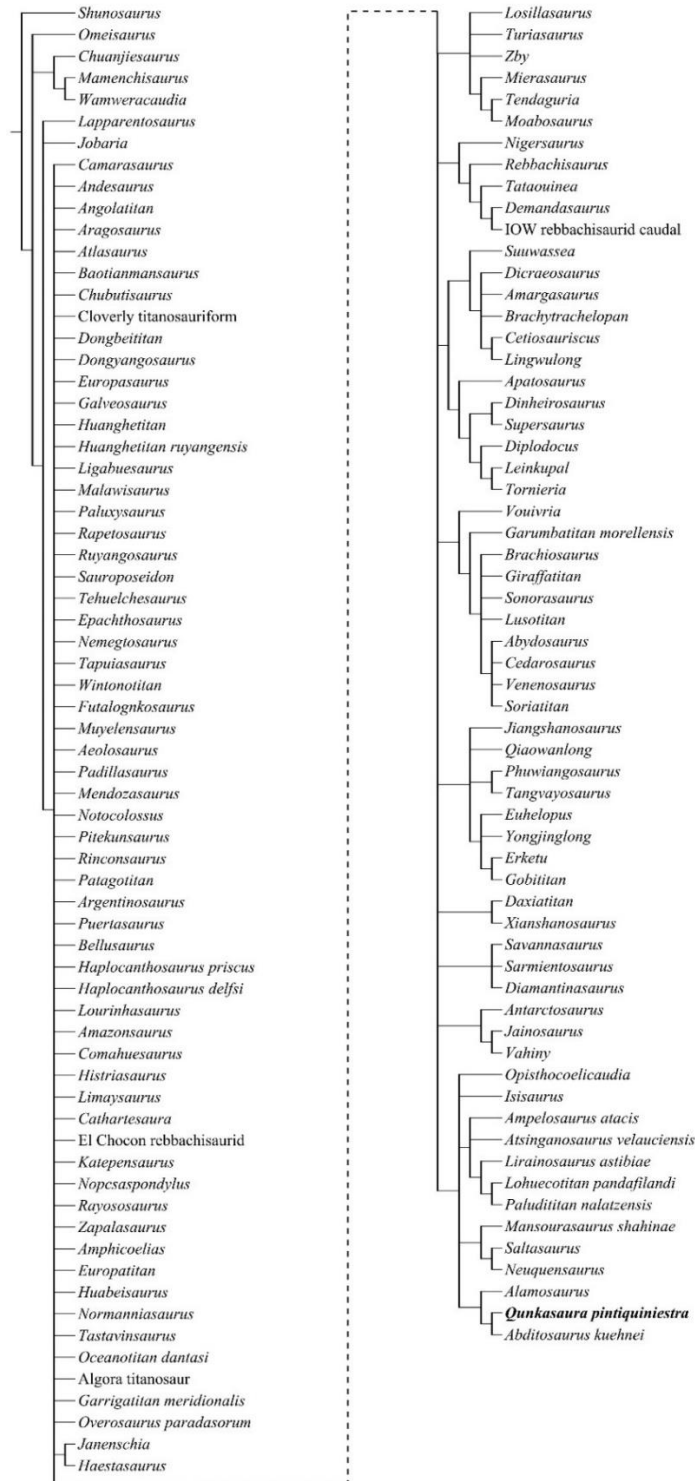
For the phylogenetic analysis for *Qunkasaura pintiquirestia* we used the dataset of Mocho et al.⁶⁶, which resulted from a direct updated of the dataset of Poropat et al.⁶⁷. This data set resulted from the updated version of ‘LSDM’ data matrix of Mannion et al.⁶ incorporating the augmented version of this matrix presented in Upchurch et al.⁶⁸, Poropat et al.^{50,69}, Mannion et al.^{13,18,50} and González Riga et al.⁹. The updated version of Mocho et al.⁶⁶ include the re-scoring of some characters of *Lusotitan atalaiensis* based on Mocho et al.¹⁹ and personal observations ([C48 (0→0&1), C59 (?→1), C145 (?→0), C162 (1→?), C188 (1→0), C189 (?→1), C191 (?→1), C206 (0→1), C210 (?→1), C211 (?→1), C235 (?→0), C334 (0→?), C372 (1→0), C419 (0→?), C481 (0→?), C483 (0→?), C500 (0→?), C524 (?→0), C525 (?→0)]; *Tastavinsaurus sanzi* [C59 (0→0&1), C162 (0→1), 163 (?→0), C168 (?→1), C169 (?→0), C175 (0→?), 256 (0→1)]; and the inclusion of *Oceanotitan dantasi* based on Mocho et al.⁷⁰ and *Garumbatitan morellensis*. The characters C339 (1→0) was updated in *Saltasaurus loricatus*. The dataset (TNT file) is provided in Supplementary Data 1. We also incorporate the scoring of the titanosaurs *Overosaurus paradasorum* (based on Coria et al.¹⁴); *Mansourasaurus shahinae* (Sallam et al.²⁶), *Neuquensaurus australis* (based on Otero⁶⁵, D’Emic and Wilson⁷¹, and pers. observ. PM 2018), the titanosaur of the Algora fossil site (based on Mocho et al.⁷²), and the recently established *Igai semkhu* (based on Gorscak et al.²⁴; used in a second run of the Analysis II and used in the Analysis III). Also, all the European titanosaurs from the Campanian-Maastrichtian of Europe have been scored for our dataset: *Lohuecotitan pandafilandi* (pers. observ. PM 2014-2020); *Lirainosaurus astibiae* (based on Sanz et al.⁷³; Díez Díaz et al.^{5,59,74,75}; pers. observ. PM 2016); *Ampelosaurus atacis* (based on Le Loeuff^{10,76}; pers. observ. FO 2011); *Atsinganosaurus velauciensis* (based on García et al.²⁹; Díez Díaz et al.¹¹); *Garrigatitan meridionalis* (based on Díez Díaz et al.⁸) and *Abditosaurus kuehnei* (based on Martín Jiménez et al.⁷⁷; Vila et al.²¹). The holotype of *Diamantinasaurus matildae* (AODF 0603) and the

referred specimens, AODF 0836 and AODF 0906 were combined as a single OTU. The list of characters from C1 to C542 can be accessed in Mannion et al.¹³, from C543 to C548 in Mannion et al.⁵⁰, from C549 to C552 in Poropat et al.⁶⁹ and C553 to C556 in Poropat et al.⁶⁷. A new character was incorporated in our analyses based on Mocho et al.⁵⁵:

C557. Middle and posterior caudal neural arches (excluding the first middle caudal vertebrae) intraprezygapophyseal lamina (tp1): located at the level of the anterior articular surface (0); anteriorly displaced and located forward to the anterior articular surface (1). (to avoid the impact of the anterior inclination of the anterior articular surface of the centrum in our scoring, we should trace a line through the ventralmost and dorsalmost point of the anterior articulation, if the tp1 is located at the level of this line, this character should be scored as '0', if this tp1 is markedly anteriorly placed, this character should be scored as '1').

Following the recent iterations of this data matrix by Mannion et al.^{13,50} and Poropat et al.^{67,69}, the characters 11, 14, 15, 27, 40, 51, 104, 122, 147, 148, 195, 205, 259, 297, 426, 435, 472 and 510 were treated as ordered multistate characters, and eight unstable and highly incomplete taxa were excluded a priori (*Astrophocaudia*, *Australodocus*, *Brontomerus*, *Fukuittan*, *Fusuisaurus*, *Liubangosaurus*, *Malarguesaurus* and *Mongolosaurus*). This pruned dataset was analyzed using the 'Stabilize Consensus' option in the 'New Technology Search' in TNT 1.5⁷⁸⁻⁸⁰, to find the most parsimonious trees (MPTs), using sectorial searches, drift, and tree fusing, with the consensus stabilized five times. After, we used the resultant trees as the starting topologies to perform a 'Traditional Search', using tree bisection–reconnection. We performed two versions of this analysis, in the first one we used equal weighting of characters and in the second one we applied extended implied weighting^{18,81}. A second run of the implied weight analysis was conducted, to explore the relationships of *Igai semkhu* and the members of Lirainosaurinae, considering the hypothesis proposed by Gorscak et al.²⁴. We applied k-value of nine, following the analyses performed by Mannion et al.⁵⁰ and Poropat et al.^{67,69}, which are

based on the recommendations of Goloboff⁸¹ and Tschopp and Upchurch⁸². To test the robustness of the phylogenetic hypotheses, Bootstrap values (absolute frequencies based on 5000 replicates) were obtained TNT 1.5⁸⁰.



Supplementary Figure 4. Phylogenetic hypothesis obtained in analysis I (equal weights) based on the data matrix of Mocho et al.⁶⁶.

Qunkasaura pintiquirestria is characterized by numerous shared features with the members of Aeolosaurini on the anatomy of the caudal vertebrae. To analyze the relationship of *Qunkasaura pintiquirestria* with aeolosaurines we scored this taxon, as well as, all the European Late Cretaceous titanosaurs, in the dataset of Silva Junior et al.²⁸. This dataset includes several aeolosaurines and corresponds to an updated version of the datasets published by Hechenleitner et al.⁵² and Silva Junior et al.⁵⁴). The list of characters be accessed in Hechenleitner et al.⁵², and the characters C423 to C426 correspond to characters C235, C238, C239, and C240 of Santucci and Arruda⁴⁶ (included by Silva Junior et al.⁵⁴). This analysis was performed in TNT 1.5⁷⁸⁻⁸⁰ following the protocols established by Silva Junior et al.²⁸, i.e. an analysis with an equal weighting of characters and tree bisection and reconnection (TBR) as the branch swapping algorithm, hold established as 50 number of additional sequences, 5000 trees to save per replication, and 0 random seeds. The characters 14, 61, 100, 102, 109, 115, 127, 132, 135, 136, 167, 180, 196, 257, 260, 277, 278, 279, 280, 300, 304, 347, 353 and 355 were considered as ordered. This dataset (TNT file) is provided in Supplementary Data 2. The characters C224 (?→2), C225 (?→1) and C337 (1→0) were updated in *Opisthocoelicaudia skarzynskii*.

2.2. Analysis I

The analysis I is an equal weight analyses based on Mocho et al.⁶⁶ dataset. The initial parsimony analysis considered equal weights for the characters. The ‘New Technology Search’ yielded 216 trees of length 2940 steps (CI: 0.200; RI: 0.602). These 216 trees were then used as the starting trees for a ‘Traditional Search’ using tree bisection–reconstruction (TBR). This analysis recovered more than 999999 most parsimonious trees (MPTs) of length 2940 steps without finishing (CI: 0.192; RI: 0.581). A strict consensus tree from this interrupted search shows little resolution in most of the topology (Supplementary Fig. 4), with an important polytomy in an internal node that raised from a polytomy with *Lapparentosaurus* and *Jobaria*, which includes all neosauropods and some deeply nested non-neosauropod eusauropods (e.g. turiasaurs).

Within this clade, several clades can be identified such as Camarasauridae, Diamantinasauria, Turiasauria, Diplodocidae, and a clade with several members commonly referred to Saltasauroidae, which includes *Qunkasaura pintiquiniestra*, *Abditosaurus kuehnei* and Lirainosaurines, and it is supported by numerous synapomorphies (this high number of synapomorphies is interpreted as consequence of the poor resolution obtained for this analysis, see Supplementary Fig. 1). *Qunkasaura pintiquiniestra* is recovered as the sister-taxon of *Abditosaurus kuehnei*, and this relationship is supported by the following synapomorphies: (1) diapophyses of the anterior–middle dorsal vertebrae are elongated and dorsoventrally narrow (C154, like brachiosaurids); (2) the anteroposterior width of the neural spine of the dorsal vertebrae is approximately constant along the height of the spine, with subparallel anterior and posterior margins (C159); and (3) the zygapophyseal articulation angle is less than 40° in anterior–middle dorsal neural arches (C337). The clade including *Qunkasaura pintiquiniestra* and *Abditosaurus kuehnei* is recovered as closely related to the North American titanosaur *Alamosaurus sanjuanensis* from the Maastrichtian, and their relationship is supported by 12 synapomorphies, from which, five can be observable in the available material of *Qunkasaura pintiquiniestra*: (i) the ratio of the mediolateral width to the dorsoventral height of the anterior surface in the anterior caudal vertebrae is less than 1.0 (C25); (ii) presence of a kink in ventral edge of iliac preacetabular process (C247); (iii) anteriorly expanded boot in the distal end of the pubis (C251); (iv) first caudal vertebra has a convex anterior articular surface (C349); and (v) the dorsal half of the neural spines of the posterior cervical vertebrae are laterally expanded (C418). The presence of a straight fibular shaft (C264) was recovered as a local autapomorphy for *Qunkasaura pintiquiniestra*.

The European titanosaurs *Atsinganosaurus velauciensis*, *Lirainosaurus astibiae*, *Ampelosaurus atacis*, *Lohuecotitan pandafilandi* and *Paludititan nalatzensis* were recovered in a monophyletic clade that corresponds to Lirainosaurinae. This clade is supported by nine synapomorphies: (i) dorsoventral height to the mediolateral width ratio of the posterior articular

face of the anterior cervical vertebrae is less than 1.0 (C16); (ii) posterior articular face of the anterior dorsal central has a mediolateral width to dorsoventral height ratio less than 1.3 (C21); (iii) average Elongation Index of the middle caudal vertebrae is 1.4 or higher (C29); (iv) the spot divided into medial and lateral branches in the neural spines of the middle-posterior dorsal vertebrae (C165); (v) absence of biconvex centra in distal caudal vertebrae (C186); (vi) the femoral distal condyles are perpendicular to the long axis of femoral shaft (C259); (vii) the distal end of anteriormost caudal ribs are ventrally deflected (C501); (viii) the ventral longitudinal hollow is absent in middle caudal centra (C506); and (ix) the ratio of the scapular anteroposterior length to the minimum dorsoventral height of the scapular blade is 5.5 or higher (C514).

2.3. Analysis II

The analysis II is an implied weight analysis based on Mocho et al.⁶⁶ dataset. This dataset was analyzed using implied weighting in TNT with a k-value of nine. The ‘New Technology Search’ yielded 157 trees of length 151.36551 steps (CI: 0.198; RI: 0.597). These 157 trees were then used as the starting trees for a ‘Traditional Search’ using tree bisection–reconstruction (TBR). This analysis recovered more than 255150 most parsimonious trees (MPTs) with a length of 151.36551 steps (CI: 0.190; RI: 0.576), with a remarkably resolved strict consensus. The Pruned Trees option in TNT recognizes *Abydosaurus*, *Nopcsaspondylus*, *Histriasaurus*, *Puertasaurus*, *Huanghetitan ruyangensis*, *Huanghetitan*, and *Vahiny* as the most unstable taxa. The general topology obtained in this analysis is better resolved (Fig. 3, Supplementary Fig. 5) than in the equal weighting analyses and it shows some differences compared to the topology achieved in the implied weight analyses by Mannion et al.^{13,50}, Poropat et al.⁶⁹ and Mocho et al.⁶⁶. All analyzed titanosaurs from Europe were recovered as members of Lithostrotia. The better resolved lithostrotian clade is Saltasauroidae (supported by 12 synapomorphies). *Qunkasaura pintiquirestia* is recovered as a deeply nested member of Saltasauroidae, sharing the following features: (i) ventral keel on the midline of the centra of anterior dorsal vertebrae

(C332); and (ii) ratio of the mediolateral width of the middle sacral centra to the first and the last sacral centra is 1.3 or greater (C347). The new clade established herein, Lohuecosauria, which includes lirainosaurines and saltasaurids (opisthocoelicaudiines and saltasaurines) is supported by ten synapomorphies: (i) dorsoventral height of the neural spine divided by posterior centrum height is 1.0 or greater in posteriormost cervical and anteriormost dorsal vertebrae (C19); (ii) dorsoventral height of the neural divided by centrum height in the anteriormost caudal vertebrae is 1.2 or greater (C32); (iii) the ratio of the maximum mediolateral width of proximal end to the proximodistal length in the ulna is 0.4 or greater (C50); (iv) the posterior surface of the basal tubera is not bordered laterally and ventrally by a raised and thickened lip (C100); (v) anterior and dorsal margins of the coracoid meet each other at an abrupt angle in lateral view (C218); (vi) humerus with a strong bulge close to the lateral margin of the posterior surface (C226); (vii) presence of a linea intermuscularis cranialis in the femoral anterior surface (C257); (viii) middle caudal centra with convex posterior articular surface dorsally displaced (C351); (ix) ratio of the maximum mediolateral width of distal end to the proximodistal length in humerus is 0.30 or greater (C370); and (x) proximal end of the metatarsal V is not expanded relatively to shaft (C395).

Qunkasaura pintiquiniestra is recovered as a member of Opisthocoelicaudiinae, which includes *Alamosaurus sanjuanensis*, at the base of the clade, and *Opisthocoelicaudia skarzynskii* and *Abditosaurus kuehnei*. The latter taxon comes from the Maastrichtian of the Tremp Basin (Spain) and is placed as the sister taxon of *Qunkasaura pintiquiniestra*. This relationship is supported by four shared features: (i) the anterior–middle dorsal diapophyses are elongated and dorsoventrally narrow (shared with brachiosaurids; C154); (ii) the anteroposterior width of the dorsal neural spines is approximately constant along the height of the spine (C159); (iii) the zygapophyseal articulation is between horizontal and less than 40° to the horizontal in anterior–middle dorsal neural arches (C337); and (iv) anteroposterior length of the centra shortens from anterior to posterior dorsal vertebrae (this is markedly abrupt in the centra of the

last dorsal vertebrae of *Qunkasaura pintiquirestria*; C466). This analysis recovered one local autapomorphy for *Qunkasaura pintiquirestria* [straight fibular shaft (C264)] and four autapomorphies for *Abditosaurus kuehnei* [(i) absence of the pcpl in middle dorsal neural arches (C148); (ii) absence of a ventral keel on midline in anterior dorsal centra (C332); (iii) lateral trochanter of the fibula visible in anterior view, (C392); (iv) presence of an anterolateral trochanter in the fibula (C548)]. These two taxa are closely related to *Opisthocoelicaudia skarzynskii*, this relationship being supported by five synapomorphies [(i) cross-section of the scapular blade is D-shaped, C217; (ii) absence of linea intermuscularis cranialis in the femur (C257); (iii) absence of osteoderms (C279); (iv) neural canal is enclosed in a deep fossa in the dorsal surface of the centrum in middle–posterior dorsal neural arches (C338); and (v) the glenoid of the coracoids does not expand laterally (C361)]. Finally, Opisthocoelicaudiinae, which includes *Alamosaurus sanjuanensis* at its base, is supported by five synapomorphies: (i) the mediolateral width of distal end to the mediolateral width at midshaft ratio is 2.0 or greater in the fibula (C69); (ii) subtriangular process at anteroventral corner of the scapular blade (C216); (iii) convex anterior articular surface of the centrum in the first caudal vertebra (C349); (iv) distal half of deltopectoral crest is mediolaterally expanded relative to proximal half (C369); and (v) posterior cervical neural spines are laterally expanded due the expansion of the lateral lamina (shared with lognkosaurs, C418). Compared to the equal weighting analyses, the topology between *Qunkasaura pintiquirestria*, *Abditosaurus kuehnei* and *Alamosaurus sanjuanensis* is similar, but now, with the inclusion of *Opisthocoelicaudia skarzynskii* within this clade.

Lirainosaurinae is recovered as a monophyletic clade with a new configuration when compared to previous studies^{8,11,83}. This clade includes the Late Cretaceous taxa of Iberia *Lohuecotitan pandafilandi* and *Liranosaurus astibiae*; the Armorican ones, *Atsinganosaurus velauciensis* and *Ampelosaurus atacis*; and *Paludititan nalatzensis* from Romania. This clade is supported by six synapomorphies: (i) posterior articular face mediolateral width to

dorsoventral height ratio in anterior dorsal centra is less than 1.3 (C21); (ii) the mediolateral to the anteroposterior width ratio for the tibial distal end is less than 1.5 (C68); (iii) absence of the podl in middle-posterior dorsal vertebrae (C152); (iv) the spol is divided into medial and lateral branches in middle-posterior dorsal neural spines (C165); (v) absence of biconvex distal caudal centra (C186); and (vi) distal end of the ulna is posteriorly expanded (C236). *Lirainosaurus astibiae* corresponds to the earliest branching member of the clade. *Lohuecotitan pandafilandi* is recovered as the sister-taxon of *Paludititan nalatzensis* (supported by six synapomorphies), and *Ampelosaurus atacis* as sister taxon of *Atsinganosaurus velauciensis* (supported by one synapomorphy). *Lohuecotitan pandafilandi* + *Paludititan nalatzensis* and *Ampelosaurus atacis* + *Atsinganosaurus velauciensis* are sister clades, and this relationship is supported by five synapomorphies. *Mansourasaurus shahinae*, from the Campanian of Egypt (North Africa) is recovered as the most basally branching member of Saltosaurinae, which does not support the close relationship of this taxon with other Campanian-Maastrichtian titanosaurs from Europe^{21,26}.

Observing the recovered topology for Lithostrotia clade, some polytomies are present within Colossosauria, namely, within the sister clade of Rinconsauria, which corresponds to the Lognkosauria. The titanosaur from the Cenomanian of Algora (Spain), which was recovered as closely related to NSNM V7157 from the Aptian of Italy (not included in these analyses, see ⁸⁴) and *Rapetosaurus krausei*, is now recovered at the base of Colossosauria. This position is supported by the following shared synapomorphies: absence of a ventral longitudinal hollow in the anterior (C181) and middle (C506) caudal centra; and absence of distinct ventrolateral ridges, extending the full length of the centrum, in anterior (C181) and middle (C507) caudal centra. Two other European titanosaurs were recovered as more deeply branched colossosaurs, the French titanosaurs *Normanniasaurus genceyi* (Albian) and *Garrigatitan meridionalis* (late Campanian). These taxa are included in a significant polytomy, which includes *Vahiny depereti*, *Jainosaurus septentrionalis*, *Puertasaurus reuili*, *Argentinosaurus huinculensis*, *Patagotitan*

mayorum, *Notocolossus gonzalezparejasi*, *Mendozasaurus neguyelap*, *Aeolosaurus rionegrinus* and *Futalognkosaurus dukei*. After pruning *Vahiny depereti*, *Normanniasaurus genceyi* is found within a polytomy that includes *Aeolosaurus rionegrinus*, *Jainosaurus septentrionalis* and *Garrigatitan meridionalis* is placed in polytomy with *Notocolossus gonzalezparejasi*, *Patagotitan mayorum* and *Puertasaurus reuili*.



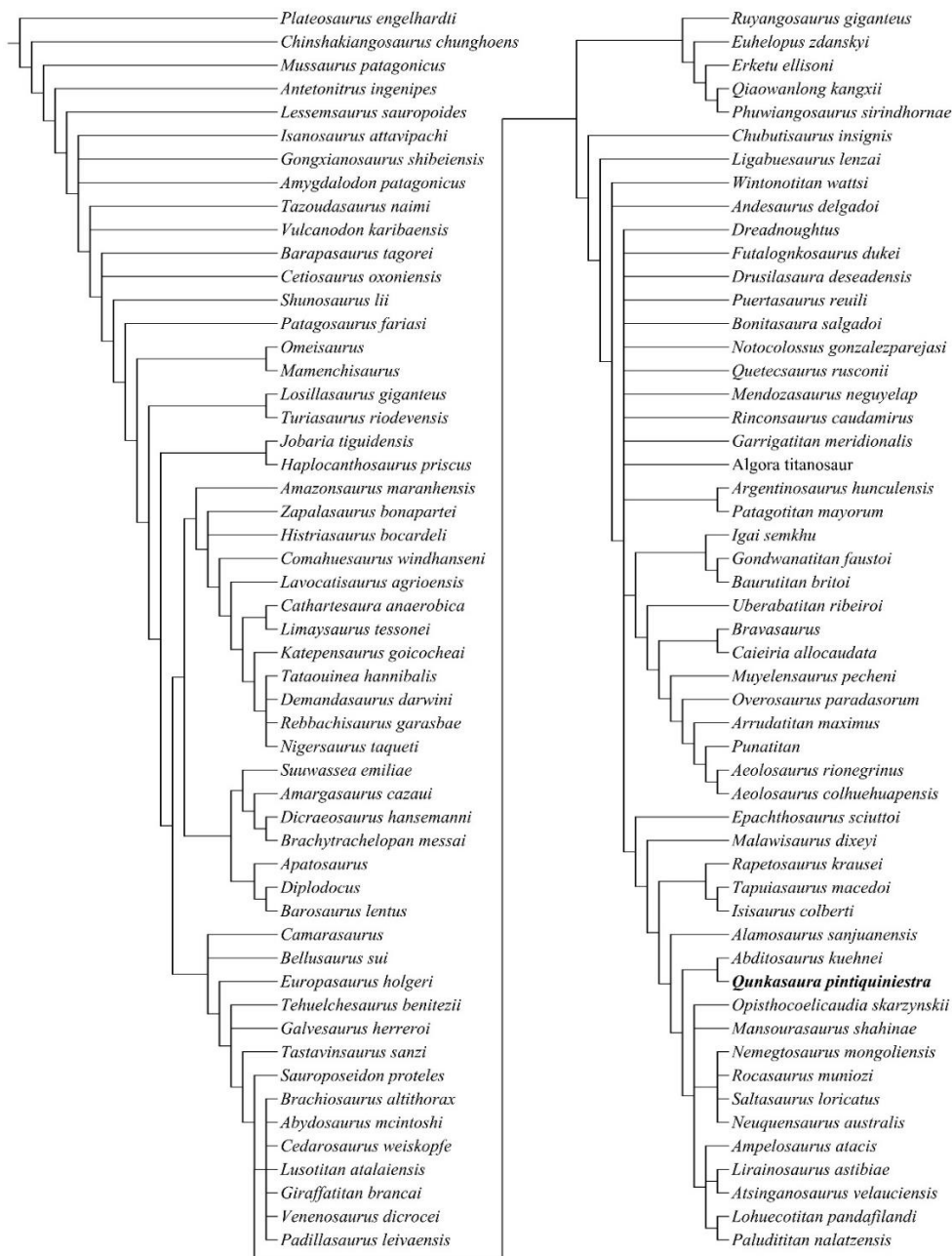
Supplementary Figure 5. Phylogenetic hypothesis obtained in analysis II (implied weights) based on the data matrix of Mocho et al.⁶⁶.

A second run of this implied weight analyses was conducted including *Igai semkhu*. The ‘New Technology Search’ resulted in 172 trees of length 151.62760 steps (CI: 0.198; RI: 0.596). These 172 trees were then used as the starting trees for a ‘Traditional Search’ using tree bisection–reconstruction (TBR). This analysis recovered more than 136080 most parsimonious trees (MPTs) with a length of 151.62760 steps (CI: 0.191; RI: 0.578). *Igai semkhu* is recovered as more deeply branched non-lithostrotian titanosaur than Diamantinasauria, in polytomy with *Xianshanosaurus* and *Daxiatitan*.

2.4. Analysis III:

The analysis III is an equal weight analysis based on Silva Junior et al.²⁸ dataset. The performed “Traditional search” yielded 4400 trees of length 1587 steps (CI: 0.333; RI: 0.722). A strict consensus tree from this search shows some degree of resolution within Titanosauria (Supplementary Fig. 6), which is similar to the pattern shown by the topology recovered in Silva Junior et al.²⁸. However, this topology is more poorly resolved than the one recovered for the implied weight analyses based on Mocho et al.⁶⁶. The main objective to perform this analysis based on Silva Junior et al.²⁸ is to assess the relationship of *Qunkasaura pintiquirestia* with Aeolosaurini and closely related forms. The results of this analyses propose that *Qunkasaura pintiquirestia* is not related with Aeolosaurines, which are recovered in a different lineage from the one that contains this new Ibero-Armorican lithostrotian titanosaur. In fact, aeolosaurines are recovered here as non-lithostrotian titanosaurs. *Qunkasaura pintiquirestia* is yielded as a member of Lithostrotia and sister taxon of *Abditosaurus kuehnei*, supporting our two first analyses. This node is supported by two synapomorphies: (i) the zygapophyseal articulation is horizontal or slightly posteroventrally oriented in anterior and middle dorsal vertebrae (C171); and (ii) the neural canal is enclosed in a deep fossa on middle and posterior dorsal vertebrae (C183). The node *Qunkasaura pintiquirestia* + *Abditosaurus*

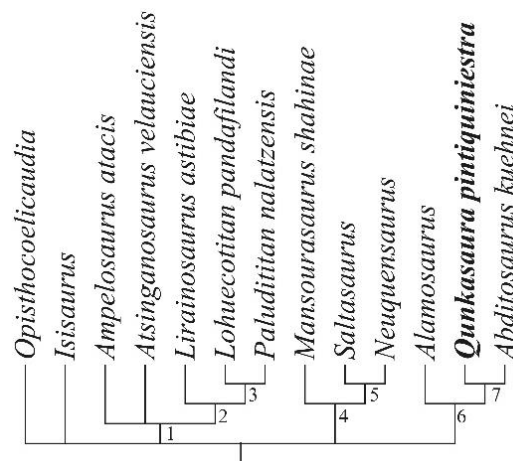
kuehnei is the sister taxon of Saltasauridae. The base of Saltasauridae includes *Opisthocoelicaudia skarzynskii*, *Mansourasaurus shahinae*, Liranosaurinae and Saltasaurinae in polotytomy, being supported by six synapomorphies. This analysis recovered *Lirainosaurus astibiae*, *Ampelosaurus atacis*, *Lohuecotitan pandafilandi*, *Atsinganosaurus velauciensis* and *Paludititan natalzensis* as members of Lirainosaurinae, as occurred in analyses I and II. Lirainosaurinae is supported by 12 synapomorphies. The Pruned Trees option in TNT recognizes the titanosaur of Algora, *Garrigatitan meridionalis*, *Isanosaurus attavipachi* and *Rebbachisaurus garasbae* as the most unstable taxa.



Supplementary Figure 6. Phylogenetic hypothesis obtained in analysis III (equal weights) based on the dataset of Silva Junior et al.²⁸.

3.5. List of Synapomorphies

Synapomorphies for the nodes within Saltasaurioidea of the phylogenetic hypothesis obtained in the analysis I (equal weights) from the data matrix of Mocho et al.⁶⁶ (Supplementary Fig. 7): **Node 1, Lirainosaurinae.** 16 (1→0), 21 (1→0), 29 (0→1), 165 (0→1), 186 (1→0), 259 (2→1), 501 (0→1), 505 (1→0), 514 (1→0); **Node 2.** 189 (0→1), 257 (0→1), 258 (0→1), 366 (0→1), 491 (0→1); **Node 3.** 65 (1→0), 147 (2→1), 148 (1→2), 182 (1→0), 353 (0→1); **Node 4, Saltasaurinae.** 41 (1→0), 225 (1→0), 517 (0→); **Node 5.** 122 (0&1→2), 328 (1→0), 361 (1→0); **Node 6.** 25 (1→0), 36 (0→1), 69 (1→0), 195 (0→1), 216 (0→1), 220 (1→0), 247 (0→1), 251 (0→1), 349 (0→1), 362 (0→1), 393 (0→1), 418 (0→1); **Node 7.** 154 (0→1), 159 (1→0), 337 (1→0).

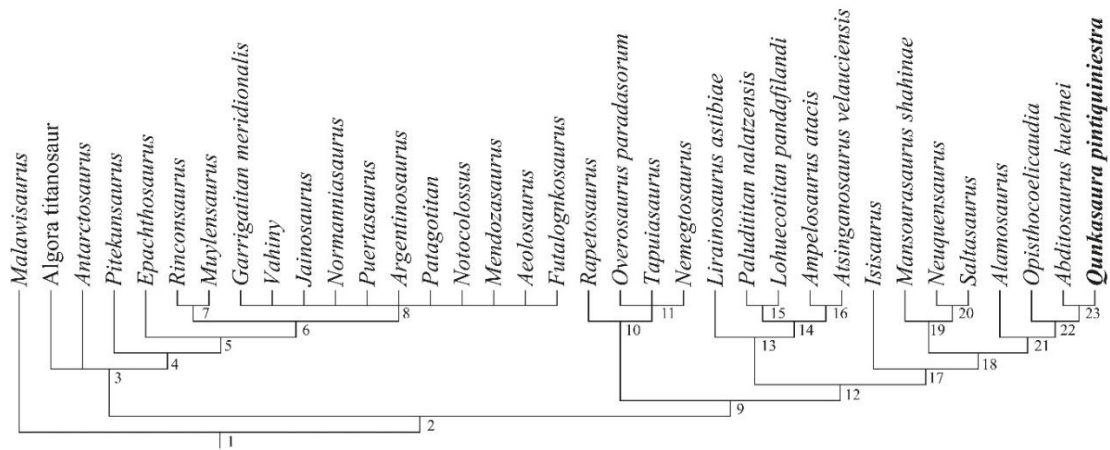


Supplementary Figure 7. Phylogenetic hypothesis obtained in the analysis I based on the dataset of Mocho et al.⁶⁶ with internal nodes numbered for list of synapomorphies.

Synapomorphies for the nodes within Listhostrofia of the phylogenetic hypothesis obtained in the analysis II (implied weights) from the dataset of Mocho et al.⁶⁶ (Supplementary Fig. 8):

Node 1, Lithostrotia. 15 (1→2), 33 (1→0), 151 (0→1), 194 (0→1), 279 (0→1), 327 (0→1), 491 (1→0); **Node 2.** 68 (1→0), 184 (0→1), 191 (1→0), 197 (0→), 234 (1→0), 303 (0→1), 318

(0→1), 319 (0→1), 372 (0→1); **Node 3, Colossosauria.** 181 (1→0), 182 (1→0), 506 (1→0), 507 (1→0), 544 (0→1); **Node 4.** 83 (1→0), 236 (1→0), 281 (1→0), 282 (0→1); **Node 5.** 50 (0→1), 234 (0→1), 356 (0→1), 372 (1→0); **Node 6.** 164 (1→0), 338 (0→1), 361 (1→0), 369 (0→1), 420 (0→1); **Node 7, Rinconsauria.** 225 (1→0), 351 (1→0); **Node 8, Lognkosauria.** 19 (1→0), 33 (0→1), 74 (0→1), 159 (1→0), 163 (0→1), 217 (0→1), 233 (1→0), 252 (1→0), 311 (1→0), 337 (1→0), 417 (0→1), 418 (0→1), 545 (0→1); **Node 9, Saltasaurioidea.** 28 (0→1), 229 (0→1), 255 (1→0), 260 (1→0), 273 (0→1), 312 (0→1), 325 (0→1), 332 (0→1), 347 (0→1), 360 (0→1), 378 (0→1), 390 (0→1); **Node 10.** 47 (1→0), 85 (0→1), 245 (1→0), 344 (0→1), 393 (1→0), 520 (0→1), 547 (0→1); **Node 11.** 104 (0→2), 122 (0→1), 162 (1→0), 169 (0→1), 291 (0→1), 292 (0→1), 299 (0→1), 436 (0→1); **Node 12, Lohuecosauria.** 19 (1→0), 32 (1→0), 50 (0→1), 100 (1→0), 218 (0→1), 226 (0→1), 257 (0→1), 351 (1→0), 370 (1→0), 395 (0→1); **Node 13, Lirainosaurinae.** 21 (1→0), 68 (0→1), 152 (0→1), 165 (0→1), 186 (1→0), 236 (1→0); **Node 14.** 194 (1→0), 333 (0→1), 372 (1→0), 507 (1→0), 557 (0→1); **Node 15.** 65 (1→0), 147 (2→1), 148 (1→2), 182 (1→0), 353 (0→1), 356 (0→1); **Node 16.** 252 (1→0); **Node 17.** 15 (2→0&1), 157 (0→1), 173 (1→0), 219 (0→1); **Node 18, Saltosauridae.** 41 (1→0), 125 (0→1), 230 (0→1), 247 (0→1), 372 (1→0); **Node 19, Saltosaurinae.** 225 (1→0), 284 (1→0), 359 (0→1), 517 (0→1); **Node 20.** 122 (0→2), 361 (1→0); **Node 21, Opisthocoelicaudiinae.** 69 (1→0), 216 (0→1), 349 (0→1), 369 (0→1), 418 (0→1); **Node 22.** 217 (0→1), 257 (1→0), 279 (1→0), 338 (0→1), 361 (1→0); **Node 23.** 154 (0→1), 159 (1→0), 337 (1→0), 466 (0→1).

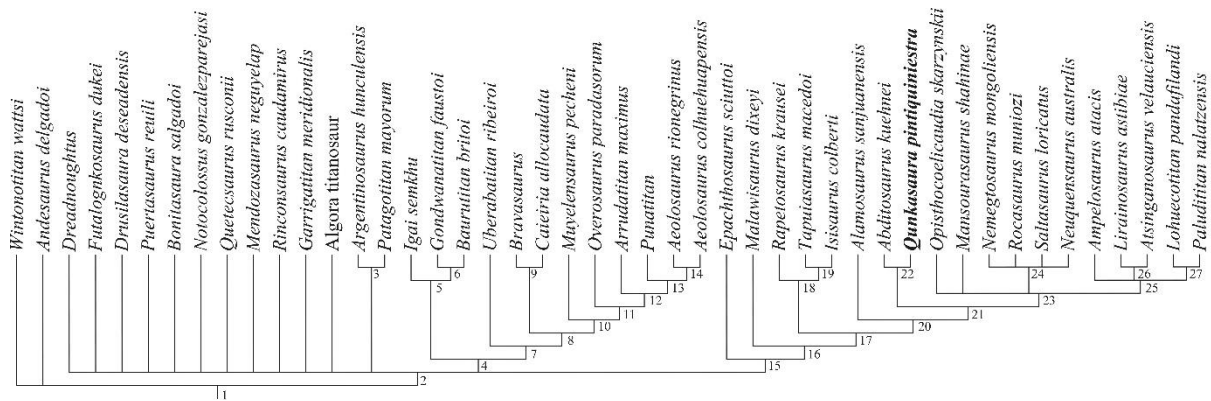


Supplementary Figure 8. Phylogenetic hypothesis for Lithostrotia obtained in analysis II (implied weights) based on the dataset of Mocho et al.⁶⁶ with internal nodes numbered for list of synapomorphies.

Synapomorphies for the nodes within Titanosauria of the phylogenetic hypothesis obtained in the analysis III based on the dataset of Silva Junior et al.²⁸ (Supplementary Fig. 9):

Node 1, Titanosauria. 165 (1→2), 178 (1→0); **Node 2.** 170 (1→2), 179 (0→1), 180 (0→2), 222 (0→1), 224 (0→1), 231 (1→3), 237 (0→2), 248 (0→1), 252 (0→3), 260 (0→1), 261 (0→1), 283 (1→0), 304 (0→1), 341 (0→1); **Node 3.** 159 (3→1), 173 (0→2), 174 (0→1), 175 (1→2), 176 (0→1), 179 (1→0), 196 (1→2); **Node 4.** 132 (2→3), 141 (1→2), 151 (0→1), 153 (1→0), 160 (1→3), 172 (0→1), 182 (0→1), 185 (1→2), 196 (1→0), 222 (1→0), 233 (0→1&2), 237 (2→1), 243 (0→2), 248 (1→0), 260 (0→1), 420 (0→1); **Node 5.** 157 (0→1); **Node 6.** 189 (0→1); **Node 7.** 122 (1→2); **Node 8.** 171 (1→2), 369 (0→1); **Node 9.** 420 (1→2); **Node 10.** 141 (2→1); **Node 11.** 234 (0→1), 254 (0→2), 255 (0→1), 423 (0→1); **Node 12.** 257 (1&2→0), 420 (1→2); **Node 13.** 251 (0→1), 413 (1→0); **Node 14.** 424 (0→2); **Node 15.** 172 (0→1), 185 (1→2), 237 (2→0), 248 (1→0), 251 (0→1), 257 (2→1), 306 (1→0), 311 (1→0); **Node 16, Lithostrotia.** 171 (1→2), 227 (1→0), 365 (0→1), 423 (0→1); **Node 17.** 2 (1→0), 14 (1→2), 87 (0→1), 108 (2→3), 206 (0→1), 305 (0→1); **Node 18.** 33 (0→1), 64 (0→1), 80 (0→1), 151 (0→1), 160 (1→3), 196 (1→0), 257 (1→2), 260 (0→1), 306 (0→1); **Node 19.** 170 (2→1), 185 (2→0); **Node 20.** 237 (0→1), 288 (0→1), 297 (0→1), 302 (0→1), 315 (0→1), 360 (0→1), 371

(0→1); **Node 21.** 162 (1→0), 233 (0→1), 298 (0→1); **Node 22.** 171 (2→1), 183 (0→1); **Node 23.** 257 (1→2), 276 (1→0), 277 (3→0), 282 (1→0), 291 (0→1), 423 (1→0); **Node 24. Saltosaurinae.** 37 (0→1), 73 (0→1), 134 (1→0), 142 (1→0), 151 (0→1), 157 (0→1), 178 (2→1), 221 (0→1), 258 (0→1), 259 (0→1), 262 (0→1), 286 (1→0), 300 (2→1), 370 (1→0), 414 (1→0), 418 (0→1), 419 (0→1); **Node 25, Lirainosaurinae.** 128 (1→0), 195 (2→0), 202 (1→0), 205 (0→1), 248 (0→1), 251 (1→0), 286 (1→0), 306 (0→1), 330 (0→1), 357 (0→1), 360 (1→0), 420 (0→1); **Node 26.** 157 (0→1), 363 (1→0); **Node 27.** 195 (0→1), 207 (2→1), 234 (1→0), 252 (3→2), 257 (2→1), 355 (2→1), 425 (0→1).



Supplementary Figure 9. Phylogenetic hypothesis for Titanosauria obtained in analysis III (equal weights) based on the dataset of Silva Junior et al.²⁸ with internal nodes numbered for list of synapomorphies.

Supplementary Note 3. *Qunkasaura pintiquiniestra* in the context of the Ibero-Armorican titanosaurs

The European fossil record from the Upper Cretaceous levels is rich in titanosaurian occurrences, spanning from the Cenomanian to the Maastrichtian, including many new discoveries during the last three decades, resulting in the establishment of new taxa^{8,21,23,29,33,55,59,72-77,85-89}. In the last twenty years, a highly diverse Campanian-Maastrichtian sauropod fauna has been identified for the Ibero-Armorican domain, with six titanosaurian taxa currently considered valid: *Lirainosaurus astibiae*⁷³, *Atsinganosaurus velauciensis*²⁹, *Ampelosaurus atacis*⁷⁶ and, more recently, *Lohuecotitan pandafilandi*²³, *Garrigatitan meridionalis*⁸ and *Abditosaurus kuehnei*²¹. However, some authors pointed to a more diverse scenario, with taxa still to be described^{21,23,85,89}. Despite the Ibero-Armorican island corresponds to the largest landmass of the European archipelago during the Campanian-Maastrichtian, a full comprehension of the ecosystems that sustain such a diverse fauna of herbivores with small- to large-sized sauropods (including some putative dwarf forms) and ornithopods, still needs to be clarified. The redescription of some previously established taxa^{5,11,59} and old specimens^{21,77}, as well as the increasing number of new phylogenetic approaches incorporating the Ibero-Armorican titanosaurian taxa^{8,11,21,83,90,91}, are improving our knowledge about the evolutionary history of the titanosaurs from the Ibero-Armorican domain.

Knowledge of the systematics of some Late Cretaceous titanosaurs from Ibero-Armorica is complex due to the lack of information on some taxa based on remains in questionable association, which may lead to an overestimation of their diversity. This scenario has dramatically changed in more recent years, first with the discovery of the Lo Hueco fossil-site in Cuenca (Spain), a Campanian-Maastrichtian multi-taxic bonebed from the Villalba de la Sierra Formation, which has yielded more than 10,000 fossils of which nearly half correspond to titanosaurian remains, including multiple skeletons; and second, with the description and establishment of *Abditosaurus kuehnei*, found in the Maastrichtian rocks of the Conques

Formation in Lleida, Spain²¹. Besides, preliminary studies indicated the presence in Lo Hueco of at least two titanosaurian forms based on the presence of two distinct morphologies of cranial, teeth, and appendicular bones⁹²⁻⁹⁶; a higher diversity has been proposed in recent works⁹⁷.

Apart from *Lohuecotitan pandafilandi* and *Abditosaurus kuehnei*, and now, *Qunkasaura pintiquiniestra*, which are based on partially articulated to associated sets of bones, the remaining taxa are mainly represented by holotypes restricted to a single bone or a small set of associated bones plus referred material from the same multi-taxic bone beds in which the degree of skeletal articulation or association is low and in which more than one titanosaur may be represented^{8,10,11,76,98-100}. The future systematic reassessment of some of these taxa will be important to: (i) find diagnostic features in the holotype specimens that can be used to support the validity of these taxa; (ii) identify elements that can be referred to these taxa with a certain degree of confidence, avoiding doubtful associations, which also can improve the diagnosis of the taxon; and (iii) update the scorings used in our morphological data sets. We consider that more conservative taxonomic approaches are necessary, and we should exclude elements with questionable association that might add uncertainty to phylogenetic analyses and affect the topological resolution of the obtained trees (this systematic review is outside the scope of this study).

In this study, we established a new titanosaurian taxon, *Qunkasaura pintiquiniestra*, that expand the already diverse sauropod fauna known from the Ibero-Armorican Island during the Campanian-Maastrichtian. The detailed description and comparison with the established European taxa and the presence of a set of exclusive features, including several exclusive autapomorphies, support the validity of *Qunkasaura pintiquiniestra*, and differentiate it from other European titanosaurs, especially, *Abditosaurus kuehnei*, which is recovered as its sister-taxon. In addition, our phylogenetic analyses recovered *Qunkasaura pintiquiniestra* in a different position from the lirainosaurines *Lohuecotitan pandafilandi*, *Lirainosaurus astibiae*, *Ampelosaurus atacis*, *Atsinganosaurus velauciensis* and *Paludititan nalatzensis*; and, from

Garrigatitan meridionalis, which is placed within Colossosauria. The morphology of the presacral vertebrae of *Qunkasaura pintiquiniestra* is markedly different from holotype specimens of *Lohuecotitan pandafilandi*, *Ampelosaurus atacis* and *Atsinganosaurus velauciensis* (and also some referred material), and the referred dorsal vertebrae of *Lirainosaurus astibiae*, highlighting the: (i) presence of rudimentary epiphyses in the posterior cervical vertebrae; (ii) strong opisthocoelous condition in posterior dorsal vertebrae and dorsalventrally compressed articular surfaces of the centrum, unlike *Lohuecotitan pandafilandi* and the referred dorsals of *Lirainosaurus astibiae*; (iii) presence of a ventral keel in anterior dorsal vertebrae, absent in *Abditosaurus kuehnei*, and in the lirainosaurines *Ampelosaurus atacis* and *Atsinganosaurus velauciensis*; (iv) laterally projected transverse processes (shared with *Abditosaurus kuehnei*); and (v) presence of concave postzygapophyses in posterior cervical and anterior dorsal vertebrae, unlike the other lirainosaurines and *Abditosaurus kuehnei*. This new taxon from Lo Hueco fossil-site is considered as a sister taxon of *Abditosaurus kuehnei*, which were found in possible younger sedimentary deposits of the Iberian Peninsula. However, the latter can be differentiated from *Qunkasaura pintiquiniestra* by the absence of the acdl in the anterior dorsals. Dorsal vertebrae of *Qunkasaura pintiquiniestra* are characterized by the presence some unique features such as a neural arch located at midpoint of the centrum not reaching the anterior surface; acpl, pcpl, acdl and pcpl preserves a M-shaped laminar structure; a highly anteroposteriorly compressed neural spines (the mediolateral width is six times its anteroposterior length); and a straight fibular shaft.

The caudal vertebrae of *Qunkasaura pintiquiniestra* preserve a peculiar morphology, which seems to converge with the morphology observed in some aeolosaurines (see Supplementary Note 4), which differs from the holotype specimen of *Lohuecotitan pandafilandi*, and the referred material of *Lirainosaurus astibiae*, *Ampelosaurus atacis* and *Atsinganosaurus velauciensis* (no caudal vertebrae have been found in *Garrigatitan meridionalis* and *Abditosaurus kuehnei*). A first biconvex anterior caudal centrum, the anterior

inclination of the neural spines and anterior articular surface, the anterior displacement of the postzygapophyses and the well-developed prezygapophyseal processes are some of these features, absent in other Campanian-Maastrichtian titanosaurs from the Ibero-Armorican island. The holotype of *Garrigatitan meridionalis* is a partially complete sacrum and differentiates from *Qunkasaura pintiquirestria* by the presence of: (i) a ventral keel extending up to from the third from the fifth (the sixth caudal vertebra is not preserved); (ii) non-camellar sacral vertebra; and (iii) rudimentary or absent supraspinous rod. In addition, the preacetabular process is more laterally projected than in *Qunkasaura pintiquirestria*, there is a circular fossa near the preacetabular process in the referred ilium of *Garrigatitan meridionalis*; and the maximum dorsoventral height is located anterior to the base of the pudic peduncle unlike *Qunkasaura pintiquirestria*. Other elements were referred to this titanosaur from the Campanian-Maastrichtian of France, but they are not preserved in the holotype of *Qunkasaura pintiquirestria*, being impossible to provide a more detailed anatomical comparison. Also, the reference of some of these remains to *Garrigatitan meridionalis* can be problematic [some of them were found in distinct sedimentary levels (see Díez Díaz et al.⁸)].

Supplementary Note 4. **Caudal vertebral morphology: Aeolosaurine-like caudal vertebrae in *Qunkasaura***

The anterior section of the tail in *Qunkasaura pintiquirestria* presents several features that have been considered as characteristic of aeolosaurines. One of these features is the inclination of the anterior articular surface of the centrum^{46,101}, which has been codified as a morphological character in some datasets^{46,50,52}. Evaluating the evolution of this inclination measured in several caudal series whose precise position (or plausible one) is known, it can be noted that several titanosaurs gain a marked anterior inclination around third and fourth caudal vertebra (see Supplementary Table 3), including the members of Aeolosaurini. This is easily observed in well-preserved caudal series such as those of *Neuquensaurus australis*³⁶, *Lohuecotitan pandafilandi* and *Qunkasaura pintiquirestria*, but this decline is not as pronounced in some other titanosaurian taxa (e.g. *Alamosaurus sanjuanensis*⁴²). However, along the second half of the anterior caudal series, particularly from the fifth-to-eleventh element of the series, this anterior inclination becomes particularly pronounced (less than 75° from the horizontal) in the aeolosaurines as *Aeolosaurus rionegrinus*^{34,56}, *Aeolosaurus* sp. (MPCA-27174, ¹⁰²), *Arrudatitan maximus*^{46,54} and *Gondwanatitan faustoi*⁵⁷, excluding *Aeolosaurus colhuehuapensis*¹⁰³ (Supplementary Table 3). This feature is also present in some lithostrotians that have been considered as possible members of this clade or closely related forms such as *Adamantisaurus mezzalirai* (MUGEO 1282, ¹⁰⁴), *Overosaurus paradisorum*¹⁴, *Punatitan coughlini*⁵², *Trigonosaurus pricei*²⁷ or *Uberabatitan ribeiroi*¹⁰⁵. *Qunkasaura pintiquirestria* shares this pronounced inclination (one of the strongest in all titanosaurs) being one of the only members of the Saltasauroida clade to have it. Other titanosaurs, including other saltasauroids and early branching members of Titanosauria yield values above 75°, which start to recover its verticality along anterior-middle section of the tail (e.g. *Neuquensaurus australis*, *Alamosaurus sanjuanensis*, *Baurutitan britoi* and *Dreadnoughtus schrani*).

Taxon / position in the caudal series	Inclination of the anterior articular surface of the centrum												
	Cd1	Cd2	Cd3	Cd4	Cd5	Cd6	Cd7	Cd8	Cd9	Cd10	Cd11	Cd12	Cd13
<i>Qunkasaura pintiuginiestra</i>	95.2*	90.0	73.9	70.5	68.1	73.2	70.5	64.9	64.1	72.3	67.4	?	?
<i>Lohuecotitan pandafilandi</i>	100.1	90.9	100.1	83.6	80.5	?	82.3*	?	82.6	82.6	?	?	?
<i>Aeolosaurus rionegrinus</i>	?	?	?	?	?	?	73.0	68.6	?	?	?	?	?
<i>Aeolosaurus colhuehuapensis</i>	?	?	?	?	77.5	?	?	?	77.2	?	?	?	?
<i>Aeolosaurus</i> sp. MPCA-27174**	?	?	85.1	?	68.7	?	?	?	?	66.2	?	?	?
<i>Overosaurus paradasorum</i>	91.7	83.3	?	?	?	?	?	?	76.0	70.9	72.3	80.0	?
<i>Arrudatitan maximus**</i>	?	?	?	85.4	75.8	76.6	?	77.6	71.1	?	?	?	?
<i>Gondwanatitan faustoi</i>	?	?	?	?	70.6	?	?	?	?	?	?	?	?
<i>Trigonosaurus pricei</i>	?	76.5	78.5	70.7	69.7	71.0	73.2	75.5	73.8	77.0	?	?	?
<i>Opisthocoelicaudia skarzynskii</i>	78.8	75.4	?	75.2	?	76.4	75.5	?	80.6	75.4	83.0	82.5	78.9
<i>Neuquensaurus australis</i>	83.9	102.9	82.2	87.1	84.8	87.1	87.3	83.7	88.9	89.7	87.2	88.1	80.0
<i>Mendozasaurus neguyelap</i>	?	?	93.1	77.7	?	?	?	76.2	?	?	?	?	?
<i>Andesaurus delgadoi</i>	84.1	80.3	?	?	?	?	?	79.1	?	75.6	79.8	84.4	90.0
<i>Dreadnoughtus schrani</i>	81.5	73.8	75.7	77.2		81.2	83.6	82.4	79.7	83.8	79.0	71.4	75.4
MOZ-Pv 1221	?	?	?	84.8	80.3	83.6	?	84.6	80.3	?	76.5	78.1	79.0
<i>Alamosaurus sanjuanensis</i>	?	85.2	85.2	76.0	?	?	80.1	79.7	78.5	79.4	90.0	80.3	81.7
<i>Baurutitan britoi</i>	91.1	85.1	80.9	78.9	71.6	77.5	76.5	78.8	82.3	76.4	81.1	83.0	85.5

Supplementary Table 3. Inclination of the anterior articular surface of the centrum from the first to the thirteenth caudal vertebrae, measured in lateral view with orientation of the chevron facets in the horizontal plane. Values were obtained for *Qunkasaura pintiuginiestra* (pers observ. PM 2019), *Lohuecotitan pandafilandi* (pers observ. PM 2019), *Aeolosaurus rionegrinus*^{34,56}, *Aeolosaurus colhuehuapensis*¹⁰³, *Aeolosaurus* sp. MPCA-27174¹⁰², *Overosaurus paradasorum*¹⁴, *Arrudatitan maximus*⁴⁶, *Gondwanatitan faustoi*⁵⁷, *Trigonosaurus pricei*²⁷, *Opisthocoelicaudia skarzynskii*²², *Neuquensaurus australis*³⁶, *Mendozasaurus neguyelap*⁹ (pers. observ. PM 2019), *Andesaurus delgadoi*⁴⁹, *Dreadnoughtus schrani*⁴¹, MOZ-Pv 1221 titanosaur¹⁰⁶, *Alamosaurus sanjuanensis*⁴² and *Baurutitan britoi*⁴³. A vertical position of the anterior articular surface of the centrum corresponds to 90°; an anterior inclination is less than 90° and a posterior one is more than 90°. *Approximated; ** estimated position.

The orientation of the neural spine in the anterior and middle caudal vertebrae is also an important feature in titanosauriforms, being used for phylogenetical analysis in several morphological datasets^{6,32}. We analyzed the evolution of this character in the first thirteen caudal vertebrae for several titanosaur (see Supplementary Table 4). The pattern of the neural

spine inclination is diverse, and the angle can be highly variable along the anterior-middle section of the tail. An anterior inclination is generally common in many titanosaurs (reaching no more than 80° from the horizontal plane) and is present in some sectors of the anterior-to-middle series of caudal vertebrae (it appears at least two times in *Mendozasaurus neguyelap*; see ⁹). Subvertical (or with slightly anteriorly deflection, no more than 80°) to posteriorly oriented neural spines can be observed in several titanosaurs such as *Andesaurus delgadoi*⁴⁹, *Rukwatitan bisepultus*¹⁰⁷, the early branching lithostrotian *Malawisaurus dixeyi*⁴⁷, the colossosaurs *Muyelensaurus pecheni*¹⁰⁸, *Rinconsaurus caudamirus*¹⁰⁹ and MOZ-Ov 1221¹⁰⁶, the saltasauroids *Alamosaurus sanjuanensis*⁴², *Isisaurus colberti*⁵¹, *Lirainosaurus astibiae*⁵, *Saltasaurus loricatus*³⁵ (PVL 4017), *Opisthocoelicaudia skarzynskii*²², *Neuquensaurus australis*³⁶, and other lithostrotians with more uncertain phylogenetic position such as *Baurutitan britoi*⁴³ and *Narambuenatitan palamoi*¹¹⁰. However, some taxa can reach an extreme anterior deflection, including the members of Aeolosaurini and some closely related taxa^{28,34,43,46,52,56,101-105}, *Mendozasaurus neguyelap*⁹ and *Qunkasaura pintiquirestia*. The anterior displacement of the anterodorsal edge of the neural spine beyond the anterior articular surface of the centrum is present in the aeolosaurines *Arrudatitan maximus*, *Aeolosaurus* sp. (MPCA-27174,¹⁰²), *Trigonosaurus pricei*²⁷, *Punatitan coughlini*⁵² and possibly *Gondwanatitan faustoi*⁵⁷, but also present in the saltasauroid *Qunkasaura pintiquirestia* and in the colossosaurs *Dreadnoughtus schrani*⁴¹ and *Mendozasaurus neguyelap*⁹ (only in the first middle caudal vertebrae, which seem to be taphonomically deformed). However, this condition is absent in some taxa with a remarkable anterior inclination of the spine such as *Pitekunsaurus macayai* and *Uberabatitan ribeiroi*^{105,111}. The eleventh caudal vertebrae of *Qunkasaura pintiquirestia* preserves one of the more extreme anterior deflections of a caudal neural spine recorded for a titanosaur.

A postzygapophysis placed at the anterior half of the centrum has been considered a diagnostic feature for the genus *Aeolosaurus*, which seems to be partially related with the

anterior inclination of anterior articular centrum facet (particularly pronounced in aeolosaurines or closely related taxa) and the anterior displacement of the neural arch (the plesiomorphic condition in Somphospondyli). This feature has been used in some morphological datasets⁴⁶. In the genus *Aeolosaurus*, the postzygapophysis is located on front of the anterior articular surface of the centrum^{34,56,103}. This anterior displacement of the postzygapophysis is also well-developed in other, but not all, aeolosaurine forms (including some forms that have been recently recovered as closely related members of the group in some phylogenetic approaches such as *Baurutitan britoi*; see²⁸). Non-aeolosaurine lithostrotians bear a postzygapophysis located at level of the mid-centrum length or posteriorly such as saltosaurines, lognkosaurs and the rincosaurs *Muyelensaurus pecheni* and *Rincosaurus caudamirus*. In lirainosaurine saltasauroids, we found some variation. Thus, in the *Paluditian nalatzensis*³³ and *Lohuecotitan pandafilandi*, the postzygapophyses are located at mid-centrum length, but in some caudal vertebrae referred to *Atsinganosaurus velauciensis* the postzygapophyses are slightly anteriorly displaced. In contrast, the opisthocoelicaudiine *Qunkasaura pintiquirestia* is characterized by an extreme anterior displacement of the postzygapophyses, located at the level of the anterior articular surface of the centrum, corresponding to the second most extreme anterior displacement observed in lithostrotians, just after the genus *Aeolosaurus* (although this character was not considered in our two first phylogenetic analyses, we consider it here as a local autapomorphy of this taxon). Another feature that seems to be significantly developed in aeolosaurines and shared by *Qunkasaura pintiquirestia* is the development of the prezygapophyseal processes. The extension beyond the anterior margin of the centrum is variable throughout the tail; and when we analyze the posterior half of the anterior series, it is possible to observe an extreme development of this feature in *Aeolosaurus*^{34,56,103}; i.e. the anteroposterior length of the prezygapophyseal processes is 113% and 93% of the anteroposterior centrum length in *Aeolosaurus colhuehuapensis* and *Aeolosaurus rionegrinus*, respectively. *Qunkasaura pintiquirestia* seems to reach the maximum development of the

prezygapophyseal process around the seventh caudal vertebra (92% of the anteroposterior length of the centrum). The remaining aeolosaurine and closely related forms preserve less developed prezygapophyseal processes (generally over than 60% of the anteroposterior length of the centrum; except for *Overosaurus paradasorum*¹⁴). *Rinconsaurus caudamirus*, *Muyelensaurus pecheni*, and most saltasauroids, including lirainosaurines (referred material to *Ampelosaurus atacis* should be re-analyzed) have less anteriorly developed prezygapophyseal processes.

Taxon / position in the tail	Inclination of the caudal neural spine												
	Cd1	Cd2	Cd3	Cd4	Cd5	Cd6	Cd7	Cd8	Cd9	Cd10	Cd11	Cd12	Cd13
<i>Qunkasaura pintiquirestia</i>	?	?	?	?	?	?	?	68.0	?	?	21.4	?	?
<i>Lohuecotitan pandafileandi</i>	113.3	115.0	120.5	104.7	?	?	95.2	92.0	84.1	?	?	?	?
<i>Aeolosaurus</i> sp. MPCA-27174**	?	?	?	?	71.4	?	?	?	?	67.0	?	?	?
<i>Overosaurus paradasorum</i>	?	?	?	?	?	?	?	?	?	?	?	?	93.0
<i>Arrudatitan maximus</i> **	?	?	?	104.5	87.8	71.3	?	78.1	60.6	?	?	?	?
<i>Gondwanatitan faustoi</i>	?	?	?	?	62.1	?	?	?	?	?	?	?	?
<i>Trigonosaurus pricei</i>	85.0	83.6	73.8	72.2	70.5	79.3	81.4	90.0	83.4	88.0	?	?	?
<i>Opisthocoelicaudia skarzynskii</i>	111.8	108.3	113.0	107.0	98.8	97.9	97.1	?	88.0	83.0	84.6	83.6	81.5
<i>Neuquensaurus australis</i>	90.0	131.0	120.9	147.0	142.0	145.0	143.0	144.0	145.0	142.0	138.0	?	?
<i>Mendozasaurus neguyelap</i> **	?	?	?	81.0	?	?	?	112.9	?	?	?	70.0*	66.0
<i>Andesaurus delgadoi</i>	?	?	?	?	?	?	?	106.2	?	105.6	110.3	113.6	114.6
<i>Dreadnoughtus schrani</i>	?	102.6	108.6	?	105.8	110.7	98.2	101.0	74.2	74.9	60.7	64.3	60.9
MOZ-Pv 1221	?	?	?	110.0	111.1	115.8	113.5	121.5	114.8	113.5	92.9	84.0	99.0
<i>Alamosaurus sanjuanensis</i>	106.1	123.0	118.7	105.1	104.0	109.0	113.2	101.6	84.5	85.4	106.5	118.0	124.0
<i>Baurutitan britoi</i>	124.8	126.8	118.0	105.0	96.2	100.0	99.0	93.0	92.6	90.0	97.3	102.0	107.0

Supplementary Table 4. Inclination of the caudal neural spine from the first to the thirteenth caudal vertebrae measured in lateral view with the chevron facets oriented at the horizontal plane. Values were obtained for *Qunkasaura pintiquirestia* (pers observ. PM 2019), *Lohuecotitan pandafileandi* (pers observ. PM 2019), *Aeolosaurus* sp. MPCA-27174¹⁰²; *Overosaurus paradasorum*¹⁴, *Arrudatitan maximus*⁴⁶, *Gondwanatitan faustoi*⁵⁷, *Trigonosaurus pricei*²⁷, *Opisthocoelicaudia skarzynskii*²², *Neuquensaurus australis*³⁶, *Mendozasaurus neguyelap*⁹ (pers. observ. PM 2019), *Andesaurus delgadoi*⁴⁹, *Dreadnoughtus schrani*⁴¹, the titanosaur MOZ-Pv 1221¹⁰⁶, *Alamosaurus sanjuanensis*⁴² and *Baurutitan britoi*⁴³. A vertical position of the caudal neural spine corresponds to 90°; an anterior inclination is less than 90° and a posterior one is more than 90°. *Approximated; ** estimated position.

The acquisition of extremely anteriorly inclined anterior articular surface of centrum, anteriorly displaced postzygapophyses, anteriorly elongated prezygapophyseal processes, and anteriorly projected neural spines in the anterior caudal vertebrae seems to characterize the peculiar tail morphology of aeolosaurines and closely related taxa. Our phylogenetic analyses support that this morphology was also achieved independently by the opisthocoelicaudiine *Qunkasaura pintiquirestria* (Fig. 3). Future studies are necessary to add more data about the morpho-functionality of the unique tail of *Qunkasaura pintiquirestria*. A recent study of the caudal biomechanics of *Aeolosaurus maximus* by Vidal et al.¹¹² suggests that aeolosaurines tails might be characterized by a sigmoidal curvature. The anterior caudal series of *Qunkasaura pintiquirestria* was found with a very slight ventral curvature not having a pronounced protonic posture after death as in *Aeolosaurus maximus*. The shared morphology of the tail between *Qunkasaura pintiquirestria* and aeolosaurines suggests that this new titanosaur might have a significantly ventrally arched tail, becoming the first evidence for this type of morphology in the Late Cretaceous titanosaurs of Europe.

Supplementary Note 5. **Digitizing the bones of *Qunkasaura pintiuniestra***

The bones from the holotype specimen were digitized by digital structure from motion photogrammetry, using the same protocol described by Mallison and Wings¹¹³. The distinct sides of the elements were photographed separately and put together in Agisoft Photoscan 1.2.6 using a virtual alignment technique. The digital models of the specimens are available in

Morphosource:

- (1) <https://www.morphosource.org/concern/media/000636805?locale=en>
- (2) <https://www.morphosource.org/concern/media/000636799?locale=en>
- (3) <https://www.morphosource.org/concern/media/000636793?locale=en>

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