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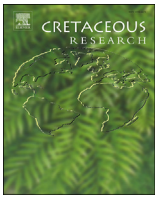

Arackar licanantay gen. et sp. nov. a new lithostrotian (Dinosauria, Sauropoda) from the Upper Cretaceous of the Atacama Region, northern Chile

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ABSTRACT

A new lithostrotian sauropod, *Arackar licanantay* gen. et sp. nov. is described based on a partial skeleton from the Upper Cretaceous (Campanian–Maastrichtian) beds of the Hornitos Formation, Atacama Region, northern Chile. The holotype consists of axial (cervical and dorsal vertebrae) and appendicular (humerus, femur and ischium) elements of a sub-adult specimen (ca. 6.3 m long). Autapomorphies characterizing this new titanosaur include: middle neural arches with wide and tall centroprezygapophyseal fossa + parapophyseal centroprezygapophyseal fossa (cprf + pacprf) extending on the entire anterior faces of the pedicles, but not above the neural canal, and reduced spinopostzygapophyseal laminae, shorter than the postzygapophyseal facet length. A phylogenetic analysis based on a data matrix of 87 taxa and 405 characters recovered *Arackar* as a derived lithostrotian titanosaur, placing it in a clade that includes *Rapetosaurus* + (*Arackar* + *Isisaurus*). This is the third dinosaur named from Chile and the third titanosaur from the western side of the Andes in South America.

1. Introduction

Titanosaurian sauropod dinosaurs were the most diverse and abundant terrestrial herbivores in the Southern Hemisphere landmasses during the Late Cretaceous (Bonaparte and Powell, 1980; Salgado et al., 1997; Curry Rogers and Forster, 2001; Wilson and Upchurch, 2003; Curry Rogers and Forster, 2001; Wilson, 2006; Gorscak et al., 2014; Lacovara et al., 2014; Otero and Salgado, 2015; Poropat et al., 2016; González Riga et al., 2016, 2018; Carballido et al., 2017; Sallam et al., 2018). Fossils of these dinosaurs have been discovered on all continents, and roughly 50 valid species are described in South America alone (González Riga et al., 2019). Furthermore, some taxa are regarded as the largest known terrestrial animals (e.g. Bonaparte and Coria, 1993; Smith et al., 2001; Novas et al., 2005; González Riga et al., 2016; Carballido et al., 2017). A special paleogeographic aspect is their diversity during the latest Cretaceous, that rivals that of the hadrosaurid and ceratopsid ornithischians of Northern Hemisphere ecosystems at the same time (Mannion et al., 2011; Coria et al., 2012; González Riga et al., 2016).

Titanosaurs are restricted to the Cretaceous and are the most common dinosaurs found in Upper Cretaceous strata of South America, particularly in Brazil and Argentina (González Riga, 2011; De Jesus Faria et al., 2015). Nevertheless, the occurrence of this clade of dinosaurs is scarce in the Pacific margin of Gondwana. In part, this is a consequence of a general scarcity of continental units, because most of the current Pacific margin of South America was

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invaded by multiple basins and formed epicontinental seas during most of the Mesozoic (Cecioni, 1970; Charrier, 1984; Jaillard et al., 2000; Aguirre-Urreta et al., 2007). Additionally, these units remain under-explored because of a historical shortage of vertebrate paleontologists in countries that comprise this region. However, the dinosaur fossil record of Chile has increased markedly in recent years (e.g. Rubilar-Rogers et al., 2012; Soto-Acuña et al., 2015; Novas et al., 2015; Salgado et al., 2015).

The fossil record of the titanosaur sauropod in this side of the continent comprises only two species: *Atacamatitan chilensis* Kellner et al., 2011, recovered from the Cretaceous beds in northern Chile, and *Yamanasaurus lojaensis* Apesteguía et al., 2020, a saltasaurid described from the Late Cretaceous of southern Ecuador. The holotype of *Atacamatitan chilensis* includes a nearly complete right femur, the proximal end of a humerus, two dorsal vertebrae, two posterior caudal vertebrae, dorsal ribs, and a fragment identified as a sternal plate. All this material comes from the Upper Cretaceous Tolar Formation in the Atacama Desert. On the other hand, *Yamanasaurus lojaensis* includes a partial sacrum, a partial mid-caudal vertebra, and several associated limb bones. This material belongs to the Rio Playas Formation, assigned to a Campanian–Maastrichtian range, and is considered the northernmost known saltasaurine.

Others references describing isolated and fragmentary material of titanosaurs include: teeth, part of a left scapula-coracoid, the proximal end of a right humerus, the anterior face of a dorsal vertebra, a caudal centrum, an almost complete rib and part of a metapodial element from the Upper Cretaceous Quebrada La Totora strata, exposed in the locality of Pichasca, Coquimbo Region, Chile (Casamiquela et al., 1969; Salinas et al., 1991; Vargas et al., 2000; Suárez, 2003); a fragment of the left humerus and rib pieces from the Upper Cretaceous Hornitos Formation outcropping in Cerro Algarrobito, Atacama Region, Chile (Chong, 1985); and four articulated caudal vertebrae that have been described for the upper Santonian to Campanian of the Celendin Formation in the north of Peru (Mourier et al., 1986).

In this paper, we describe *Arackar licanantay* gen. et sp. nov., a new lithostrotian titanosaur sauropod from the Late Cretaceous of Chile that improves our understanding of anatomical and phylogenetic relationships of these huge and diverse herbivorous vertebrates. This discovery represents the third titanosaur named from the western side of the Andes in South America.

2. Materials and methods

The specimen SNGM-1 was recovered from La Higuera ravine, 75 km south from the Copiapó city in the Atacama Region, northern Chile (Fig. 1C). The fossils were discovered by one of the authors (C. Arévalo) in 1993. Later, in February 1994, C. Arévalo and A. Rubilar, both from the Servicio Nacional de Geología y Minería, excavated and collected the material of the present study. All these bones were discovered in yellow lacustrine mudstone beds, interbedded with reddish fluvial plain sandstones of strata belonging to the Hornitos Formation (Fig. 1D), which is considered to be Late Cretaceous in age (Segerstrom, 1959). The remains were mechanically prepared to remove part of the matrix that covered some of the bones. We conducted a phylogenetic analysis based on the dataset of Carballido et al. (2017). The data entry was made using Mesquite V 2.74 (Maddison and Maddison, 2011). The matrix was analyzed using TNT (Tree analysis using New Technology) v. 1.5 (Goloboff and Catalano, 2016).

Institutional abbreviations—SNGM, Sección de Paleontología y Estratigrafía, Servicio Nacional de Geología y Minería (SERNAGEOMIN), Santiago, Chile.

3. Geological setting

Upper Cretaceous units in the Atacama Region represent a drastic palaeogeographic change from the classic arc/back-arc scheme (Uyeda, 1982) prevalent during the Jurassic–Early Cretaceous. They represent a series of thick sedimentary and volcanic successions exposed in different structural blocks that formed a single wide volcanic-sedimentary chain established along the Precordillera on the earlier Mesozoic basement. Widespread sequences of sediments, rhyolitic tuffs, trachybasalts and andesites were deposited, some of them in structurally controlled basins such as the Hornitos Formation (Segerstrom and Parker, 1959).

The Hornitos Formation (Segerstrom, 1959; amended by Arévalo, 2005) consists of a continental sequence of massive conglomerates, well-bedded sandstones, lacustrine limestones (titanosaur-bearing levels) and ash and pumice tuffs (Fig. 2A and B). Upper lava flow deposits cover and partially interfinger with the sediments, extending as far as the western border of the Precordillera. The sequence fills a 20–40 km wide, NNE trending tectonic depression of graben to half-graben geometry (Hornitos Basin, Arévalo et al., 1994). The deposits have been recognized between the Carrera Pinto town, in the north, and Quebrada Yerbas Buenas (28S), 100 km further south. The existence of similar deposits in front of Vallenar suggests that the same structure could continue for at least another 50 km down to the south. The deposits lie unconformably on the Cerrillos Formation to the west that constitutes the basement of the basin in that direction. Talus breccias interstratified within the Hornitos deposits taper from the contact with the Cerrillos strata to the east indicating erosion from topographic heights (located to the west) at the time of the deposition. This observation as well as changes in general facies from the western boundary (proximal western to eastern distal facies) indicate that the western boundary was a growth fault that bordered the basin to the west. To the east, the deposits appear dissected by faults or overlie (with a gentle onlap relation) a basement formed by Triassic to Lower Cretaceous strata. K/Ar ages obtained in lavas and minor dioritic bodies and granodiorites that crosscut the lavas suggest an age range of 80–65 Ma (Arévalo, 2005). Thus, a Campanian–Maastrichtian age can be assigned to the titanosaur-bearing levels.

The fossils consist of a partial skeleton composed of associated and disarticulated axial and appendicular elements that were found close together in approximately 2 m^2 (Figs. 2C and D). The presence of the biggest bones of the skeleton such as femur and humerus, vertebral centra and arches, as well as the pelvic elements, and the absence of the most proximal and distal elements, together with the smallest bones such as autopodial elements (e.g. phalanges) suggest that the remains would have been deposited synchronically in the place of final burial and fossilization. Therefore, the disarticulation and transport of smaller pieces of the anatomic regions preserved (thoracic and appendicular skeleton), that are more exposed to low energy transport agents and or more susceptible to disaggregation through small scavengers' action (i.e. small fish), would be the result of the delayed burial of the specimen.

On the other hand, other large parts of the skeleton may have been eroded, since the specimen was found mostly exposed in an active erosive portion of the ravine. Nevertheless, it is not possible to rule out that missing skeletal elements were never preserved, due to previous disconnection in the stage of carcass (i.e. floating carcass usually disarticulate neck/head and caudal portions first), or simply were not buried at the same time, due to sedimentation rate, action of macrophagous scavengers or other unknown factors.

In the same manner, neural arches and vertebral centra are preserved disarticulated but in close proximity to each other (a few

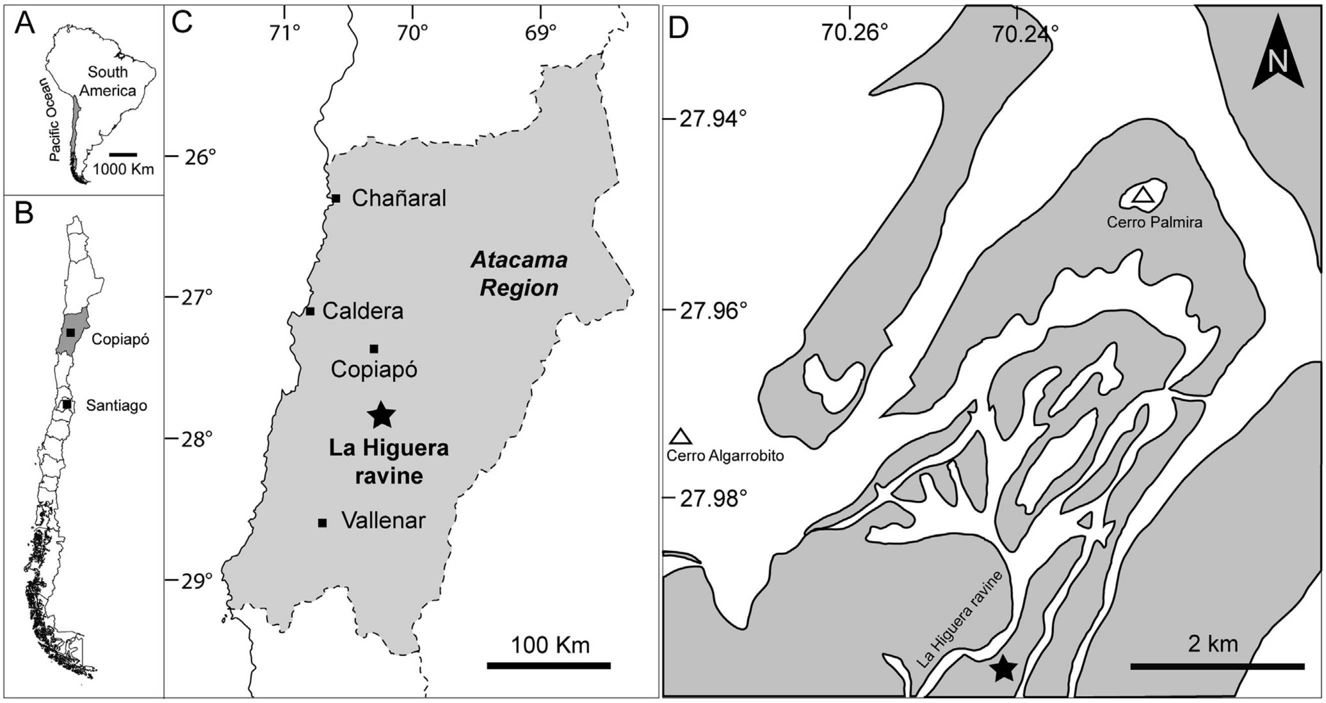


Fig. 1. A: Location of Chile in South America. B: Location of the Atacama Region and the city of Copiapó. C: Location of La Higuera ravine, 75 km south from the Copiapó city, Atacama Region, northern Chile. D: Distribution of the outcrops of the Hornitos Formation, in gray [Member 26, Ksho (b), Arévalo, 2005] and the location of the finding of *Arackar licanantay* (star).

centimeters), also indicating delayed burial with very low energy physical transport agents or small scavenging action. Nevertheless, the absence of marks on the surface of all the larger bones preserved and their corresponding anatomical positions suggest low action of scavenging at least on these bones. All elements preserved are anatomically and size correlated, presenting no duplicated elements. Sedimentological data suggest very low energy facies (mudstone, interpreted as a lake environment) which rules out transportation and accumulation of the larger bones reaffirming the conclusion that these are a part of synchronic parautochtonous deposit with one incomplete specimen/individual preserved.

Additionally, over the years other 3 expeditions to the general site were performed (2006, 2007 and 2011), resulting in the excavation of one more specimen in similar condition, showing a low density of bones preserved in similar manner (several elements consistent anatomically and in size with a single individual) separated by a hundred meters from each other (Rubilar-Rogers, 2007; Rubilar-Rogers et al., 2011).

Anatomical abbreviations—**acdl**, anterior centrodiapophyseal lamina; **acet**, acetabulum; **acpl**, anterior centroparapophyseal lamina; **aspdl**, anterior spinodiapophyseal lamina; **cc**, cervical centrum; **cdf**, centrodiapophyseal fossa; **clr**, concave laterodorsal ridge; **cls**, concave lateral surface; **cpol**, centropostzygapophyseal lamina; **cprf**, centroprezygapophyseal fossa; **cprl**, centroprezygapophyseal lamina; **dc**, dorsal centrum; **dp**, diapophysis; **dpc**, deltopectoral crest; **ef**, extensor fossa; **fc**, fibular condyle; **fe**, femur; **fic**, fibular condyle; **ft**, fourth trochanter; **gt**, greater trochanter; **hd**, head; **icf**, intercondylar fossa; **il**, ilium; **ilped**, iliac peduncle; **lb**, lateral bulge; **na**, neural arch; **pacprf**, parapophyseal centroprezygapophyseal fossa; **pcdl**, posterior centrodiapophyseal lamina; **pocdf**, postzygapophyseal centrodiapophyseal fossa; **podl**, postzygodiapophyseal lamina; **posl**, postspinal lamina; **pozg**, postzygapophysis; **pp**, parapophysis; **ppdl**, paradiapophyseal lamina; **pped**, pubic peduncle; **pproc**, posterior process; **prcdf**, prezygapophyseal centrodiapophyseal fossa; **prdl**, prezygodiapophyseal lamina; **prpadf**, prezygapophyseal parapodiapophyseal lamina; **prpl**, prezygoparapophyseal lamina; **prsdf**, prezygapophyseal spinodiapophyseal fossa; **prsl**, prespinal lamina; **przg**, prezygapophysis; **pspdl**, posterior spinodiapophyseal lamina; **rac**, radial condyle; **spdl**, spinodiapophyseal lamina; **spol**, spinopostzygapophyseal lamina; **sprf**, spinoprezygapophseal fossa; **tic**, tibial condyle; **tp**, transverse process; **tpol**, intrapostzygapophyseal lamina; **tprl**, intraprezygapophyseal lamina; **ulc**, ulnar condyle.

4. Systematic paleontology

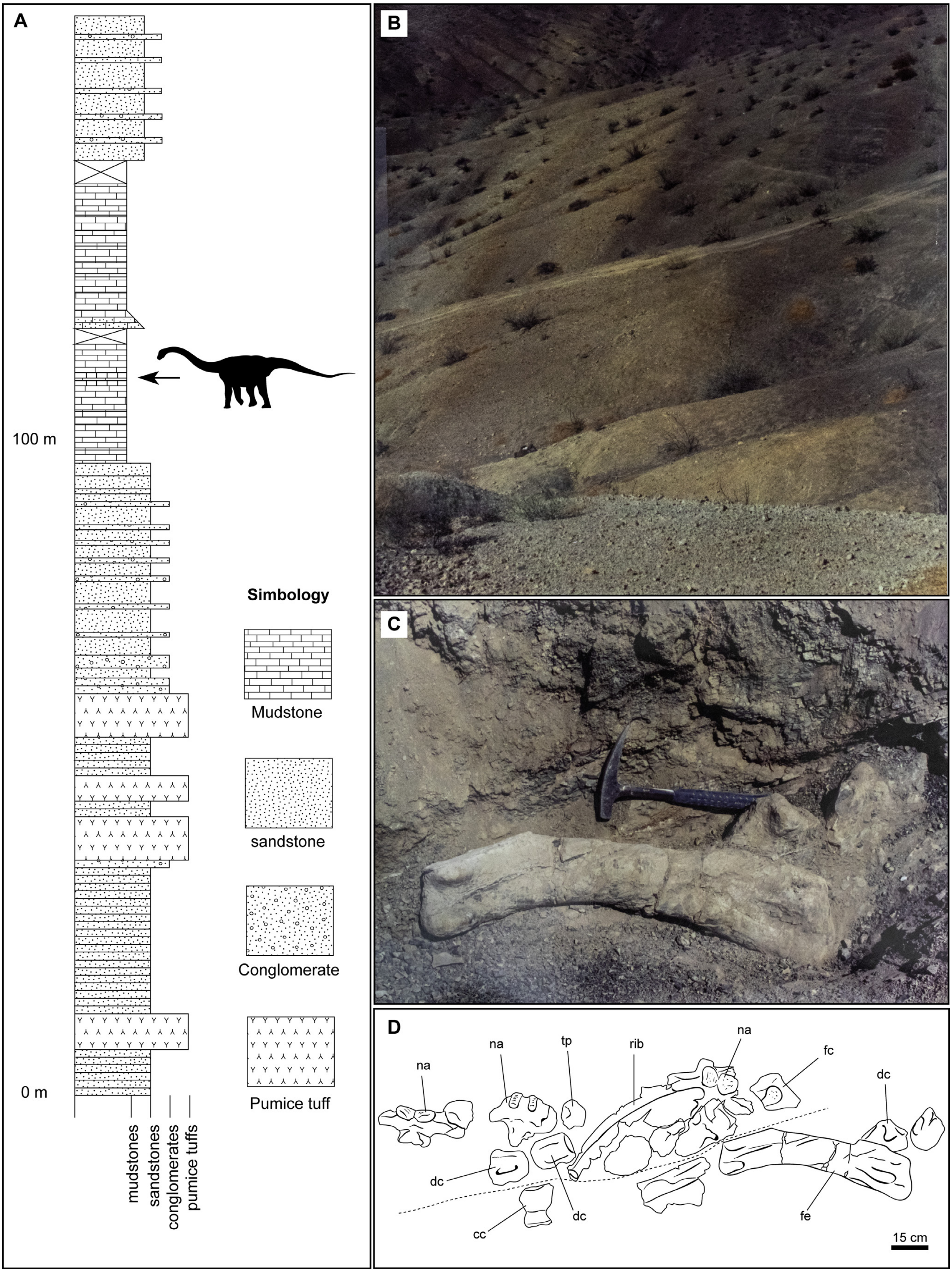
Anatomical nomenclature. For the axial skeleton we use the terminology proposed by Salgado and Powell (2010) and Wilson et al. (2011).

Dinosauria Owen, 1842
Sauropoda Marsh, 1878
Titanosauriformes Salgado, Coria and Calvo, 1997
Titanosauria Bonaparte and Coria, 1993
Lithostrotia Upchurch et al., 2004

Arackar gen. nov.
LSID: urn:lsid:zoobank.org:act:412A32F8-34D0-4179-975A-32CB061161DF
Type species. *Arackar licanantay* sp. nov., monotypic.

Derivation of name. In reference to “bones of the atacamenians” in Kunza, the language of the original indigenous people of the Atacama region (Vilte, 2004).
Diagnosis. as for the species, below

Arackar licanantay sp. nov.
LSID: urn:lsid:zoobank.org:act:0D4AF9FE-E270-4E0B-BBB3-2BC103FCD1A6
Figs. 5–11


A
100 m
0 m
mudstones
sandstones
conglomerates
pumice tuffs
Simbology
Mudstone
sandstone
Conglomerate
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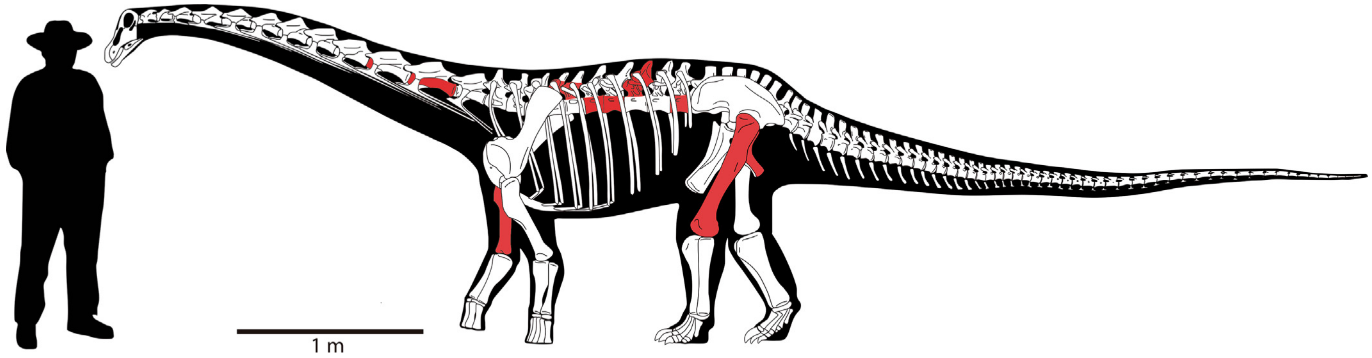


Fig. 3. Schematic representation of the skeleton of *Arackar licanantay* gen. et sp. nov. Preserved bones are highlighted. Modified scheme from Hechenleitner et al. (2020). Human scale = 1.7 m.

Holotype. SNGM-1/1-23, a well-preserved partial postcranial skeleton comprising two cervical centra, two anterior dorsal neural arches, one posterior dorsal neural arch, three dorsal centra, right humerus, left ischium, left femur, and various unidentified fragments (Fig. 3).

Locality and *horizon*. La Higuera ravine, approx. 75 km south Copiapó city, Atacama Region, northern Chile (Fig. 1). Lower-to-middle levels of the Hornitos Formation, Campanian–Maastrichtian.

Diagnosis. *Arackar* can be diagnosed on the basis of the following unique association of features (autapomorphies marked with an asterisk): anterior dorsal arches with (1) spinopostzygapophyseal lamina inclined laterally less than 20° to the horizontal, with an anterodorsal concave (saddle shaped) face (2) absence of intrapostzygapophyseal lamina (tpol) (3) prezygapophyseal facets well separated from each other and located at half the distance between the diapophysis and the sagittal plane (4) lateromedially narrow pedicles of the neural arch, as wide as the neural canal. The middle neural arches present (5) anteroposterior distance of the parapophysis-diapophysis longer than the articular surfaces of the pedicle in lateral view; (6) wide and tall centroprezygapophyseal fossa + parapophyseal centroprezygapophyseal fossa (cprf + pacprf) extending on the entire anterior faces of the pedicles*; (7) reduced spinopostzygapophyseal laminae (spol), shorter than the postzygapophyseal facet length*; (8) absence of postzygodiapophyseal laminae (podl); (9) presence of anterior spinodiapophyseal laminae (aspdl); (10) neural spines strongly directed posteriorly more than 40° with respect to the vertical; (11) absence of triangular aliform processes in neural spines. The ischium presents (12) a relatively long pubic articulation, greater than the anteroposterior length of the proximal plate peduncle; and (13) a relatively short and narrow posterior process (Fig. 4).

5. Description

Axial Skeleton. The axial skeleton is represented by two cervical centra, three dorsal neural arches, and three isolated dorsal centra.

Cervical Vertebrae. Two dorsoventrally flattened strongly opisthocoelous cervical centra are preserved (Fig. 5A–C). They are relatively short (average elongation index value of 1.97 following character 15 sensu dataset of Mannion et al. (2019)) and are referred to middle-posterior cervicals based on comparison to *Rapetosaurus* (Curry Rogers, 2009: 1065), *Trigonosaurus* (Campos et al., 2005: 571) and *Uberabatitan* (Silva Junior et al., 2019: 404). In these taxa the length of cervical centra increase toward the middle-posterior section of the series and decrease towards the end of neck. The anterior half of the centrum SNGM-1/12 is incomplete (Fig. 3A) and a wing-like, triangular lamina corresponding to the right parapophysis is preserved. It is slightly concave dorsally and is located ventrally close to the anterior portion of the centrum. The centrum SNGM-1/13 (Fig. 5B–C) is clearly dorsoventrally flattened (see Table 1) and transversely constricted at mid-length. Their lateral face is anteroposteriorly concave without any fossae; their ventral face is slightly concave transversely and there is no any midline ridge or keel. The neural arches were not preserved, leaving an irregularly surfaced bilaterally symmetrical marks that bow medially at mid centrum to form an 'X' -like mark on the dorsal face of the centrum (see Table 2).

Dorsal Vertebrae.Three disarticulated neural arches and three centra were recovered (Fig. 5D–O). The dorsal centra (SNGM-1/6-8) is opisthocoelous, like in most macronarians (Salgado et al., 1997; Wilson and Sereno, 1998) although some taxa like *Argentinosaurus* (MCF-PVPH-1, Bonaparte and Coria, 1993) have amphiplatyan dorsal centra. In the case of *Andesaurus* (MUCPv-132, Calvo and Bonaparte, 1991), the anterior convexity of one dorsal named Dv2 is not particularly prominent, but this is interpreted as some distortion by crushing (Mannion and Calvo, 2011, Fig. 2A and B).

The dorsal centra of *Arackar* are relatively short (they are slightly dorsoventrally depressed, that is, the mediolateral width to dorsoventral height ratio is 1.05–1.25; see Table 1). In contrast, some titanosaurs like *Bravasaurus* have strongly depressed centra, up to twice as wide as tall (Hechenleitner et al., 2020: 5).

The assignment of these centra in the dorsal series is difficult. Tentatively, the centra SNGM-1/6 and 1/7 are referred to anterior-middle dorsals whereas SNGM-1/8 is referred to a posterior one. In the lateral faces, a deep and large anteroposteriorly elongate pleurocoel extends over almost the full length of the centra (Fig. 5F, J, N). Only in the dorsal SBGM- 1/8 (Fig 5M–N) the pleurocoel is acuminate posteriorly. Unlike *Bravasaurus*, *Arackar* has not a shelf that extends laterally on the dorsal edge of the pleurocoels (Hechenleitner et al., 2020: 5). The ventral faces are anteroposteriorly concave and transversely convex, and lack any midline ridge or keel (Fig 5O). In contrast, among derived lithostrotian titanosaurs, *Saltasaurus* (Zurriaguz and Powell, 2015:292) and *Neuquensaurus* (Salgado et al., 2005:626) possess a poorly developed ventral keel.

Fig. 2. A, stratigraphical column from the Hornitos Formation, indicating the horizon where the SNGM-1 material was discovered (dinosaur silhouette); B, yellow lacustrine mudstone exposed in the La Higuera ravine; C, the femur (SNGM-1/2) *in situ*; D, schematic drawing indicating the arrangement of fossils *in situ* (modified from the field notes of Alfonso Rubilar).

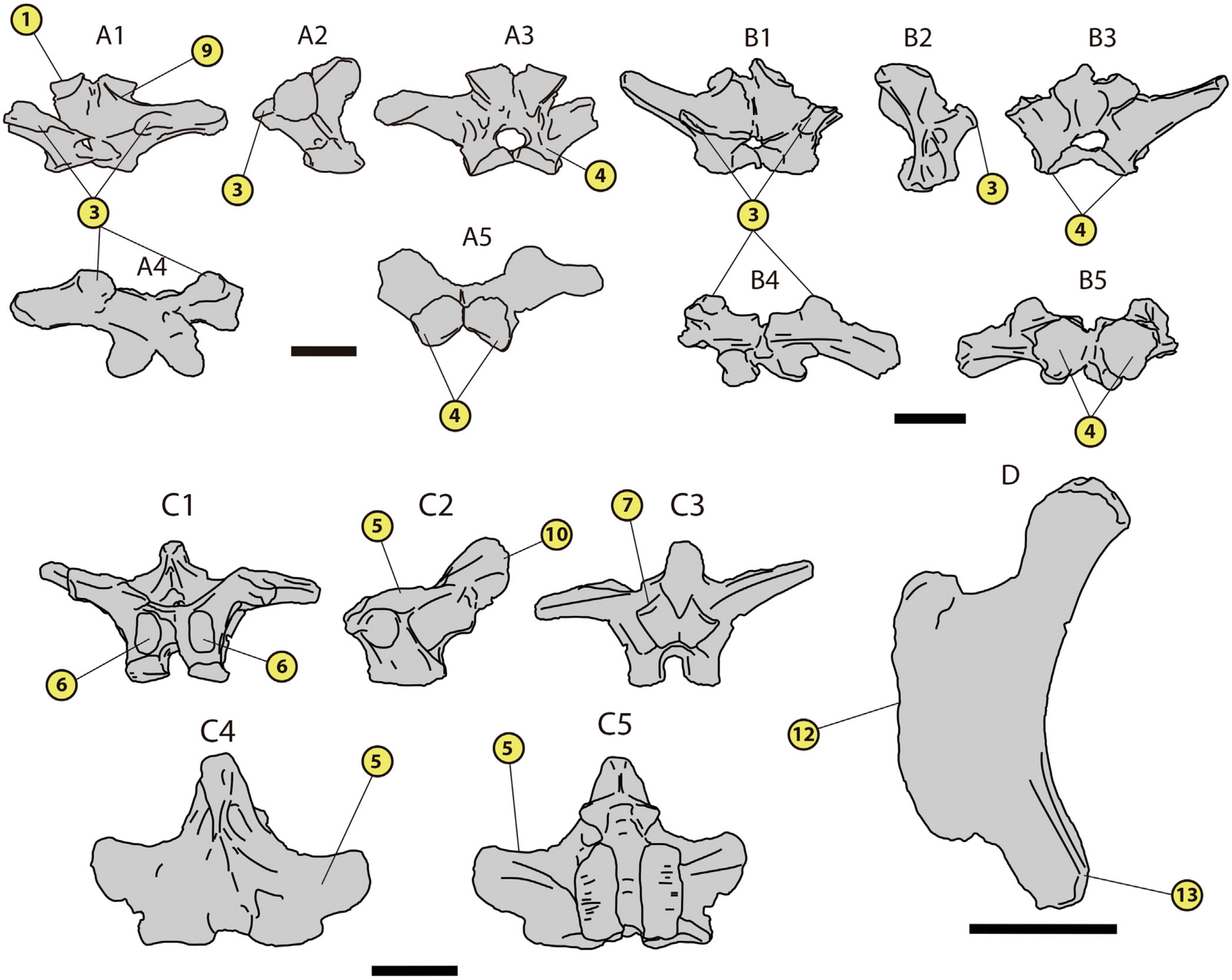


Fig. 4. Schematic representation of the bones that have the diagnostic characters of *Arackar licanantay* gen. et sp. nov. The numbers in the figure correspond to the list of diagnostic characters provided in the text. A1-A5, anterior dorsal neural arch (SNGM-1/3) in anterior (A1), lateral (A2), posterior (A3), dorsal (A4) and ventral (A5) views. B1–B5, anterior dorsal neural arch (SNGM-1/4) in anterior (B1), lateral (B2), posterior (B3), dorsal (B4) and ventral (B5) views. C1–C5. Posterior dorsal neural arch (SNGM-1/5) in anterior (C1), lateral (C2), posterior (C3), dorsal (C4) and ventral (C5) views. D. Left ischium in lateral view. Scale bars equals 10 cm.

The most anterior neural arch (SNGM-1/3, Fig. 6) have parapophyses located at the base of the neural arch, and therefore is interpreted as the second or third dorsal, following the articulated series of *Overosaurus* (Coria et al., 2013: 362; B.G.R. pers. obs.) and *Trigonosaurus* (Campos et al., 2005: 577; D.R.-R. pers. obs.). In anterior view, it is clearly seen that the neural arch is relatively low, that is, the width of neural arch -including the width of neural peduncles plus the neural canal-is the double of the neural arch's height from the base of the neural peduncles up to the level of the diapophysis. This morphology is not so pronounced in *Rapetosaurus* (Curry Rogers, 2009: 1056) and very different to other titanosaurs like *Mendozasaurus* where the neural arch is as high as wide (Gonzalez Riga et al., 2018:146). The neural canal is large and dorsomedially depressed (transverse diameter: 4.3 cm, dorsoventral diameter: 3.1 cm), partially similar to that of *Bonitasaura* (Apesteguía, 2005a; Gallina, 2011) and *Rapetosaurus* (Curry Rogers and Forster, 2001; Curry Rogers, 2009). In contrast, other titanosaurs such as *Mendozasaurus* (González Riga, 2003, 2005), *Notocolossus* (González-Riga et al., 2016), *Trigonosaurus* (Campos et al., 2005), *Uberabatitan* (Salgado and Carvalho, 2008) and *Patagotitan* (Carballido et al., 2017) exhibit pedicles wider than the neural canal. The articular surfaces of the vertebral pedicles are anteroposteriorly convex and show a rugose pattern. They have a roughly square contour, with the innermost posteromedial corner turned upwards.

The neural arch has transversely expanded diapophyses (Fig. 6) as in *Rapetosaurus*, *Overosaurus* and some other titanosaurs. They are almost horizontal and laterally projected in this anterior section of the series, as in *Mendozasaurus* (González Riga et al., 2018: figure 8) and *Rapetosaurus* (Curry Rogers, 2009: figures 14–18), among others. The diapophysis is supported by the prezygodiapophyseal (prdl), spinodiapophyseal (spdl) and posterior centrodiapophyseal laminae (pcdl). Because of this, it is possible to observe three sides of this structure: anteroventral, posteroventral and dorsal. A well-developed prezygapophyseal parapodiapophyseal fossa (prpadf) is present below the diapophysis as in *Rapetosaurus* (Wilson et al., 2011: figure 11). The posterior centrodiapophyseal lamina (pcdl), which extends from the outer posterior corner of the

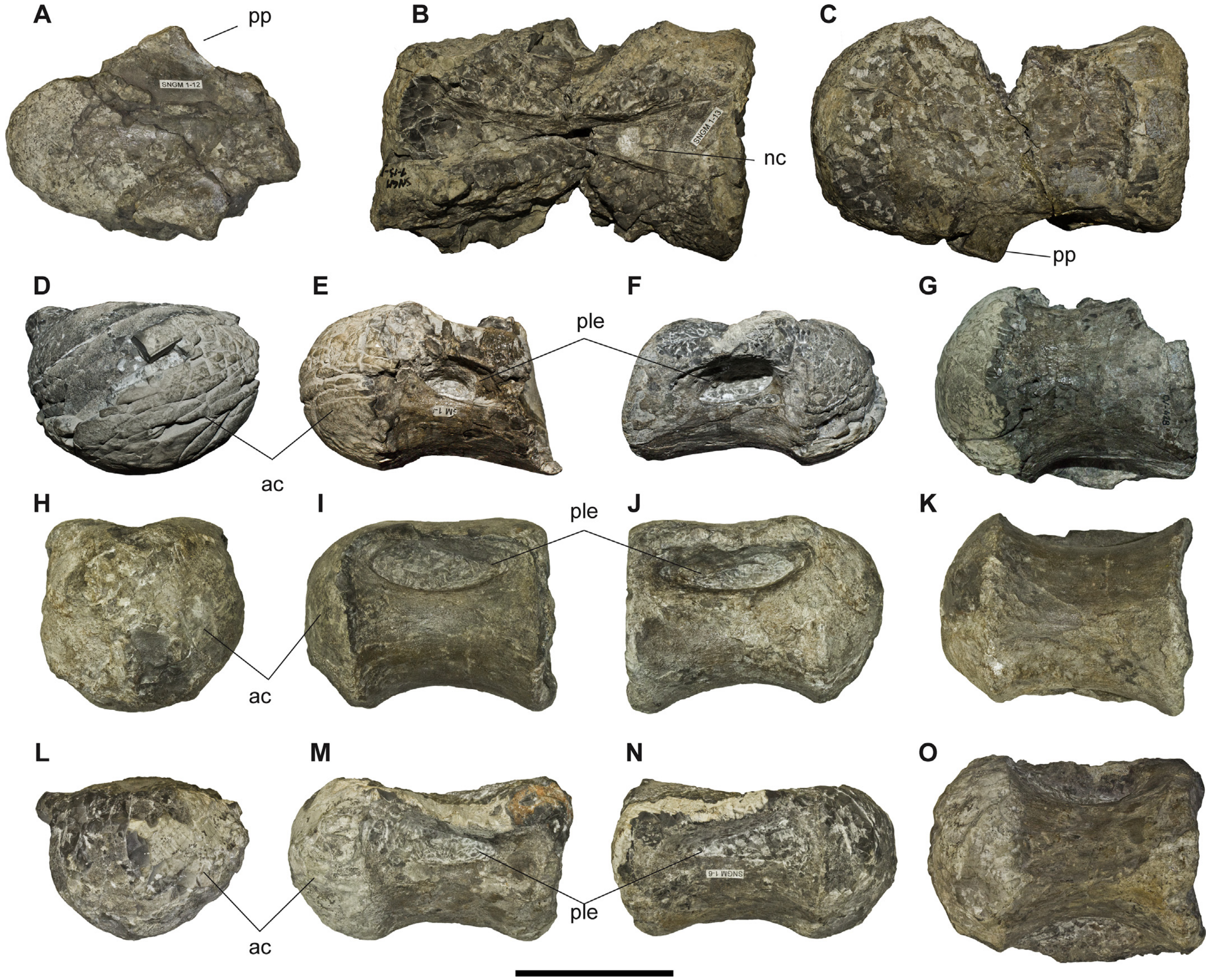


Fig. 5. *Arackar licanantay* gen. et sp. nov. vertebral centra. Cervical centra: A–C. A, ventral view of SNGM-1/12; C, dorsal and ventral view of SNGM-1/13. Dorsal centra: D–O (SNGM-1/6-8) in: D, H, L, anterior view; E, F, I, J, M, N, lateral view; G, K, O, ventral view. Scale bar equals 10 cm.

Table 1
Measurements of presacral vertebrae (in mm). *Preserved length.

	SNGM-1/3	SNGM-1/4	SNGM-1/5	SNGM-1/6	SNGM-1/7	SNGM-1/8	SNGM-1/12	SNGM-1/13
Centrum length (including ball)	–	–	–	143	139	132	*157	~228
Centrum length (excluding ball)	–	–	–	107	107	93	*119	~180
Anterior centrum height	–	–	–	85	89	81	~44	~64
Anterior centrum width	–	–	–	110	98	112	~70	~118
Posterior centrum height	–	–	–	88	99	82	–	~78
Posterior centrum width	–	–	–	104	104	~103	–	~131
Neural arch height	–	–	169	–	–	–	–	–
Neural spine height	–	–	57	–	–	–	–	–
Maximum mediolateral width of neural spine	–	–	78	–	–	–	–	–
Anteroposterior length of neural spine	–	–	84	–	–	–	–	–
Total width across diapophyses	~386	~350	280	–	–	–	–	–

pedicles towards the diapophysis, shows a forward inclination of about 45°.

In anterior view, the prezygapophyseal facets are well separated from each other; in fact, these facets are located halfway between the diapophysis and the sagittal plane. This position of facets displaced laterally, is clearly observed in anterior view (Fig. 6E). The intraprezygapophyseal lamina (tprl) is reduced and shows a concave contour in anterior view.

In posterior view, postzygapophyseal processes are well separated from each other and have large subcircular articular facets lateroventrally directed. The intrapostzygapophyseal lamina (tpol) is absent, unlike some titanosaurs (see for example, *Rapetosaurus*;

Table 2
Measurements of the appendicular bones of *Arackar licanantay* (in mm).

Bone/Measurement	mm
Femur	
Proximodistal length	740
Distance from proximal end to distal tip of fourth trochanter	360
Midshaft mediolateral width	104
Midshaft anteroposterior length	54
Midshaft minimum circumference	250
Distal end anteroposterior length on tibial condyle	163
Distal end anteroposterior length on fibular condyle	139
Distal end mediolateral width on tibial condyle	70
Distal end mediolateral width on fibular condyle	127
Humerus	
Proximodistal length	590
Proximal end maximum mediolateral width	235
Distance from proximal end to distal tip of deltopectoral crest	155
Midshaft mediolateral width	81
Midshaft anteroposterior length	56
Midshaft minimum circumference	225
Distal end mediolateral width (as preserved)	182
Distal end maximum anteroposterior length	126
Ischium	
Total length	284
Anteroposterior length of iliac articular surface	37
Transverse width of iliac articular surface	85
Dorsoventral height of pubic articulation	175
Maximum anteroposterior length of proximal plate	97

Curry Rogers, 2009: 1056). Left and right spinopostzygapophyseal laminae tend to converge, projecting upward and medially; these laminae are incomplete but the portion preserved over the postzygapophyseal procesess are inclined laterally less than 20° to the horizontal and have an anterodorsal concave (saddle shaped) faces (Fig. 6B and D).

The spinodiapophyseal laminae are sheet-like structures and are connected to the lower margin of the postzygapophyseal facets. The spinodiapophyseal lamina has been described in titanosaurs such as *Argentinosaurus* (Bonaparte and Coria, 1993), *Opisthocoelicaudia* (Borsuk-Bialynicka, 1977), and *Lirainosaurus* (Sanz et al., 1999), but these laminae are absent in anteromedial neural arches of *Rinconsaurus* (Calvo and González-Riga, 2003).

No hyposphene-hypantrum articulations are present on this or any other neural arches. The prespinal sector is damaged and the postspinal lamina is absent at least at level of the base of the neural spine.

The dorsal neural arch SNGM-1/4 (Fig. 7) has a relatively low arch as previously described for the more anterior one (SNGM-1/3). The anterior portion of the articular surfaces of the vertebral pedicles is missing. The parapophyses are placed at the base of the neural arch suggesting that this arch corresponds to an anterior dorsal, probably the third or fourth. The diapophyses project laterodorsally, being more elevated than SNGM-1/3. The

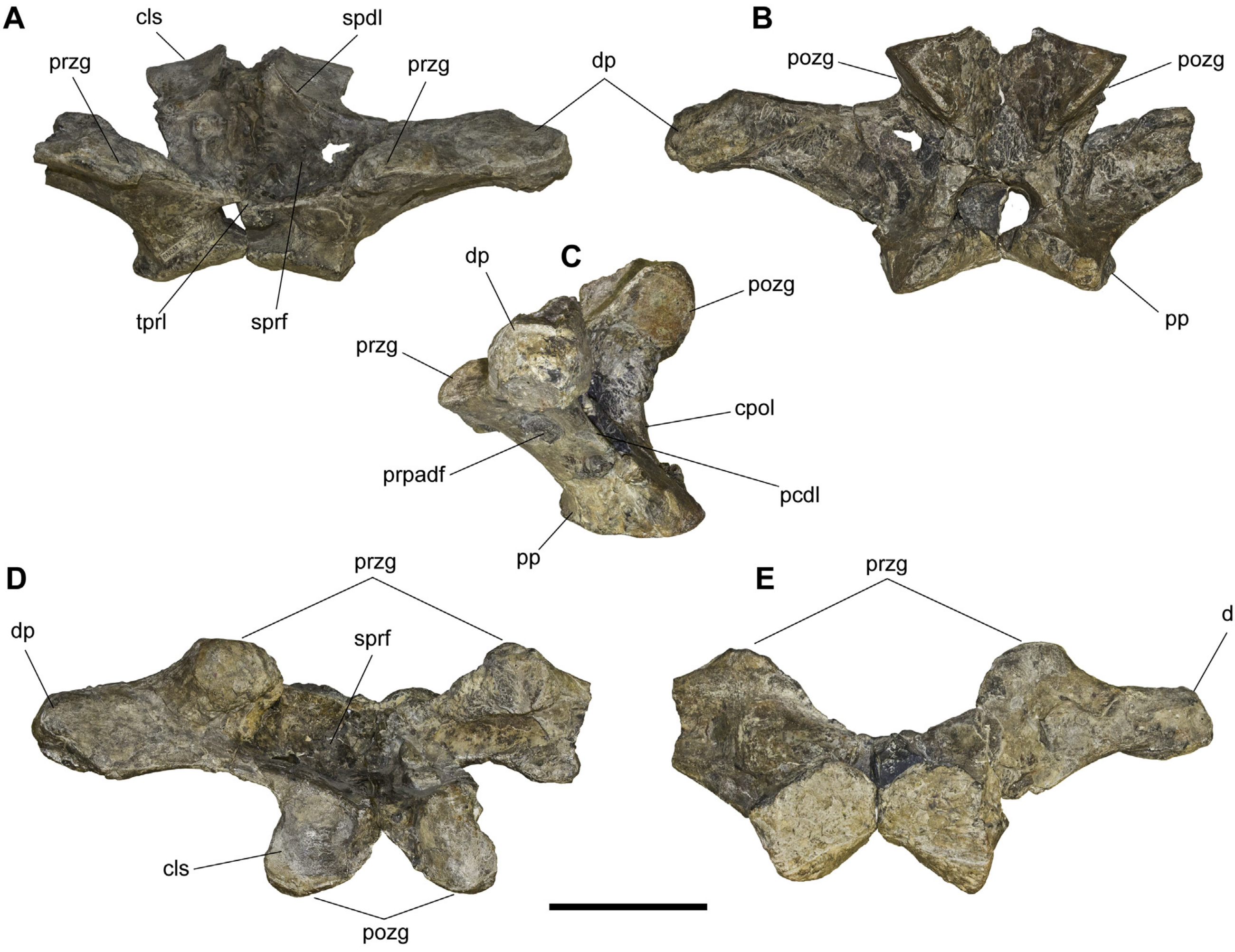


Fig. 6. *Arackar licanantay* gen. et sp. nov. anterior dorsal neural arch (SNGM-1/3) in: A, anterior view; B, posterior view; C, lateral view; D, dorsal view; E ventral view. Scale bar equals 10 cm.

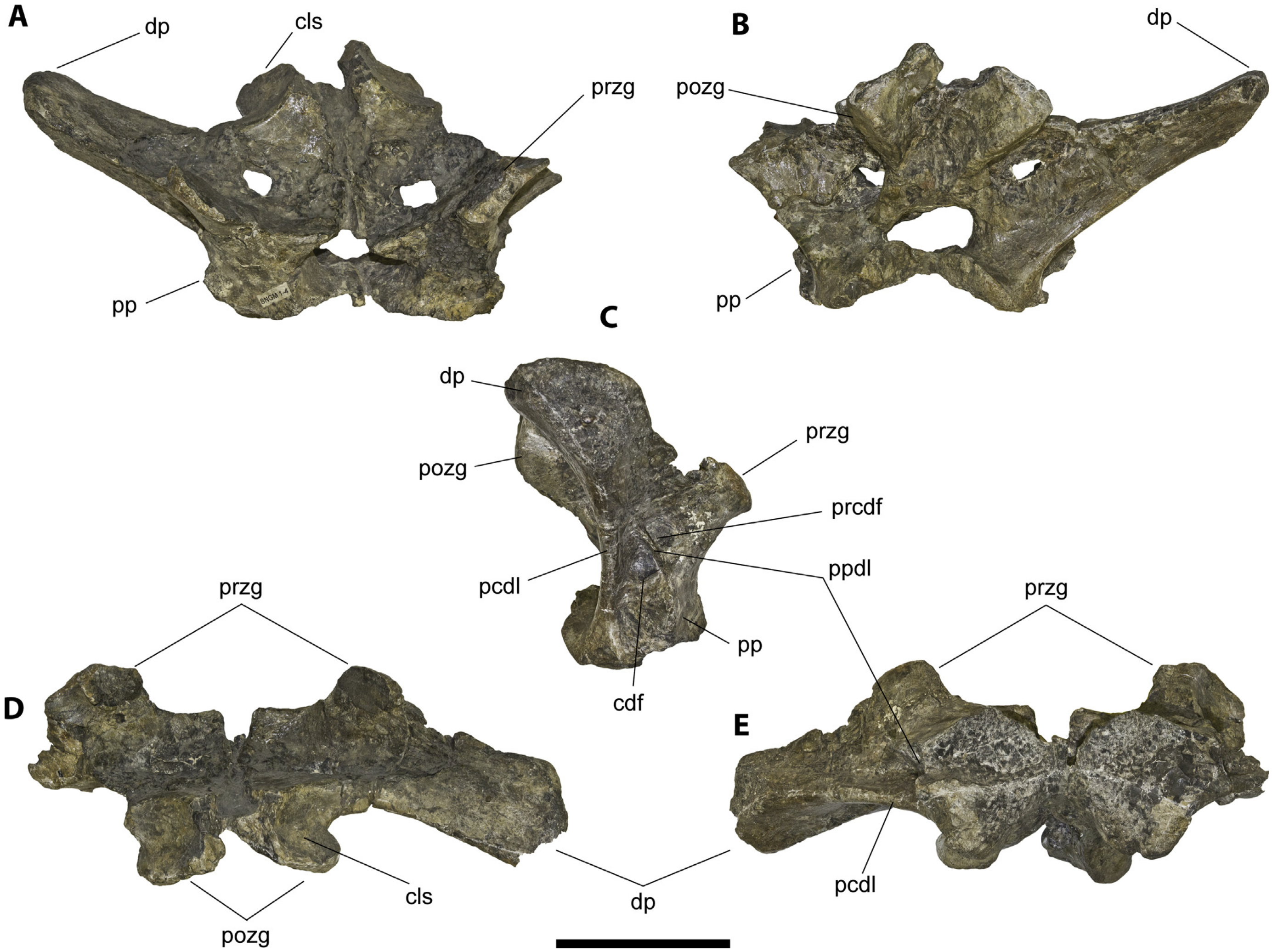


Fig. 7. *Arackar licanantay* gen. et sp. nov. anterior dorsal neural arch (SNGM-1/4) in: A, anterior view; B, posterior view; C, lateral view; D, dorsal view; E ventral view. Scale bar equals 10 cm.

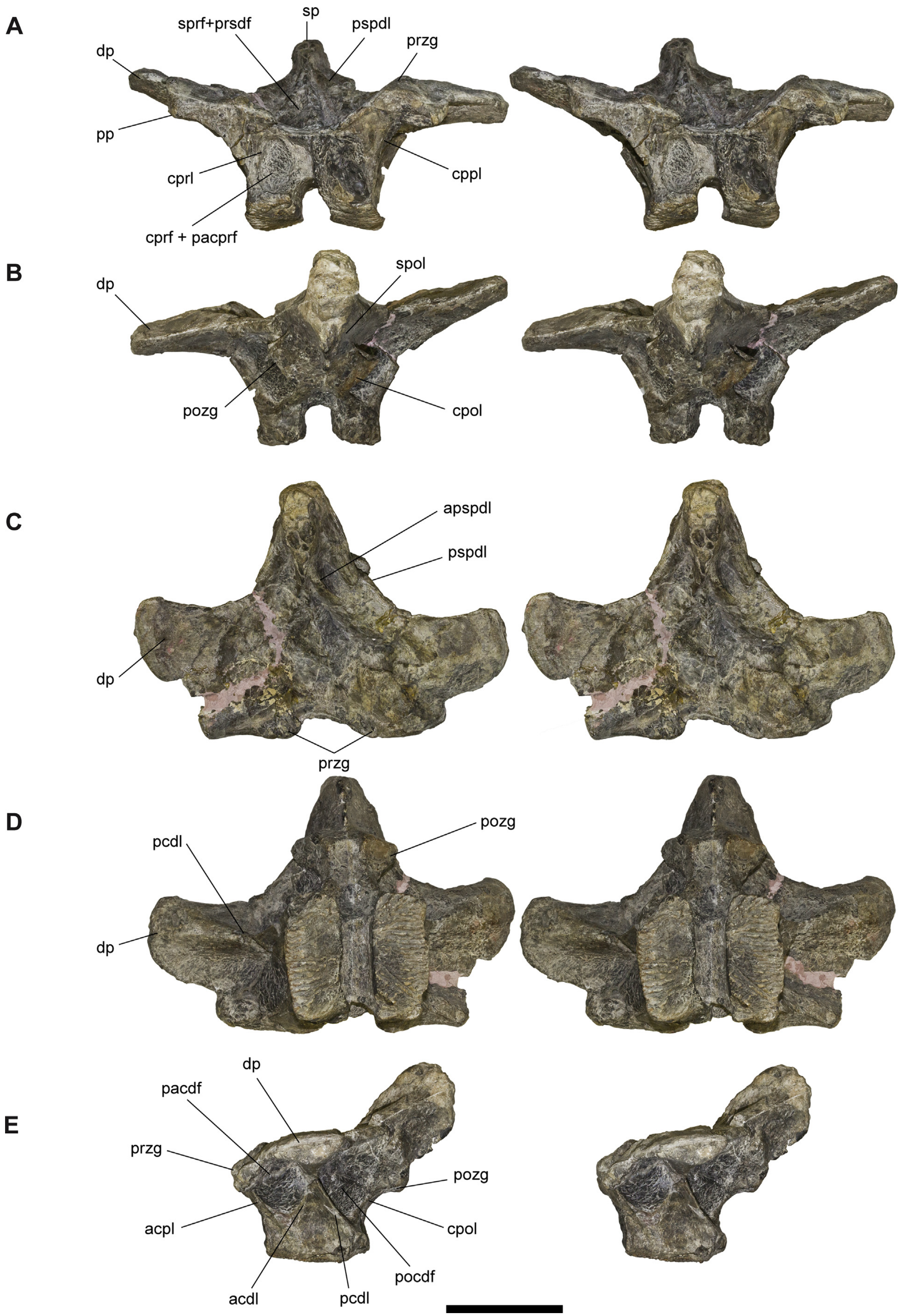
pcdl are projected laterodorsally and do not have an anterior inclination like that observed in the dorsal SNGM-1/3. In lateral view, under the diapophysis, there are well-defined paradiapophyseal (ppdl) and pcdl laminae that define a tall and subtriangular centrodiapophyseal fossa (cdf). Over the ppdl, a subcircular and small prezygapophyseal centrodiapophyseal fossa (prcdf) is present.

The articular facets of both pre- and postzygapophyses are smaller and narrower than those of SNGM-1/3. The postzygapophyseal processes are well separated from each other and show a dorsal surface that is a slightly concave towards the articular facets, unlike most other titanosaurs in which this surface is flat. The tpol is absent, as in the dorsal SNGM-1/3.

SNGM-1/5 belongs to a middle dorsal vertebra (Fig. 8), probably the 6th based on comparisons with *Trigonosaurus* (e.g. the relative position of parapophysis and diapophysis, orientation of neural spines; D.R.R., A.O.V. and B.G.R. pers. obs.).

The neural spine is inclined posteriorly around 40° with regard to the vertical, being thicker distally. Unlike *Arackar*, some derived titanosaurs have more inclined neural spines, up to 55° such as the case of *Bravasaurus* (Hechenleitner et al., 2020, figure 3e). The prespinal lamina (prsl) extends anteriorly near to the intraprezygapophyseal lamina, and the neural spine forms a complex structure formed by the prespinal lamina itself, the two anterior spinodiapophyseal laminae, and the thick posterior spinodiapophyseal laminae.

In dorsal view, and the top of the spine, it is possible to see a pair of fossae on both sides of the spine; this is due to the separation of the spinodiapophyseal lamina in two rami: anterior and posterior. This structure is present in *Argentinosaurus*, *Trigonosaurus*, *Barrosasaurus*, *Epachthosaurus*, *Opisthocoelicaudia*, *Drusilasaura*, and *Patagotitan*, among others. Following the nomenclature proposed by Wilson et al., 2011, these structures should correspond to the spinodiapophyseal lamina fossa (spdl-f). In anterior view (Fig. 8A), wide and tall centroprezygapophyseal fossae + parapophyseal centroprezygapophyseal fossae are developed along the entire anterior faces of pedicles of the neural arch, but they do not extend above the neural canal as observed in *Trigonosaurus* (D.R.-R. and B.G.R. pers. obs.) This character is absent in other titanosaurs and is interpreted here as an autapomorphy. The neural canal is rounded in shape (dorsoventral diameter = 2.4 cm, transverse diameter = 2.35 cm) and relatively large, as wide as each pedicle. A thin centroprezygapophyseal laminae (cprl) is present, as in the anterior dorsal vertebrae. The diapophyses project laterally and a peculiar character, better preserved in dorsal view of the right side, is the development of a flat,


A
sp
sprf+prsdf
pspdl
przg
dp
pp
cprl
cppl
cprf + pacprf
B
spol
dp
pozg
cpol
C
apspdl
pspdl
dp
przg
D
pozg
pcdl
dp
E
dp
pacdf
przg
pozg
acpl
cpol
pocdf
acdl
pcdl

horizontal and almost quadrangular surface defined by the spinodiapophyseal, paradiapophyseal and prezygoparapophyseal laminae. This structure is described in the diagnosis as an anteroposterior distance of the parapophysis-diapophysis longer than the articular surface of the pedicle. The articular surfaces of the pedicles have anteroposterior elongated subrectangular contours and do not meet medially as those of the anterior dorsal arches.

In posterior view, it is possible to see that the postzygapophyseal processes are relatively small and are located in a low position with respect to the neural spine. They have very reduced and suboval articular facets directed posterolaterally. The spinopostzygapophyseal laminae (spdl) are very short, in fact shorter than the postzygapophyseal facet length, a condition that is described here as an autapomorphy. Both postzygapophyseal processes form a narrow structure and are in contact with each other ventrally; because of this, the tpol is absent. In this configuration, the posterior spinodiapophyseal laminae (spdl) are lateromedially broad and surpass the width of the postzygapophyseal processes. Because of this, the postzygapophyseal processes are not visible in anterior view (Fig. 8A). In this compact structure of the postzygapophyseal processes, the postspinal laminae (posl) disappear before reaching the level of the dorsal margin of the postzygapophyseal facets. The postzygodiapophyseal lamina (podl) is absent, as in posterior dorsals of *Opisthocoelicaudia* and *Muyelensaurus*. The distribution of this character is variable within titanosaurs: in *Trigonosaurus* it is present only in the two most posterior dorsals (B.G.R., pers. obs.), in *Mendozasaurus* it is present in the only anterior dorsal preserved (Gonzalez Riga et al., 2018: 148), in *Epachthosaurus* it is present in the tenth dorsal vertebra (Martínez et al., 2004; B.G.R. pers. obs.), in *Overosaurus* (Coria et al., 2013; B.G.R. pers. obs.) it is present from the 5th to the 10th dorsals, in *Rinconsaurus* it is preserved in the two recovered posterior dorsal vertebrae (Calvo and González-Riga, 2003; B.G.R. pers. obs.), and in *Rapetosaurus* it is present in all dorsals (Curry Rogers, 2009). In lateral view, under the parapophysis, there are well-defined paradiapophyseal (ppdl) and anterior centrodiapophyseal lamina (acdl) that define a parapophyseal centroprezygapophyseal fossa (pacdf). A huge triangular postzygapophyseal centrodiapophyseal fossa (pocdf) on the posterolateral neural arch is defined by the posterior centrodiapophyseal, spinodiapophyseal and centropostzygapophyseal laminae.

Appendicular skeleton

Humerus. A complete humerus with a narrow diaphysis is recovered (SNGM-1/1; Fig. 9). It is slightly twisted and has a Robustness Index (sensu Wilson and Upchurch 2003) of 0.281. It is more robust than that of *Muyelensaurus* (RI: 0.18) but slender to those of *Saltasaurus* and *Neuquensaurus*, where the RI reach values up to 0.32. Moreover, it is more gracile than that of *Bravasaurus* (Fig.4a in Hechenleitner et al., 2020; RI 0.35).

The proximal end is anteroposteriorly flattened and transversally wider than the distal end. The border of the proximal end is relatively flat like in *Mendozasaurus* and *Rapetosaurus*, and different to the sigmoid curve observable in *Saltasaurus loricatus* (Bonaparte and Powell, 1980) and the concave profile present in *Bravasaurus arrierosorum* (Fig.4a in Hechenleitner et al., 2020). In addition, its contour in anterior view shows a roughly square proximolateral corner, while in *Bravasaurus* is more rounded (Fig.4a in Hechenleitner et al., 2020). The proximal third of the humerus is transversely expanded, with a concave anterior face, the borders of the humerus bowing anteriorly to form a large concavity, roughly triangular in anterior view. The posterior surface of the humerus is convex, but its distal quarter is slightly concave. The humerus has a bowed "C" shaped cross-section. The lateral border of the depression forms the deltopectoral crest, which is anterolaterally oriented, and its distal half is mediolaterally expanded. The deltopectoral crest shows a prominent tubercle at its summit. The upper border is thickened. There is a bulge placed on the laterodistal portion of the deltopectoral crest, which can be seen both in anterior and posterior view. This bulge corresponds to the site where the *scapulohumeralis* muscle was attached (Borsuk-Bialynicka, 1977). Close to the center of the depression but slightly shifted towards the articular head there is a slight elevation that may correspond to the insertion of the *coracobrachialis* muscle (Borsuk-Bialynicka, 1977). The large proximal anterior excavation disappears as the humerus narrows transversally at about midlength, where the diaphysis acquires an oval shape in cross-section. The diaphysis is slender, unlike the diaphysis of the humerus of *Bravasaurus arrierosorum*, which is much more robust (Fig. 4a in Hechenleitner et al., 2020). A well-developed internal tuberosity is found on the posterior face of the proximal end, immediately lateral to the forward-bowed articular head and forms part of the posterior expansion of the border of the proximal end of the humerus. The deltopectoral crest is straight and well extended proximodistally. Lateral to this tuberosity, but on the anterior face, a small elevation close to the proximal border is found. The articular head has an anterior elevation which along with the deltopectoral crest gives the borders of the proximal end of the humerus a sinusoidal contour when viewed from the proximal end. A strong bulge can be found on the posterolateral face of the humerus, at approximately the same level of the distal tip of the deltopectoral crest, which corresponds to the site of insertion of the muscle latissimus dorsi (Otero, 2010; D'Emic, 2012). The distal third of the humerus is expanded and a prominent radial condyle is present midway along the anterior face at the very distal end. The radial condyle does not extend much upwards onto the diaphysis and no grooves can be seen flanking its sides or extending onto the diaphysis, contrary to most sauropods. The ulnar condyle at the lateral side of the distal end of the humerus protrudes anteriorly. In addition, the ulnar condyle is undivided. The posterior face of the distal third of the humerus shows a broad olecranon groove, which extends onto the diaphysis as a semi-conical channel that narrows and becomes shallower towards the midshaft of the humerus. The medial side of the humerus in this region is very flat and slopes towards the olecranon groove, becoming the groove's medial border.

Ischium. An almost complete left ischium (SNGM-1/9) is preserved (Fig. 10). It is a relatively flat and crescent-shaped bone in lateral view. The posterior border describes a gentle concave curve connecting the iliac pedicle and the posterior process in contrast with some titanosaurs like *Rocasaurus* that has a strongly curved posterior border (García and Salgado, 2013: fig. 8; MPCA–Pv 46/12). The pubic articulation is greater than the anteroposterior length of the proximal plate. The iliac articulation is transversely widened with respect to the base of the iliac peduncle. A relatively long iliac peduncle, measured from the level of the dorsal border of the pubic peduncle is longer than the posterior process, measured from the level of the ventral border of the pubic peduncle. This posterior process is almost complete, and an examination of the bone indicates that only a fragment of 1 cm

Fig. 8. *Arackar licanantay* gen. et sp. nov. posterior dorsal neural arch (SNGM-1/5) stereo pair photos in: A, anterior view; B, posterior view; C, dorsal view; D, ventral view; E, lateral view. Scale bar equals 10 cm.

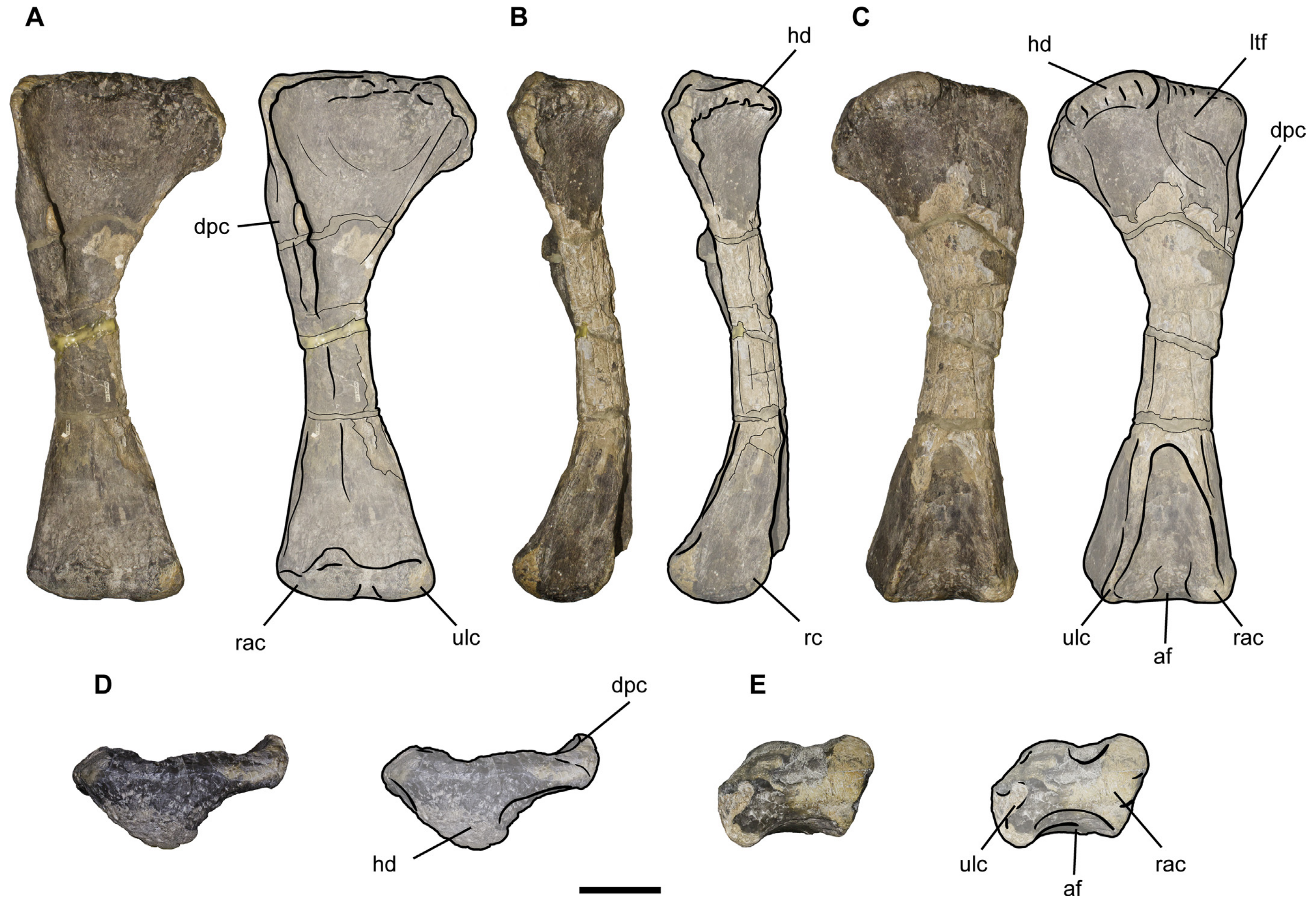


Fig. 9. Right humerus (SNGM-1/1) of *Arackar licanantay* gen. et sp. nov. in: A, anterior view; B, medial view; C, posterior view; D, proximal view (anterior towards top); and E, distal view (anterior towards top). Scale bar equals 10 cm.

length is missing in the posterodistal portion of this bone. In this case, the very short posterior process is an unusual character present in selected titanosaurs like *Rocasaurus* (MPCA–Pv 46/11; B.G.R. obs. pers.), a juvenile of *Alamosaurus* (Lehman and Coulson, 2002; TMM 43621-1), and *Rapetosaurus* (Curry Rogers, 2009, Figure 41; FMNH PR 2209) but in these cases, the posterior process is anteroposteriorly broader. It contrasts dramatically with the ischia of *Aeolosaurus maximus* (Santucci and De Arruda-Campos, 2011), *Aeolosaurus rionegrinus* (Powell, 1987), *Gondwanatitan faustoi* (Kellner and Acevedo, 1999), *Rinconsaurus caudamirus* (Calvo and Riga, 2003), *Sonidosaurus saihangaobiensis* (Xu et al., 2006), and *Muyelensaurus pecheni* (Calvo et al., 2007b) that have a relative long posterior process.

The relative size of the posterior process can be measured following Salgado et al. (1997), using the ratio between the pubic peduncle and the distance from the upper corner of the pubic plate up to the distal end of the posterior process. In this case, *Arackar* has a value of 0.65, similar to that of *Alamosaurus* (0.56–0,62) and *Rapetosaurus* (0.60). In contrast, this ratio is lower in *Andesaurus* (0.46), *Neuquensaurus* (0.45), *Aeolosaurus* (0.52), *Saltasaurus* (0.47), *Opisthocoelicaudia* (0.42), and *Malawisaurus* (0.47).

Ilium.A fragment of the iliac blade is preserved attached to the proximal portion of anterior surface of the femur (Fig. 11). This element has a relatively robust rim, and the preserved surface is concave. However, the fragmentary state of the material makes it difficult to determine the position of this fragment in the ilium, or to make more detailed comparisons.

Femur. The femur (SNGM-1/2) is slender and straight in anterior and posterior views (Fig. 11), about 74 cm long and 9.8 cm wide (minimum transverse length). It is anteroposteriorly flattened, becoming flattest at its mid-length, as in *Atacamatitan chilensis* (Kellner et al., 2011). In addition, the femur of *Arackar* is slightly less slender and proportionally shorter proximodistally than the femur of *Atacamatitan chilensis* (see Fig.4 in Kellner et al., 2011). The proximal end is more antero-posteriorly flattened than the distal end. In several titanosaurs, especially saltasaurids, the mediolateral width of the diaphysis is relatively constant throughout its length (e.g., Powell, 1992). In contrast, the mediolateral width of the diaphysis of *Arackar* is variable throughout its extension, and less than the width between the lateral surfaces of the radial and tibial condyles, a condition that is shared with *Atacamatitan chilensis* (Kellner et al., 2011). The articular head is directed medially and upwards, with the upper border of the femur sloping downwards from the articular head towards the greater trochanter. The articular head forms a gentle curve towards the shaft. A well-developed greater trochanter is present on the posterior face of the proximal end, extending onto the proximal fourth of the femur. Somewhat below the greater trochanter, there is a moderate lateral bulge, which is 30% bigger than the minimum width of the diaphysis (see definition of Salgado et al., 1997). A groove extends along the proximal third of the femur, medial to the greater trochanter. The anterior face of the proximal end of the femur cannot be characterized until further

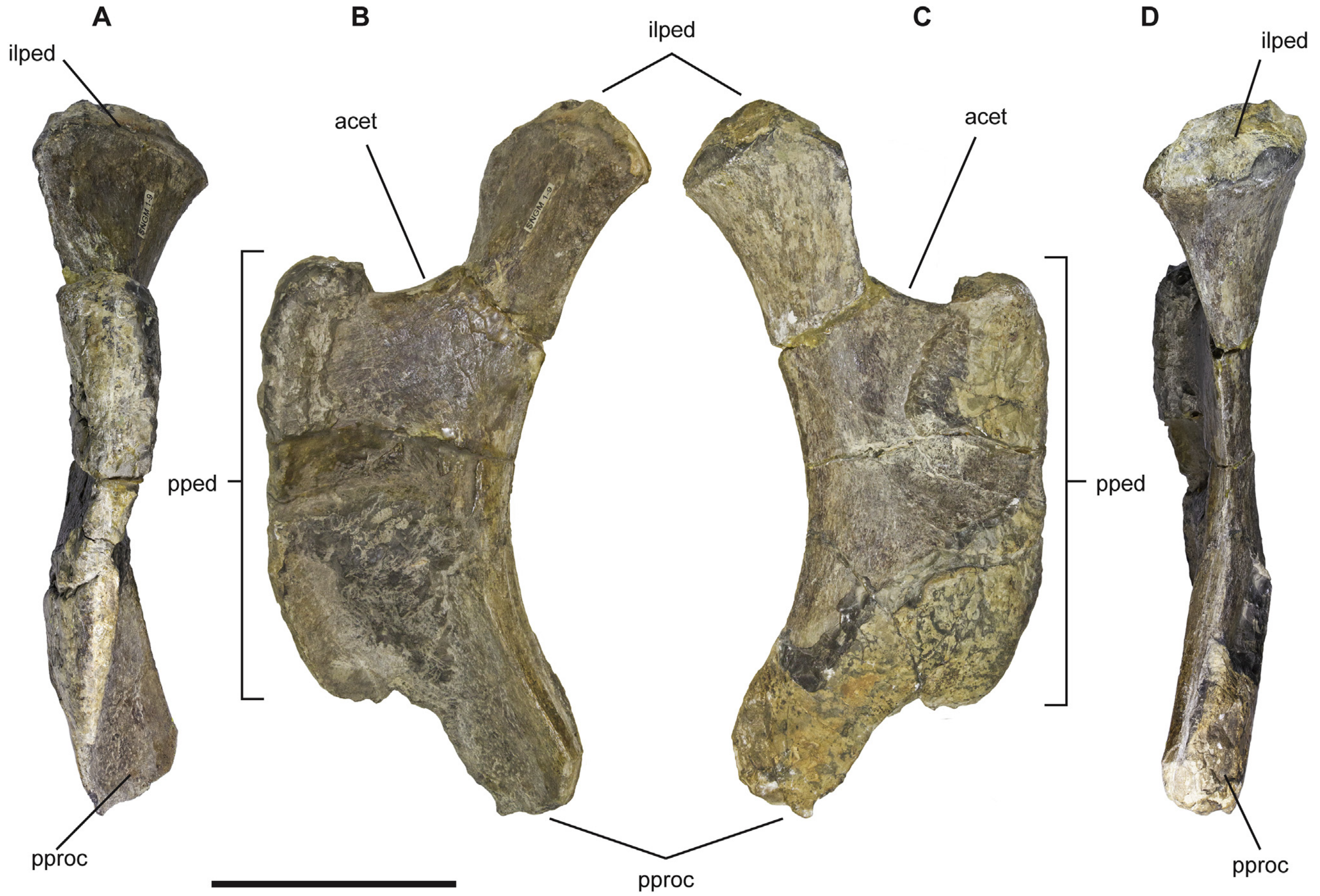


Fig. 10. Left ischium (SNGM-1/9) of *Arackar licanantay* gen. et sp. nov. in: A, anterior view; B, lateral view; C, medial view; D, posterior view. Scale bar equals 10 cm.

preparation (the ilium is affixed to it with matrix). The posterior face of the distal end of the femur shows a well-pronounced intercondylar fossa separating the tibial and fibular condyles. The lateral condyle is missing its posterolateral-most portion. The tibial condyle nevertheless appears to have been greater, anteroposteriorly elongate, protruding strongly anteriorly and posteriorly. The extensor fossa is well-pronounced, as the intercondylar fossa.

6. Phylogenetic relationships

We conducted a phylogenetic analysis to assess the affinities of *Arackar licanantay*, using the dataset of Carballido et al. (2017). The matrix is composed of 87 taxa and 405 characters. The data entry was made using Mesquite V 2.74 (Maddison and Maddison, 2011). Some multistate characters were treated as ordered (14, 61, 100, 102, 109, 115, 127, 132, 135, 136, 166, 179, 195, 256, 259, 276, 277, 278, 279, 299, 303, 346, 352, and 354) (See Appendix and Supplementary data).

The matrix was analyzed under equal character weighting using TNT (Tree analysis using New Technology) v. 1.5 (Goloboff and Catalano, 2016). Methodologically, the data matrix was analyzed using New Technology Search with the functions 'sectorial searches', 'drift' and 'tree fusing'; 'get tree' from 'driven search' and 'stabilize consensus' was also used five times. The resultant trees were searched by Traditional Search using the option 'tree bisection-reconstruction'. This process resulted in 500 MPTs of 1323 steps and produced a relatively well-resolved strict consensus tree (RI: 0.721; CI: 0.367) (Fig. 12).

The consensus tree is relatively well resolved and clearly shows two main clades: Colossosauria and Lithostrotia. Colossosauria comprise most of truly giant titanosaurs like *Argentinosaurus*, *Notocolossus*, *Patagotitan* and *Puertasaurus*. It was recently erected as "the most inclusive clade containing *Mendozasaurus neguyelap* but not *Saltasaurus loricatus* or *Epachthosaurus sciuttoi*" (González Riga et al., 2019).

Within Colossosauria, we recovered Lognkosauria (sensu Calvo et al., 2007a), Rinconsauria (sensu Calvo et al., 2007b) and Aeolosaurini (after new phylogenetic definition of Carballido et al., 2017). A recent study places Aeolosaurini nested in Rinconsauria (Hechenleitner et al., 2020), as a least inclusive group of dinosaurs closely related to *Aeolosaurus*.

Lithostrotia include most derived titanosaurs like *Saltasaurus*, *Opisthocoelicaudia* and *Rapetosaurus*, and some of them represent the latest sauropods that live toward the end of the Cretaceous. Lithostrotia is traditionally defined as "*Malawisaurus dixeyi*, *Saltasaurus loricatus*, their most recent common ancestor and all its descendants" (Upchurch et al., 2004). *Saltasaurus* and *Neuquensaurus* are included in the Saltasaurinae clade, and *Alamosaurus* and *Opisthocoelicaudia* are recovered as a sister-taxon of Saltasaurinae, like in most previous studies (e.g. Salgado et al., 1997; Curry Rogers and Forster, 2001; Wilson, 2002, 2006; González Riga, 2003; Wlison and Upchurch, 2003, 2016, 2018, 2019; Carballido et al., 2017; Hechenleitner et al., 2020).

Arackar is recovered as a derived lithostrotian titanosaur. In our analysis, the clade Lithostrotia is supported by four unambiguous synapomorphies: absence of prespinal lamina in middle and posterior cervical vertebrae (character 139, state 0), prominent

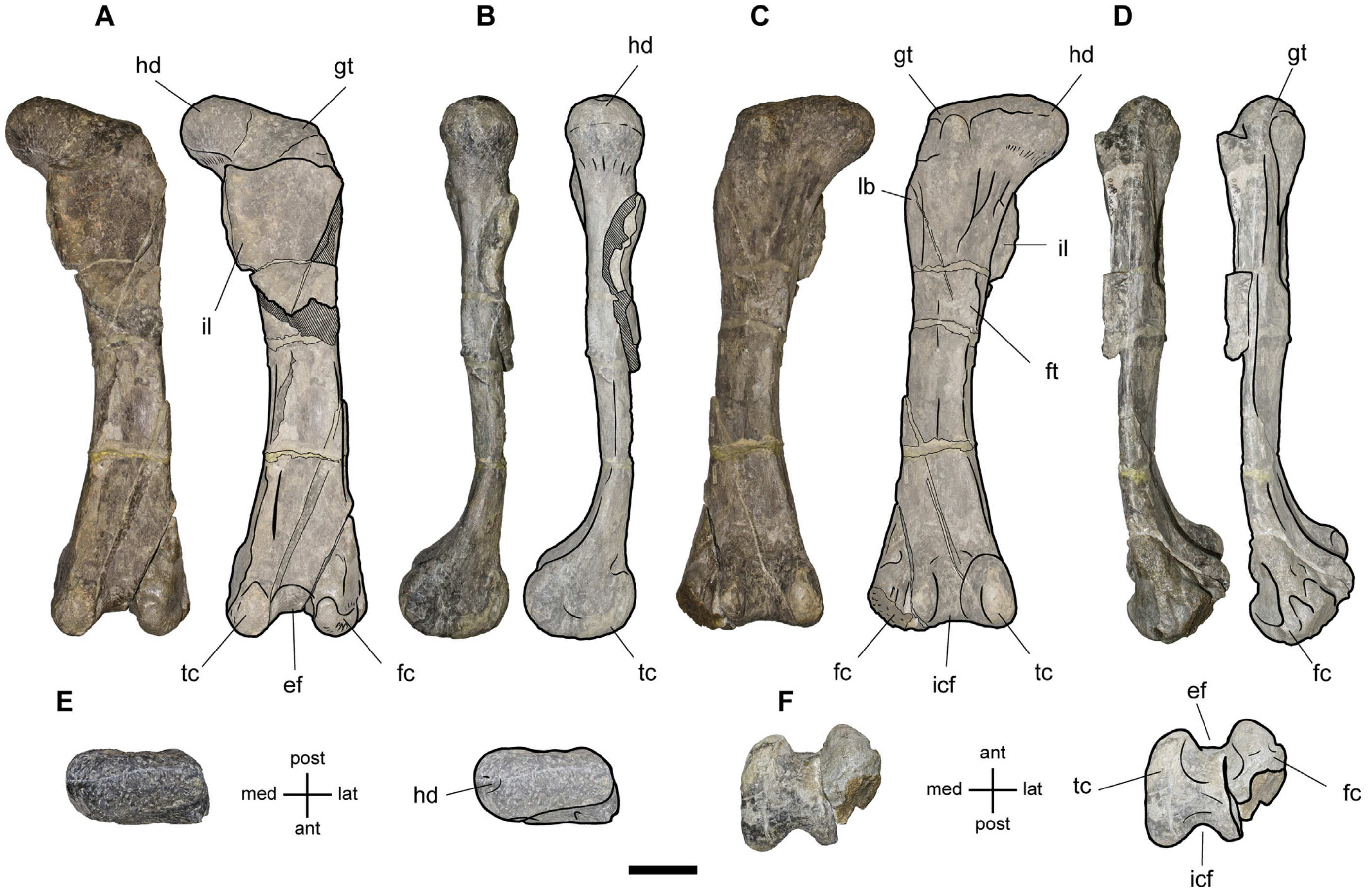


Fig. 11. Left femur (SNGM-1/2) of *Arackar licanantay* gen. et sp. nov. in A, anterior view; B, medial view; C, posterior view; D, lateral view; E, proximal view; F, distal view. Scale bar equals 10 cm.

ulnar olecranon process (character 311; state 0), Ischia, anteroposterior pubic pedicel width divided the total length of the ischium 0.5 or larger (character 343, state 1), and tibia, distal breadth: more than twice midshaft breadth (character 365, state 1).

Arackar is recovered in a clade that includes *Rapetosaurus* + (*Arackar* + *Isisaurus*) and is supported by two unambiguous synapomorphies: non bifid neural spine in middle to posterior dorsal vertebrae that possess lateral margins dorsomedially inclined, that approach each other (character 160, state 3), and absence of triangular aliform processes in neural spines of middle and posterior dorsal vertebrae (character 196, state 0). Other two characters that support this clade are ambiguous and are not present in all of these three taxa: strongly directed posteriorly neural spine in anterior-posterior caudal vertebrae (character 260, state 2), and femur, pronounced ridge on posterior surface between greater trochanter and head (Character 357, estate 1).

Alternative test

We execute an alternative test based on the recently enlarged dataset of Mannion et al. (2019). This matrix was analyzed under the same methodology previously mentioned, using New Technology Search and then, Traditional Search. The matrix analyzed has 544 characters and 107 taxa and we added two characters (543 and 544) (see Appendix). The matrix was analyzed under equal character weighting and characters 11, 14, 15, 27, 40, 51, 104, 122, 147, 148, 195, 205, 259, 297, 426, 435, 472, 510, 543 and 544 were treated as ordered. This process resulted in 3240 MPTs of 2543. The consensus tree is well resolved at level of Diplodocimorpha, but does not have good resolution in the Titanosauria clade, as explained by Mannion et al. (2019: 851; Figure 41). We tested this dataset with different alternatives, but we recovered a polytomy with *Puertasaurus*, *Argentinosaurus*, *Patagotitan* and *Notocolossus*. Moreover, some taxa are recovered in an unusual position: for example, the basal *Andesaurus* lies more derived than *Malawisaurus*, the non-lithostrotian *Xianshanosaurus* and *Dongyangosaurus* are related with *Opisthocoelicaudia*. However, this test is important because *Arackar* is recovered as a derived lithostrotian titanosaur, according to their anatomical features. In this way, two phylogenetic analyses based on independent datasets confirm the position of *Arackar* in the tree, nested in the lithostrotian titanosaurs.

7. Discussion

Some characters of dorsal vertebrae of *Arackar* are important to discuss. Large circumneural cavities (cprf + pacprf) are present in the middle-posterior dorsal (SNGM-1/5) of *Arackar*, that extend alongside almost the entire height of the pedicles, from the prezygapophyses to the base. This is notably different from the similar number 6 dorsal vertebra of *Trigonosaurus* that presents only very small, shallow circumneural excavations restricted to the dorsal most aspect of the neural canal. In relation to the expansion of the perineural cavities, a notably thin centroprezygapophyseal lamina

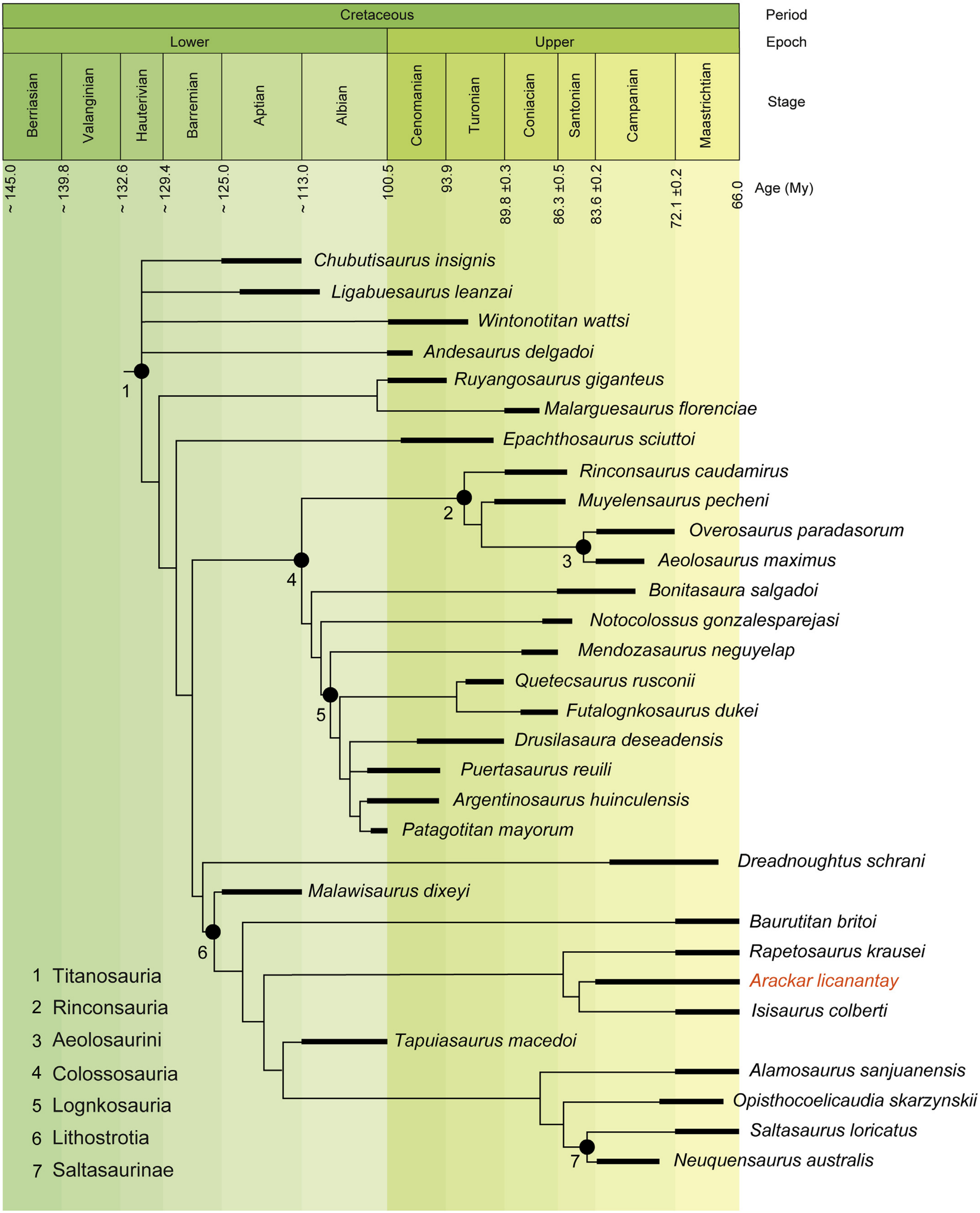


Fig. 12. Strict consensus tree based on a data matrix of 76 taxa and 428 characters recovered *Arackar licanantay* as a derived lithostrotian titanosaur, placing it as a sister taxon of Opisthocoelicaudiinae + (*Trigonosaurus* + Saltasaurinae) (330 MPTs of 1706 steps, CI: 0.264; RI: 0.569).

can be observed in *Arackar*, a condition that is absent in other titanosaurs.

Arackar shares the absence of hyposphene-hypantrum structures in dorsal vertebrae with most titanosaurs. This structure is cited by Apesteguía (2005b) in *Epachthosaurus sciuttoi* (Powell, 1990) and *Argentinosaurus huinculensis* (Bonaparte and Coria, 1993). In *Patagotitan mayorum,* a small hyposphene-hypantrum articulation is present only in the 3rd and 4th dorsals (Carballido et al., 2017).

In *Arackar*, the ischium is much reduced as in *Gondwanatitan faustoi* (Kellner and Azevedo, 1999) and presents a short posterior process as in the Saltasaurinae. The iliac process of the ischium is also much reduced as in *Isisaurus* (Wilson and Upchurch, 2003).

From taphonomic viewpoint, the bones of *Arackar* were found associated in a small area (about 2 m^2) do not present duplicated elements, any, and relative size of preserved elements are consistent with a single individual. The humerus/femur length ratio of *Arackar* is 0.79 and is congruent to derived titanosaurs like *Opisthocoelicaudia* (0.72), *Isisaurus* (0.74), and *Rapetosaurus* (0.80). The skeleton size of holotype' specimens is difficult to estimate accurately. It is represented by a relatively small sub-adult individual that is phylogenetically related with *Rapetosaurus* and *Isisaurus*, according to our cladistic analysis. Articulated and complete skeletons of derived titanosaurs are not available and different taxa show some variation of their anatomical proportions. However, some inferences could be made to estimate the order of magnitude of this specimen. According to Mazzetta and Blanco (2001), in titanosaurs the ratio gleno-acetabular distance/high articulation of the femur shows values that range from 0.97 to 1.26, with an average of 1.09. The total length of the body depends on the neck and tail, aspects with a great variation among titanosaurs. For example, the skeletal reconstruction of *Rapetosaurus* (Curry Rogers, 2009) indicates that the total length of the body (B) is around femur length/0.12, but *Rapetosaurus* has a relatively longer neck than *Arackar*, based on the proportion of the cervical centra (Curry Rogers, 2009: 1084). Anyway, if we assume, as an approach, that *Arackar* has similar proportions to *Rapetosaurus*, it can be estimated to have measured around 6.3 m long.

8. Conclusions

Arackar licanantay is a new lithostrotian titanosaur represented by associated bones that belong to a single sub-adult specimen of around 6.3 m long. This sauropod represents the third dinosaur species discovered in Chile and is diagnosed by a unique association of features of dorsal vertebrae and appendicular bones. *Arackar* shares some characters with *Rapetosaurus* and *Bravasaurus*, and does not belong to the derived Saltasaurinae clade from Patagonia. Phylogenetically, this new taxon is recovered in a lithostrotian clade that includes *Rapetosaurus* + (*Arackar* + *Isisaurus*). For the time being, the *Arackar licanantay* specimen represents the most complete sauropod dinosaur recorded in Chile and the south Pacific margin of South America.

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APPENDIX. New taxa and scores

The score of *Arackar* in the matrix of Carballido et al. (2017) is: 156(1), 157(0), 158(0), 159(0), 160(0), 162(0), 163(1), 164(1), 165(2), 166(1), 168(1), 169(1), 170(2), 171(2), 172(1), 173(0), 177(2), 178(0), 179(1), 180(2), 181(0), 182(0), 183(0), 184(0), 185(2), 186(1), 187(1), 188(0), 189(1), 190(0), 191(0), 192(1), 193(1), 194(0), 195(2), 196(0), 197(1), 198(0), 199(0), 200(1), 201(0), 202(1), 203(1), 204(0), 205(0), 207(2), 208(1), 209(0), 298(0), 299(1), 300(1), 301(1), 302(1), 304(1), 305(1), 306(0), 307(1), 308(1), 310(1), 338(0), 339(0), 340(0), 341(1), 342(1), 343(1), 344(1), 345(1), 346(0), 347(0), 349(0), 350(0), 351(1), 352(1), 353(2), 354(1), 355(2), 356(1), 357(1), 358(1), 359(1), 360(0), 361(1), 362(0).

In the Supplementary data is available the matrix (tnt. format). The character list is available in Carballido et al. (2017). In this list, the character 160 must be corrected as follow: Middle to posterior dorsal vertebrae, non-bifid neural spine in anterior or posterior view: (0) possess subparallel lateral margins; (1) possess lateral margins which slightly diverge dorsally; (2) possess lateral margins which strongly diverge dorsally; (3) possess lateral margins dorsomedially inclined, that approach each other; (Wilson, 2002; Upchurch et al., 2004; Carballido et al., 2017).

Alternative test

The score of *Arackar* in the dataset of Manion et al. (2019) is: 15(0), 17(0), 21(0), 22(1), 40(1), 41(1), 42(1), 43(1), 61(0), 62(1), 65(1), 66(0), 118(1), 119(0), 120(1), 121(0), 122(0), 141(2), 142(0), 143(1), 144(0), 145(0), 146(1), 147(2), 148(0), 149(1), 151(0), 152(1), 153(0), 154(0), 155(1), 156(1), 159(1), 160(1), 161(0), 162(0), 164(1), 165(0), 166(1), 167(1), 168(0), 169(0), 223(1), 224(0), 225(0), 226(0), 227(1), 228(1), 229(1), 230(1), 252(1), 253(1), 256(1), 257(1), 258(1), 280(1), 332(0), 333(0), 334(0), 335(1), 336(0), 337(1), 338(0), 340(1), 341(1), 342(1), 343(0), 344(1), 345(0), 364(0), 365(1), 366(1), 367(0), 368(1), 369(0), 370(0), 386(0), 388(1), 389(1), 390(1), 467(0), 470(0), 471(0), 472(0), 473(1), 474(0), 475(0), 476(1), 479(0), 480(0), 481(0), 483(0), 488(0), 516(0), 517(0), 518(0), 526(0), 527(0), 528(0), 529(1), 530(0), 532(1), 534(1), 535(0).

Moreover, two characters are added: 543. Number of phalanges in pedal digit II: three (0), two (1) (González Riga et al., 2016). 544. Number of phalanges in pedal digit V: two (0), one (1), zero (2) (Gonzalez Riga et al., 2019).

The score of these characters are: *Shunosaurus*: 543(0), 544(0), *Omeisaurus*: 543 (0), 544(0), *Cedarosaurus*: 543(0), 544(1); *Apatosaurus* 543(0), 544(1); *Diplodocus*: 543(0), 544(0); *Camarasaurus*: 543(0), 544(1); *Janenschia*: 543(1), 544(1); *Gobititan* 543(1), 544(0); *Epachthosaurus*: 543(1), 544(2); *Mendozasaurus*: 543(1), 544(2); *Notocolossus*: 543(1), 544(2); *Opisthocoelicaudia*: 543(1), 544(2); *Alamosaurus*: 543(1), 544(2).

The character list and matrix is available in the paper of Mannion et al. (2019).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2021.104802.