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A large hadrosaurid dinosaur from Presa San Antonio, Cerro del Pueblo Formation, Coahuila, Mexico

ROGELIO ANTONIO REYNA-HERNÁNDEZ, HÉCTOR E. RIVERA-SYLVA,
LUIS E. SILVA-MARTÍNEZ, and JOSÉ RUBÉN GUZMAN-GUTIÉRREZ



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New hadrosaurid postcranial material is reported, collected near Presa San Antonio, Parras de la Fuente municipality, Coahuila, Mexico, in a sedimentary sequence belonging to the upper Campanian of the Cerro del Pueblo Formation, in the Parras Basin. The skeletal remains include partial elements from the pelvic girdle (left ilium, right pubis, ischium, and incomplete sacrum), a distal end of a left femur, almost complete right and left tibiae, right metatarsals II and IV, cervical and caudal vertebrae. Also, partially complete forelimb elements are present, which are still under preparation. The pubis shows characters of the Lambeosaurinae morphotypes, but the lack of cranial elements does not allow us to directly differentiate this specimen from the already described hadrosaurid taxa from the studied area, such as *Velafrons coahuilensis*, *Latirhinus uitstlani*, and *Kritosaurus navajovius*. This specimen, referred as Lambeosaurinae indet., adds to the fossil record of the hadrosaurids in southern Laramidia during the Campanian.

Key words: Dinosauria, Hadrosauridae, Lambeosaurinae, Cretaceous, Campanian, Mexico.

Rogelio Antonio Reyna-Hernández [rogelio.reynahr@gmail.com], Luis E. Silva-Martínez [luis.silva.paleo@gmail.com], Laboratorio de Paleobiología, Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, Av. Pedro de Alba y Manuel L. Barragán s/n, Ciudad Universitaria, San Nicolás de los Garza, Nuevo León, México. C.P. 66455. Héctor E. Rivera-Sylva [hrivera@museodeldesierto.org] (corresponding author), José Rubén Guzman-Gutiérrez [paleoveri@yahoo.com.mx], Departamento de Paleontología, Museo del Desierto, Carlos Abedrop Dávila 3745, Saltillo, Coahuila, México. C.P. 25022.

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Introduction

Hadrosaurids are a very distinctive and common group of ornithomimid dinosaurs in Late Cretaceous ecosystems. Their stratigraphic range begins in the late Santonian and ends together with the other non-avian dinosaurs at the K/Pg extinction event at the end of the Maastrichtian. They also have a wide geographical distribution, as specimens of this clade have been found on all continents except Oceania (Horner et al. 2004; Lund and Gates 2006; Prieto-Márquez 2010a; Longrich et al. 2021). These ornithomimids differ from the other groups of dinosaurs due to the adaptations of the nasal region, where the bones have been modified in specialized structures such as cranial crests (e.g., Lull and Wright 1942; Ostrom 1961b). Furthermore, they present a complex dental arrangement made up of different series of rows of teeth and keratinous bills that allowed them a more efficient herbiv-

orous diet (Morris 1970; Nabavizadeh 2014; Nabavizadeh and Weishampel 2016). Most of the diagnostic elements for this family are found in the cranial region (Prieto-Márquez 2010b), from which large number of species has been differentiated. However, the pectoral and pelvic girdles also provide a wide range of taxonomic information that does not always receives the proper importance (Brett-Surman 1989; Campione 2014).

In Mexico, the Hadrosauridae presents the widest record of any group of dinosaurs, with most of the reports coming from the northern region (Ramírez-Velasco et al. 2014; Rivera-Sylva and Carpenter 2014; Ramírez-Velasco and Hernández-Rivera 2015). Despite this, the study of Mexican specimens has been relatively scarce due to the fragmentary condition of most of the specimens, although the number of hadrosaurid studies in Mexico has recently increased (Kirkland et al. 2006; Serrano-Brañas et al. 2006; Ramírez-Velasco et al. 2014; Serrano-Brañas

and Espinosa-Chávez 2017; Rivera-Sylva et al. 2019a; Rybakiewicz et al. 2019).

The Cerro del Pueblo Formation is one of the most studied geological formations in Mexico with a very diverse faunal record, composed mainly of dinosaurs and other reptiles (Wolfeben 1977; Rodríguez-de la Rosa and Cevallos-Ferriz 1998; Kirkland et al. 2000; Cifuentes-Ruiz et al. 2006; Rivera-Sylva and Espinosa-Chávez 2006; Loewen et al. 2010; Brinkman 2014; Rivera-Sylva et al. 2018, 2019b; Serrano-Brañas et al. 2020), flora (Rodríguez-de la Rosa and Cevallos-Ferriz 1994; Estrada-Ruiz and Cevallos-Ferriz 2007; Estrada-Ruiz et al. 2009; Cevallos-Ferriz and Vázquez-Rueda 2016), and trace fossils (Rodríguez-de la Rosa and Cevallos-Ferriz 1998; Rodríguez-de la Rosa 2007; Rivera-Sylva et al. 2017; Serrano-Brañas et al. 2018a, b, 2019). Three hadrosaurid taxa are known so far from this formation: *Kritosaurus navajovius* Brown, 1910 (Kirkland et al. 2006; Prieto-Márquez 2014b), *Latirhinus uitstlani* Prieto-Márquez and Serrano Brañas, 2012 (Prieto-Márquez and Serrano Brañas 2012) and *Velafrons coahuilensis* Gates, Sampson, Delgado de Jesús, Zanno, Eberth, Hernandez-Rivera, Aguillón-Martínez, and Kirkland, 2007 (Gates et

al. 2007). The latter species was described based on cranial elements only, despite the fact that there are a number of preserved postcranial elements.

We describe a new hadrosaurid specimen consisting only of postcranial material from the Cerro del Pueblo Formation collected in Parras de la Fuente municipality, Coahuila, Mexico. The study of these materials would allow for better overview of the faunal diversity within the fossil ecosystems of the Upper Cretaceous in Mexico and provide a more robust anatomical knowledge of the species of the region.

Institutional abbreviations.—AEHM, Amur Natural History Museum of the Far Eastern Institute of Mineral Resources, FEB RAS, Blagoveshchensk, Russia; CPC, Colección Paleobiológica de Coahuila, Museo del Desierto, Saltillo, Mexico; FCBUANL, Colección Paleobiológica, Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, San Nicolás de los Garza, Mexico; GMH, Geological Museum of Heilongjiang, Harbin, China; IGM, Museo de Paleontología, Instituto de Geología, Universidad Nacional Autónoma de México, Mexico City, Mexico; LACM, Natural History Museum of Los Angeles County, Los Angeles, USA.

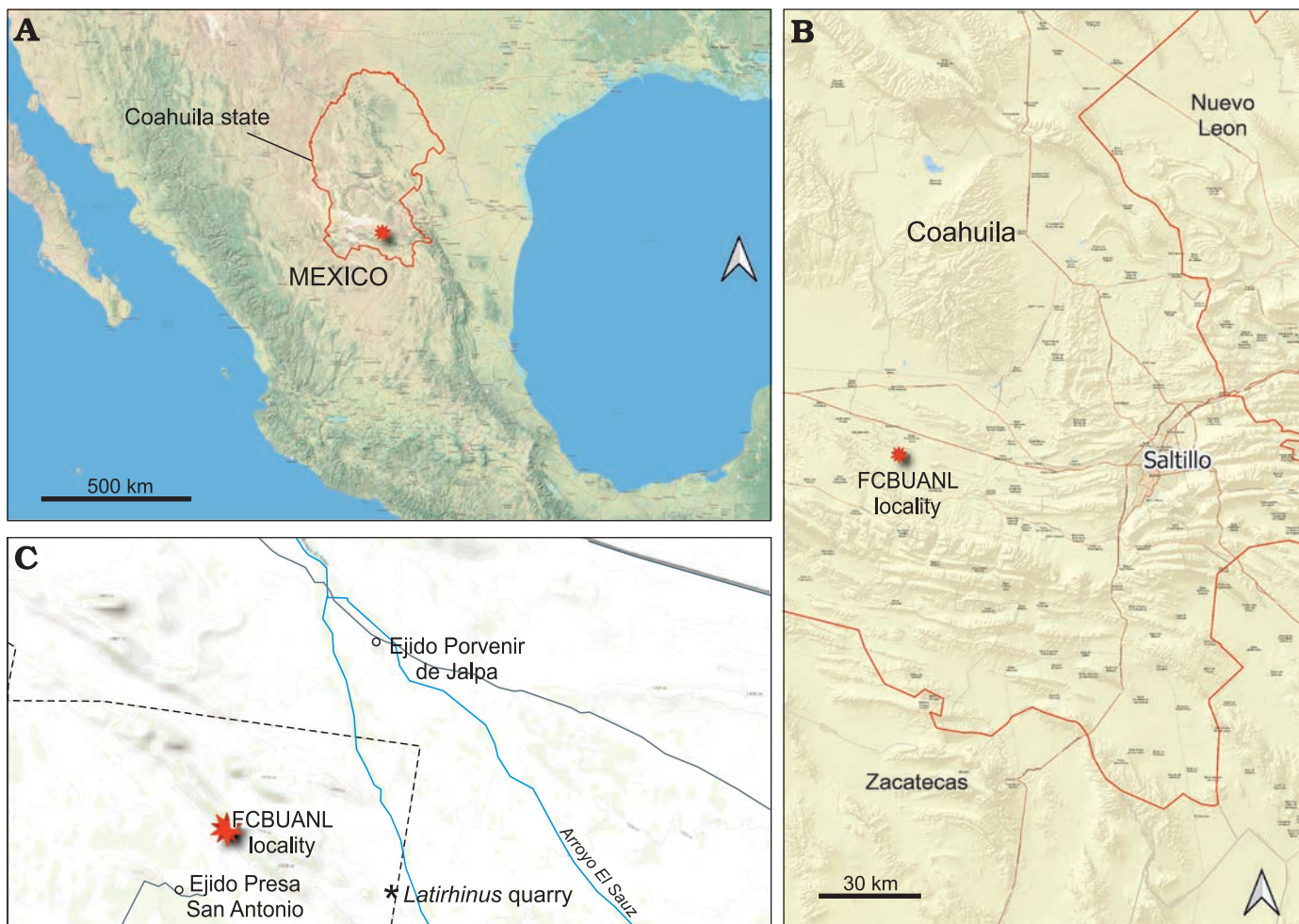


Fig. 1. Map showing location of the Coahuila state (A) and FCBUANL locality (B) where studied fossils were found. Detailed map indicating the principal localities of Cerro del Pueblo Formation (C), FCBUANL_2711 locality represented by red star.

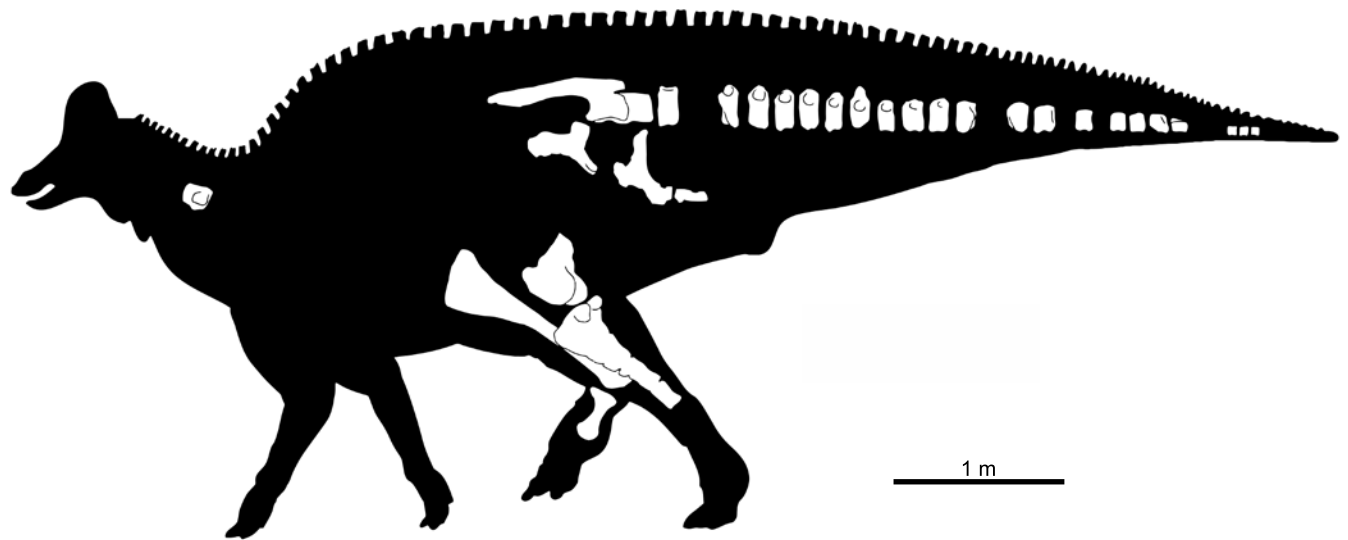


Fig. 2. Skeletal composition of the FCBUANL_2711. The silhouette was obtained from phylopic.org vectorized by T. Michael Keesey from the work of Dmitry Bogdanov.

Material and methods

The specimen FCBUANL_2711 was collected by a team of the Laboratorio de Paleobiología, FCB UANL, during 1992 near the Ejido Presa San Antonio, located in the Parras de la Fuente municipality, Coahuila state, northeastern Mexico (Fig. 1). The specimen was deposited in the Colección Paleobiológica of the UANL Facultad de Ciencias Biológicas. The preparation process has been slow due to space restrictions. Mechanical techniques have been used for this purpose with tools as electric engravers and brushes. The present material was photographed with a Canon EOS Rebels XT camera and Canon 28 mm lens and Canon PowerShot SX280 HS.

Systematic palaeontology

Dinosauria Owen, 1842

Ornithischia Seeley, 1887

Ornithopoda Marsh, 1881

Hadrosauridae Cope, 1870

Lambeosaurinae Parks, 1923

Lambeosaurinae indet.

Material.—FCBUANL_2711, left ilium, right pubis, right ischium, partial sacrum, distal end of left femur, right and left tibiae, II and IV right metatarsals, one cervical and 21 caudal vertebrae (Fig. 2); from Near Ejido Presa San Antonio, Parras de la Fuente municipality, Coahuila, Mexico. The material was recovered from a thick lodo-lite layer dominated by the gastropod *Tympanotonus nodosa* with thin sandstone intercalations, at Cerro del Pueblo Formation, upper Campanian.

Description.—*Ilium*: Only the left ilium is preserved, missing the posterior region, including the supracetabular crest. The length of the preserved portion is 780 mm (Fig. 3A₁). The preacetabular process is thick and shows a deep projection close to the anterior end, extruding posteriorly in the direction of the tip. The lateral surface is flattened and in dorsal view it shows a slight concavity with respect to the lateral plane (Fig. 3A₂). This process is 597 mm in length and shows a minimal degree of ventral deflection

Table 1. Measurements (in mm) of the caudal vertebrae centra of Lambeosaurinae indet. FCBUANL_2711. Element numbers are tentative and do not consider the missing vertebrae.

Element	Height	Width	Length
1	172	194	83
2	182	179	98
3	187	166	91
4	177	176	93
5	178	157	91
6	174	142	85
7	165	152	82
8	155	144	95
9	152	120	98
10	141	135	92
11	147	120	92
12	123	129	96
13	119	114	101
14	113	84	79
15	91	83	84
16	81	85	88
17	96	90	88
18	?	80	91
19	51	63	55
20	54	66	52
21	47	50	58

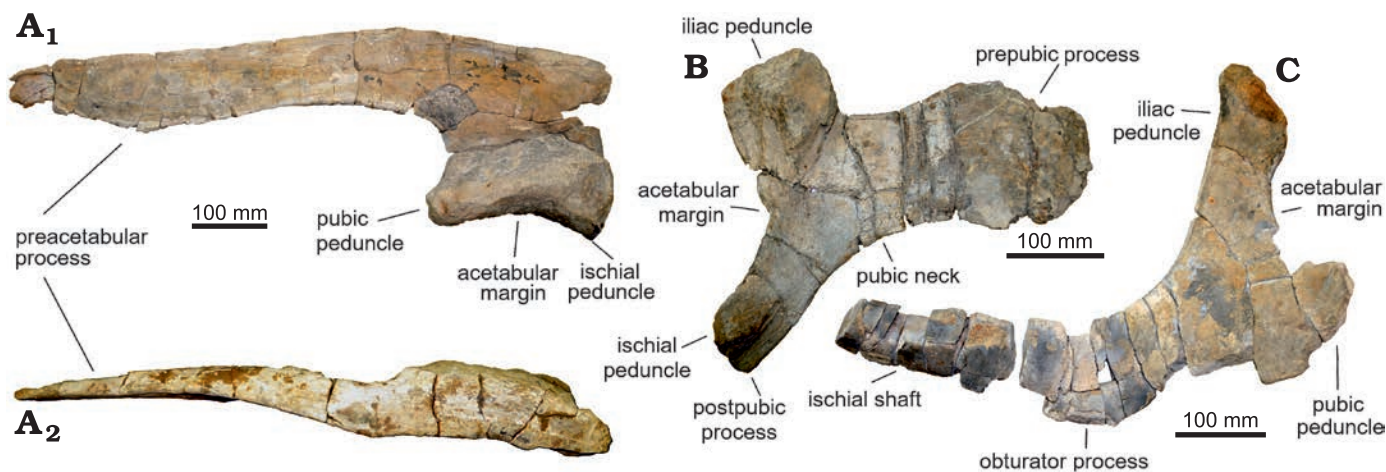


Fig. 3. Lambeosaurinae indet., pelvic girdle elements of FCBUANL_2711, from Ejido Presa San Antonio, Coahuila, Mexico, upper Campanian. A. Left ilium in lateral (A₁) and dorsal (A₂) views. B. Right pubis in lateral view. C. Right ischium in lateral view.

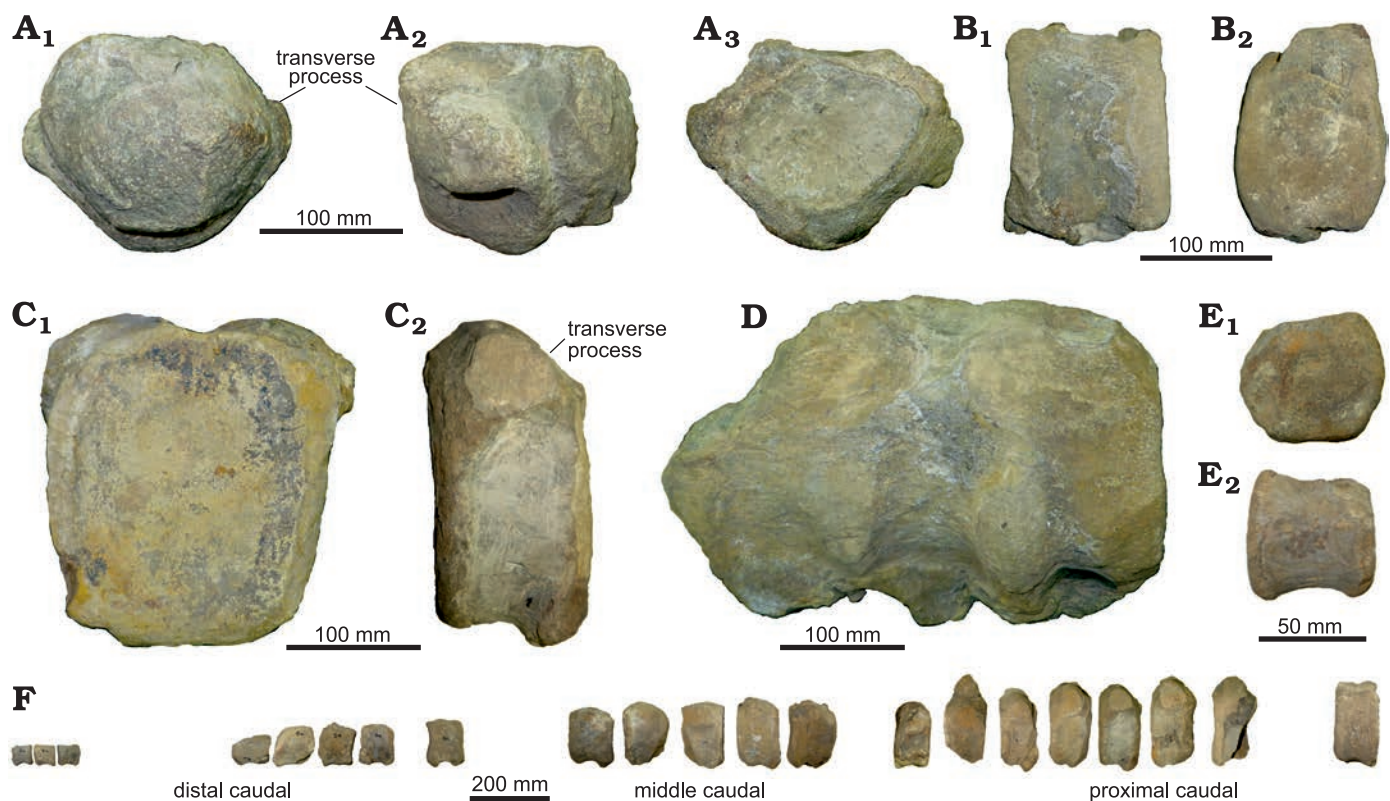


Fig. 4. Vertebrae of Lambeosaurinae indet.(FCBUANL_2711) from Ejido Presa San Antonio, Coahuila, Mexico, upper Campanian. A. Cervical vertebrae, in cranial (A₁), lateral (A₂), and caudal (A₃) views. B. Middle caudal vertebra, in lateral (B₁) and cranial (B₂) views. C. Proximal caudal vertebra, in cranial (C₁) and lateral (C₂) views. D. Sacrum in ventral view. E. Distal caudal vertebra in cranial (E₁) and lateral (E₂) views. F. Caudal vertebrae in lateral view.

(164°). The ratio between the length of the preacetabular process and the length of the acetabulum is 3.14. Although the length measurements seem to indicate that this process has a considerable elongation compared to the ilium, it is not possible to confirm this assumption this without knowing the proportions of the postacetabular process.

Pubis: The pubis (Fig. 3B) has a wide and short pubic blade. The dorsal margin starts to project notably dorsally at the beginning of the prepubic process, while the ventral margin does the same in the ventral direction. Due to the

absence of the dorsal and ventral margins of the distal portion of the prepubic process, the shape of this region cannot be determined. However, this process is hypothesized to be short, based on its distal margin. The iliac peduncle is massive and wide, with a triangular section and mediodorsally expanded in the distal region. The distal end of the ischiadic peduncle is absent, and the proximal region shows a protuberance at the base. The distal region of the postpubic process is not preserved and the base is slightly ventrally projected. The acetabular margin is concave and an angle

of 134° is observed between the portion of the margin that corresponds to the iliac peduncle and the margin of the ischial peduncle, giving the appearance of an abrupt change of direction in the margin.

Ischium: Only the proximal region of the right ischium is present, and it is poorly preserved (Fig. 3C). The iliac peduncle is strongly dorsally projected, giving a longer appearance in comparison with the pubic peduncle, which is eroded. The dorsal and ventral margins of the iliac peduncle are convergent. The dorsal one is nearly straight from the base to the tip of the iliac peduncle, and the vertex between dorsal and articular margin is slightly dorsally projected. Only the base of the obturator process is preserved, and it is strongly eroded. The ischiadic shaft shows a clockwise torsional deformation at the base.

Cervical vertebra: Only one cervical vertebra was collected (Fig. 4A). It presents a markedly opisthocoelus condition with a length close to 110 mm. The centrum is wider than high, and the neural canal is wide. There is no neural arch associated with this vertebra and both transverse processes are short and centrally located.

Sacrum: The sacrum (Fig. 4D) is preserved as a single fragmented block composed of 3 sacral vertebrae. It has an approximate length of 350 mm. The last centrum is as tall as wide. Dorsally, it has a neural arch and associated spines. The ventral side is heavily eroded.

Caudal vertebrae: 21 elements are preserved, eight proximal, five middle and eight distal caudal vertebrae (Fig. 4B, C, E, F). Table 1 lists the measurements of the caudal vertebrae. The proximal caudal vertebrae (Fig. 4C) have amphicoelus centra, rectangular to pentagonal in anterior view, being taller than wide and compressed craniocaudally. The neural canal is relatively narrow. Vascular foramina are present in the lateral sides of the centra. In the first vertebra the transverse processes on the centrum are eroded and missing, whereas the following vertebrae present them on the upper lateral part. Also, the articular surfaces of

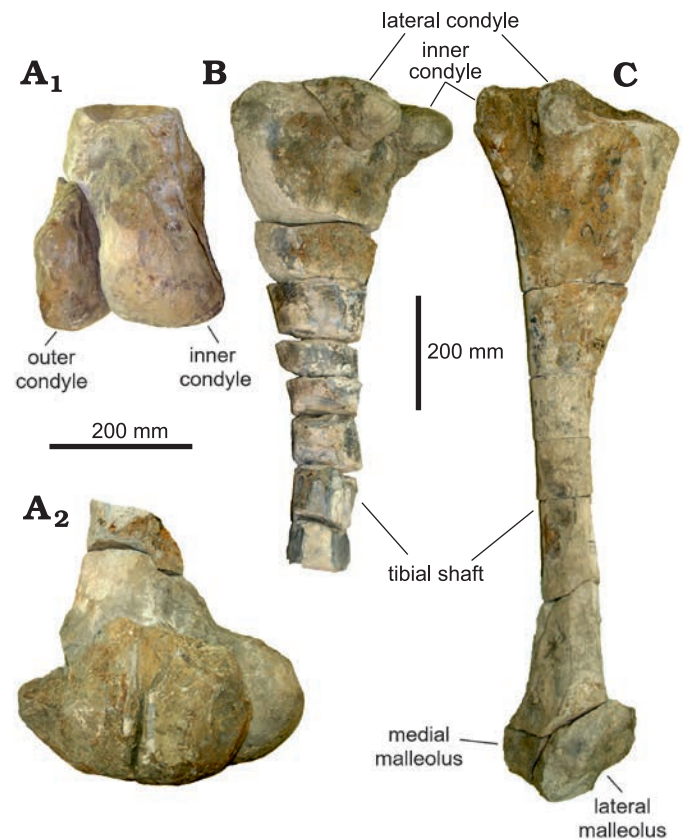


Fig. 5. Hindlimb elements of Lambeosaurinae indet. (FCBUANL_2711) from Ejido Presa San Antonio, Coahuila, Mexico, upper Campanian. A. Distal end of the left femur, in caudal (A₁) and lateral (A₂) views. B. Left tibia in lateral view. C. Right tibia in lateral view.

the chevrons are absent on the first vertebra, but they are present on the following elements. The neural arches and spines are present however they are still under preparation. The middle caudal vertebrae (Fig. 4B) are smaller than the proximal caudal vertebrae and hexagonal in anterior view. The articular surfaces of the chevrons are slightly projected

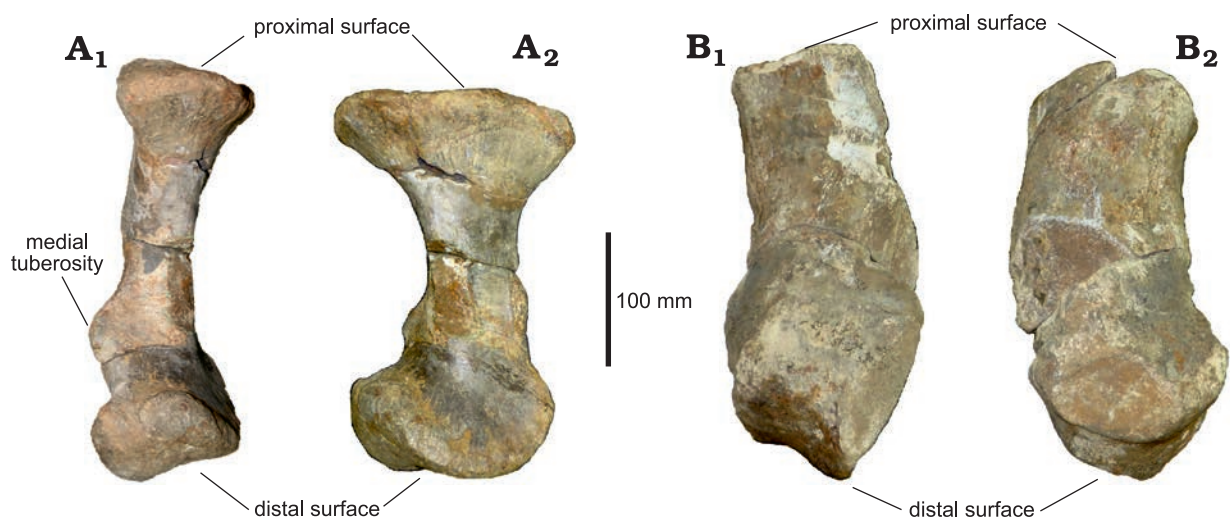


Fig. 6. Metatarsals of Lambeosaurinae indet. (FCBUANL_2711) from Ejido Presa San Antonio, Coahuila, Mexico, upper Campanian. A. Metatarsus II, in dorsal (A₁) and lateral (A₂) views. B. Metatarsus IV, in dorsal (B₁) and lateral (B₂) views.

ventrally. The centra are less compressed than the proximal vertebrae, maintaining the amphicoelus centra and the narrow neural canal. The distal caudal vertebrae (Fig. 4E) have the smallest centra with cubic proportions. They lack the transverse processes, and the articular surfaces of the chevrons are completely reduced.

Femur: Only the distal end of the left femur is preserved (Fig. 5A₂). The cranial portion is absent, the outer condyle is smaller and more lateromedially compressed than the inner condyle. The latter is more caudally projected, the intercondylar groove is narrow distally, widening proximally (Fig. 5A₁).

Tibiae: Both tibiae are present (Fig. 5B, C). However, the left one is missing the distal end and the shaft is transversely fragmented multiple times (Fig. 5B). The right tibia is complete (Fig. 5C), with minor eroded areas and a total length of about 1300 mm. Both tibiae have a wide craniocaudal expansion at their proximal ends and the inner condyle is larger than the lateral condyle, forming a well-defined intercondylar groove. The cnemial crests are eroded on both tibiae. The central shaft of the tibia is sub-cylindrical and very thin compared to the width of the proximal end. In the right tibia the lateral malleolus is smaller than the medial malleolus.

Metatarsals: The right metatarsal IV (Fig. 6B) measures about 330 mm in length. Near mid-length, the bone is strongly deflected laterally. The proximal surface is markedly concave. The distal surface is heavily eroded on the sides. The right metatarsal II (Fig. 6A) is much better preserved than the previous one, with a length of approximately 340 mm. The proximal surface is flat, unlike metatarsal IV, and expanded dorsoplantarily. A medial tuberosity is located above the distal end of metatarsal II, where the bone curves medially.

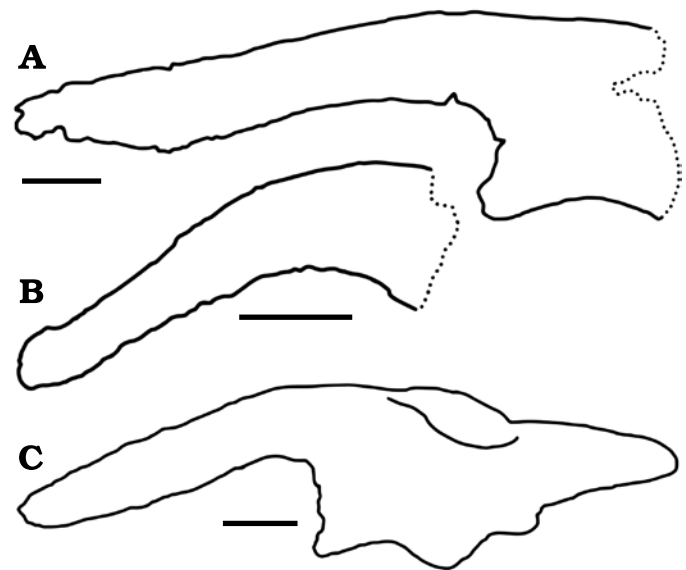


Fig. 7. Comparison of ilia of hadrosaurids from Cerro del Pueblo Formation. A. Lambeosaurinae indet., FCBUANL_2711. B. *Latirhinus uitstlani* (Prieto-Márquez and Serrano Brañas 2012). C. *Velafrons coahuilensis*, CPC 59 (Gates et al. 2007). Scale bars 100 mm.

Discussion

Comparisons with *Latirhinus* and *Velafrons*.—*Latirhinus uitstlani* Prieto-Márquez and Serrano Brañas, 2012 is the only species described so far with postcranial material from the Cerro del Pueblo Formation (Prieto-Márquez and Serrano Brañas 2012). The ilium of FCBUANL_2711 (Fig. 7A) differs markedly from *L. uitstlani* IGM 6583 (Fig. 7B) by presenting a sigmoidal curvature in the ventral margin of the preacetabular process, which narrows anteriorly. The distal

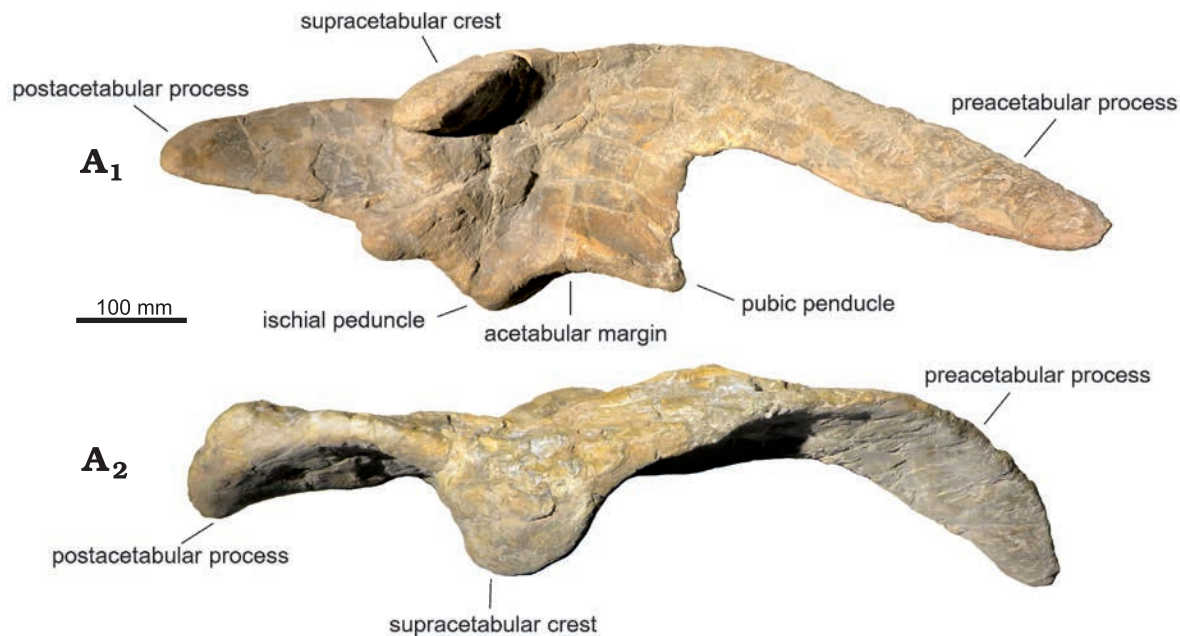


Fig. 8. Ilium of hadrosaurid dinosaur *Velafrons coahuilensis* Gates, Sampson, Delgado de Jesús, Zanno, Eberth, Hernandez-Rivera, Aguillón-Martínez, and Kirkland, 2007 (CPC 59) from Rincón Colorado, Coahuila, Mexico, upper Campanian; in lateral (A₁) and dorsal (A₂) views.

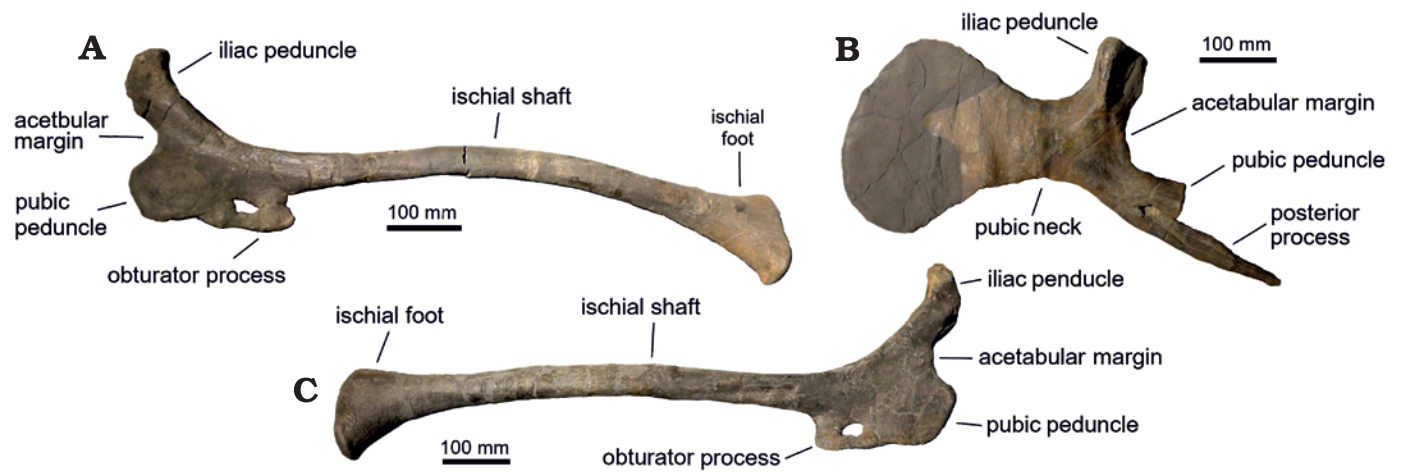


Fig. 9. Pelvic girdle elements of hadrosaurid dinosaur *Velafrons coahuilensis* Gates, Sampson, Delgado de Jesús, Zanno, Eberth, Hernandez-Rivera, Aguillón-Martínez, and Kirkland, 2007 (CPC 59) from Rincón Colorado, Coahuila, Mexico, upper Campanian. A. Left ischium in lateral view. B. Left pubis in lateral view, shading indicates the reconstructed area. C. Right ischium in lateral view.

end of the iliac peduncle of one of the ischias is also assigned to IGM 6583, but due to its fragmentary condition, a direct comparison is not possible.

The holotype of the hadrosaurid *Velafrons coahuilensis* (CPC 59) includes the right ilium, left pubis and both ischia, but these elements were never described. The ilium of CPC 59 (Fig. 7C) has a total length of 690 mm and shows a wide and straight preacetabular process in lateral view (Fig. 8A₁), whereas in dorsal view this process is strongly craniolaterally curved (Fig. 8A₂). The preacetabular notch is wide and the ischiadic peduncle is not strongly projected cranially. In contrast, the preacetabular process of FCBUANL_2711 is concave in dorsal view with respect to the lateral axis but it does not present a deformation as marked as in CPC 59. Furthermore, the preacetabular notch is narrower, highlighting the cranial projection of the pubic peduncle, which is more robust than in CPC 59. The ilium of FCBUANL_2711, despite being incomplete, is longer than the ilium of CPC 59, which has been previously regarded as a juvenile specimen (Gates et al. 2007). Both specimens show a ventral deflection of the preacetabular process greater than 150°, 153° in CPC 59 and 164° in FCBUANL_2711. According to Brett-Surman and Wagner (2007), this character is highly variable, even between the two ilia of the same individual, therefore a difference of 10° of ventral deflection is not sufficient for the differentiation of FCBUANL_2711 from *V. coahuilensis*. The designation of FCBUANL_2711 as an adult specimen of *V. coahuilensis* is possible, however Prieto-Márquez (2014a) indicates that in *Edmontosaurus annectens* Marsh, 1892, there is an ontogenetic change in the ventral deflection of the preacetabular process of the ilium. In juveniles it is slightly deflected (157° to 165°) whereas adults shows a more pronounced deflection (138° to 147°) (Prieto-Marquez 2014a). A more detailed study of this character in other species is necessary to determine whether ontogenetic variation of the deflection of this process is generalized among hadrosaurids, or if it is only present in *E. annectens*.

The left pubis of CPC 59 (Fig. 9B) shows the common morphology of lambeosaurines, presenting a high iliac peduncle with triangular cross-section and a short prepubic constriction. The prepubic process is incompletely preserved. The margins of the prepubic constriction are divergent, and the dorsal margin arises dorsally without reaching the level of the proximal end of the iliac peduncle. The pubis of FCBUANL_2711 and that of CPC 59 are similar, differing in the more robust iliac peduncle in the former and the slightly narrower prepubic constriction in CPC 59.

CPC 59 preserves both complete ischia (Fig. 9A, C), characterized by the “thumb-like” shape of the dorsal and articular margin of the iliac peduncle. The distal end of the ischiadic shaft ends in the typical lambeosaurine “foot” shape, but it lacks the “heel”, a feature also absent in species of *Corythosaurus* and *Lambeosaurus* (Brett-Surmann 1989). The ischium is the least well preserved element of the three pelvic bones of FCBUANL_2711, showing the “thumb like” iliac peduncle as well, although erosion reduces the visibility of this character. Both the pubic peduncle, the obturator process, and the notch are not well preserved, preventing a more extensive comparison with the material assigned to *Velafrons*. The absence of the distal end of the ischial shaft precludes a more accurate assignment of this material to Lambeosaurinae, as well as its differentiation from *V. coahuilensis*.

Comparisons with other hadrosaurids.—The angle of ventral deflection of the ilium greater than 150°, present in FCBUANL_2711 and *Velafrons coahuilensis*, is also present in the material tentatively referred to the Asian hadrosaurine *Kundurosaurus nagorny* Godefroit, Bolotsky, and Lauters, 2012b, AENM 2/922-7L (Godefroit et al. 2012b), relegated as a junior synonym of *Kerberosaurus manakini* Bolotsky and Godefroit, 2004, by Xing et al. (2014), in the south American hadrosaurine *Bonapartesaurus rionegrensis* Cruzado-Caballero and Powell, 2017 (Cruzado-Caballero and Powell 2017), and the Asian lambeosaurine *Sahaliyania elunchunorum* Godefroit, Shulin, Tingxiang, and Lauters,

2008 (Godefroit et al. 2008). The ilium of FCBUANL_2711 differs from *K. manakini* by having a wide preacetabular process, a notable characteristic in lambeosaurines (Brett-Surman 1989). The preacetabular process of the ilium also shows a ventral projection close to the cranial end where it narrows distally, as in other lambeosaurine specimens like FMNH P27393 *Parasaurolophus cyrtocristatus* Ostrom, 1961a (Ostrom 1961a), LACM 20874 *Magnapaulia laticaudus* Morris, 1981 (Prieto-Márquez et al. 2012) and AEHM 2/846 *Olorotitan arharensis* Godefroit, Bolotsky, and Alifanov, 2003 (Godefroit et al. 2012a). The ilium shows a similar morphology to the GMH W103 an ilium referred to *S. elunchunorum* (Godefroit et al. 2008), but the preacetabular notch of FCBUANL_2711 is narrower than in GMH W103. The absence of the supracetabular crest and postacetabular process prevents a more extensive comparison, since in these regions possess important diagnostic characters for the clade (Prieto-Márquez 2010b).

The pubis of FCBUANL_2711 resembles the V morphotype proposed by Brett-Surman (1989) which corresponds to the Parasaurolophini clade, while differs from the morphotypes of the Hadrosaurinae by having a short and wide prepubic constriction. Despite the incomplete condition, the prepubic process is similar to the morphology of the *Hypacrosaurus stebingeri* Horner and Currie, 1994, pubis (see Guenther 2009: fig. 10c). The material referred to *S. elunchunorum* includes a left pubis (GMH W179) that differs from FCBUANL_2711 in having an almost straight ventral margin of the prepubic process, resulting in a more elongated appearance of the bone, similar to the V morphotype of Brett-Surman (1989). The pubis of GMH W179 bears a robust iliac peduncle, although to a lesser extent than in FCBUANL_2711. The incomplete condition of the prepubic process complicates a better systematic resolution, but the recognized features suggest lambeosaurine affinities.

Conclusions

The hadrosaurid specimen described in this paper shows lambeosaurine affinities, therefore distinct from *Kritosaurus navajovius* and *Latirhinus uitstlani*, both present in the Cerro del Pueblo Formation. The differentiation from to *Velafrons coahuilensis* is not clear; because FCBUANL_2711 is a large individual, it is possible that it is a fully developed adult individual of this species, but an osteohistological analysis would be necessary to confirm this. The lack of cranial elements in FCBUANL_2711 prevents the assignment of the specimen to *V. coahuilensis* or to a different species. Therefore, this specimen is referred only as Lambeosaurinae indet. Paleontological studies of this clade, along with other groups of dinosaurs, have increased in recent years in Mexico, but several other materials need to be studied from other geological formations of Campanian–Maastrichtian Mexico. This will allow a better understanding of the terrestrial environments during these ages in southern Laramidia.

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