



## DESCRIPTION OF A TITANOSAURID CAUDAL SERIES FROM THE BAURU GROUP, LATE CRETACEOUS OF BRAZIL<sup>1</sup>

(With 27 figures)

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**ABSTRACT:** A new titanosaurid, *Baurutitan britoi* n. gen., n. sp., is described and compared with other taxa of that sauropod clade. The specimen (MCT 1490-R) consists of the last sacral followed by a sequence of 18 caudal vertebrae that were found in the continental deposits of the Late Cretaceous Bauru Group that outcrop at the Peirópolis region, near the town of Uberaba, State of Minas Gerais, Brazil. This new taxon is distinguished from other titanosaurians by several features, including subrectangular to square outline of the anterior articulation surface of the anterior and middle caudals, strongly pointed laterally directed process intercepting the spinoprezygapophyseal lamina in caudal 1; dorsal prezygapophyseal tuberosity on the lateral margin of the prezygapophyses of caudals 2-4, that smoothens out in midcaudals. This material demonstrates that the horizontal ridge present in middle and posterior caudals of some titanosaurs, in *Baurutitan britoi* is homologous with a dorsal tuberosity and not with the transverse process.

**Key words:** Dinosauria. Sauropoda. Titanosauria. Titanosauridae. Cretaceous. Brazil.

**RESUMO:** Descrição da série caudal de um titanossaurídeo do Grupo Bauru, Cretáceo Superior do Brasil.

Um novo titanossaurídeo, *Baurutitan britoi* n. gen., n. sp., é descrito e comparado com outros membros desse clado de saurópodes. O espécime é composto por uma última vértebra sacral seguida de uma sequência de 18 vértebras caudais (MCT 1490-R) proveniente das cercanias do povoado de Peirópolis, no Município de Uberaba (Estado de Minas Gerais, Brasil), tendo sido encontrado nos depósitos continentais do Grupo Bauru (Cretáceo Superior). Entre as características que distinguem esse novo táxon dos demais Titanosauria estão a face subretangular ou quadrada da articulação anterior das caudais, processo lateral bem desenvolvido interceptando a lamina espinopré-zigapofisiária da caudal 1, tubérculo dorsal na margem lateral das pré-zigapófises das caudais 2-4, que se torna em uma rugosidade que tende a se tornar menos pronunciada nas caudais médias. Este material também demonstra que em *Baurutitan britoi* n. gen., n. sp. a crista lateral nos centros das caudais medianas é o resultado de uma diminuição de um processo dorsal e não é homólogo do processo transverso.

**Palavras-chave:** Dinosauria. Sauropoda. Titanosauria. Titanosauridae. Cretáceo. Brasil.

### INTRODUCTION

Up to date the richest locality in Brazil with titanosaur remains is Peirópolis (Fig. 1). In the past, the most productive site was the Caieira quarry that yielded hundreds of titanosaur bones (CAMPOS & KELLNER, 1999). Among the recovered material is a series of 19 vertebrae (the last sacral and 18 caudals) collected in 1957, housed in the collection of the Earth Science Museum (MCT) of the Departamento Nacional de Produção Mineral

(DNPM, Rio de Janeiro) under the number MCT 1490-R. This specimen was briefly described by POWELL (1987) as the "Series C" and referred as *Titanosaurus* sp. It is one of the few articulated titanosaurid caudal sequences and has been used several times to determine the place in the tail of isolated or partially articulated caudals from other dinosaurs (e.g., GONZÁLEZ RIGA, 2003; MARTÍNEZ *et al.*, 2004).

In this paper we redescribe MCT 1490-R and establish a new titanosaurid taxon, *Baurutitan britoi*

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n. gen., n. sp. We also include a detailed description of the chevrons that have not been studied before. This species is compared with the following titanosaurs: *Aeolosaurus rionegrinus* POWELL (2003); *Aeolosaurus* sp. SALGADO & CORIA (1993); *Aeolosaurus* sp. SALGADO, CORIA & CALVO, (1997b); *Alamosaurus sanjuanensis* GILMORE, 1922; *Epachthosaurus sciuttoi* POWELL, 1990 (MARTINEZ *et al.*, 2004); *Gondwanatitan faustoi* KELLNER & AZEVEDO, 1999; *Mendozasaurus neguyelap* GONZÁLEZ RIGA, 2003; *Neuquensaurus australis* (Lydekker 1893); *Opisthocoelicaudia skarzynskii* BORSUK-BIALYNICKA, 1977; *Pellegrinisaurus powelli* SALGADO, 1996; *Rinconsaurus caudamirus* CALVO & GONZÁLEZ RIGA, 2003; *Saltasaurus loricatus* BONAPARTE & POWELL, 1980; *Titanosaurus araukanicus* (HUENE, 1929); *Titanosaurus colberti* JAIN & BANDYOPADHYAY 1997 (renamed as *Isisaurus colberti* by WILSON & UPCHURCH, 2003); *Lirainosaurus astibiae* SANZ *et al.*, 1999, and MCT 1488-R/ MCT 1719-R (CAMPOS *et al.*, 2005 - this volume). The data from most of the mentioned titanosaur taxa was obtained from the original description and complemented with other papers including CORIA *et al.* (1998), POWELL (1992, 2003), BONAPARTE (1996), and SALGADO, CORIA & CALVO, 1997a. The sedimentary rocks of this area

belong to the Marília Formation (BERTINI, 1993) from the Bauru Basin (FERNANDES & COIMBRA, 1996). For a review of the paleontological content of this and other stratigraphic units of the Bauru Basin see BERTINI (1993) and BERTINI *et al.* (1993). Abbreviations as follows: (dtu) dorsal tuberosity, (nc) neural canal, (ns) neural spine, (posl) postspinal lamina, (poz) postzygapophysis, (prsl) prespinal lamina, (prz) prezygapophysis, (prztu) prezygapophyseal tuberosity, (tp) transverse process, (sprl) spinoprezygapophyseal lamina, (sri) sacral rib, (l) left, (r) right.

#### BRIEF HISTORY OF THE CAIEIRA QUARRY

In 1958, after several years working at one particular point in Peirópolis (the Caieira quarry of CAMPOS & KELLNER, 1999), L.I. Price understood that this fossil deposit was more extensive than he had anticipated and provided a summary of the activities done so far in his annual report for the Geology and Mineralogy Division of the Departamento Nacional de Produção Mineral (DNPM). This report was published the next year by the director of the DNPM, A.R. Lamago, with some pictures of the quarry that are reproduced here (Fig.2).



Fig.1- The Caieira site, near Uberaba, Minas Gerais State.

According to PRICE (1955), he examined this region in 1947 based on the information of Jesuino Felicissimo Junior, of the Instituto Geográfico e Geológico de São Paulo, who pointed out the presence of fossil vertebrates in the Uberaba area. The next year (1948) he prepared the opening of a quarry which

was done only in 1949. Still according to Price's report of 1958, fossils have been collected in six different occasions (he did not precise the dates), with the recovery of several specimens, including turtles, crocodylomorphs, theropods (Coelurosauria - two species, "Carnosauria" - isolated teeth) and sauropod

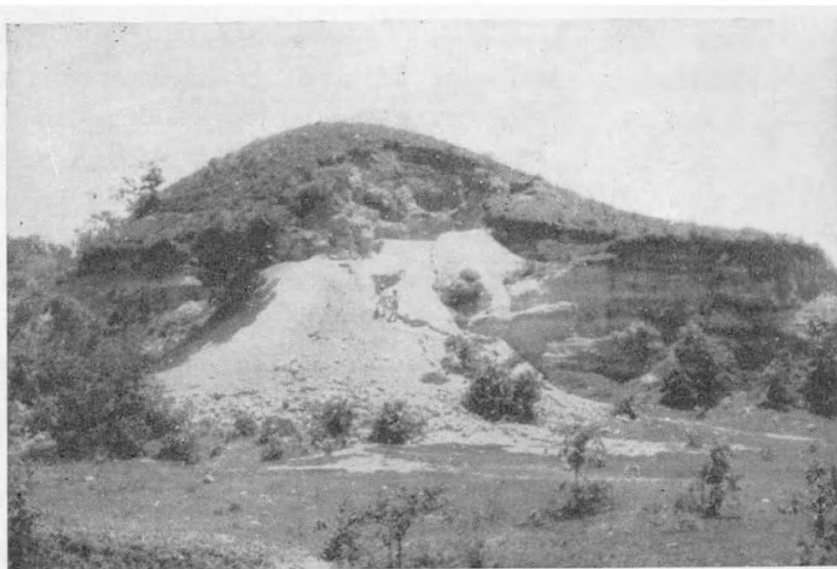


Fig. 23 — Desmonte na jazida fossilífera em Peirópolis, Estado de Minas Gerais, em arenitos da formação Bauru de idade cretácica.



Fig. 24 — Encontro de parte de uma coluna vertebral ainda articulada de um dinossauro saurópodo, na jazida fossilífera em Peirópolis, Estado de Minas Gerais.

Fig. 2- Reproduction of the likely first published picture of the Peirópolis site, showing the Caieira quarry (on top) and the pelvis MCT 1488-R still in the field. This picture was reproduced from Price's report published in LAMEGO (1959).

dinosaurs. Other fossils were also recovered such as fragments of fishes, freshwater invertebrates (gastropods, bivalves), ichnofossils (invertebrate tubes), egg shale fragments, and plant remains (PRICE in LAMEGO, 1959:181-182). The overburden that had to be removed in order to reach the main fossiliferous layer varied between 4 to 18 (!) meters, what was done manually. Extremely hard sedimentary rocks were removed occasionally by dynamite. Price also pointed out that until the excavation of 1957, he regarded the titanosaur bones collected belonging to three individuals of distinct sizes, all representing the same genus. However, in 1957 he and his crew had found a series of 19 vertebrae (at that point he thought all were caudals) that clearly demonstrated the presence of a second distinct genus, making the re-evaluation of the assignment of all collected elements necessary.

Although not published in his report, Price was also working on a quarry map showing the main specimens recovered. A photo of this map was published by CAMPOS & KELLNER (1999) and showed that the excavations at the Caieira quarry were done in 1949, 1950, 1953, 1955, 1957, 1958, and 1959. A second copy of this picture was found recently and includes the year 1961 handwritten by Price (Fig.3). Possible this was the last year of excavation at the Caieira quarry and apparently has not yielded any significant specimen.

Examining the material collected by Price, POWELL (1987) described some remains of the Caieira quarry, including a partial vertebral column and pelvis (the series "B") and the articulated series of the last sacral and 18 caudals (the series "C"). This study was partially reprinted recently (POWELL, 2003).

Until 1999, none of those specimens were numbered. CAMPOS & KELLNER (1999) provided some numbers of some important specimens collected in the Peirópolis area (including the series B and C from the Caieira quarry) and most elements have been numbered recently by one of the authors during his master dissertation (M.N.F. Trotta).

#### SYSTEMATIC PALEONTOLOGY

Saurischia Seeley, 1888

Sauropodomorpha Huene, 1932

Sauropoda Marsh, 1878

Titanosauria Bonaparte & Coria, 1993

Titanosauridae Lydekker, 1893

*Baurutitan* n.gen.

Type-species – *Baurutitan britoi* n.sp.

**Etymology** – The generic name is formed by *Bauru*, in allusion to the Bauru Group and *titan*, from the giants of the Greek myths.

**Diagnosis** – The same as for the species.

*Baurutitan britoi* n.sp.

**Holotype** – Last sacral vertebrae articulated with a sequence of 18 caudal vertebrae, belonging to a single individual. This specimen (MCT 1490-R) is housed at the Museu de Ciências da Terra - MCT (Earth Science Museum) of the Departamento Nacional de Produção Mineral (DNPM), in Rio de Janeiro, Brazil (Figs.4-27).

**Etymology** – The specific name is given in honor of Ignacio Aureliano Machado Brito (1938-2001), an important Brazilian paleontologist, who advised several students including two authors of this paper (DAC and AWAK).

**Type-locality** – MCT 1490-R was collected in the Peirópolis site, at the point known as "Caieira" which is an abandoned quarry at the São Luis Farm located at the Veadinho Hill. This point is situated about 2km North of Peirópolis, Municipality of Uberaba, Minas Gerais State, Southeastern Brazil.

**Geological setting** – As all specimens collected from the Caieira point, MCT 1490-R was found in fine to medium grained white and yellow sandstones from the Marília Formation, Serra da Galga Member, at a height of 835m (BERTINI, 1993). The age of this stratigraphic unit is regarded as Maastrichtian (GOBBO-RODRIGUES, PETRI & BERTINI, 1999).

**Diagnosis** – Titanosaurid dinosaur characterized by the following potential autapomorphies: strongly pointed laterally directed process intercepting the spinoprezygapophyseal lamina on the caudal 1; anterolaterally directed spinoprezygapophyseal lamina. It is further distinguished from other titanosaurs by the following combination of characters: first caudal biconvex; developed dorsal tuberosity on the neural arch that turns into a lateral ridge in the middle caudals; neural spines in the most anterior caudals (1-4) inclined posteriorly, changing to a more vertical to subvertical inclination in caudal 5 to 10; prezygapophyseal tuberosity on the lateral margin of the prezygapophysis of caudals 2-4, which becomes less developed in the posterior elements, smoothing out in the midcaudals; subrectangular outline of anterior articulation of the caudal centrum, getting more squared towards the end of the tail.



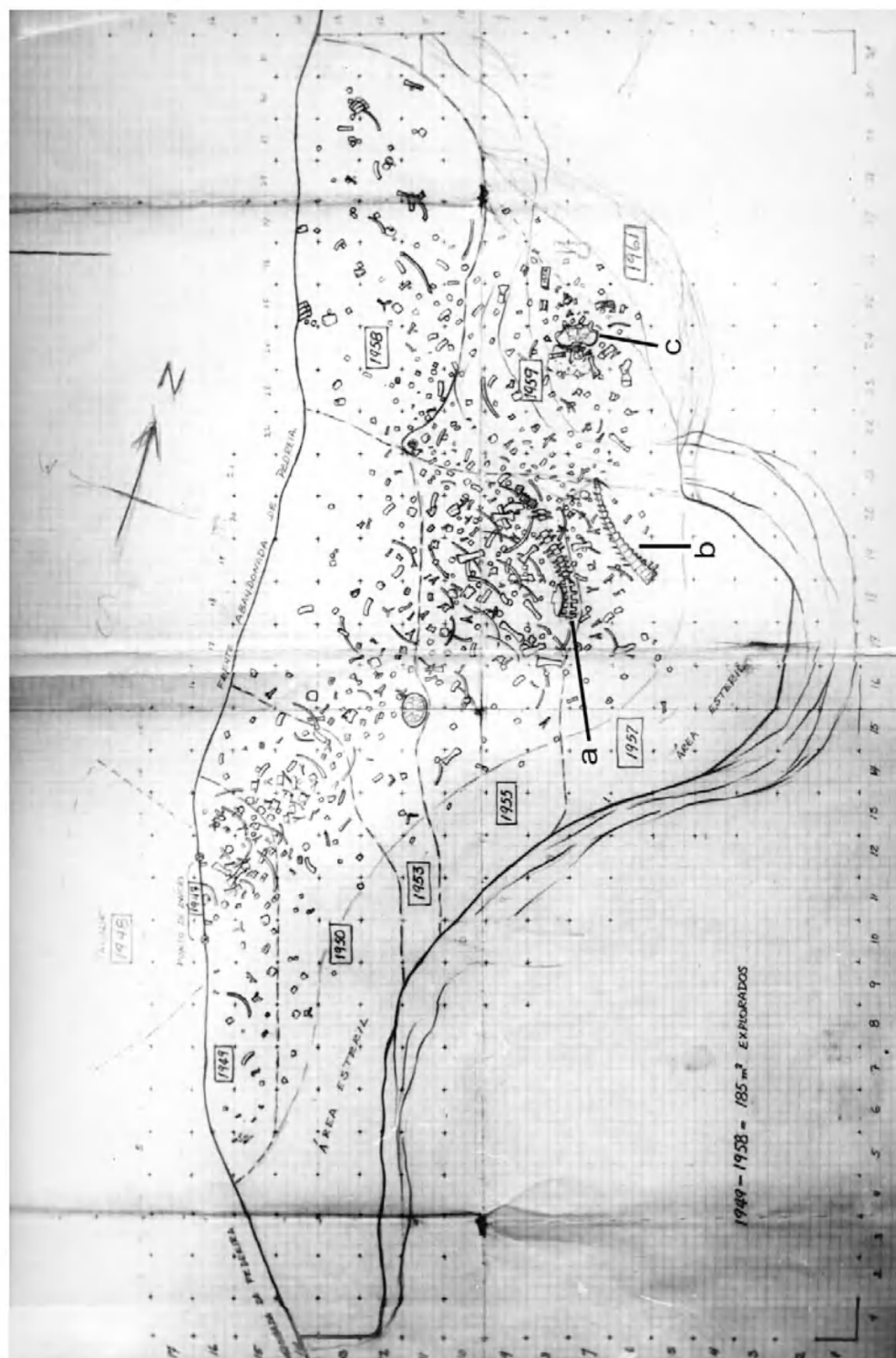


Fig.3- Map showing the position of the bones collected at the Caieira quarry made by L.I.Price. This figure reproduces a picture of the map taken by someone of Price's crew. Note that the year 1961 was added by Price after this picture was taken, which is the only difference of this map and the one published by CAMPOS & KELLNER (1999). Arrows indicate the main specimen recovered: (a) MCT 1488-R (see CAMPOS *et al.*, 2005), (b) *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R) and (c) MCT 1536-R.

## DESCRIPTION AND COMPARISON

The material of *Baurutitan britoi* consists of 19 vertebrae, starting with the last sacral and subsequent caudals. All elements were found articulated (Fig.3). The material is well preserved, lacking any major postmortem compression, and is complete except for part of the left neural arch of the sacral and the right transverse process of the 3rd and 7th caudal. The centra of the 7th and 8th caudal were damaged possibly by a drilling instrument during the collecting process. After being prepared (some decades ago) this sequence was numbered continuously starting with the last preserved sacral. Therefore, the numbers written on the caudals (left on the specimen for historical reasons) do not refer to their anatomical position in the tail (e.g., caudal numbered as 3 is, in fact, the 2nd caudal).

For descriptive purposes, this vertebral series is divided into sacral vertebrae (only the last one preserved), first caudal, anterior caudals (2nd-7th), and middle caudals (8th-18th). Although admittedly arbitrary, the distinction between anterior and middle caudals is made by the presence of a well developed transverse process. In *Baurutitan britoi*, the first caudal where this process starts to be vestigial is the 8th which is here regarded as the beginning of the middle caudal series. The nomenclature regarding different lamina is based on WILSON (1999).

### SACRAL VERTEBRA

The right side of the last sacral is complete, whereas the left side lacks the basal part of the neural spine, the neural arch, the diapophysis, parapophysis and prezygapophysis (Figs.4-7). The centrum is complete except for the most anterior surface. Despite that, it is clear that the articulation with the preceding sacral was slightly convex. The posterior articulation surface is strongly concave, suggesting that this sacral had an opisthocoelous condition. Overall the centrum is rounded, slightly wider than high at the posterior surface. Laterally, it is longer than high, having a shallow depression below the transverse process. On the right side, close to the dorsoanterior corner, the centrum is pierced by two foramina. The centrum of the last sacral was not fused with the precedent element.

The neural arch is fused with the centrum and shows a complex morphology. The neural canal is not complete in anterior view but posteriorly has an oval shape, being higher than wide. The neural spine is tall and transversally expanded with a rectangular apex in dorsal view. The anterior surface is irregular, showing shallow depressions and ridges. On the right side of the neural arch (the left part is not preserved) the presence of a prezygodiapophyseal lamina (partially broken) is observed. A bony ridge at the anterior surface of the neural spine is connected with the prezygodiapophyseal lamina, delimitating a subtriangular cavity with the apex situated ventrally. Posteriorly the neural spine has a deep cavity located between the postzygapophyses. In lateral view, the neural spine is inclined posteriorly, with the vertical projection of the posterodorsal corner placed behind the posterior margin of the centrum.

Pre- and postspinal laminae are present. The prespinal lamina is well developed and projects anteriorly. In the middle part, it has a width between 6 and 10mm. The lateral surface is irregular, with several shallow depressions. At both sides of the contact surface with the neural spine there are irregular and dorsoventrally elongated cavities which are deeper at the right side. These cavities are present from the base of the neural spine until at least two thirds of its length and do not reach the apex. The postspinal lamina is less projected than the prespinal lamina, keels posteriorly with a wide base (~15mm) and disappears near the postzygapophyses above a concavity located at the base of the neural spine. Laterally, the dorsal part of the postspinal lamina is more developed getting gradually lesser projected toward the base. Lateral to this lamina, a dorsoventrally elongated depression is observed, bordered by a comparatively thick spinopostzygapophyseal lamina. There are some depressions on the postspinal lamina, as well as on the adjacent surfaces of the neural spine.

The spinodiapophyseal lamina is well developed and thick, covering the anterolateral margin of the neural spine until reaching its middle region. The posterior surface shows two laterally placed cavities. The dorsal one is oval and deep. The ventral is much larger, has a rounded shape and is deep too, being perforated by several foramina.

Only the right prezygapophysis is preserved. It is very short, having the articulation surface expanded anteroposteriorly. The postzygapophyses are located very close to the neural spine and show elongated articulation surfaces for the first caudal. The parapophysis shows a pyramidal structure, with the ventral surface being parallel to the horizontal plane, and a dorsal edge rising dorsally as a thick bony blade (proximal part of the sacral rib),

partially preserved on the right side. Uniting the parapophysis and the centrum is a strong and thick bony bridge oriented anteriorly that does not form a true lamina. A deep subtriangular cavity is present on the dorsal surface of this bridge.

The sacral rib is partially preserved on the right side. Although being fused to the centrum, the limits can be observed particularly at the region corresponding to the parapophysis.

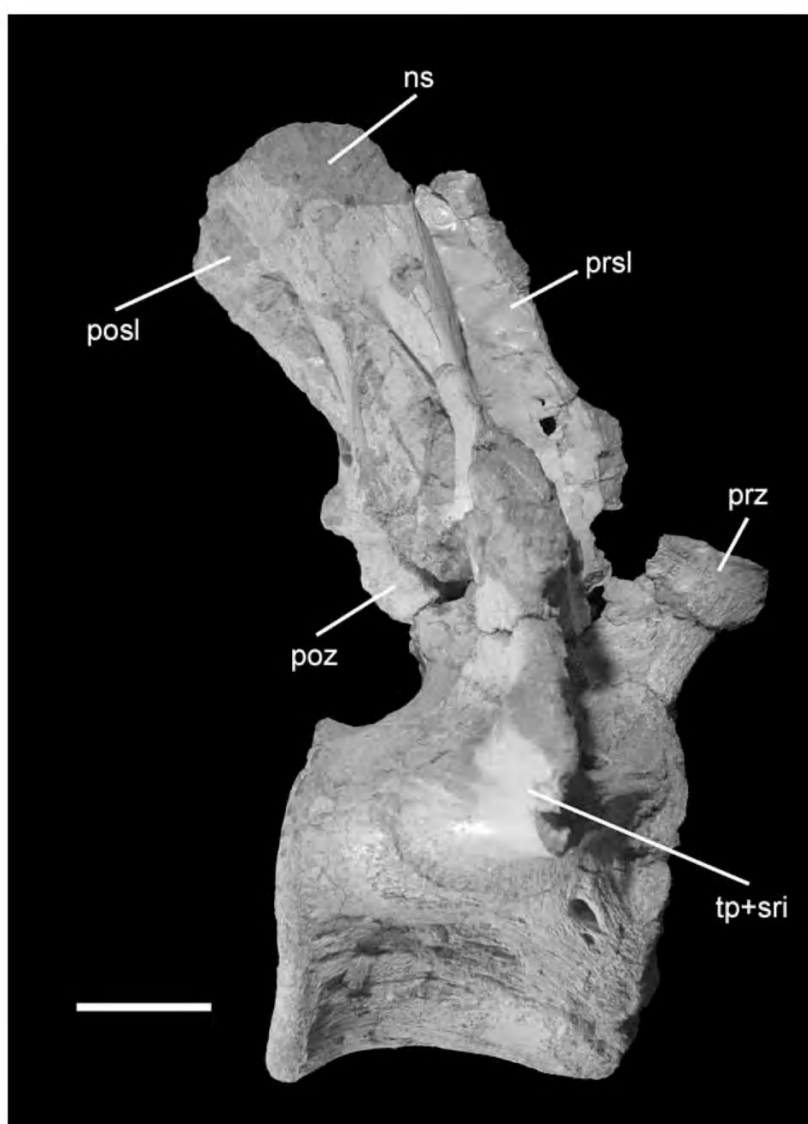


Fig.4- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), sacral vertebra in right lateral view. Scale bar = 50mm. See text for abbreviations.

Comparisons with other titanosaurid taxa are difficult since in most the last sacral is either not present or not described in detail. The degree of fusion in the sacrals varies among titanosaurid or closely related taxa. In *Baurutitan britoi* the last sacral was not fused to the precedent sacral, similar to *Gondwanatitan faustoi* (KELLNER & AZEVEDO, 1999) but differing from *Opisthocoelicaudia skarzynskii*, *Isisaurus colberti*, *Neuquensaurus australis*, and *Saltasaurus loricatus* where the sacrum is formed by six well coossified vertebrae (BORSUK-BIALYNICKA, 1977; JAIN & BANDYOPADHYAY,

1997; POWELL, 2003). *Baurutitan britoi* has the posterior articulation surface strongly concave, differing from the convex condition found in *Isisaurus colberti*, *Saltasaurus loricatus*, and *Epachthosaurus sciuttoi* (JAIN & BANDYOPADHYAY, 1997; POWELL, 2003; MARTÍNEZ, *et al.*, 2004). The last sacral of *Gondwanatitan faustoi* is procoelous (KELLNER & AZEVEDO, 1999), differing from the opisthocoelous condition of *Baurutitan britoi*. *Neuquensaurus australis* has the posterior articulation of the last sacral slightly concave (POWELL, 2003), while in *Baurutitan britoi* the

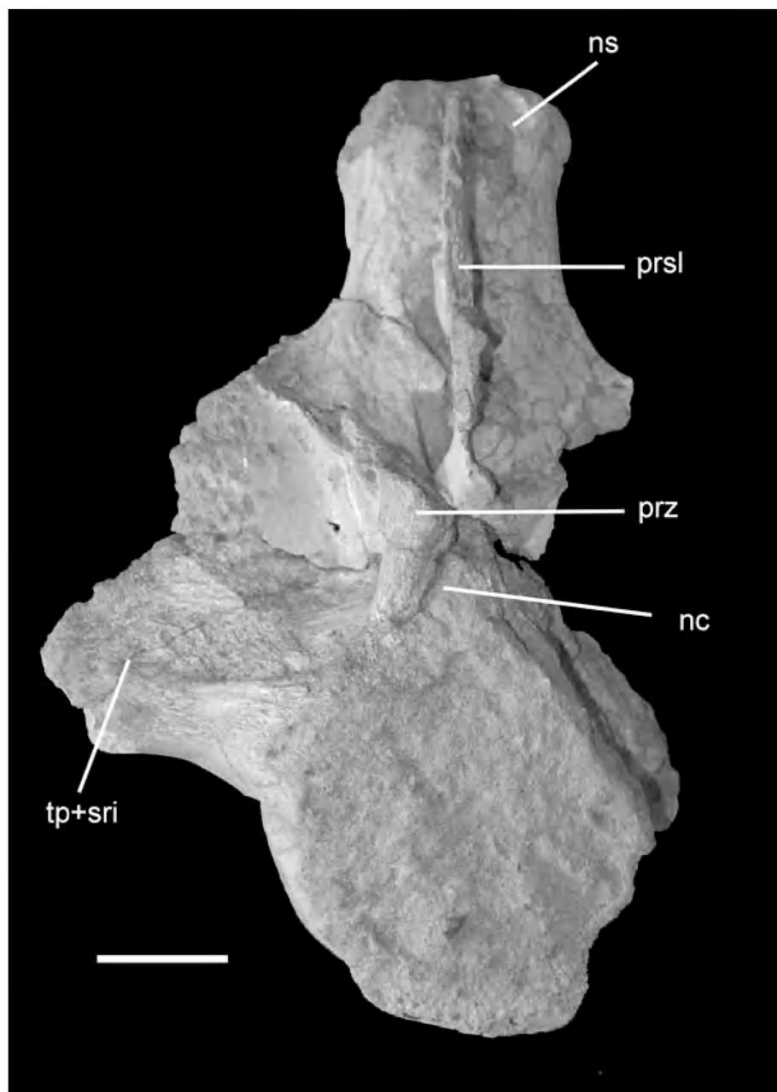


Fig.5- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), sacral vertebra in anterior view. Scale bar = 50mm. See text for abbreviations.



concavity is more pronounced. The posterior articulation of the last sacral of *Opisthocoelicaudia skarzynskii* and *Baurutitan britoi* are strongly concave, but the former is flattened dorsoventrally (BORSUK-BIALYNICKA, 1977: plate 5, fig.4), contrasting to the more rounded condition found in the latter. According to JAIN & BANDYOPADHYAY (1997), *Isisaurus colberti* has a longitudinal depression on the ventral surface of the sacral centra that is absent in *Baurutitan britoi*.

There are three almost complete sacra recovered from the Peirópolis region (CAMPOS & KELLNER, 1999) than can be compared with *Baurutitan britoi*. Two were collected at the same point (Caieira) (MCT 1536-R and MCT 1488-R/MCT 1719-R, the latter being diagnosed in this volume, see CAMPOS *et al.*, 2005 and the third one, collected at the Rodovia site (MCT 1489-R). All were regarded as belonging to three distinct species of Titanosauridae, respectively sp. A, B, and C of CAMPOS & KELLNER (1999). While

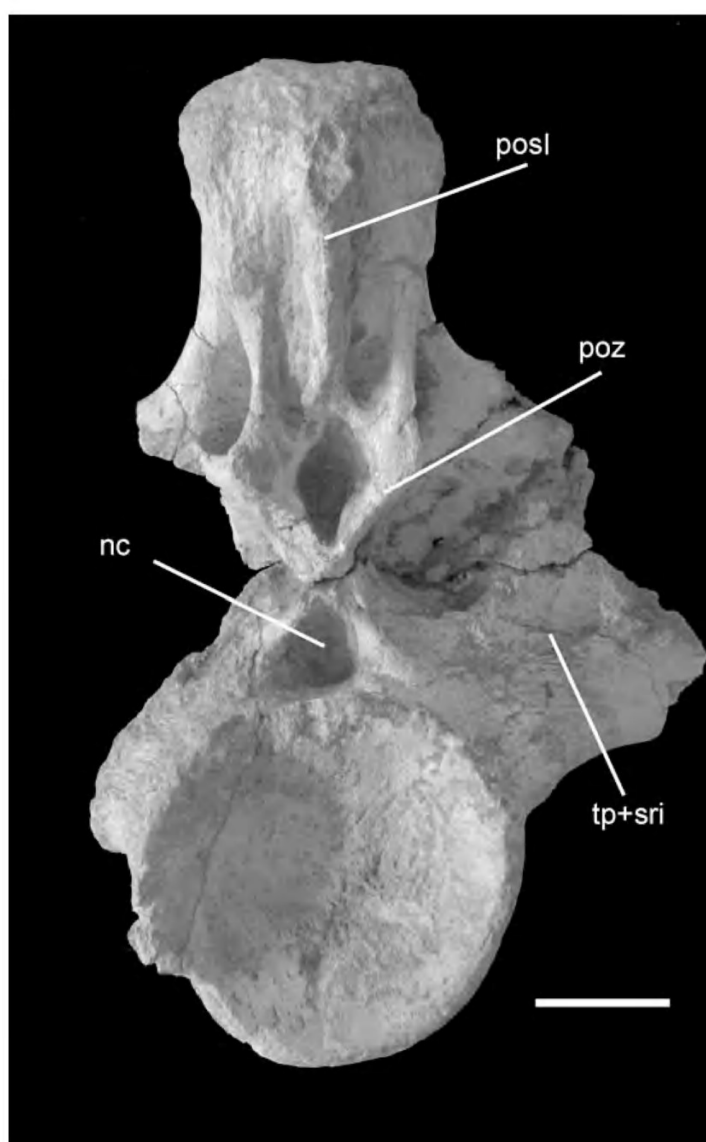


Fig.6- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), sacral vertebra in posterior view. Scale bar = 50mm. See text for abbreviations.

MCT 1536-R and MCT 1488-R have the last sacral unfused to the precedent element as observed in *Baurutitan britoi*, in MCT 1489-R all six elements of the sacrum are fused. The last sacral of *Baurutitan britoi* differs from MCT 1536-R by having the centrum the posterior articulation surface more set apart from the sacral ribs, whose ventral margin is comparatively thinner (e.g., more compressed anteroposteriorly). The last sacral of MCT 1536-R, that represents a smaller animal (estimated length of the centrum ~ 80mm), is dorsoventrally flattened with the posterior articulation surface less concave. The last sacral of MCT 1488-R and MCT 1489-R also differs from *Baurutitan britoi* by having the centrum dorsoventrally flattened, the neural spine dorsally expanded and by having the posterior articulation surface strongly convex. MCT 1488-R further differs by having the neural spine more inclined posteriorly.

#### FIRST CAUDAL VERTEBRA

The first caudal is longer than the preceding sacral

and has a biconvex centrum with the posterior articulation more projected than the anterior one (Figs.8-11). The anterior articulation of the centrum is larger dorsoventrally (118,8mm) than the posterior articulation (108,6mm). In anterior view the centrum is oval, slightly wider (131,4mm) than high (118,8mm), with the dorsal and ventral margins flattened. The lateral surface and the ventral margin are concave, giving the centrum the typical spool-shaped appearance. In lateral view the centrum is longer than high, a result basically due to the expanded posterior condyle which is displaced dorsally (Fig.8). This condyle displays a sagittal dorsoventrally oriented groove on the upper half of the centrum which does not appear to be of taphonomic origin. The neural arch is placed on the anterior half of the centrum. The neural canal is oval, higher than wide. The transverse processes are robust, compressed anteroposteriorly, directed laterally and slightly posteriorly (Fig.11). Those processes are twisted so that the dorsal margin at the distal end is displaced posteriorly.

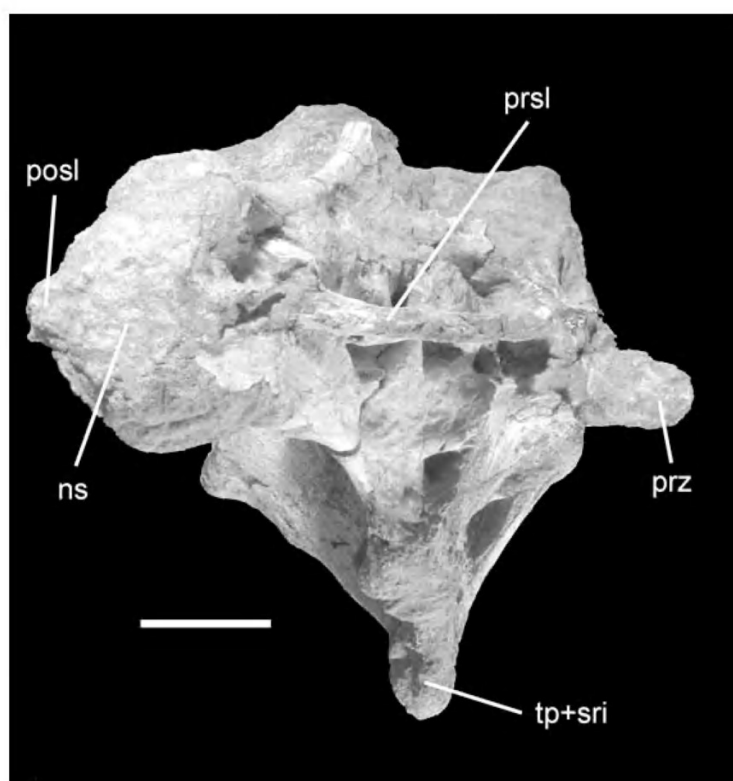


Fig.7- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), sacral vertebra in dorsal view. Scale bar = 50mm. See text for abbreviations.

The neural spine is elongated and inclined posteriorly, so that, in lateral view, the vertical projection of the posterior corner is placed on the condyle. The neural spine is transversally expanded, particularly at the apex, although it has almost the same width. The prespinal lamina is present and well developed, although less than in the sacral vertebra, and extends from the base of the neural spine to the apex. The postspinal lamina is also present, being thicker and shorter than the prespinal lamina.

Spinoprezygapophyseal laminae are present, well developed, and run over the anterolateral corner of the neural spine, disappearing before reaching the apex. The prezygapophyses are short and have elliptical articular facets which are longer transversally than anteroposteriorly. Behind each prezygapophysis, but placed at a higher position, there is a pointed elevation named herein prezygapophyseal tuberosity which is the meeting point of the spinoprezygapophyseal lamina and the dorsal border of the transverse process. In

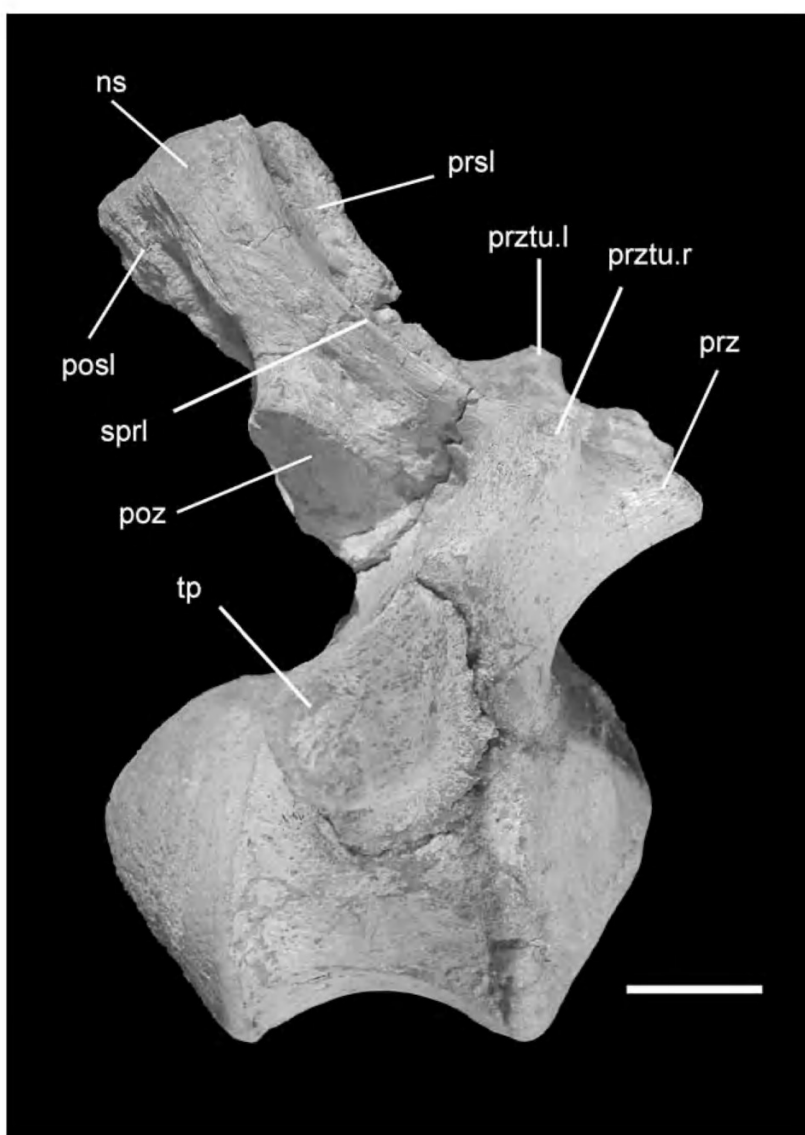


Fig.8- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 1 in right lateral view. Scale bar = 50mm. See text for abbreviations.

caudal 1 the prezygapophyseal tuberosity intercepts the spinoprezygapophyseal lamina before it reaches the prezygapophysis. The spinoprezygapophyseal lamina is well defined and directed anterolaterally connecting the neural spine and the prezygapophyseal tuberosity. The postzygapophyses are positioned very close to the neural spine and have long, lateroventrally directed articulation surfaces, with the major axis directed dorsoventrally. Spinopostzygapophyseal laminae are not very developed, presented as blunt ridges.

Comparisons with some titanosaurid taxa are limited since for most the first caudal is either unknown or only briefly described. As far as comparisons are possible, *Lirainosaurus astibiae* differs from *Baurutitan britoi* by having a procoelous first caudal and by having a comparatively smaller centrum and a dorsoventrally expanded neural arch (SANZ *et al.*, 1999). *Opisthocoelicaudia skarzynskii* differs by having the first caudal opisthocoelous with broader but shorter transverse processes. Although incomplete, the first caudal of *Pellegrinisaurus powelli* is also biconvex, but differs from *Baurutitan*

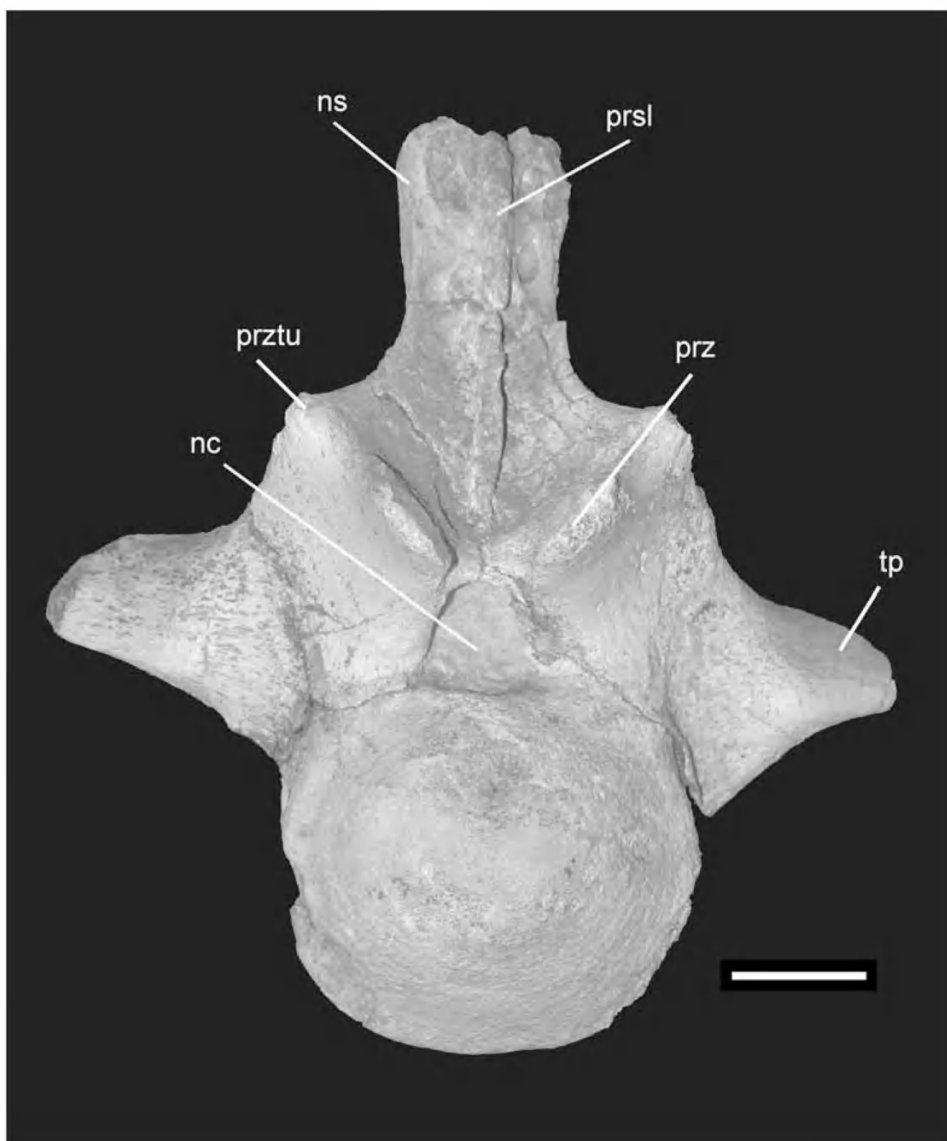


Fig.9- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 1 in anterior view. Scale bar = 50mm. See text for abbreviations.



*britoi* by having a comparatively shorter centrum and a marked depressed area under the transverse process (SALGADO, 1996: fig.3). Also incomplete, the first caudal of *Gondwanatitan faustoi* differs from the one of *Baurutitan britoi* by being procoelous and having a comparatively shorter centrum (KELLNER & AZEVEDO, 1999).

Regarding *Epachthosaurus sciuttoi*, the first caudal is procoelous and shows longer and posteriorly more developed transverse processes with a distally expanded bony blade (MARTÍNEZ *et al.*, 2004) which is absent in *Baurutitan britoi*. Furthermore, the neural arch of the first caudal of *Baurutitan britoi* is comparatively more set apart from the centrum, giving the vertebrae a higher aspect.

*Baurutitan britoi* has a larger neural canal, the tip of the neural spine broader and the postspinal laminae more developed.

The first caudal of *Alamosaurus sanjuanensis* also has a biconvex centrum but differs from *Baurutitan britoi* by having the anterior articulation with a subrectangular outline that is higher than wide (GILMORE, 1946: pl.5, fig.1; pl.8, fig.1). In both the anterior articulation surface is larger than the posterior one, but in *Alamosaurus sanjuanensis* this difference is even bigger. Furthermore, *Baurutitan britoi* has the ventral margin of the centrum more concave, the neural spine inclined posteriorly with a stronger postspinal lamina, and prezygapophyses facing less inward than in *Alamosaurus sanjuanensis*.

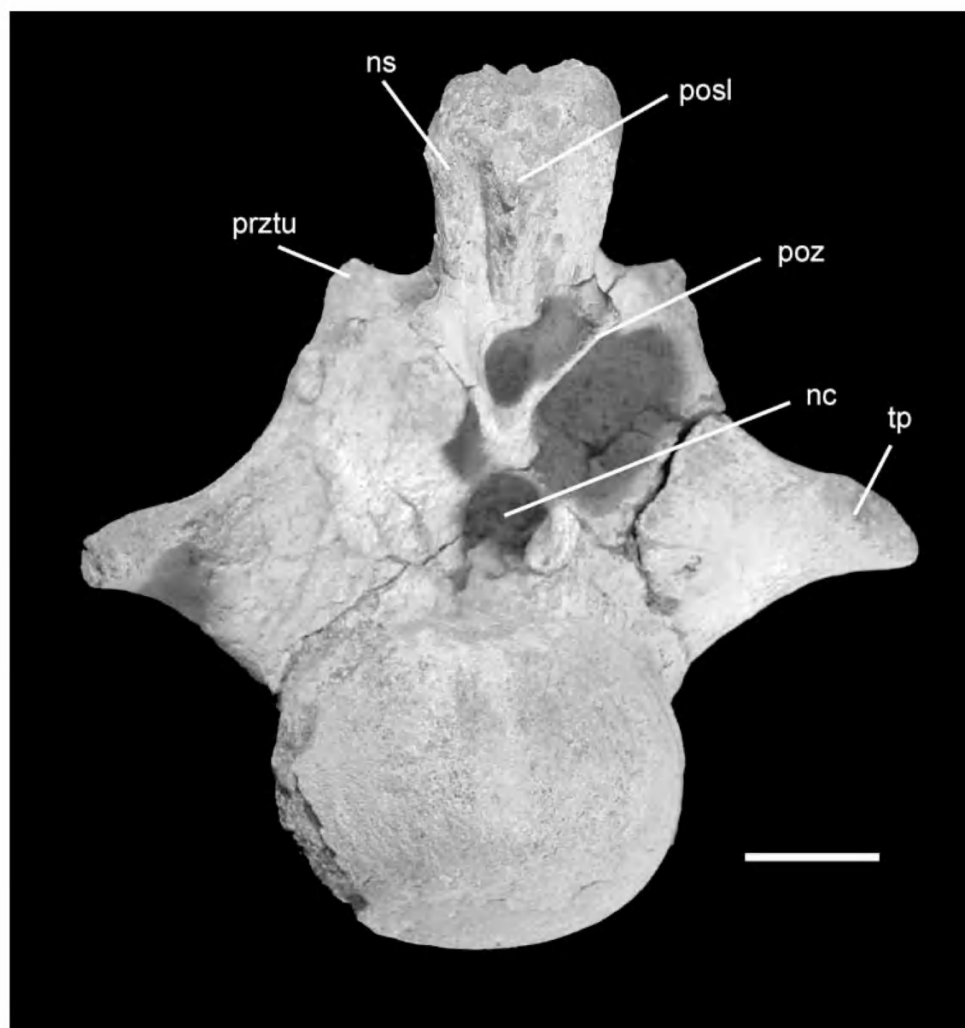


Fig.10- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 1 in posterior view. Scale bar = 50mm. See text for abbreviations.

Regarding saltasaurines, the first caudal of *Saltasaurus loricatus* is quite distinct from *Baurutitan britoi* by being procoelous and dorsoventrally flattened. *Saltasaurus loricatus* further differs by showing long and robust transverse processes (similar to the last sacral) and the pre- and postspinal laminae comparatively thinner. The neural canal of *Baurutitan britoi* is also comparatively larger and the postzygapophyses are positioned closer to each other with the articulation surface displaced more laterally. *Neuquensaurus australis* has also a biconvex first caudal (HUENE, 1929: pl.3, fig.3), but in *Baurutitan britoi* the neural spine is more inclined posteriorly and the ventral margin is more concave.

Besides the differences pointed out above, *Baurutitan britoi* also shows a distinct prezygapophyseal tuberosity,

which intercepts the spinoprezygapophyseal lamina. To our knowledge, such a projection was not reported (or illustrated) in this position and with this shape and size in any titanosaurid first caudal before. Apparently *Alamosaurus sanjuanensis* has a similar process, but it is less developed and is not laterally projected as in *Baurutitan britoi* (GILMORE, 1946: pl.5, fig.1; pl.8, fig.1). *Epachthosaurus sciuttoi* also shows a distinct projection, but it is situated on the dorsal part of the transverse process and its relation with the spinoprezygapophyseal lamina cannot be determined (MARTÍNEZ *et al.*, 2004: fig.6). In this context, the presence of a prominent prezygapophyseal tuberosity united with the neural spine by an anterolaterally oriented spinoprezygapophyseal lamina is considered a potential autapomorphy of *Baurutitan britoi*.

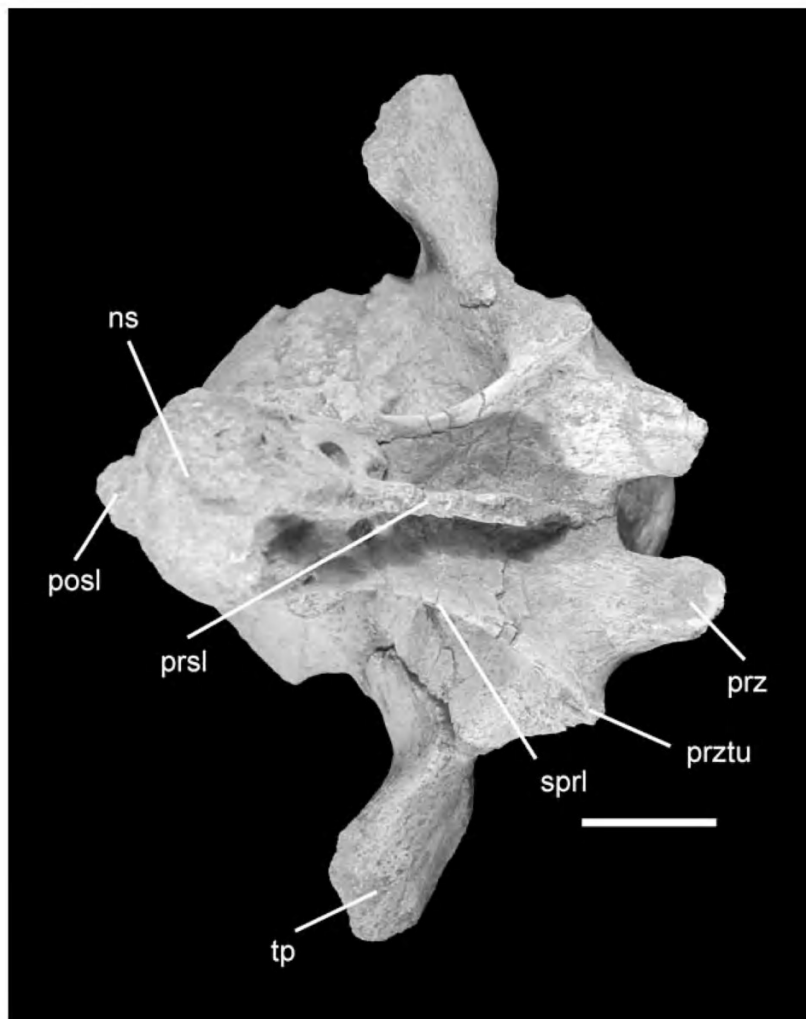


Fig.11- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 1 in dorsal view. Scale bar = 50mm. See text for abbreviations.

## ANTERIOR CAUDAL VERTEBRAE

Starting at caudal 2, all anterior caudals are procoelous, having the posterior condyle well developed in a medial position, except in caudal 7 where it is slightly displaced dorsally (Figs. 12-18). The longest caudal is the 4th, followed by the 2nd, 5th, 3rd, 6th, and 7th (see Table 1). The most anterior element has the widest centrum and all subsequent get gradually narrower. Starting on caudal 3 all have the ventral portion compressed laterally, forming a flattened to slightly concave surface. In anterior view the centrum has a subrectangular outline, being wider than high with the dorsal and ventral margins flattened. The posterior part of the centrum changes from elliptical (e.g., wider than high) in caudals 2 and 3, to a more "heart-shaped" condition of caudals 4-7 (and the caudal 8, here considered to be the first middle caudal). The dorsal surface above the posterior end of the centrum has a shallow concavity, limited posteriorly by a thickening of the dorsal rim of the posterior articulation. The condyle of caudals 4 to 6 shows a dorsoventrally oriented sagittal groove (as observed in the last sacral) which gets shallow posteriorly and turns to a rounded depression in the mid-caudals (see below). In caudal 5 this groove is more developed than in

any other vertebrae. Starting at caudal 4 the centrum bears two laterally placed and ventrally oriented projections for the chevron which are largest in caudal 5 and get gradually smaller towards the end of the series.

The neural arch is placed over the anterior half of the centrum, near the rim of the anterior margin. The neural canal is oval, higher than wide, with the basal part slightly wider than the apex. The neural spine of caudal 2 is inclined posteriorly, similar to the condition of caudal 1. The vertical projection of the anterior corner of the neural spine is placed behind the middle part of the centrum and the vertical projection of the posterior corner rests over the distal articulation, similar to the condition observed in caudal 1. Starting at caudal 3 the neural spine is less inclined, with the vertical projection of the anterior corner shifted towards the middle part of the centrum and the vertical projection of the posterior corner placed at the beginning of the distal articulation. Starting at caudal 4 the neural spine is less inclined with the vertical projection of the anterior (and posterior) corner of the neural spine shifting gradually towards the anterior and middle part of the centrum, a condition present until the first middle caudal vertebra (caudal 8).

TABLE 1. Length of the vertebrae of *Baurutitan britoi* n.gen., n.sp. (in millimeters)

VERTEBRAE	TOTAL LENGTH OF CENTRUM	MAXIMUM LENGTH OF CENTRUM (LEFT SIDE) WITHOUT CONDYLE	MAXIMUM HEIGHT OF CENTRUM ANTERIOR FACE	MAXIMUM WIDTH OF CENTRUM ANTERIOR FACE
sacral 6	128	128	117	115
caudal 1	175	93	119	131
caudal 2	134	89	118	141
caudal 3	129	95	109	132
caudal 4	136	102	101	121
caudal 5	133	95	97	111
caudal 6	127	96	90	108
caudal 7	124*	92	85	101
caudal 8	115 *	88*	79*	98*
caudal 9	115	96	74	90
caudal 10	115	91	76	87
caudal 11	112	89	76	80
caudal 12	114	92	75	72
caudal 13	113	92	74	69
caudal 14	116	96	74	67
caudal 15	117	94	70	68
caudal 16	121	98	68	70
caudal 17	121	99	65	71
caudal 18	118	101	67	68

Obs.: (c.7\*) preserved portion (articular condyle broken); (c.8\*) preserved portion (anterior portion broken)

Pre- and postspinal laminae are well developed in all anterior caudals, with the postspinal lamina always more robust. The prespinal lamina covers the entire length of the neural spine (incompletely preserved in caudal 7). The postspinal lamina tends to be thicker at the apex, reducing gradually in ventral direction, ending in the vacuity between the postzygapophyses. In caudals 2 and 3, due to the great development of the postspinal lamina, the dorsal surface formed by the neural spine and postspinal laminae is triangular, with the apex directed posteriorly. Starting on caudal 4, this dorsal surface gets gradually more elliptical with the main axis directed anteroposteriorly. Some cavities are observed on the anterior surfaces of the neural spines in caudals 2 to 6, adjacent to the prespinal lamina. The position of those cavities varies in number and size, being most of the time more developed on one side.

Spinoprezygapophyseal laminae are present and well developed in caudal 2, running from the dorsal portion of the prezygapophyses, merging with the neural spine. The spinoprezygapophyseal lamina

of the right side bifurcates and sends a dorsomedially projected subsidiary lamina that ends at the prespinal lamina. In caudals 3-5, the spinoprezygapophyseal laminae are gradually less developed. Subsidiary laminae are present in caudals 3 (at both sides); 4 (at the left side) and 5 (at the right side), closer to the base of the neural spine always ending at the prespinal lamina. In caudals 6-7 the spinoprezygapophyseal laminae are reduced to ridges situated more closely to the base of the neural spine.

The prezygapophyses of the anterior caudals are well developed, project dorsoanteriorly in caudal 2 and become gradually more horizontal until assuming a subhorizontal position in caudal 5, a condition kept by the remaining vertebrae. The prezygapophyses of caudals 2 and 3 are comparatively shorter and more robust than the other elements of the anterior series. The anterior tip of the prezygapophyses reaches the middle part of the preceding centrum. The articulation surfaces are large, roughly "D" shaped, and become smaller in the posterior elements.

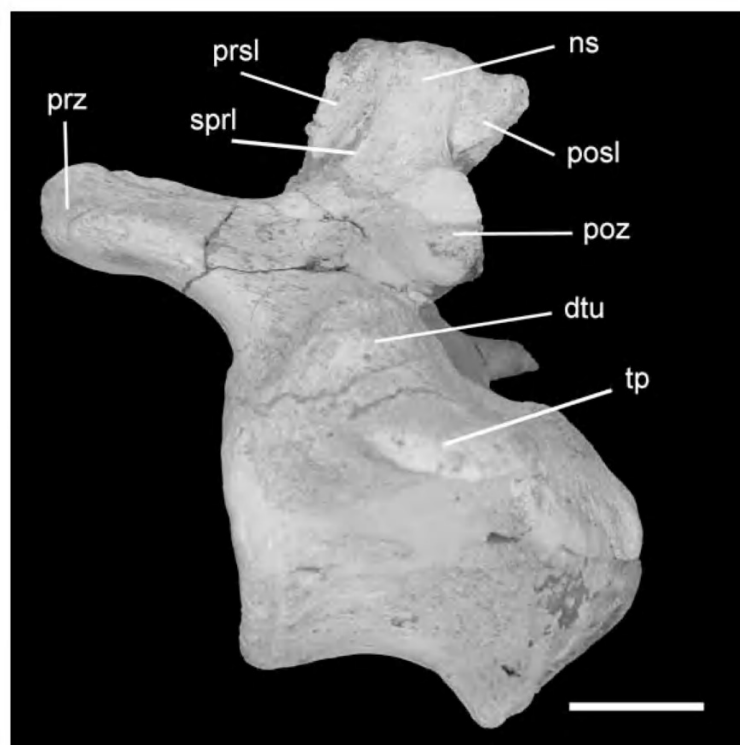


Fig.12- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 5 in left lateral view. Scale bar = 50mm. See text for abbreviations.



There is a well developed rugose elevation placed on the lateral surface of the prezygapophyseal process, close to the spinoprezygapophyseal lamina. This feature corresponds to the prezygapophyseal tuberosity of caudal 1 but differs here by being smaller and by not intercepting the spinoprezygapophyseal lamina. It becomes gradually smaller and less perceptible in caudals 3 and 4, until turning to a small lateral rugosity that smoothens out in caudals 9 and 10 (see below).

The postzygapophyses are well developed in all anterior caudals, always positioned close to the neural spine. The postzygapophyseal articular facets in caudal 2 are elliptical (with the largest axis oriented dorsoventrally) and become gradually smaller and more oval in the posterior elements. Posteriorly the postzygapophyses have a thick medial margin and form a "V" shaped interpostzygapophyseal opening. Spinopostzygapophyseal laminae are present in all anterior caudals, but vary in thickness and projection, being thick in caudal 2, more laminar in caudals 3-5, and reduced in caudals 6 and 7.

All anterior caudals have developed posterolaterally oriented transverse processes that become gradually shorter along the sequence until becoming vestigial (and eventually disappearing) in the middle caudal vertebrae. Those processes are compressed dorsoventrally and become more posteriorly oriented along the sequence, until assuming a hook-shape on caudals 5 to 7. Although in all caudals the transverse processes are fused with the centrum and the neural arch, their limits can be observed by rugose surfaces, particularly visible on the more anteriorly placed elements.

Starting at caudal 3, the dorsal tuberosity (situated on the contact surface between the transverse processes and the neural arch) forms a rounded and thick bone projection that is present along all preserved caudals and in the anterior series never surpasses the extension of the transverse process (contrary to the middle caudals - see below).

There are several differences between the supposed titanosaurid *Opisthocoelicaudia skarzynskii* (e.g., SALGADO, CORIA & CALVO, 1997a) and *Baurutitan*

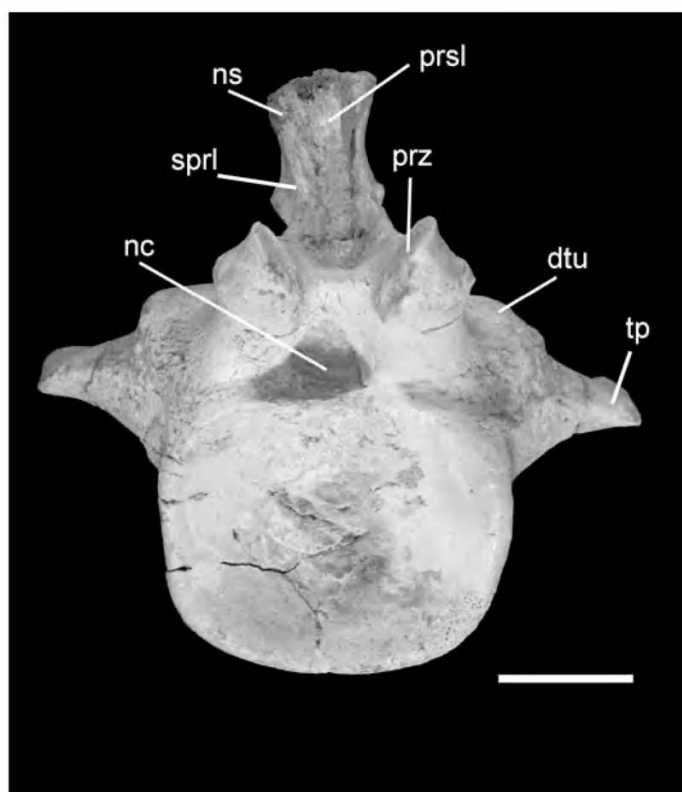


Fig.13- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 5 in anterior view. Scale bar = 50mm. See text for abbreviations.

*britoi*. The most striking ones are the opisthocoelous condition of the former (BORSUK-BIALYNICKA, 1977) and the shorter centra which are rounded (BORSUK-BIALYNICKA, 1977: pl.5, figs.1b, 1c, 2c, 3) and lack the quadrangular aspect observed in *Baurutitan britoi*. According to BORSUK-BIALYNICKA (1977, p.15), the centra of *Opisthocoelicaudia skarzynskii* show a ventral concavity bordered by ventrolateral ridges throughout the caudal series which are absent in *Baurutitan britoi*. The bases of the neural spines of caudal 2-7 of *Opisthocoelicaudia skarzynskii* are set over the distal half of the respective centra (BORSUK-BIALYNICKA, 1977: pl.4, figs.1b, 2a; pl.5, fig.2a) which in *Baurutitan britoi* are positioned in the anterior half. The prezygapophyses of *Opisthocoelicaudia skarzynskii* are shorter and dorsoanteriorly oriented in caudals 2-7 (and caudal 8, BORSUK-BIALYNICKA, 1977: pl.4, figs.1b, 2a; pl.5, fig.2a) which in caudals 4-7 of *Baurutitan britoi* are less dorsally oriented. Another difference is the position of the postzygapophyses which in *Opisthocoelicaudia skarzynskii* are set closer to the

posterior margin, surpassing it in caudal 2 (BORSUK-BIALYNICKA, 1977: pl.4, fig.1b). The transverse processes of *Opisthocoelicaudia skarzynskii* are rudimentary, heavy blunt knobs, projecting outwards and backwards and decrease in size posteriorly (BORSUK-BIALYNICKA, 1977:15). In *Baurutitan britoi* the transverse processes are more developed, being curved posteriorly until the last anterior caudal (caudal 7).

*Epachthosaurus sciuttoi* differs from *Baurutitan britoi* by the presence of hyposphene-hypantrum articulations in the anterior (and middle) caudals, regarded by MARTÍNEZ *et al.*, (2004) as autapomorphic for the Argentinean taxon. Based on the illustration of the seventh caudal (MARTÍNEZ *et al.*, 2004, fig.7), the centra of *Epachthosaurus sciuttoi* are elliptical and do not show the quadrangular outline present in *Baurutitan britoi*. The condyle is very large and slightly displaced dorsally and the articulation surfaces for the chevrons more closely spaced than in the Brazilian species. The neural spine in caudal 7 of *Epachthosaurus sciuttoi* tends to be vertical to

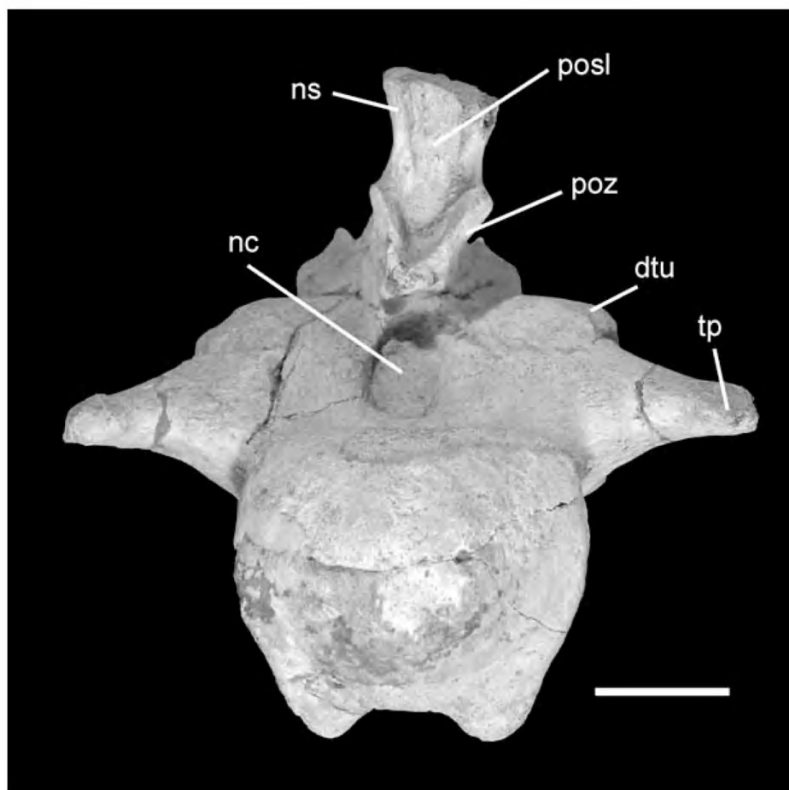


Fig.14- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 5 in posterior view. Scale bar = 50mm. See text for abbreviations.

subvertical (what possible is also the condition in other anterior elements) and the prezygapophyses are shorter. The neural arch is lower compared to *Baurutitan britoi* and the postzygapophyses are consequently placed closer to the dorsal margin of the centrum. No information is available regarding the pre- and postspinal laminae, but based on the published illustrations they are comparatively less developed in *Epachthosaurus sciuttoi* compared to *Baurutitan britoi*.

Besides the biconvex condition observed in the first caudal, the anterior caudals of *Alamosaurus sanjuanensis* resemble *Baurutitan britoi* by having posteriorly oriented neural spines and a similar shape of the neural canal. *Alamosaurus sanjuanensis* differ by having the centra of caudal 2-7 higher than wide, comparatively shorter prezygapophyses (particularly in caudals 2-5) which tend to be more inclined anterodorsally (GILMORE, 1946). The prezygapophyses of some vertebrae have the ventral margin curved, contrasting to the straighter condition observed in *Baurutitan britoi*. Furthermore, *Alamosaurus*

*sanjuanensis* have the neural arches strongly directed backward and high neural spines, features absent in *Baurutitan britoi*.

POWELL (2003) has referred a caudal series of a juvenile titanosaurid (MPCA 1501) to *Titanosaurus araukanicus*, but did only briefly describe it, what makes the comparison with *Baurutitan britoi* limited. Based on the figured anterior caudals (POWELL, 2003: pl.6, Figs:1-5), MPCA 1501 lacks the quadrangular outline of *Baurutitan britoi*. According to POWELL (2003:23), MPCA 1501 has almost vertical neural spines, contrasting to the more inclined condition observed in *Baurutitan britoi*.

Based on the figured proximal caudals, *Isisaurus colberti* displays very high neural spine and shorter prezygapophyses compared to *Baurutitan britoi*. Furthermore, the posterior condyle of *Isisaurus colberti* displays a rounded outline, differing from the more quadrangular condition of *Baurutitan britoi*. Ventral projections for the chevrons are apparently poorly developed in the anterior elements of *Isisaurus colberti*.

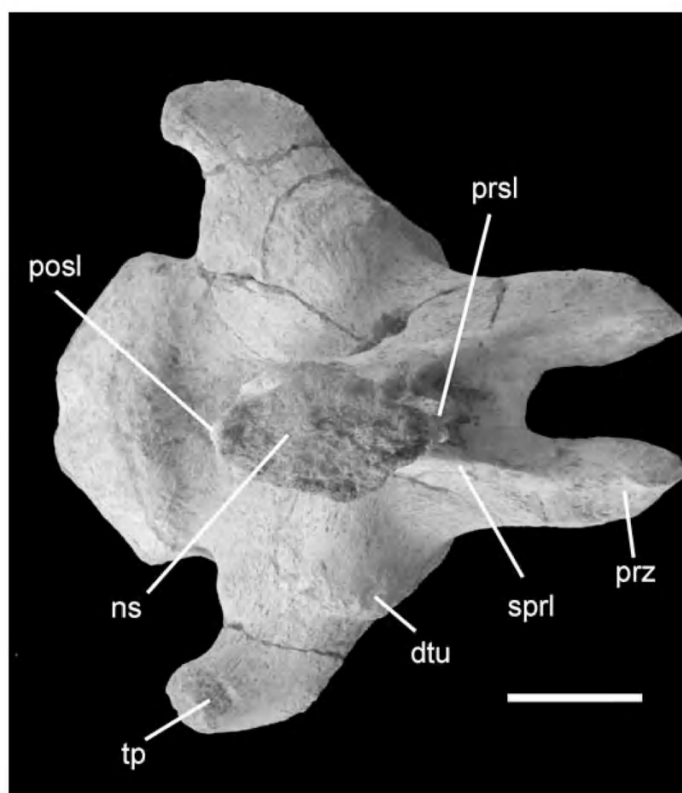


Fig.15- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 5 in dorsal view. Scale bar = 50mm. See text for abbreviations.

The anterior caudals of *Baurutitan britoi* are different from the holotype of *Aeolosaurus rionegrinus* (POWELL, 2003) and the specimens referred to *Aeolosaurus* sp. from the Allen Formation (SALGADO & CORIA, 1993) and from the Los Alamitos Formation (SALGADO, CORIA & CALVO, 1997b) by having neural spines posteriorly inclined and not placed on the anterior half of the centrum, and comparatively shorter prezygapophyses. The condyle in all *Aeolosaurus* specimens tends to be displaced dorsally. The pre- and postspinal laminae are not well developed (or were not described) in the known elements (e.g., SALGADO & CORIA, 1993). A pleurocoel-like depression is observed in one side of caudal 3 in *Aeolosaurus rionegrinus* (POWELL 2003) which is absent in *Baurutitan britoi*. The pre- and postspinal laminae that are preserved in both mentioned specimens of *Aeolosaurus* sp. are comparatively thinner than those of *Baurutitan*

*britoi*. The anterior caudal of *Aeolosaurus* sp. from the Allen Formation (MPCA 27174) apparently has a dorsal tuberosity on the dorsal surface at the contact region of the transverse process and the neural arch (SALGADO & CORIA, 1993: fig.2), but is less developed than in *Baurutitan britoi*.

Judging from the preserved parts of the neural spines of the anterior caudals of *Gondwanatitan faustoi*, these were inclined dorsoanteriorly, differing from *Baurutitan britoi*. The caudal 3 of *Gondwanatitan faustoi* shows a well developed bony ridge on the ventral part of the prezygapophyses that terminates in a protuberance directly in front of the anterolateral corner of the centrum, and a second ridge, dorsoventrally directed which is connected to this protuberance (KELLNER & AZEVEDO, 1999:125 and fig.11). Furthermore, caudal 3 of *Gondwanatitan faustoi* has a lateral elongated

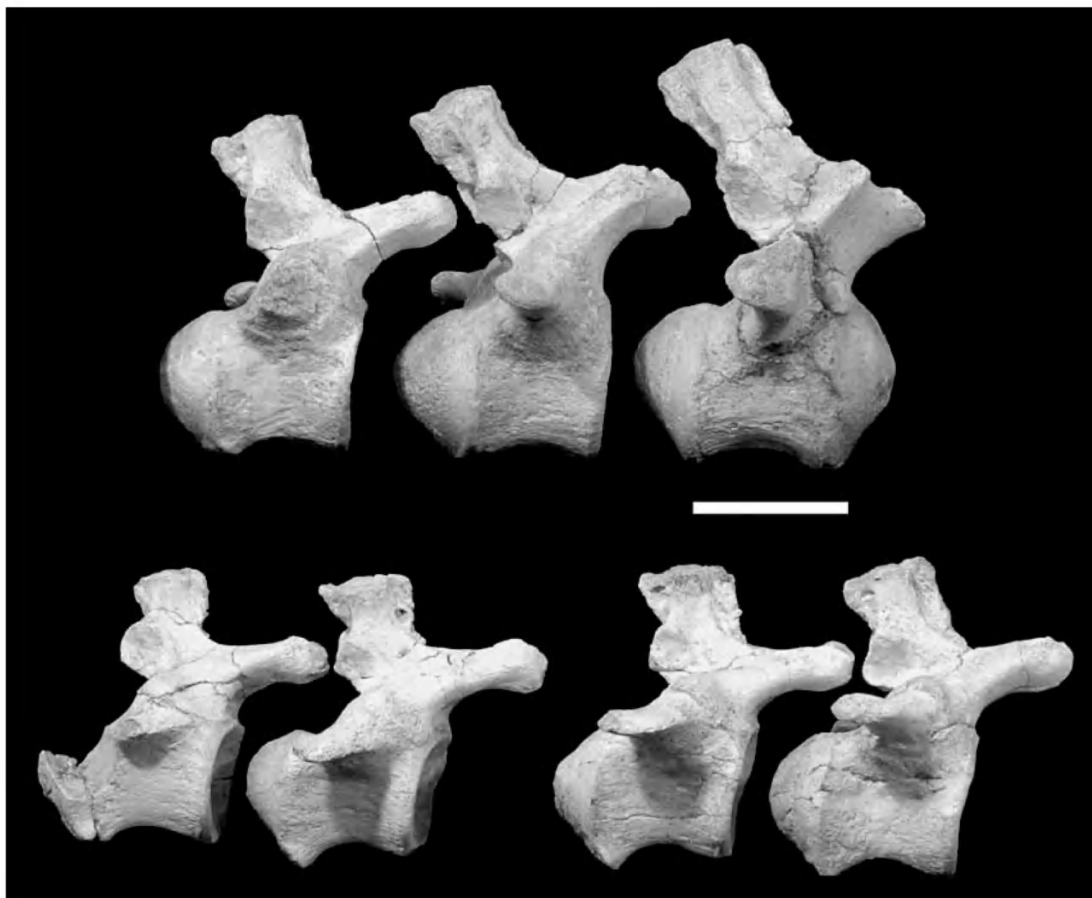


Fig.16- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 1-7 in right lateral view. Scale bar = 100mm.



depression on the centrum that is absent in *Baurutitan britoi*. The “heart-shaped” posterior surface of the centrum is similar in both taxa, but in *Gondwanatitan faustoi*, the centrum tends to be more flattened dorso-ventrally. Where preserved, the prezygapophyses of *Gondwanatitan faustoi* are comparatively more gracile and thinner and more laterally directed than in *Baurutitan faustoi*, and there is no sign of a prezygapophyseal tuberosity. The postzygapophyses tend to have a larger articulation surface, forming a dorsal rim that is laterally directed, features absent in *Baurutitan britoi*. *Gondwanatitan faustoi* also lacks a tuberosity above the transverse process.

The anterior caudals of MCT 1719-R (new taxon that is being described in this volume - see CAMPOS *et al.* 2005) differ from *Baurutitan britoi* by having the anterior outline of the centrum rounded (and not quadrangular), a shorter centrum and the ventral margin more concave. MCT 1719-R has the condyle of the anteriormost preserved caudal (possible caudal 2) set apart from the centrum by a thick bony rim, being more rounded and higher than in *Baurutitan britoi*. The neural spine in MCT 1719-R is very high, has a thinner base and broadens towards the apex. It is further directed anterodorsally and placed on the anterior half of the centrum close to the anterior margin.

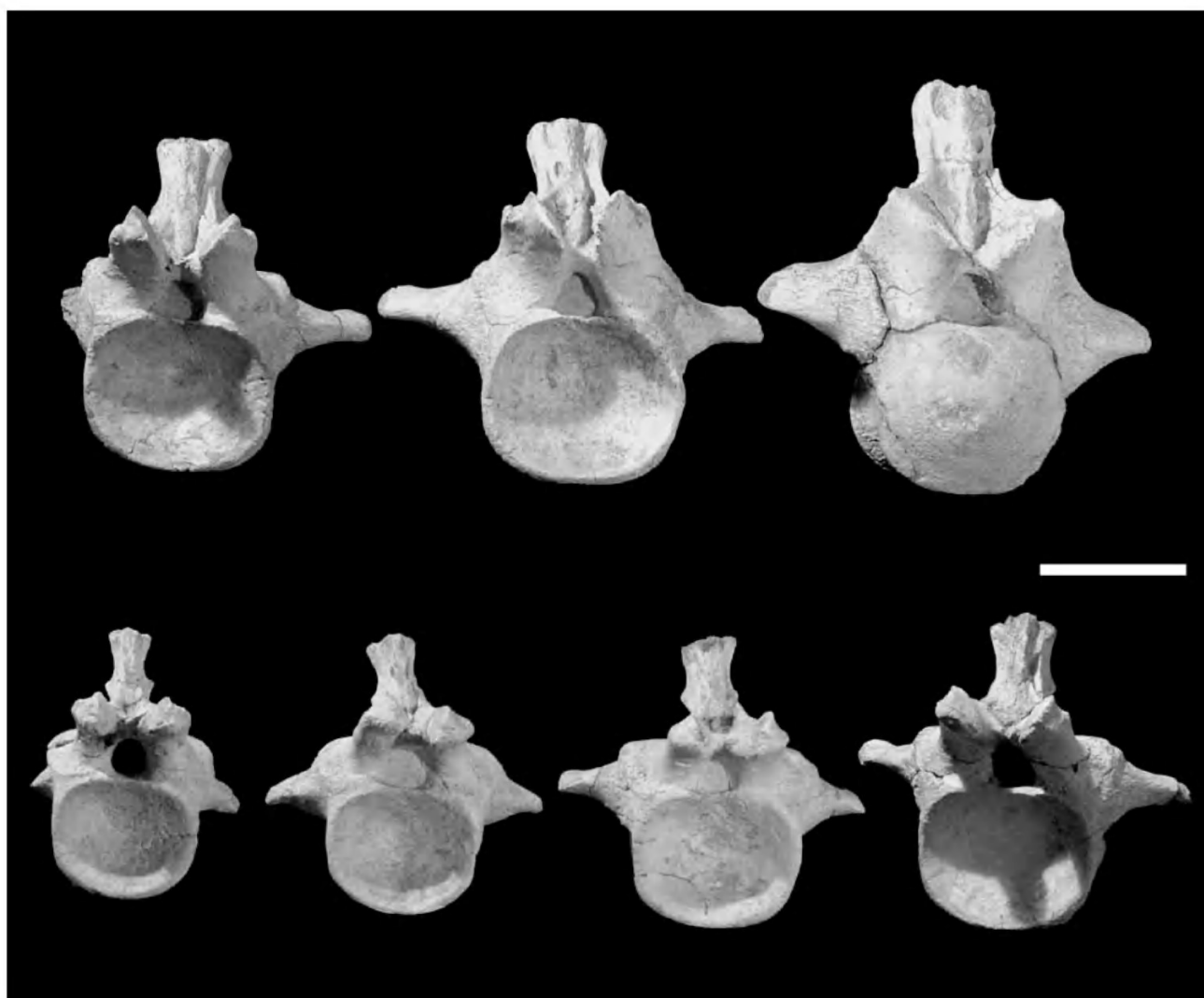


Fig. 17- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 1-7 in anterior view. Scale bar = 100mm.

Where observed, the prespinal lamina is more developed than the postspinal lamina in MCT 1719-R, contrary to the condition observed in *Baurutitan britoi*, where the postspinal lamina is very thick. The postzygapophyses of MCT 1719-R are more developed, having a more concave articulation surface with the dorsal border projected laterally. The interpostzygapophyseal space is also "V" shaped but form a more acute angle than in *Baurutitan britoi*. MCT 1719-R further differs from *Baurutitan britoi* by the absence of a dorsal tuberosity on the contact region between the transverse process and the neural arch. Among the caudal vertebrae of *Mendozasaurus neguyelap* there is an anterior caudal (IANIGLA-PV 065/1) regarded as a first or second caudal (GONZÁLEZ RIGA, 2003: fig.4D-E). The centrum

is procoelous and if this element is indeed the first caudal, differs from the biconvex caudal 1 of *Baurutitan britoi*. As in *Baurutitan britoi*, some caudal vertebrae of the Argentinean species show strong postspinal lamina, more developed than the prespinal lamina on anterior caudals. The anterior caudals of *Mendozasaurus neguyelap* can be differentiated from the other anterior caudals of *Baurutitan britoi* by having a short centrum, a high and vertically oriented neural spine and the presence of a large interzygapophyseal cavity, which was regarded as a probable autapomorphy of *Mendozasaurus* (GONZÁLEZ RIGA, 2003: p.160). IANIGLA-PV 065/1 displays a small depression on the distal articular condyle which is distinct from the sagittal groove that appears on the dorsal surface of the articular condyle

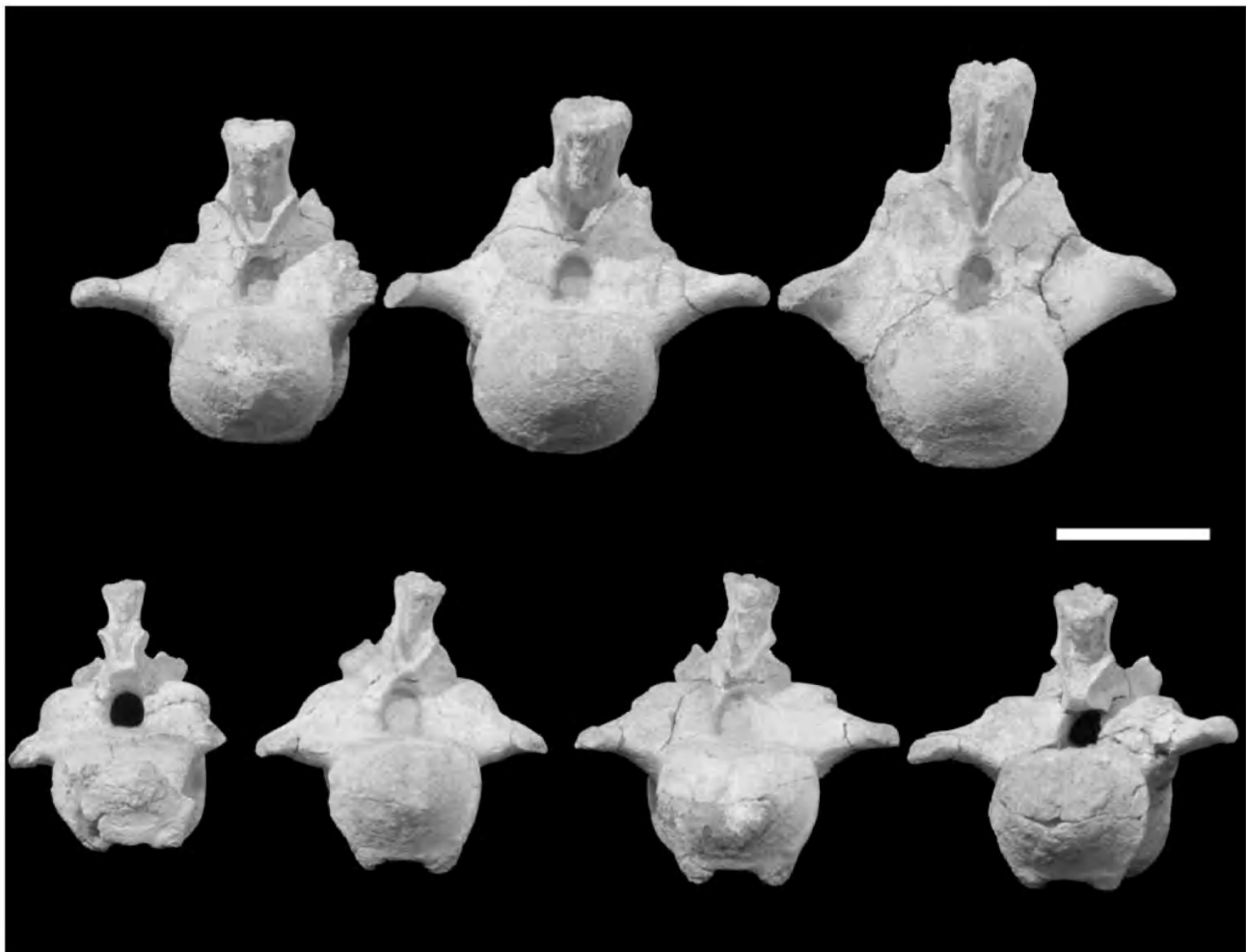


Fig.18- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 1-7 in posterior view. Scale bar = 100mm.

of caudal 1 of *Baurutitan britoi*. The following anterior caudals of *Mendozasaurus neguyelap* have subcircular articular faces (GONZÁLEZ RIGA, 2003: p.160), differing from the quadrangular articular faces of *Baurutitan britoi*. The centra are strongly procoelous, with prominent posterior condyles up to the 5<sup>th</sup> caudal (more pronounced than in the same elements of *Baurutitan britoi*), but this procoely decreases distally in the tail of *Mendozasaurus neguyelap*, while it persists in *Baurutitan britoi*. Ventral projections for the chevrons are absent or poorly developed in *Mendozasaurus* (GONZÁLEZ RIGA, 2003: fig.5E-F). The neural spines of *Mendozasaurus neguyelap* are laterally compressed in the base, but broaden distally (GONZÁLEZ RIGA, 2003), differing from the transversely expanded neural spines of *Baurutitan britoi*. The neural spines in the anterior caudals are slightly oriented posteriorly, so that the posterodorsal edges are placed posteriorly with respect to the posterior margin of the postzygapophyses, a trait that, in *Baurutitan britoi*, appears only in middle caudals (beginning in 12). *Mendozasaurus neguyelap* is also distinct from *Baurutitan britoi* by having prezygapophyses with wide and dorsomedially projected articular facets of quadrangular contour. Finally, in the Argentinean taxon the anterior caudals have a reduced bony prominence - the prezygapophyseal tuberosity - over the spinoprezygapophyseal lamina, but differ from *Baurutitan britoi* by being positioned on the dorsal margin of the prezygapophyseal processes. This feature is apparently absent in the first or second caudal of *Mendozasaurus neguyelap* (González Riga, pers. infor., 2005).

According to SALGADO (1996:358), the original sequence of the anterior caudals of *Pellegrinisaurus powelli* was lost, the numeration given below being established by comparison with hypodigm of *Titanosaurus araukanicus* (MPCA 1501). The anterior caudals of *Pellegrinisaurus powelli* display a pleurocoel placed below the base of the transverse process (SALGADO, 1996; POWELL, 2003), a feature not present in any of the caudals of *Baurutitan britoi*. The centrum of caudal 6 of *Pellegrinisaurus powelli* is more depressed, having a posterior condyle which is more pointed and comparatively wider than in *Baurutitan britoi*. In posterior view, this condyle is not quadrangular, having instead convex ventral and lateral margins (SALGADO, 1996: fig.4). According to SALGADO (1996:358 and fig.4), there is a rounded ridge running obliquely from the base of the transverse process to almost the edge of the posterior articulation, a feature absent in *Baurutitan britoi*.

Caudal 7 of *Pellegrinisaurus powelli* shows a thinner and taller neural spine, apparently with poorly developed pre- and postspinal laminae (SALGADO, 1996: fig. 5). This vertebra has a protuberance at both sides of the centrum in the posteroventral corner of the lateral surface (SALGADO, 1996: p.359 and fig.5 - LP), a feature not present in *Baurutitan britoi*. Caudals 6 and 7 of *Pellegrinisaurus powelli* have postzygapophyses placed at a lower position, closer to the centrum than the corresponding elements of *Baurutitan britoi*.

The centrum of the possible second caudal (MRS-Pv 23) of *Rinconsaurus caudamirus* has "pleurocoel-like" lateral depression (CALVO & GONZÁLEZ RIGA, 2003:338), a feature not present in any of the anterior caudals of *Baurutitan britoi*. Besides the holotype (MRS-Pv 26), *Rinconsaurus caudamirus* is represented by several incomplete series of anterior caudals (MRS-Pv 23, 24, 25) (CALVO & GONZÁLEZ RIGA, 2003), that have the centra higher than wide, differing from *Baurutitan britoi*. At least in the holotype (MRS-Pv 26, CALVO & GONZÁLEZ RIGA, 2003: pl.2A), the ventral margins of the centra are flat or comparatively less concave than in *Baurutitan britoi*. *Rinconsaurus caudamirus* further shows a bony process separating the articular facets of the postzygapophyses from the neural spine (CALVO & GONZÁLEZ RIGA, 2003).

The anterior caudals of *Saltasaurus loricatus* have centra which are comparatively more dorsoventrally depressed than those of *Baurutitan britoi*. The centra also have convex lateral walls, differing from the almost vertical lateral walls of *Baurutitan britoi*. The bases of the transverse processes are much more dorsoventrally developed in *Saltasaurus loricatus* than in *Baurutitan britoi*. The ventral borders of the transverse processes reach the middle of the centrum in the Argentinean species (POWELL, 2003: fig.33). The neural spine in the anterior caudals of *Saltasaurus loricatus* is displaced in posterior direction, the base of which is placed over the posterior half of the centrum (POWELL, 2003: fig.33), differing from the spines of *Baurutitan britoi*, the bases of which are placed over the anterior half of the centra. A further distinguishing feature of *Baurutitan britoi* is the well developed postspinal lamina, always larger than the prespinal lamina, a prezygapophyseal tuberosity and a dorsal tuberosity at the base of the neural arch which is well developed until the last anterior caudal (caudal 7). *Alamosaurus sanjuanensis* apparently also shows a dorsal tuberosity (GILMORE, 1946: pl.5, pl.8), but smaller than in the Brazilian taxon.

## MIDDLE CAUDAL VERTEBRAE

As the anterior caudals, all preserved elements of the middle series (caudals 8-18) are procoelous with a well developed posterior condyle and anterior cotyle (Figs.19-24). The size of the centrum varies (Tab.1), with the vertebrae placed more posteriorly slightly longer (caudals 14-18). There is some variation in the width of the centrum, but overall the more posterior elements tend to be more compressed laterally. The anterior surface of the centrum in middle caudals changes from being wider than high in caudals 8-10 to a more square outline from caudals 11 to 15 and back to a more rectangular outline (i.e., wider than high) in caudals 16-18. The lateral margin of the anterior articulation surface varies from being almost vertical (e.g., caudals 12-15) to slightly rounded (e.g., caudal 10). As in the anterior caudals, a shallow dorsal concavity is present on the posterior portion of the centrum, with the bony rim that limits the posterior end very pronounced in most elements. Except for

caudals 8, 16 and 17, all show a shallow and rounded depression at the condyle. This depression can be slightly displaced ventrally (caudals 10-13) or is positioned at the most posteriorly projected part. The posterior part of the centrum bears lateral ventrally oriented projections for the chevron that get gradually less developed posteriorly, disappearing in caudals 15-18.

The neural arch is placed over the anterior half of the centrum. The neural canal is oval, but contrary to the anterior caudals, is wider than high in most elements of the middle series. The neural spine gets gradually more inclined posteriorly, shifting the vertical projection of the anterior corner from the anterior part (caudal 8) to the middle part of the centrum (remaining elements).

At the same time, the tip of the neural spine tends to get more elongated and a marked change is observed from caudal 13 to 14, with the neural spine getting more elongated with a broader posterior end, a trend followed in the remaining preserved elements.

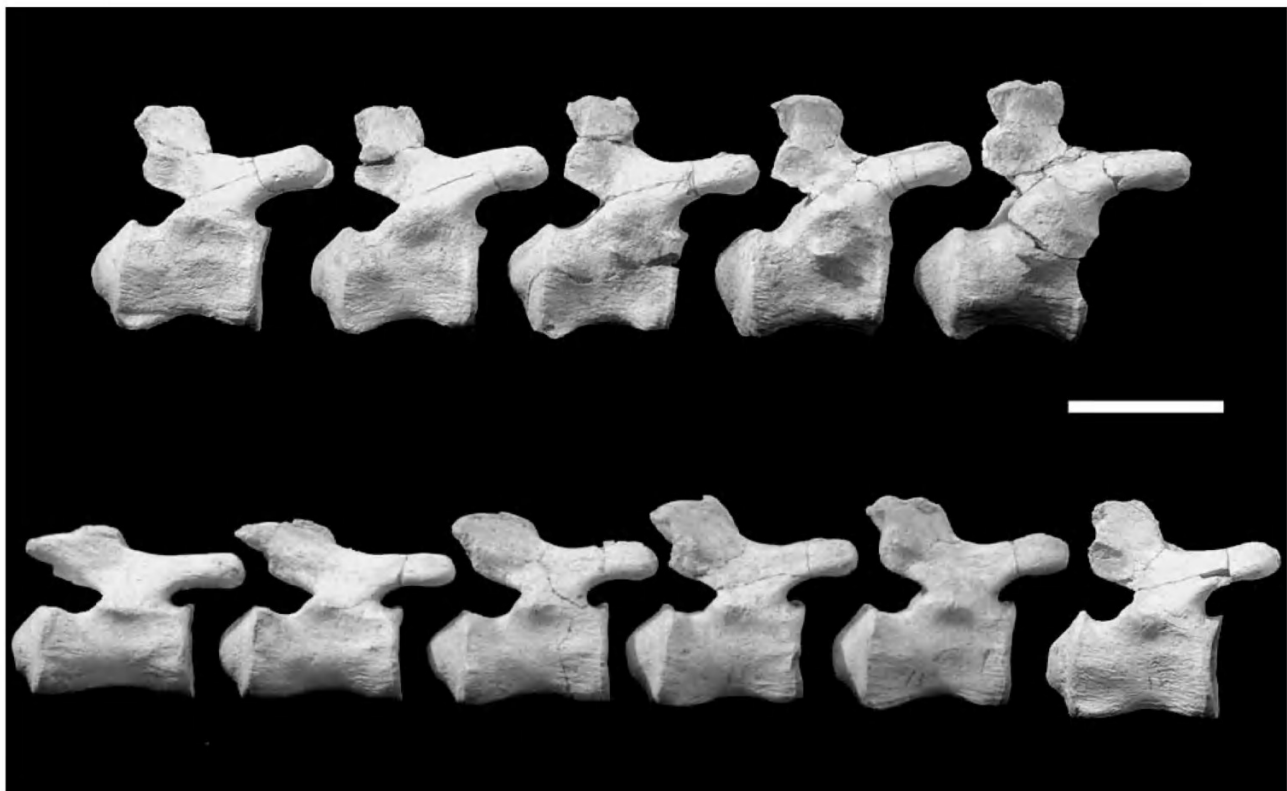


Fig.19- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 8-18 in right lateral view. Scale bar = 100mm.

Pre- and postspinal laminae can be individualized in the first elements of the middle series, but gradually tend to merge with the neural spine. The prespinal lamina is individualized up to caudal 13, being completely merged with the neural spine thereafter. The postspinal lamina, more robust than the prespinal lamina, completely merges with the neural spine starting on caudal 16.

Spinoprezygapophyseal laminae are reduced, forming blunt ridges that run from the neural spine to the dorsomedial portion of base of the prezygapophyses. A cavity is formed between these ridges, delimited ventrally by the intraprezygapophyseal lamina.

The prezygapophyses are well developed, being more slender compared to those of the anterior caudals. The anterior margins of the prezygapophyses reach the middle part of the preceding vertebrae, but gradually shift to the posterior half of the more posterior elements. The prezygapophyses gradually assume a more horizontal position, becoming subparallel to the horizontal plane at caudal 14. The prezygapophyseal articulation surfaces are rounded and subvertically oriented, becoming less marked posteriorly. Starting at caudal 16, the prezygapophyseal articulation

surfaces cannot be distinguished from the remaining part of the prezygapophyses. Caudals 8 to 15 show a marked dorsal ridge above the prezygapophyseal articulation surfaces which tend to disappear in the more posterior elements that lack distinct prezygapophyseal articulation surfaces. This ridge does not connect with the spinoprezygapophyseal lamina.

The postzygapophyses are placed very closely to the neural spine. They tend to be displaced posteriorly but in caudals 8 and 9 are still positioned above the middle part of the centrum whereas from caudal 10 to 18 they are completely placed over the distal half of the centrum. From caudals 8 to 14, there is a well developed postzygapophyseal articulation surface of oval shape which is present only on the right side at caudal 15. Starting at caudal 16, the postzygapophyses turn to a thick projection at the posteroventral part of the neural spine without any distinguishable articulation surface. The "V" shaped interpostzygapophyseal opening gets gradually smaller, disappearing at caudal 15. Spinopostzygapophyseal laminae become reduced posteriorly, present as a bony ridge on caudal 8 and absent in the subsequent elements.

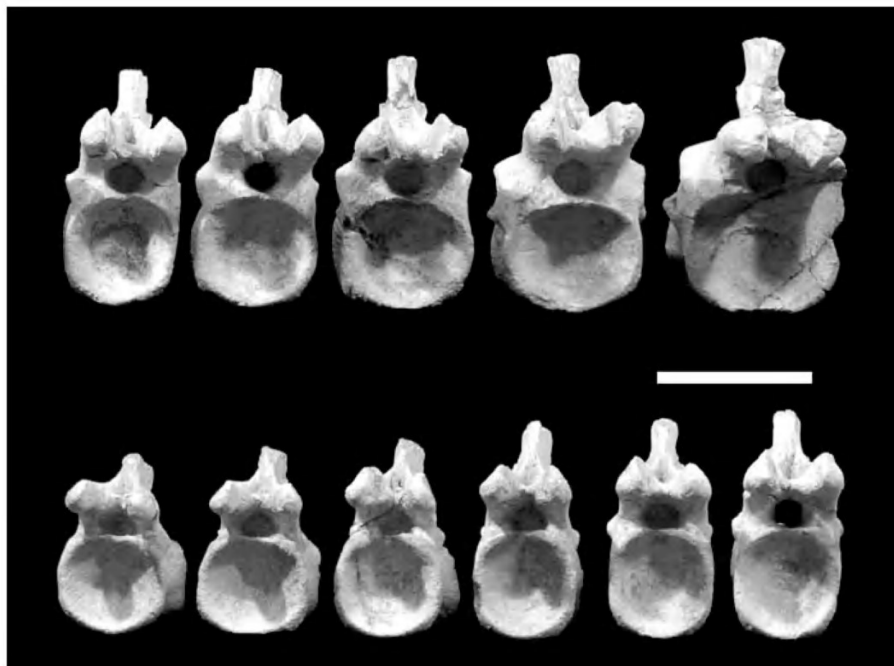


Fig.20- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 8-18 in anterior view. Scale bar = 100mm.



In the elements of the middle caudal series, the transverse processes are only observed (albeit reduced) in caudals 8 and 9 (on both sides) and 10 (only on the right side), disappearing in the remaining elements. Where present, no limits between the transverse process and the centrum or neural arch can be observed. The dorsal tuberosity is well developed in caudal 8, becoming gradually smaller and more elongated anteroposteriorly. It is clear that at least in *Baurutitan britoi*, the lateral extension seen in some titanosaurids (e.g., *Gondwanatitan*), is not formed by the transverse process but by this independent dorsal tuberosity (see Discussion).

As the anterior elements, the posterior caudals of *Opisthocoelicaudia skarzynskii* differ from *Baurutitan britoi* by being opisthocoelous until caudal 15, turning to amphiplatyan at caudal 16 to 27 (BORSUK-BIALYNICKA, 1977). The centra are shorter and rounded (BORSUK-BIALYNICKA, 1977: pl.6, figs.4a, 5a), and not quadrangular as in *Baurutitan britoi*. The ventral concavity bordered by ventrolateral ridges (absent in *Baurutitan britoi*) is still present in the middle caudals of *Opisthocoelicaudia skarzynskii* (BORSUK-BIALYNICKA (1977:15). The bases of the neural

spines of middle caudals of *Opisthocoelicaudia skarzynskii* are set over the distal half of the respective centra (BORSUK-BIALYNICKA, 1977: pl.5, fig.5; pl.6, fig.7a), always more posteriorly placed than in the respective elements of *Baurutitan britoi*. The prezygapophyses of *Opisthocoelicaudia skarzynskii* are shorter (BORSUK-BIALYNICKA, 1977: pl.4, figs.1b, 2a; pl.5, fig.2a), but show a similar orientation as in *Baurutitan britoi*. The postzygapophyses of both species are placed on the posterior half of the centrum, but in *Opisthocoelicaudia skarzynskii* they are set closer to the posterior margin (BORSUK-BIALYNICKA, 1977: pl.5, fig.5; pl.6, figs.1b, 7a). In *Opisthocoelicaudia skarzynskii* the caudals of the middle series tend to have a more subvertically oriented neural spine (BORSUK-BIALYNICKA, 1977: pl.5, fig.5; pl.6, fig.7a).

An important feature that distinguishes *Baurutitan britoi* from *Epachthosaurus sciuttoi* is the presence in the latter of hyposphene-hypantrum articulations in caudals 8-14 (MARTÍNEZ *et al.*, 2004). Some of the middle elements show a ventral longitudinal groove which is absent in *Baurutitan britoi*. The neural spine in *Epachthosaurus sciuttoi* tend to be more anteroposteriorly elongated, and the

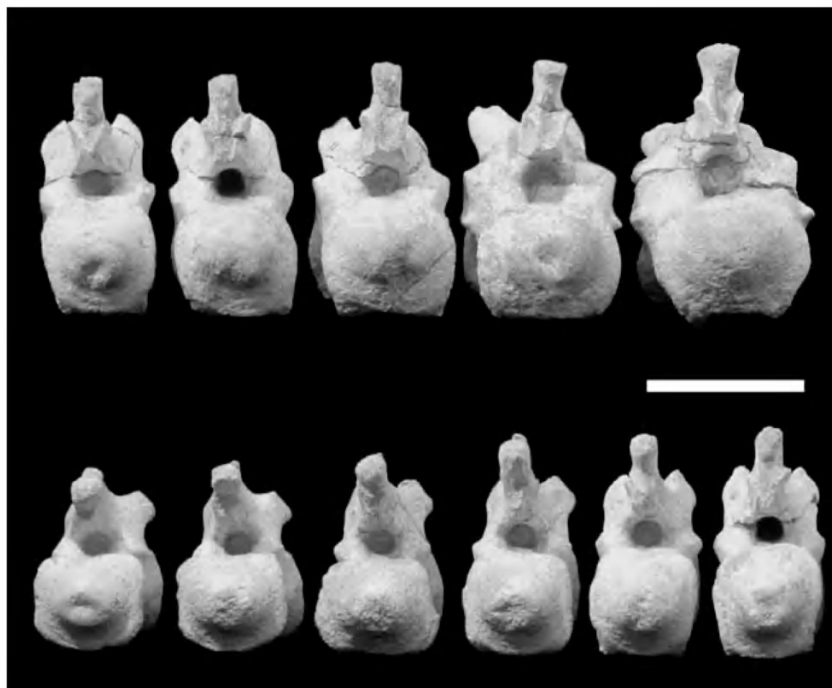


Fig.21- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudals 8-18 in posterior view. Scale bar = 100mm.

postzygapophyses are apparently not well delineated (“weak”, according to MARTÍNEZ *et al.*, 2004). As in the anterior elements, the middle caudal vertebrae of *Alamosaurus sanjuanensis* also differ

from *Baurutitan britoi* by having the outline of the centrum more rounded, lacking the quadrangular shape of the latter. The ventral projections for the chevrons are comparatively more developed in

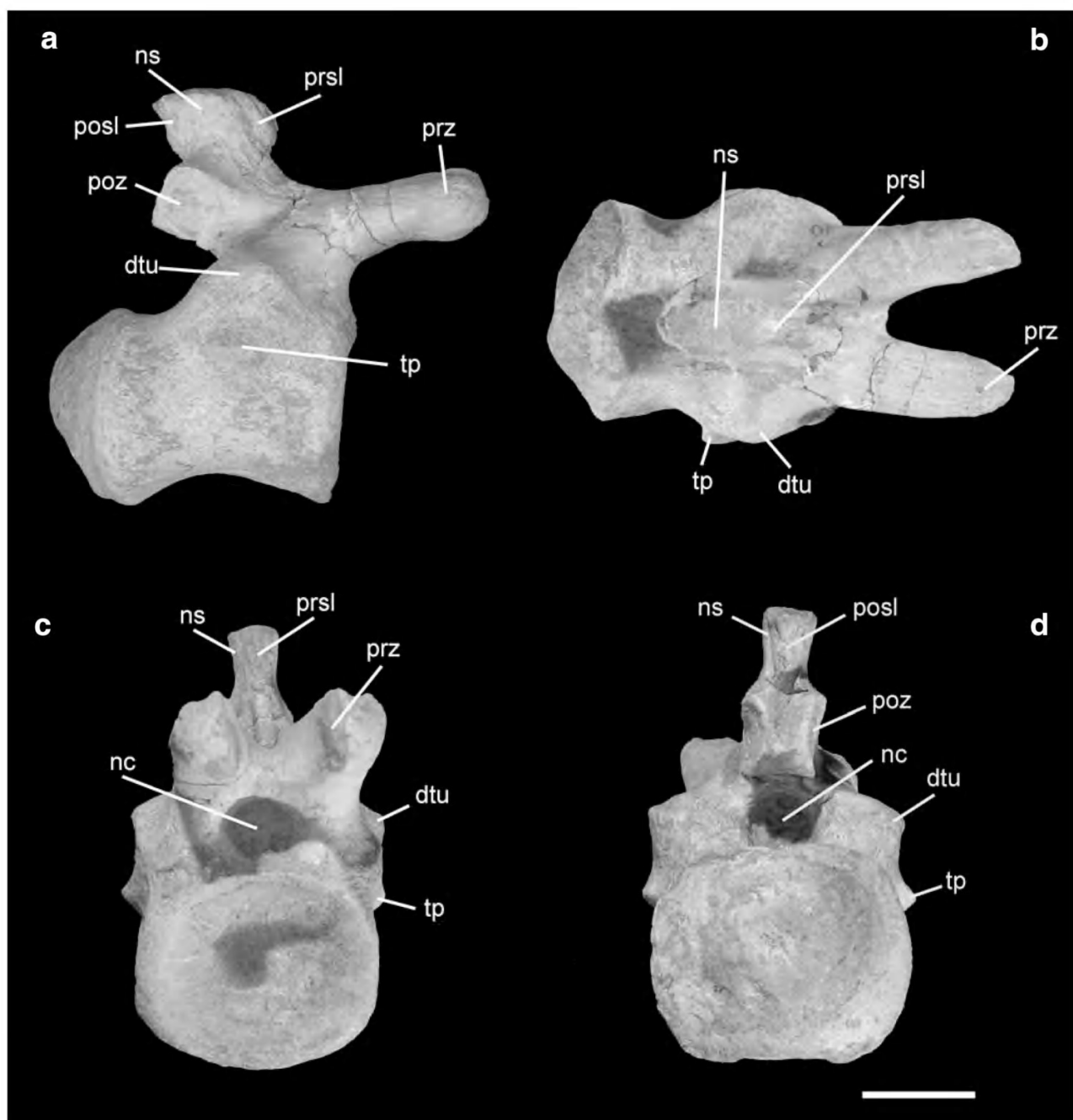


Fig.22- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 9 in: (a) right lateral, (b) dorsal, (c) anterior, and (d) posterior views. Scale bar = 50mm. See text for abbreviations.

*Alamosaurus sanjuanensis*, particularly in caudals 8-13, and the ventral margin of the centra are more concave. The prezygapophyses tend to be comparatively thinner and in caudals 8-10 show a tuberosity which is absent in the corresponding vertebrae of *Baurutitan britoi*. Furthermore, in *Alamosaurus sanjuanensis* the neural spine gets more elongated anteroposteriorly starting at the caudal 11, while this happens only in caudal 14 in *Baurutitan britoi*.

Midcaudals of *Isisaurus colberti* display high neural spines and shorter prezygapophyses than *Baurutitan britoi*. The outline of the posterior articulation is rounded contrasting to the more quadrangular condition observed in *Baurutitan britoi*. The condyle in the Indian taxon is very projected anteroposteriorly ("cone-like") and displaced dorsally. According to JAIN & BANDYOPADHYAY (1997) the mid- and distal caudals of *Isisaurus colberti* show developed anterior and posterior facets for the chevrons which in *Baurutitan britoi* tend to be reduced and present only on the ventral part of the posterior articulation surface. Furthermore, *Isisaurus colberti* shows the ventral surface of the centrum concave (JAIN & BANDYOPADHYAY, 1997: fig.12D), differing from the more flattened condition of *Baurutitan britoi*.

As far as comparisons are possible, the main

difference from the middle caudals of *Gondwanatitan faustoi* and *Baurutitan britoi* is the presence of a lateral anteroposteriorly elongated ridge that is more developed in the former. As demonstrated in *Baurutitan britoi*, this process corresponds to the tuberosity present in more anterior elements and not the transverse process. If this is also the case in *Gondwanatitan faustoi* cannot be demonstrated and the questions if those two lateral ridges of those taxa are homologous remains open.

According to SANZ *et al.* (1999) only few caudals are known from *Lirainosaurus astibiae* that, except for the first (which is the holotype), are considered paratypes. Comparing the last preserved caudal of *Baurutitan britoi* with the middle caudal of *Lirainosaurus astibiae* figured by SANZ *et al.* (1999: pl.3, fig.A), the Spanish taxon differs by having the neural spine occupying a more central position, shorter prezygapophyses with a more expanded end, the postzygapophyses comparatively more set apart from the neural spine with more expanded articulation surfaces, and the ventral margin of the centrum more concave.

The middle caudals of *Mendozasaurus neguyelap* have centra with slightly procoelous, circular anterior faces (not rectangular or square as in *Baurutitan britoi*). The posterior faces have reduced

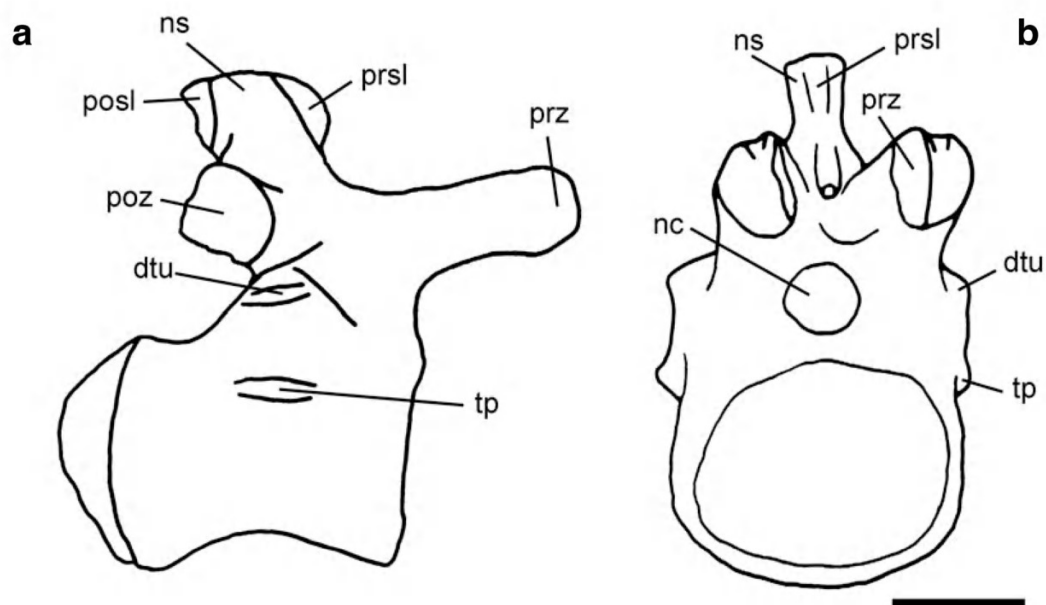


Fig.23- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), drawing of caudal 9 in (a) right lateral and (b) anterior views. Scale bar = 50mm. See text for abbreviations.

condyles displaced dorsally, which is regarded as an autapomorphy of *Mendozasaurus neguyelap* (GONZÁLEZ RIGA, 2003). The neural spines are depressed, flat and more elongated anteroposteriorly than in *Baurutitan britoi*. The anterodorsal corner of the neural spine in caudals 12-13 is higher and thicker than the posterodorsal one. This condition disappears in caudal 17, where the dorsal border of the neural spine straightens and becomes horizontal, with the anterodorsal corner forming a right angle (GONZÁLEZ RIGA, 2003, fig.5C). This condition is not present in the distalmost preserved caudals of *Baurutitan britoi*.

Beginning in caudals 8-10, the middle caudals of *Pellegrinisaurus powelli* display a comparatively longer and lower centrum than in the correspondent elements of *Baurutitan britoi*

(SALGADO, 1996:359). The midcaudal centra are dorsoventrally depressed, having convex lateral faces, differing from the quadrangular shape of the centra of *Baurutitan britoi*. Beyond the 15<sup>th</sup> vertebra, the centra of *Pellegrinisaurus powelli*, in anterior view, become depressed, with convex lateral walls (SALGADO, 1996: fig.6C), contrasting with the quadrangular shape of caudals 15-18 of *Baurutitan britoi*. In these distalmost elements, the neural spines of *Pellegrinisaurus powelli* are lower and more anteroposteriorly elongated than in *Baurutitan britoi*. They reach the posterior end of the caudal centrum, and have the anterodorsal corner of the neural spine set at a higher position in respect to the posterodorsal corner (SALGADO, 1996: fig.6A), a condition present only in the last preserved caudal of *Baurutitan britoi*.

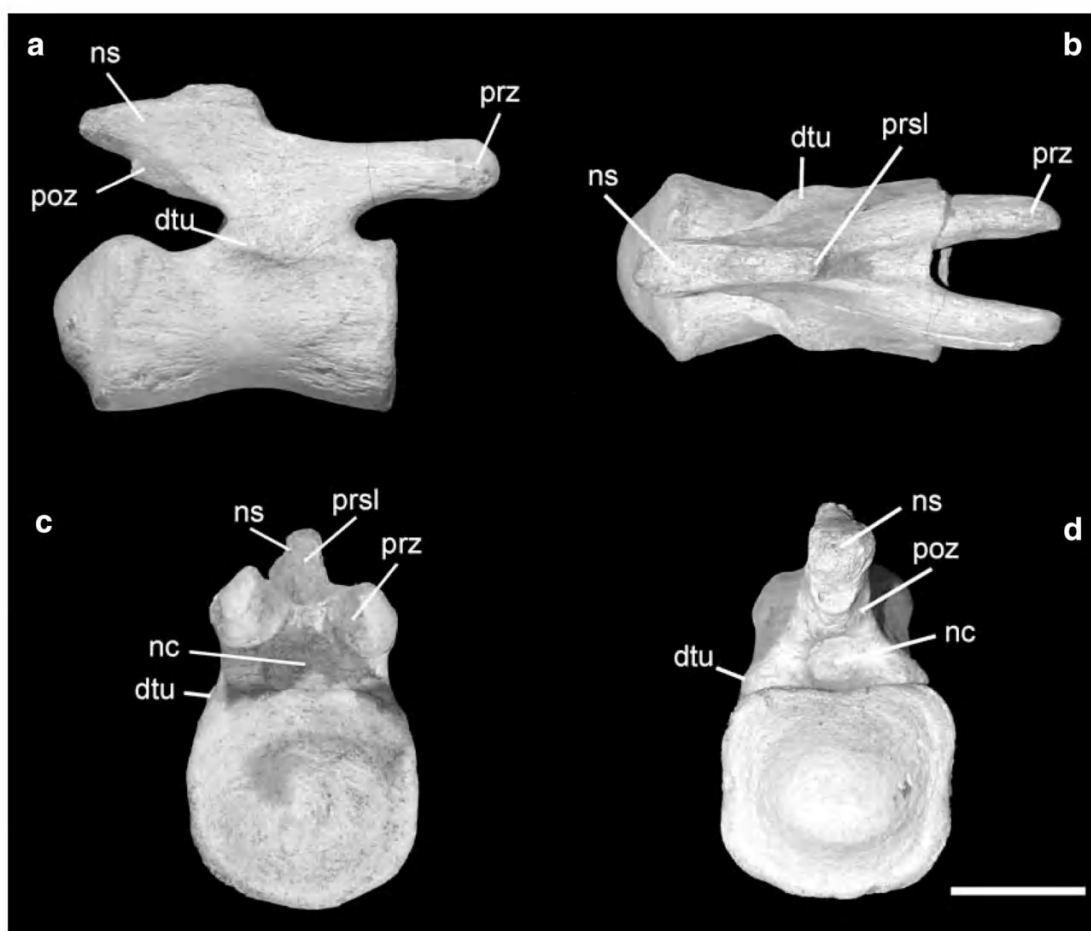


Fig. 24- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), caudal 18 in: (a) right lateral, (b) dorsal, (c) anterior, and (d) posterior views. Scale bar = 50mm. See text for abbreviations.

The middle caudals of *Rinconsaurus caudamirus* can be distinguished from those of *Baurutitan britoi* by the presence of bony processes separating the articular faces of the postzygapophyses from the neural spine, a character considered an autapomorphy of *Rinconsaurus caudamirus* (CALVO & GONZÁLEZ RIGA, 2003). Among the distal caudals of *Rinconsaurus caudamirus*, there is a series (MRS-Pv 29) with unusual centra, showing a procoelous plus amphicoelous plus biconvex articulations (CALVO & GONZÁLEZ RIGA, 2003: pl.3, fig.A). Since the posterior part of *Baurutitan britoi* is lacking, it is not possible to tell, in the present time, whether this condition was present in this taxon. It should be noted, however, that a similar condition has been reported in a caudal series (DGM 497-R) found in the same sedimentary deposits, in a nearby quarry (TROTTA, CAMPOS & KELLNER, 2002).

Regarding the Saltasaurinae *Saltasaurus loricatus* and *Neuquensaurus australis*, the main difference is the anteroposteriorly elongated depression,

divided by a sagittal crest on the ventral surface of the centra (POWELL, 2003) which is absent from *Baurutitan britoi*.

#### CHEVRONS

Fifteen chevrons of *Baurutitan britoi* were recovered (Figs.25-27). By the available information, they were found articulated with the caudal series (Fig.3). As the caudals, after being prepared (some decades ago) they were numbered according to the vertebrae to which they were connected. Therefore, the numbers written on the chevrons (also left on the specimen for historical reasons) do not refer to the anatomical position of the caudals in the tail (e.g., chevron 4-5 was found connected to caudals 3 and 4). The eight anteriormost chevrons show two numbers (e.g. 4-5; 5-6; 6-7), suggesting that they were probably in contact between two vertebrae. The last seven chevrons received single numbers and were possible more closely associated with one vertebra.



Fig.25- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), chevrons in left lateral view. The last chevron is figured in ventral view. Scale bar = 100mm.



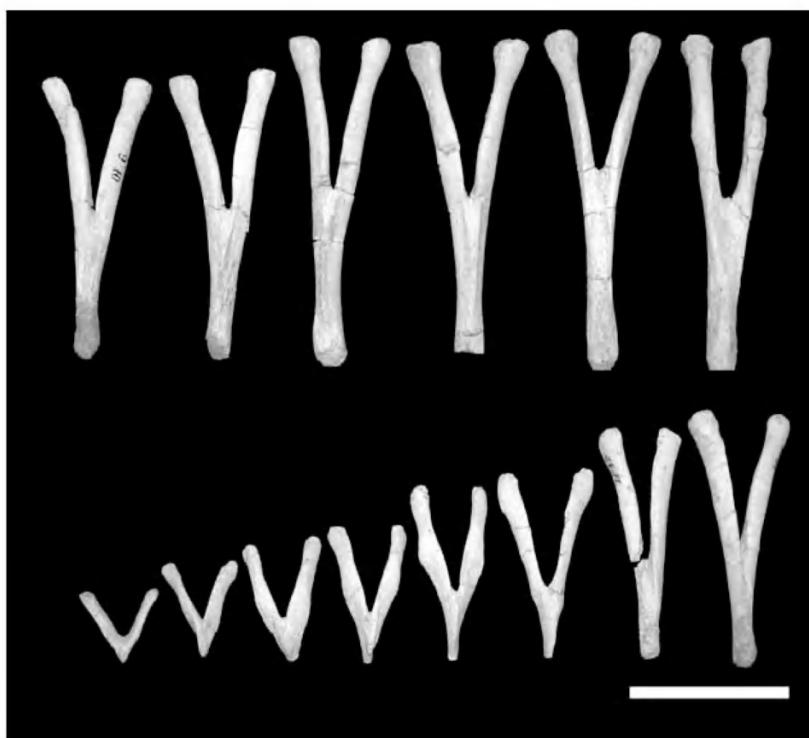


Fig.26- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), chevrons arches in anterior view. Scale bar = 100mm.

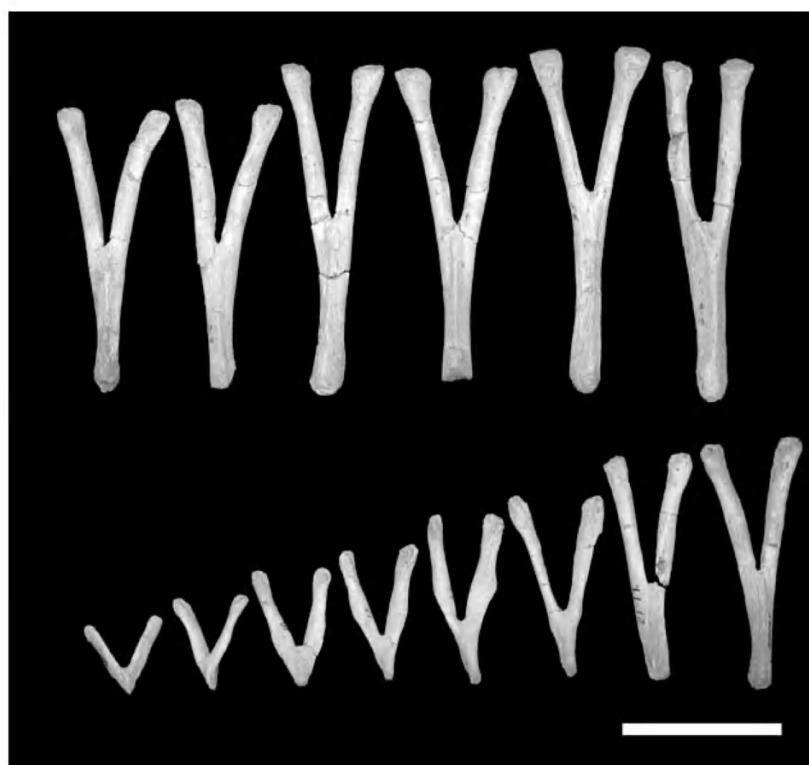


Fig.27- *Baurutitan britoi* n.gen., n.sp. (MCT 1490-R), chevrons arches in posterior view. Scale bar = 100mm.

All chevrons are well preserved and complete, with exception of the ventral tip of some elements. The chevron series begins on caudal 3 and 4 and extends until caudal 18. Therefore one chevron is missing (between the caudals 11-12). All chevrons are open, displaying a large haemal canal. The four anteriormost chevrons (corresponding to the caudals 3/4 - 6/7) are the largest (subequal in size) with long ventral process. From the fifth chevron on, their sizes gradually decrease, with the last preserved element (corresponding to caudal 18) divided into two ossifications that do not fuse ventrally. In the more anterior elements, the ventral fused portion of the chevrons tend to very large (subequal or larger in size compared to the proximal processes), getting gradually shorter in the more posteriorly placed elements. The depth from the haemal canal changes from being shorter than the whole chevron in the anterior elements until being much larger in the most posterior elements (corresponding to caudals 13 to 18). The ventral portion corresponding to the fused part of the chevron is laterally compressed, forming an anteroposteriorly oriented blade-like lamina that gets gradually more reduced in the more posteriorly situated elements.

The anterior and posterior surface of this region shows longitudinal ridges. The bone of the lateral surface of the chevron corresponding to caudal 13 is thickened, differing from the preceding elements. The posteriorly placed chevrons also have a similar but less developed thickened bone surface.

*Opisthocoelicaudia skarzynskii* has chevrons starting at the last sacro-caudal as far back to caudal 19, beyond which they were probably absent or quite rudimentary (BORSUK-BIALYNICKA, 1977), differing from *Baurutitan britoi* (chevrons starting at caudal 3). In the anterior caudals of *Opisthocoelicaudia skarzynskii*, the haemal canal is about one third of the chevrons length, differing from the anterior chevrons of *Baurutitan britoi*, which have haemal canals equivalent to half of the chevrons length. The ventral projection of the chevrons 4 to 8 in *Opisthocoelicaudia skarzynskii* is pointed, a feature not present in any of the chevrons of *Baurutitan britoi* where they are rounded. The chevrons from 6 to 15 of *Opisthocoelicaudia skarzynskii* are fused to the centra, a condition not present in *Baurutitan britoi*. Furthermore, the chevrons of *Opisthocoelicaudia skarzynskii* have comparatively larger and stronger articular facets than those of *Baurutitan britoi*.

The chevron of *Aeolosaurus rionegrinus* (POWELL, 2003: pl.11, fig.3) is distinguished from those of *Baurutitan britoi* by having a haemal canal more or

less equivalent to a third of the whole length of the bone, flanked by two well developed proximal processes both transversally and anteroposteriorly more expanded than in the Brazilian taxon. The proximal part of the ventral process is also transversally wider than in *Baurutitan britoi*.

*Alamosaurus sanjuanensis* has chevrons from the first caudal to the 25<sup>th</sup> (GILMORE, 1946). The arms of the chevrons in *Alamosaurus sanjuanensis* are set closer to each other than in *Baurutitan britoi*, resulting in a more acute "V" shaped profile. The articular heads are more developed in being anteroposteriorly and laterally more expanded than in the Brazilian taxon (GILMORE, 1946: fig.4).

The chevron of *Mendozasaurus neguyelap* (GONZÁLEZ RIGA, 2003: fig.5D) has both arms set closer to each other than in *Baurutitan britoi*, resulting in a more acute "V" shaped profile. The articular heads of the chevron are more expanded, both anteroposteriorly and laterally, in the Argentinean taxon. The ventral spine of *Mendozasaurus neguyelap* is thinner in anterior view than in *Baurutitan britoi*. The chevrons of *Mendozasaurus neguyelap* have double articular facets in proximal ends (GONZÁLEZ RIGA, 2003: p.162), a trait not present in *Baurutitan britoi*.

The haemal canal of an anterior chevron of *Isisaurus colberti* (JAIN & BANDYOPADHYAY, 1997: fig. 17) is less deep than half of the length of the entire bone, thus differing from the corresponding deeper haemal canals present in *Baurutitan britoi*. The bone is more expanded anteroposteriorly in the Indian taxon. It shows also extremely developed articular facets, with clearly anterior and posterior articulating surfaces (JAIN & BANDYOPADHYAY, 1997: p.121), which are absent in the Brazilian taxon. Below the canal, the haemal arches of *Isisaurus colberti* have a rounded shape in cross section (JAIN & BANDYOPADHYAY, 1997), differing from *Baurutitan britoi*, in which the haemal arches have a more elliptical cross section, with the longest axis directed anteroposteriorly.

The anterior chevrons of *Saltasaurus loricatus* are more robust than the same elements of *Baurutitan britoi*, being comparatively more expanded both transversally and anteroposteriorly, with well developed articular heads (POWELL, 2003: fig.36a). Although the ventral spine of *Saltasaurus loricatus* also displays an anterior ridge, it is thicker and restricted to the distal portion of the spine compared to *Baurutitan britoi*. The haemal canal is less deep in the Argentinean taxon, being less than a third of the entire length of the bone.

## DISCUSSION

Dinosaurs in Brazil are known for a long time (KELLNER, 1996; 1998) and there are several localities where specimens have been recovered but few have been actually named or studied properly (KELLNER & CAMPOS, 2000). Regarding sauropods, only three species have been described so far: one diplodocid (CARVALHO, AVILLA & SALGADO, 2003) and two titanosaurids. The first titanosaurid, "*Antarctosaurus brasiliensis*" (ARID & VIZOTTO, 1971), is unfortunately based on material that cannot be diagnosed (e.g., KELLNER & CAMPOS, 2000). The second is *Gondwanatitan faustoi*, which is closely related to *Aeolosaurus rionegrinus* (KELLNER & AZEVEDO, 1999). From all known localities with titanosaurid dinosaurs, Peirópolis was always regarded as the richest (CAMPOS & KELLNER, 1991; BERTINI *et al.*, 1993; KELLNER & CAMPOS, 1997), showing some diversity (PRICE in LAMEGO, 1959; POWELL, 1987; CAMPOS & KELLNER, 1999; TROTTA, CAMPOS, & KELLNER, 2001).

From all specimens discovered at the Peirópolis site, the partially articulated vertebral columns known in the literature as the sequences A (cervical vertebrae and three dorsals), B (cervical, dorsal and caudal vertebrae - see CAMPOS *et al.*, 2005 - this volume), and C (last sacral and caudal vertebrae) were regarded as the most important ones (POWELL, 1987). Of those, the sequence C, here named *Baurutitan britoi*, is the most complete articulated caudal sequence from Brazil known to date (caudal 1 to 18), making it very useful to place isolated anterior and middle caudal elements in the tail. Based on comparisons with MCT 1488-R (that has a partial neck, the complete dorsal series) and MCT 1719-R (incomplete caudal series), the length of *Baurutitan britoi* is estimated between 12 and 14 meters.

One of the most outstanding features *Baurutitan britoi* is the presence of a dorsal tuberosity situated on the contact surface between the transverse processes and the neural arch. This process forms a rounded and thick bone projection that starts in caudal 2 and gets gradually smaller and more elongated in the posterior elements, being present in the last preserved caudal (caudal 18). The transverse process is present and well developed in all anterior elements, always larger than the dorsal tuberosity. In caudals 8 and 9, the transverse process is reduced, while in caudal 10 it is perceptible only on the right side as a tiny knoblike projection that completely disappears in caudal 11.

Starting on caudal 8, the dorsal tuberosity, however, despite getting gradually smaller in the posterior elements, is always more projected than the transverse process. This unequivocally shows that the lateral bony ridge present in the posterior elements of the middle series is homologous with the dorsal tuberosity and not with the transverse process. *Alamosaurus sanjuanensis* has the transverse processes getting smaller posteriorly and according to GILMORE (1946), are replaced by "raised rectangular areas" which are replaced by longitudinal ridges that disappear at caudal 27. Judging from the published pictures, *Alamosaurus sanjuanensis* also bears a dorsal tuberosity (albeit less developed than in *Baurutitan britoi*) and the bony lateral ridges on the base of the neural arch, might also be homologous to the dorsal tuberosity instead to the transverse processes.

The presence of a lateral ridge in caudals from the middle (and posterior) series has been observed in *Epachthosaurus sciuttoi* (MARTÍNEZ *et al.*, 2004: fig. 8a), where it was interpreted as the transverse process. Similar longitudinal ridges were observed in *Gondwanatitan faustoi* (KELLNER & AZEVEDO, 1999). SALGADO, CORIA & CALVO (1997a) also mention the presence of prominent lateral bony ridges in the saltasaurines *Neuquensaurus australis* and *Saltasaurus loricatus*. Since those taxa apparently lack a dorsal tuberosity on the anterior caudals, the homology of those bony ridges is not clear.

Regarding the phylogenetic position of *Baurutitan britoi*, the procoelous condition of anterior caudals allows its allocation within Titanosauria (SALGADO, CORIA & CALVO, 1997a). The strongly procoelous condition of midcaudals indicates that it is not a basal titanosaurid, such as *Andesaurus delgadoi* Calvo & Bonaparte 1991 where the mid- and posterior caudals are amphiplatyan, a primitive feature within Titanosauria (CALVO & BONAPARTE, 1991; SALGADO, CORIA & CALVO, 1997a). The new Brazilian taxon also lacks several caudal traits found in the saltasaurines that includes strongly dorsoventrally flattened centrum of anterior caudals, with centrum significantly wider than high, and the position of the neural spine, with the anterodorsal edge positioned posteriorly relative the anterior border of the postzygapophyses. *Baurutitan britoi* is also not a member of the clade formed by *Aeolosaurus* + *Gondwanatitan*, lacking the strongly anterodorsally oriented neural spine and the very anteriorly displaced neural arch. However, as in *Gondwanatitan faustoi* and *Aeolosaurus rionegrinus*

(Kellner pers. obs. 1999), some of the anterior caudal vertebrae show the ventral part of the centrum constricted, giving the posterior surface of the centrum a "heart-shaped" appearance, and potentially could indicate some relationships of those mentioned taxa with *Baurutitan britoi*. The new species also shares some features with *Alamosaurus sanjuanensis* (e.g., dorsal tuberosity that continues in the posterior elements as a prominent lateral ridge).

Concluding, *Baurutitan britoi* is a new titanosaurid sauropod from Brazil, which is neither a basal (e.g., *Andesaurus*) nor a derived (e.g., *Saltasaurinae*) taxon. It shows some similarities to *Aeolosaurus rionegrinus* and *Gondwanatitan faustoi* ("heart-shaped" centrum of some anterior caudals), also with *Alamosaurus sanjuanensis*. More information about its phylogenetic position can only be achieved by a detailed phylogenetic analysis of the Titanosauria.

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