



## BORTOLIN SITE, A NEW FOSSILIFEROUS LOCALITY IN THE TRIASSIC (LADINIAN/CARNIAN) OF SOUTHERN BRAZIL

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**ABSTRACT** – A new fossiliferous site from the Pinheiros-Chiniquá Sequence (Santa Maria Supersequence) with typical tetrapod components of the *Dinodontosaurus* Assemblage Zone (AZ) is here described. The new site is included in the Faxinal do Soturno Structural Block. The fossil content is characterized by cranial and postcranial material of rauisuchian archosaurs, traversodontid and chiniquodontid cynodonts and dicynodonts, the first occurrence of a large-sized coelacanth fish in the Brazilian Triassic, as well as ichnological material, represented by coprolites. The presence of *Luangwa* together with *Massetognathus* raises interesting questions regarding the age of this site included in the *Dinodontosaurus* AZ when compared with other localities of Southern Brazil, western Argentina and Africa. As in other localities of this AZ, the fossil specimens recovered in Bortolin site exhibit remarkable differences on their fossil preservation: those from the lower portion of the outcrop (distal floodplain) possess a heterogeneous preservation (variable between poor to fairly good) whereas those from the top levels (proximal floodplain) are comparatively better preserved. This new locality, with a large amount of stratigraphically controlled fossils, constitutes a key-locality to study the distribution of Triassic terrestrial tetrapods and to perform comparisons with other sites of this AZ, in which several historical records lack a precise provenance.

**Keywords:** *Dinodontosaurus* Assemblage Zone, Santa Maria Supersequence, *Luangwa*, coelacanth.

RESUMO – Um novo sítio fossilífero é descrito para a Sequência Pinheiros-Chiniquá (Supersequência Santa Maria) com tetrápodes típicos da Zona de Associação (ZA) de *Dinodontosaurus*. Este novo sítio está incluído no Bloco Estrutural Faxinal do Soturno. O conteúdo fóssil é caracterizado por materiais cranianos e pós-cranianos de arcossauros rauissuquídeos, cinodontes chiniquodontídeos e traversodontídeos e dicinodontes, a primeira ocorrência de um peixe celacanto de grande tamanho, além de materiais icnológicos, representados por coprólitos. A presença de *Luangwa* juntamente com *Massetognathus* levanta interessantes questões acerca da idade desse sítio, incluído na ZA de *Dinodontosaurus*, quando comparado com outras localidades do sul do Brasil, oeste da Argentina e África. Assim como em outras localidades desta ZA, os espécimes fósseis coletados no sítio Bortolin apresentam diferenças notáveis na preservação dos fósseis: fósseis do nível inferior do afloramento (planície de inundação distal) apresentam preservação heterogênea (variando entre pobre a razoavelmente bem preservado) enquanto que nos níveis superiores (planície de inundação proximal), o registro fóssil é comparativamente melhor preservado. Esta nova localidade, com uma grande quantidade de fósseis estratigraficamente controlados, constitui uma localidade chave para o estudo da distribuição dos tetrápodes terrestres do Triássico e sua comparação com outros sítios desta ZA, na qual vários registros históricos carecem de uma proveniência precisa.

**Palavras-chave:** Zona de Associação de *Dinodontosaurus*, Supersequência Santa Maria, *Luangwa*, celacanto.

## INTRODUCTION

In the last two decades, several new fossiliferous sites from the Lower (e.g. Da-Rosa *et al.*, 2009; Dias-da-Silva & Da-Rosa, 2011), upper Middle (e.g. Da-Rosa *et al.*, 2004, 2005) and Upper Triassic (e.g. Bonaparte *et al.*, 1999, 2010; Da-Rosa *et al.*, 2006; Cabreira *et al.*, 2011; Müller *et al.*, 2015; Pavanatto *et al.*, 2018) were discovered, improving considerably the faunal composition of the Triassic of Southern Brazil (e.g. Langer *et al.*, 2007; Dias-da-Silva *et al.*, 2017). These new sites and their fossil content are useful keys for the delimitation of structural blocks (Da-Rosa & Faccini, 2005) and for biostratigraphic purposes (Langer *et al.*, 2007; Soares *et al.*, 2011; Da-Rosa *et al.*, 2012; Martinelli *et al.*, 2017; Müller *et al.*, 2017).

Da-Rosa & Faccini (2005) delimited six structural blocks in sedimentary rocks from the central portion of the Rio Grande do Sul State: the Santa Maria, São João do Polêsine, Faxinal do Soturno, Agudo, Paraíso do Sul and Candelária blocks. Later, Da-Rosa (2013, 2015) added more seven: Mata, São Pedro do Sul, Vale do Sol, Vera Cruz, Santa Cruz do Sul, Venâncio Aires, and Bom Retiro do Sul blocks. These structural unities were identified exclusively based on fault displacements resulting from Late Mesozoic post-depositional tectonics.

The Faxinal do Soturno block has so far provided fewer fossiliferous outcrops in comparison with other blocks. However, in the last years, systematic field work has resulted in the discovery of several new sites, including the one presented herein – Bortolin site –, as well as several new tetrapod taxa and records (e.g. Bonaparte *et al.*, 2010; Cabreira *et al.*, 2016; Müller *et al.*, 2015, 2017; Pacheco *et al.*, 2018). The Bortolin site, which crops out nearby the urban area of the municipality of Dona Francisca, Rio Grande do Sul State (Figure 1A-C), was preliminarily reported by Da-Rosa *et al.* (2008) and prospected by different Brazilian researchers. Its fossiliferous assemblage was considered as belonging to the *Dinodontosaurus* Assemblage Zone (AZ) due to the presence and dominance of the kannemeyeriid *Dinodontosaurus* and the traversodontid cynodonts *Luangwa* and *Massetognathus* (Barberena *et al.*, 1985; Schultz *et al.*, 2000; Langer *et al.*, 2007). In this contribution, we analyze both the geology

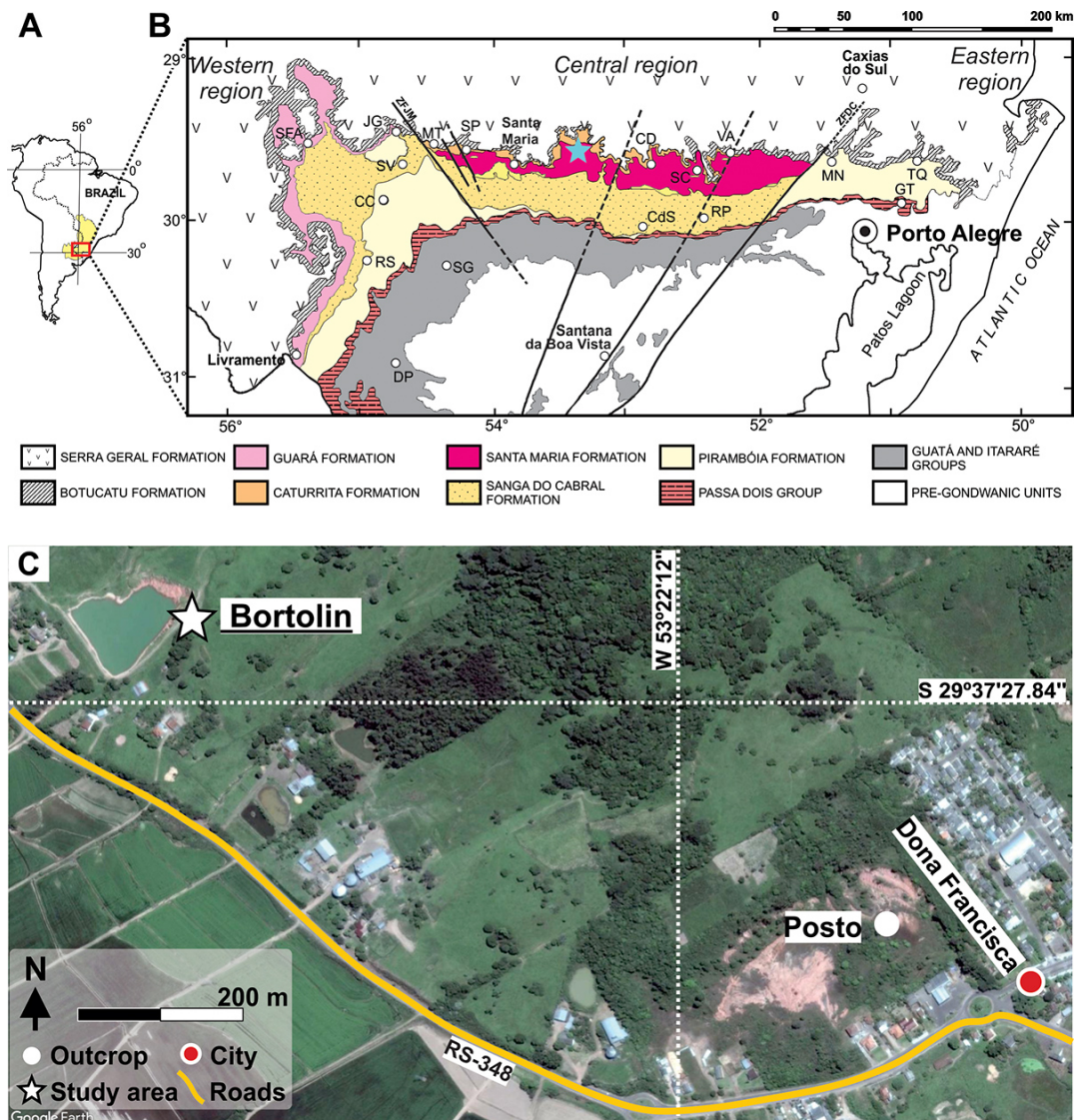
and the faunal content of the Bortolin site, highlighting the biostratigraphic importance of its fossil record and its impact in a broader biostratigraphic scheme for the latest Middle-earliest Late Triassic of Southern Brazil.

## LOCATION AND GEOLOGICAL SETTING

The Bortolin site, named after the owners of the property where it is located, is located about 100 m from the highway RS 149, km 8 (29°37'24.04''S / 53°22'33.92''W), and about 1.5 km westward of the crossroad to the municipality of Dona Francisca. It occurs alongside the margins of an artificial water dam, in a private area (Figures 1C; 2B). Faunal components of this site, also named as Antonini Bortolin site, were briefly reported in several scientific meetings (Silva & Cabreira, 2009; Hanich *et al.*, 2012, 2013; Siefert *et al.*, 2017 a,b).

The sedimentary rocks belong to the base of the Pinheiros-Chiniquá Sequence (Horn *et al.*, 2014) of the Santa Maria Supersequence (Zerfass *et al.*, 2003), formerly known as the Alemoa Member, Santa Maria Formation (Andreis *et al.*, 1980). The most important fossiliferous outcrops of the Faxinal do Soturno block are the Linha São Luiz site, in the municipality of Faxinal do Soturno (Norian, *Riograndia* AZ; Bonaparte *et al.*, 2010; Soares *et al.*, 2011; Langer *et al.*, 2018) and the Posto de Gasolina/Fogliarini site in the municipality of Dona Francisca (Middle-Late Triassic boundary, *Dinodontosaurus* AZ; e.g. França *et al.*, 2011; Martinelli *et al.*, 2017), both about 11 kilometers away from each other (in a straight line). Several authors (e.g. Holz & Schultz, 1998; Da-Rosa *et al.*, 2004, 2005; Horn *et al.*, 2013) stated that the variances regarding preservational processes in these AZs are related to different depositional environments and exposure time of the remains to the environment. Permineralization and carbonate substitution are the most common features in these fossils, in addition to the occurrence of ferric or carbonatic incrustations or even recrystallization.

Bortolin site exposure (Figures 2A–B) comprises massive red mudstones with a minimum thickness of 8 m, divided into two walls with a length of about 20 m each, which form the north and east slopes of the artificial dam. It contains small layers of inter-fingered fine-grained sandstones, showing plane-parallel lamination and cross stratification, strongly



**Figure 1.** Location and geological context of Bortolin site. **A**, location map of the Paraná Basin in South America. **B**, sedimentary units in Southern Brazil, orange and striped area (striped) represents the Passa Dois Group (Permian); yellow area (dotted) represents the Sanga do Cabral Formation; dark pink area (dark grey) represents the Santa Maria Formation (modified from Scherer *et al.*, 2000). The star indicates the location of Bortolin site within the sedimentary units of Southern Brazil. In parenthesis are indicated patterns for black and white figure. **C**, Satellite image showing the location of the Bortolin site. **Abbreviations:** DP, Dom Pedrito; SG, São Gabriel; RS, Rosário do Sul; CC, Cacequi; SV, São Vicente do Sul; JG, Jaguarí; MT, Mata; SP, São Pedro do Sul; CD, Candelária; CH, Cachoeira do Sul; SC, Santa Cruz do Sul; RP, Rio Pardo; VA, Venâncio Aires; MN, Monte Negro; GT, Gravataí; TQ, Taquara.

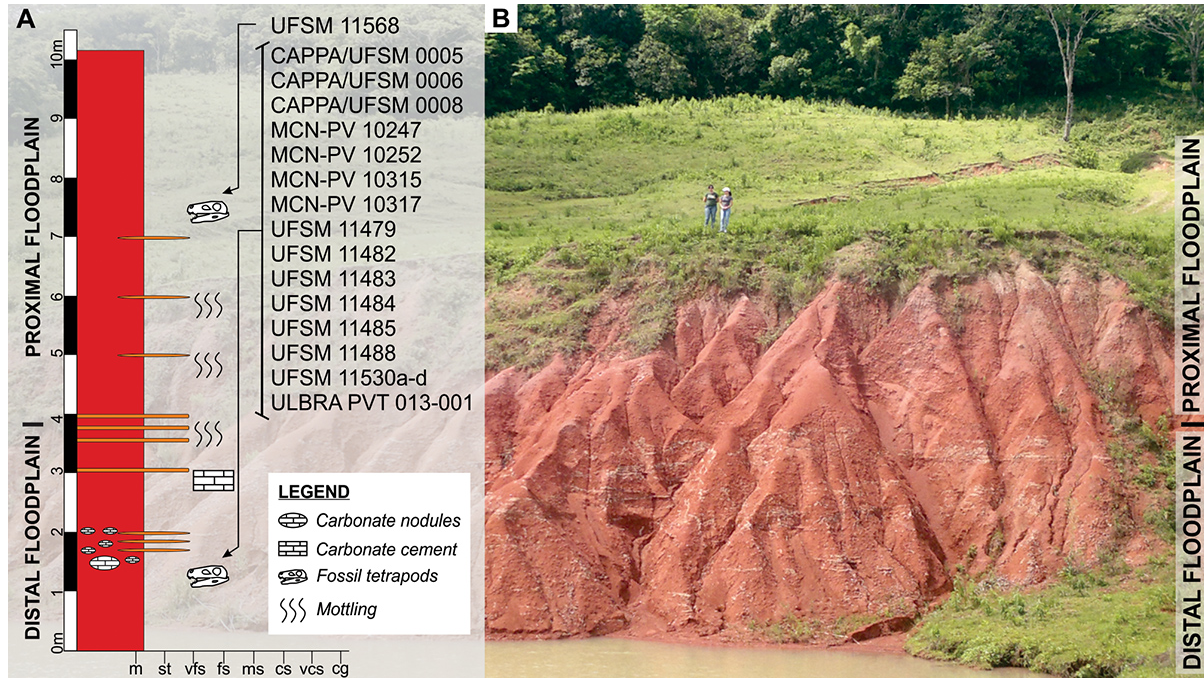
cemented by calcium carbonate. Carbonate nodules and punctual mottling are common in the mudstones, especially at the base of the outcrop, whereas tubular or irregular carbonate concretions and mottling of significant lateral continuity are present in the sandstones. The whole sedimentary package was deposited in a fluvial environment, in which the red mudstones represent deposition in the floodplains, whereas small layers of fine-grained sandstones are interpreted to be related to the distal facies of crevasse deposits. The distal floodplains have a great concentration of sandstones, whereas in the proximal floodplains the sandstones are quite rare.

The fossils from the lower portion of the outcrop (distal floodplain) possess a heterogeneous preservation, including permineralization and carbonate substitution; the presence

of iron oxide and/or carbonate crust and also partial recrystallization (identifiable by the loss of internal structures of the bone and volume distortion). Conversely, in the top levels of the outcrop (proximal floodplain), the fossils are comparatively better preserved. These permineralized and substituted bones usually bear iron oxide crusts directly over their surfaces, without significant amount of carbonate. According to Da-Rosa (2011, 2015), these two forms of preservation are associated with both sedimentary facies: distal and proximal floodplains.

**Institutional abbreviations.** CAPP/UFMS, Centro de Apoio à Pesquisa Paleontológica da Quarta Colônia - Universidade Federal de Santa Maria, São João do Polésine, Rio Grande do Sul, Brazil; MCN-PV, Museu de Ciências





**Figure 2.** A, Stratigraphic log of the Bortolin site, with fossil content position. B, general view of the outcrop. **Abbreviations:** cg, conglomerate; cs, coarse sandstone; fs, fine sandstone; m, mudstone; ms, medium sandstone; st, siltstone; vcs, very coarse sandstone; vfs, very fine sandstone.

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## SYSTEMATIC PALEONTOLOGY

DIAPSIDA Osborn, 1903  
ARCHOSAURIA Cope, 1869  
RAUISUCHIA Huene, 1942  
(Figures 3A–I)

**Material.** UFSM 11488, left jugal; UFSM 11530a, b, c, humerus (a) and two isolated vertebrae (b, c).

**Description.** In UFSM 11488 (Figure 3I) the ascendant, anterior and posterior processes of the jugal are preserved. The bone is fractured just anteriorly to its anterior process, which is slightly broken in its anterior limit. The posterior (quadratojugal) process is slightly compressed dorsoventrally, showing an articulation area with the quadratojugal in its ventral surface. The dorsoposteriorly directed ascendant process is more robust, and larger than the posterior one. The sizes of both processes are similar and they form an acute (“v-shaped”) angle. The space between the ascendant and anterior processes is short, constraining a narrow orbit above the level of the posterior process. UFSM 11530b

(Figures 3A–C) represents a cervical vertebra. The centrum is amphicoelous and bears well-marked lateral constriction and an elongated anteroposteriorly and lateral fossae. The centrum is longer than tall, more elongated and slightly smaller than the second element (UFSM 11530c). The anterior and posterior articular surfaces of the centrum are circular in outline, the posterior articular surface being slightly larger than the anterior one. It is not possible to recognize keels on its ventral surface. The parapophyses are present and located lateroventrally at the anterior border of the lateral surface of the centrum. The neural canal is large. Both prezygapophyses are broken, the right one slightly after its base and the left at a more apical portion. The prezygapophyses are semicircular in outline and, in their lateral surface, there is a crest which probably corresponds to the prezygodiapophyseal lamina. The postzygapophyses are subtriangular and the right postzygapophysis is broken at its lateral surface. The postzygodiapophyseal lamina is well-developed, lateroventrally oriented and the spinopostzygodiapophyseal lamina is robust. Both zygapophyseal elements reach the same dorsoventral level, projecting at an angle about 45° from the vertical plane and are connected to the centrum by the centropre- and centropostzygapophyseal laminae. The transverse processes and the neural spine are fractured in their proximal region. UFSM 11530c (Figure 3D–F), the second vertebra is an anterior dorsal element. The vertebral centrum is slightly amphicoelous, with the articular surfaces slightly concave, approximately as long as tall. The lateral fossae are relative smaller in comparison to UFSM 11530b. The articular surfaces are subcircular, with the anterior one larger and more dorsoventrally elongated than the posterior counterpart. It is not possible to recognize keels on its ventral surface. The



diapophyses are stout, with a circular outline and laterally oriented. The diapophyses are connected to the parapophyses by a robust paradiapophyseal lamina and with the centrum by a well-developed posterior centrodiapophyseal lamina. The zygapophyses are poorly preserved. The left prezygapophysis is broken, whereas the left postzygapophysis is partially preserved. The articular surfaces of the zygapophyses are horizontally oriented in relation to the vertical plane. The prezygodiapophyseal lamina is barely visible, probably because of preservational issues. The hyposphene is present and clearly visible below the postzygapophyses. The centropre- and centropostzygapophyseal laminae are robust in comparison to the cervical element (UFSM 11540b). The neural spine is fractured just above its base. UFSM 11530a (Figure 3G-H) is a robust right humerus, having its extremities anteroposteriorly expanded and the shaft being approximately oval in cross-section. The well-developed deltopectoral crest forms about 30% of the total humeral length. The proximal extremity is flattened with a concave anterior surface and more expanded than the distal one. The humeral head is poorly preserved. The medial tuberosity is well-developed and projected from the medial surface of the proximal extremity. At the distal extremity, the entepicondyle is larger, more distally projected, and separated by the ectepicondylar fossa. The supinator ridge is present and extends laterodorsally to the ectepicondyle.

**Remarks.** The ascendant and posterior jugal processes of UFSM 11488 form an acute, v-shaped, angle of about 45° that is similar to that of *Decuriasuchus quartacolonina* (see França *et al.*, 2011). UFSM 11488 differs from the condition observed in UFRGS-PV-0629-T, referred to *Prestosuchus chiniquensis* by Mastrantonio *et al.* (2019), in which the ascendant and posterior jugal processes form an angle of almost 90°. However, the inferred orbit of UFSM 11488 is shorter and higher than in *D. quartacolonina*. UFSM 11530a, b, c was recovered in association and presumably belongs to the same specimen. UFSM 11530b was considered a cervical vertebra because, according to Romer (1956), in “thecondonts” the vertebral centrum is elongated anteroposteriorly and the parapophyses are located anteroventrally in the centrum. In addition, UFSM 11530b has some characters present in all rauisuchian cervical vertebrae (sensu Nesbitt 2005), as, parapophyses located at the anterior end of the centrum; small lateral fossae, ventral to the neurocentral suture; and presence of the diapophyseal laminae, although only the prezygodiapophyseal is preserved, the other three laminae (prezygodiapophyseal; posterior centrodiapophyseal and paradiapophyseal) are not preserved in UFSM 11530b, since the transverse process is broken in both sides. UFSM 11530c, in turn, was attributed to an anterior dorsal vertebra because, also according to Romer (1956), in the dorsal vertebrae of “thecondonts” the diapophyses and the parapophyses are positioned at the transverse process. The specimen is an anteriormost element because the diapophyses and the parapophyses are not united to form a diapophyses-parapophyses bar, as occurs in the posteriormost dorsal vertebrae of other rauisuchians (Nesbitt, 2005; Gower &

Schoch, 2009; Wienbaum, 2013). The vertebral centrum of the cervical element (UFSM 11530b) is reel shaped, as in both *P. chiniquensis* (UFRGS-PV-0629-T; Mastrantonio, 2010) and *D. quartacolonina* (França *et al.*, 2011). The articular surfaces of the vertebral centrum of the dorsal vertebra (UFSM 11530c) do not lie in the same level to each other, being the anterior surface more ventrally projected, as in *Postosuchus kirkpatricki* (Peyer *et al.*, 2008), and contrasting with *P. chiniquensis* (UFRGS-PV-0629-T; Mastrantonio, 2010) and *Decuriasuchus quartacolonina*, as both lie in the same level. The absence of keels on the ventral surfaces of both vertebrae might be result of taphonomic processes. The deltopectoral crest (30% of total humeral length) of UFSM 11530a possesses about the same proportion described for *D. quartacolonina* (25% in *Prestosuchus chiniquensis* UFRGS-PV-0629-T; Mastrantonio, 2010; Lacerda *et al.*, 2016). Size and orientation differences between the entepicondyle and ectepicondyle are quite similar to *P. chiniquensis* (UFRGS-PV-0629-T; Mastrantonio, 2010; Lacerda *et al.*, 2016), whereas it is comparatively less pronounced in *D. quartacolonina*. The similarities between UFSM 11530a, b, and c with UFRGS-PV-0629-T suggest that they probably belong to the same taxon, but additional evidence is necessary to corroborate this assumption. Due to this, we consider these specimens as *Rauisuchia* indet.

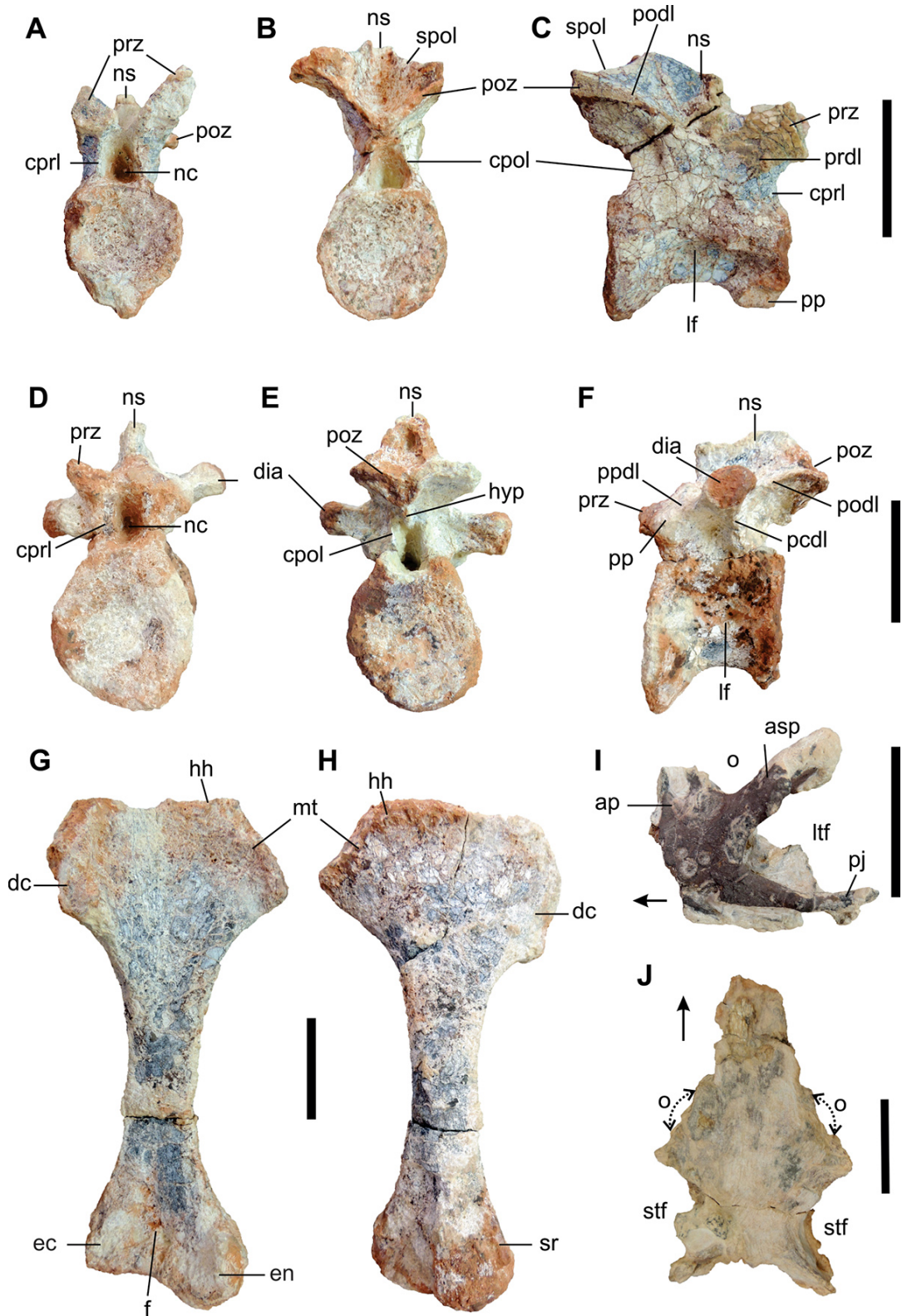
cf. *Decuriasuchus quartacolonina* França,  
Ferigolo & Langer, 2011  
(Figure 3J)

**Material.** MCN-PV 10317, a partial skull roof.

**Description.** The specimen is poorly preserved, with no visible sutures. It preserves the medial outlines of the supratemporal fenestrae, frontals, as well as part of the parietals and postfrontals. The laterosphenoid (only visible ventrally), and the supraoccipital (located between the parietals in occipital view) are poorly preserved. The paraoccipital processes are lateroventrally oriented, of about 45°. The ventral and occipital views were not depicted, as they are badly preserved.

**Remarks.** Despite the poor preservation of MCN-PV 10317, it is possible to observe similarities with MCN-PV 10004, which is referred to *Decuriasuchus quartacolonina* (see França *et al.*, 2013); although somewhat slender, possibly as result of ontogenetic variations. MCN-PV 10317 and *D. quartacolonina* share the narrower frontal region, in relation to *Prestosuchus chiniquensis* (UFRGS-PV-0629-T; Mastrantonio *et al.*, 2019); the shape of the medial outlines of the supratemporal fenestrae slight rounded (however not so rounded as in *Batrachotomus kupferzellensis* and *Postosuchus kirkpatricki*; Gower, 1999; Wienbaum, 2011). Based on its similar shape and size, MCN-PV 10317 is tentatively referred to *D. quartacolonina*.

SYNAPSIDA Osborn, 1903  
THERAPSIDA Broom, 1905  
DICYNODONTIA Owen, 1859  
(Figures 4A–G)



**Figure 3.** Archosauria from Bortolin site. UFSM 11530b, cervical vertebra in **A**, anterior view; **B**, posterior view; **C**, right lateral view. UFSM 11530c, dorsal vertebra in **D**, anterior view; **E**, posterior view; **F**, left lateral view. UFSM 11530a, right humerus in **G**, anterior view; **H**, posterior view. UFSM 11488, jugal in **I**, left lateral view. MCN-PV 10317, cf. *Decuriasuchus quartacolon* skull roof in **J**, dorsal view. **Abbreviations:** **ap**, anterior process of jugal; **asp**, ascendant process of jugal; **cpol**, centropostzygapophyseal lamina; **cpri**, centroprezygapophyseal lamina; **dc**, deltopectoral crest; **dia**, diapophysis; **ec**, ectepicondyle; **en**, entepicondyle; **f**, fossa; **hh**, humeral head; **hyp**, hyposphene; **itf**, inferior infratemporal fenestra; **lf**, lateral fossa; **mt**, medial tuberosity; **nc**, neural canal; **ns**, neural spine; **o**, orbit; **pcdl**, posterior centrodiapophyseal lamina; **podl**, postzygodiapophyseal lamina; **poz**, postzygapophysis; **pp**, parapophysis; **ppdl**, paradiapophyseal lamina; **pj**, posterior process of jugal; **prdl**, prezygodiapophyseal lamina; **prz**, prezygapophysis; **spol**, spinopostzygapophyseal lamina; **sr**, supinator ridge; **stf**, supratemporal fenestra. The arrow denotes anterior direction. Scale bars = 50 mm.

**Material.** UFSM 11482, distal fragment of tusk; UFSM 11483, isolated tusk; UFSM 11530d, neural spine; UFSM 11568, left nasal; MCN-PV 10252, right humerus.

**Description.** UFSM 11568 (Figures 4A–B) includes an isolated left nasal with fragments of both septomaxilla and premaxilla. It is fractured just below the contact area with the frontal and prefrontal. The nasal sutures to the septomaxilla to form the nares. The contact between nasal and premaxilla is interdigitated and thinner, in relation to the contact area of the nasal with the right nasal and the frontal, forming a characteristic “v-shaped” suture. The distal fragment of tusk (UFSM 11482) is semicircular in cross-section (Figure 4C); whereas UFSM 11483 is elongated, slightly curved and semi-circular in cross-section (Figure 4D). UFSM 11530d (Figure 4E) is a robust and relatively tall neural arch, possibly belonging to a cervical vertebra. The transversal section of the neural spine is almost circular, not expanded laterally. The tip of the neural spine is slightly anteroposteriorly compressed and, at the same time, more laterally enlarged, in relation to the rest of its length. The prezygapophyses and part of the right transverse process are also preserved. The prezygapophyses are wide and slight rounded and the transverse process is straight and laterally projected. MCN-PV 10252 (Figures 4F–G) is a robust, poorly preserved, right humerus. Its extremities are broad and the shaft is quite narrow. The humeral head is semi-spherical. The deltopectoral crest occupies all the length of the proximal extremity and runs towards the medial region of the shaft where it abruptly ends. The expanded distal extremity bears a radial condyle that is more prominent than the ulnar condyle and an ectepicondyle thicker than the entepicondyle.

**Remarks.** Lack of less inclusive diagnostic features only allows the assignment of these material to Dicynodontia. The humerus MCN-PV 10252 is similar to that from *Dinodontosaurus*, as it possesses a broad deltopectoral crest and a quite large, expanded distal extremity (Lucas & Harris, 1996). UFSM 11530d was recovered together with UFSM 11530a-c, considered *Rauisuchia* indet. However, the general morphology of UFSM 11530d differs from the other elements. The rounded neural spine with enlarged tip, wide prezygapophyses and a transverse process straight and laterally projected, are similar to other Dicynodontia vertebrae described (Cox, 1965; Lucas, 2002; Vega-Dias & Schultz, 2004).

*Dinodontosaurus* sp.  
(Figures 4H–K)

**Material.** MCN-PV 10247, skull and associated right humerus; ULBRA PVT 013-001, a complete skull (only observable in lateral view as it is still inserted in the sedimentary matrix).

**Description.** MCN-PV 10247 is a robust and almost complete skull (Figures 4H–I), except for parts of the premaxilla, left zygomatic arch and right orbit. The tusks are broken but, presumably, they were well-developed, as indicated by the large transversal section showing successive semicircular

growth lines. The interorbital region preserves the pineal foramen, located posteriorly to the orbits and anteriorly to the sagittal crest. The intertemporal is relative wide. The rostrum is wide, ventrally projected, and there is a conspicuous “v-shaped” suture between nasals and premaxillae. The occipital region, poorly preserved, is expanded. The right humerus (Figure 4J) is robust, with a reduced shaft and expanded extremities. The deltopectoral crest is about 2/3 of its total length. Distal condyles are not clear and the ectepicondyle is thicker than the entepicondyle. ULBRA PVT 013-001, as mentioned above, is still inserted in the sedimentary matrix, so only part of its right lateral view is observable (Figure 4K). The right lateral view of the rostrum is tall and wide, ventrally projected. The right tusk is broken, being preserved approximately 1/3 of its length. The orbit is large and rounded in shape. The zygomatic arch is robust, probably mainly formed by the squamosal. Lateroposteriorly, the squamosal is wide and broad, which dorsal margin is rounded.

**Remarks.** As in *Dinodontosaurus*, MCN-PV 10247 and ULBRA PVT 013-001 possesses well-developed tusks, a large intertemporal region (only observable in MCN-PV 10247), and a ventrally projected rostrum (Lucas & Harris, 1996; Morato, 2006). The humerus was assigned to *Dinodontosaurus* as it is directly associated with the skull. As in *Dinodontosaurus*, it possesses an overly broad deltopectoral crest and an expanded distal end (Lucas & Harris, 1996).

CYNODONTIA Owen, 1861  
CHINIQUEODONTIDAE Huene, 1936

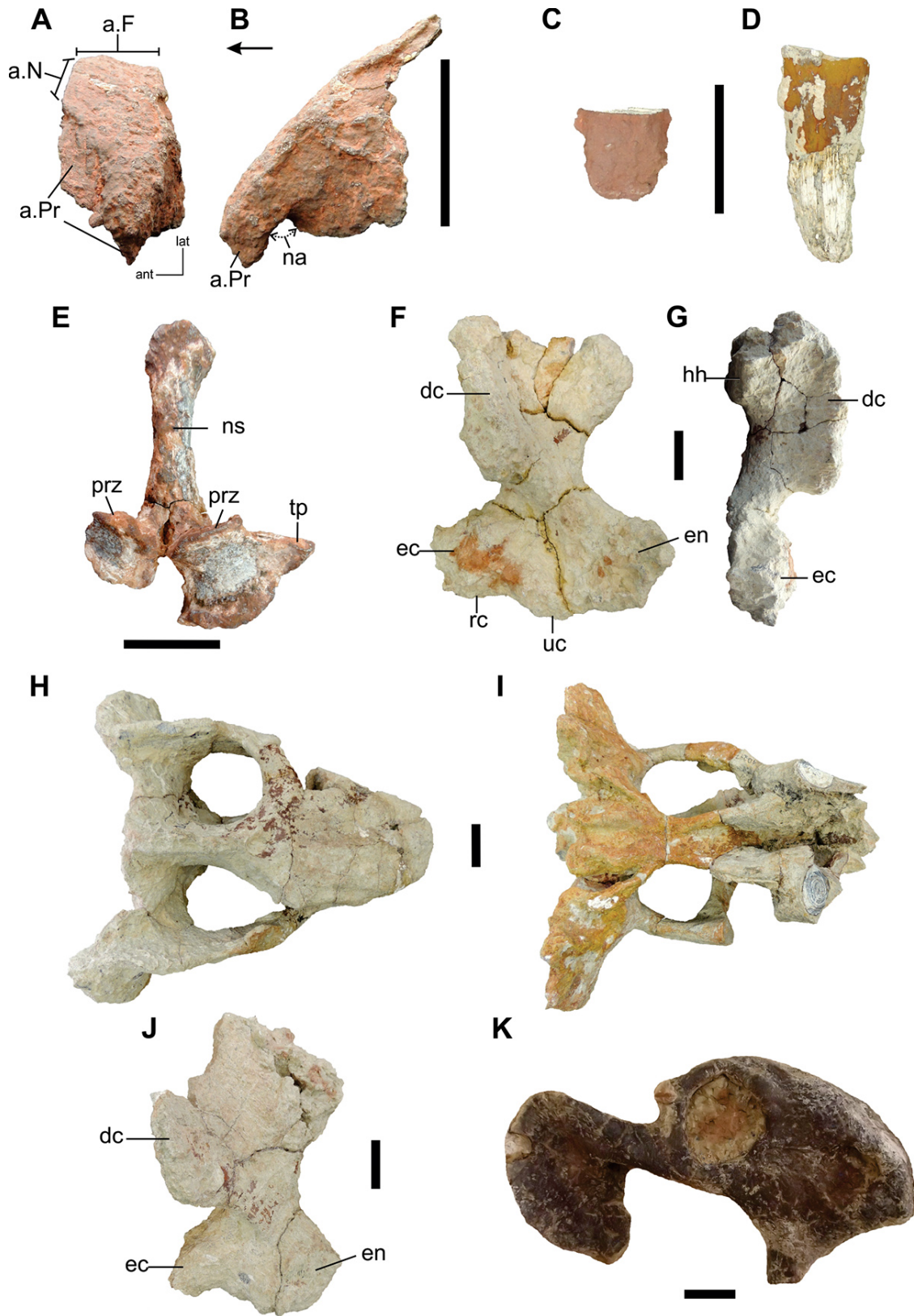
*Chiniquodon* sp.  
(Figures 5A–B)

**Material.** MCN-PV 10315, an incomplete lower jaw.

**Description.** Both mandibular rami are fused, with part of the anterior portion of the symphysis broken off. The horizontal ramus of the dentary is relatively high, with a straight ventral border. The coronoid process is prominent and well-developed dorsally. The angular process is also well-developed, with an almost square angle between its posterior and ventral borders. The number of incisors is unknown. The right canine preserves only its root and, based on its oval cross-section, it is considerably large. The left side only preserves the alveolus of the canine. There is a small diastema between canines and postcanines, corresponding approximately to the size of the first postcanine. The left mandibular ramus preserves eight laterally compressed (sectorial) postcanine bases, whereas the right one bears only three. Unfortunately, the crowns are not preserved preventing the visualization of individual cusps. The size of the first postcanines is reduced. The remaining ones gradually increase in size posteriorly, with the last reaching the larger size, of approximately twice larger than the first postcanine.

**Remarks.** The shape of the horizontal ramus and coronoid process, fused jaws, and size of canines of MCN-PV 10315 are characteristic features of chiniquodontid cynodonts (Abdala





**Figure 4.** Dicotylodontia from Bortolin site. UFSM 11568, left nasal in **A**, anterior view; **B**, left lateral view. **C**, UFSM 11482, distal fragment of tusk. **D**, UFSM 11483, tusk. **E**, UFSM 11530d, neural arch in anterior view. MCN-PV 10252, right humerus in **F**, ventral view; **G**, anterior view. MCN-PV 10247, *Dicotylodontosaurus* sp. skull in **H**, dorsal view; **I**, ventral view; **J**, right humerus in ventral view. **K**, ULBRA PVT 013-001; *Dicotylodontosaurus* sp. skull in right lateral view. **Abbreviations:** a., surface/facet for articulation with; **ant**, anterior; **dc**, deltopectoral crest; **ec**, ectepicondyle; **en**, entepicondyle; **F**, frontal; **hh**, humeral head; **lat**, lateral; **N**, nasal; **na**, nares; **Pr**, premaxilla; **ns**, neural spine; **rc**, radial condyle; **tp**, transverse process; **uc**, ulnar condyle. The arrow indicates anterior direction. Scale bars = 50 mm.

& Giannini, 2002; Martinelli *et al.*, 2017). Apparently, postcanine (pc) teeth are transversely narrow, (although some postcanine, *e.g.* left pc2 and 4, are more rounded at its base, in relation to the other postcanine) similar to *Chiniquodon theotonicus*, previously recorded in the same AZ (Abdala & Giannini, 2002), and differing from the close related *Aleodon*, which presents wide transversely expanded postcanine teeth (Martinelli *et al.*, 2017). Based on these features, we tentatively refer MCN-PV 10315 as *cf. Chiniquodon*.

#### TRAVERSODONTIDAE Huene, 1936

##### *Luangwa sudamericana* Abdala & Sá-Teixeira, 2004 (Figures 5C–D)

**Material.** MCN-PV 10314, disarticulated cranial bones, several postcanines and postcranial elements.

**Description.** MCN-PV 10314 includes a partially disarticulated skeleton, which is currently under laboratorial preparation and will be subject of further studies. The preserved teeth are numerous, mostly isolated from their alveoli. Upper postcanines are sub-ovoid in occlusal view, with a low crown and a long root that tapers to the root apex. The figured upper postcanine (Figures 5D–E) has a transverse crest on the distal edge of the crown with a large main labial

cusps, and a lingual cusps. A worn-out central cusps on the transverse crest is also evident. On the mesiolabial portion of the crown there is well-developed labial cingular crest, bearing at least three cusps. The posterior cingulum is present but poorly developed and bears small crenulations. The overall morphology of this postcanine resembles that of *Luangwa sudamericana* (Abdala & Teixeira, 2004).

**Remarks.** At this point, postcanine tooth elements are the most diagnostic material to recognize the genus *Luangwa* in the Bortolin site. MCN-PV 10314 was briefly reported by Hanich *et al.*, (2013), indicating the presence of *Luangwa sudamericana*. These teeth have the typical subovoid occlusal morphology of basal traversodontids. Also, they lack the shouldering mechanism among postcanine teeth present in *Massetognathus* species. Based upon the morphology of the postcanines, MCN-PV 10314 is referred to *L. sudamericana* (Abdala & Sá-Teixeira, 2004).

#### SARCOPTERYGII Romer, 1955

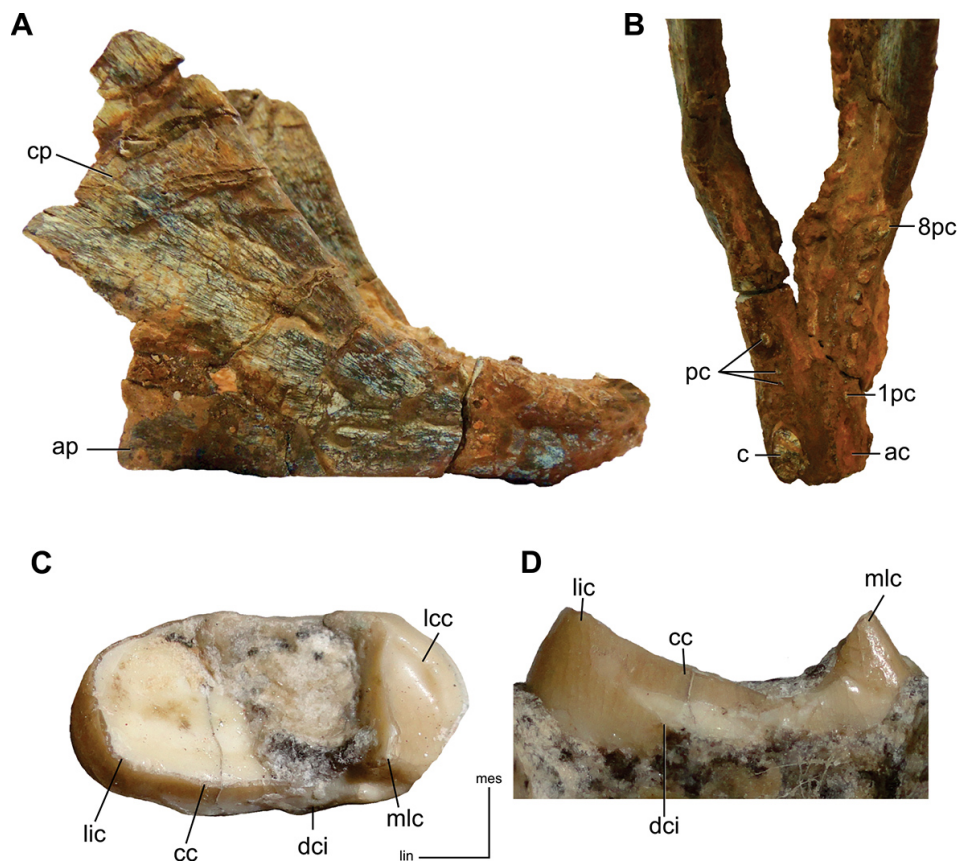
#### ACTINISTIA Cope, 1871

#### COELACANTHIFORMES Huxley, 1861 (sensu Arratia & Schultze, 2015)

#### LATIMEROIDEI Schultze, 1993

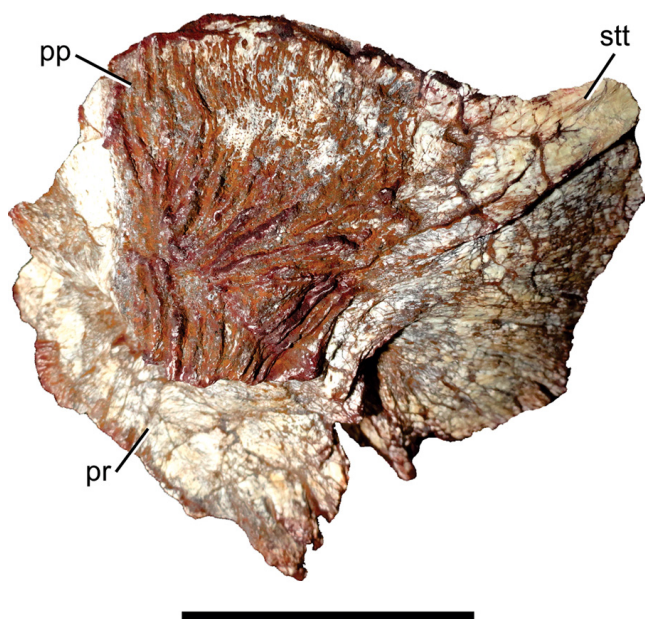
#### MAWSONIIDAE Schultze, 1993

(Figure 6)



**Figure 5.** Cynodontia from Bortolin site. MCN-PV 10315, *Chiniquodon* sp., lower jaw in **A**, right lateral view; **B**, dental series in dorsal view. MCN-PV 10314, *Luangwa* sp., upper left postcanine of the posterior portion of the tooth row, in **C**, occlusal; **D**, distal views. **Abbreviations:** ac, lower canine alveolus; ap, angular process; c, lower canine; cc, central cusps; cp, coronoid process of dentary; dci, distal cingulum; lcc, labial cingular crest; lic, lingual cusps; lin, lingual; mes, mesial; mlc, main labial cusps; pc, lower postcanine. Scale bars: A–B = 10 mm; C–D = 5 mm.





**Figure 6.** Mawsoniid coelacanth from Bortolin site. MCN-PV 10346, fragment of otoccipital region in dorsal view. **Abbreviations:** pp, postparietal; pr, prootic; stt, supratemporal. Scale bar = 50 mm.

**Material.** MCN-PV 10346, fragment of the otoccipital region.

**Description.** MCN-PV 10346 comprises most of the otoccipital region of a skull roof of relatively large size. It is a thick plate with most of its edges broken off. The dorsal aspect of the plate has a well-ornamented trapezoidal surface belonging to the postparietal bone, which bears ridges separated by wide shallow grooves. The unornamented surface is placed in a lower position than the trapezoidal ornamented portion and mostly corresponds to the prootic and supratemporal.

**Remarks.** The specimen is currently under study and further details will be provided elsewhere. The large size, thickness, and ornamentation of MCN-PV 10346 allows to refer it to mawsoniid coelacanths (Forey, 1998; Dutel *et al.*, 2015; Cavin *et al.*, 2016). The presence of sharp ridges and wide grooves are more frequent in mawsoniids than in latimerians, which usually present marked tubercles or faint ridges (Forey, 1998). The presence of a mawsoniid is for the first time recorded in the Triassic of Brazil. Recently, a fragment of skull roof of a mawsoniid from the *Massetognathus-Chanaresuchus* AZ of the Chañares Formation was described (Gouric-Cavalli *et al.*, 2017), so this specimen increases the faunal similarity between both units. Also, such large sized mawsoniid in the Bortolin site would be indicative of large fresh-water bodies to support the presence of this taxon.

#### ICHOLOGICAL MATERIAL (Figures 7A–B)

**Material.** UFSM 11484, an ovoid coprolite; UFSM 11485, a cylindrical coprolite.

**Description.** UFSM 11484 (Figure 7A) is an ovoid agglomeration of pellets of rugose texture, with superficial and deep fissures. Its coloration is light red. UFSM 11485 (Figure 7B) is a single cylindrical structure without fissures and with a darker coloration.

**Remarks.** UFSM 11484 and 11485 were attributed to coprolites because of its external texture and morphology composed by pellets, similar to the extrusion pattern observed to current forms; and matrix with fine granulation, mainly UFSM 11485 (Hunt *et al.*, 1994; Souto, 2017). Souto (2001, 2008) suggested that the shape of a coprolite is a good indication of diet. Isolated or composite ovoid masses are generally associated to herbivores, whereas isolated or composite cylindrical coprolites may be related to carnivores. More recently Hunt *et al.* (2013), after analyzing coprolites from the *Dinodontosaurus* AZ, found the same pattern observed by Souto (2001). After these studies, UFSM 11484 might be considered as product of an herbivorous animal, whereas UFSM 11485 was possibly produced by carnivorous one. However, Francischini *et al.* (2018) found bone fragments inclusions in the surface of coprolites of both shapes, which prevents attribute the coprolite producer by its shape. Because of this, we prefer to not refer UFSM 11484 and 11885 to a particular vertebrate producer.



**Figure 7.** Coprolites from Bortolin site. A, UFSM 11484; B, UFSM 11485. Scale bar = 50 mm.

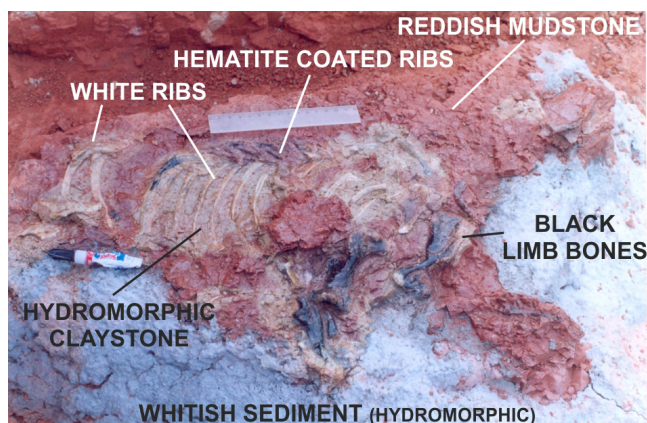
## DISCUSSION AND CONCLUSIONS

The Bortolin site is a fossiliferous outcrop from the Pinheiros-Chiniquá Sequence (Horn *et al.*, 2014) of the Triassic Santa Maria Supersequence (Zerfass *et al.*, 2003) in southern Brazil. This locality presents a fossil assemblage typical of the *Dinodontosaurus* AZ, with similar fossil preservation to what is observed in other outcrops belonging to this same AZ (Da-Rosa *et al.*, 2004, 2005). Its fossiliferous content, so far including rauisuchian archosaurs, cynodonts, and dicynodonts, is similar to that from the “Posto de Gasolina” outcrop (also called “Dona Francisca”) (Bonaparte *et al.*, 2006; França *et al.*, 2011, 2013; Mastrantonio *et al.*, 2013; Martinelli *et al.*, 2016, 2017). The fragmentary and poor



preservation of most specimens from the Bortolin site only permits supraspecific taxonomic assignments, except for cf. *Decuriasuchus*, *Chiniquodon*, *Luangwa*, *Dinodontosaurus*, and *Massetognathus* (this last one with several specimens currently under study, see Siefert *et al.*, 2017a, b). Moreover, further studies on each individual specimen are currently being developed.

Diagenetical signatures vary among different layers of the outcrop, as noted elsewhere. More particularly, differential diagenesis is sometimes observed among individual elements of the same specimen (Figure 8). Permineralized bones acquire a whitish color, but the colors may change to purple, when hematite coating is present, or even black. White bones correlate to fine-grained sediments, such as clay associated to the distal floodplain (Da-Rosa, 2011, 2015). Hematite coating is suggestive of biofilm formation before burial, by decomposition of animal tissues. Since the decay process of the carcasses releases organic acids, acidifying its surroundings, making the environment unfavorable to calcium carbonate precipitation, because lower pH levels can dissolve the calcium carbonate (Berner, 1968; Bao *et al.*, 1998). In addition, these organic acids resulting of the decay process can improve the dissolution of iron-bearing minerals, which are precipitated in the bones, once bones are providing favorable substrate to iron oxide precipitation, probably because of the apatite present in the bones or to the previously deposited calcium carbonate, originating the hematite coating (Bao *et al.*, 1998). However, pH levels can float during the decay process, because also basic substances are released, and the pH levels can increase, favoring the calcium carbonate precipitation (Bao *et al.*, 1998; Berner, 1968). According to Holtz & Schultz (1998), different fossilization patterns indicate that the diagenesis process is not homogenous and constant in a fossiliferous level, probably because to different flow regimes, varying of concentrations of calcium carbonate in the groundwater or subsidence, which might explain the differential diagenesis in a same specimen, as seen in Figure 8.



**Figure 8.** Example of the variation in the fossilization process on a same fossil (cynodont postcranium).

The presence of *Luangwa* in the Bortolin site is particularly relevant, as the exact location from where the original materials of *L. sudamericana* were recovered is unknown (Abdala & Sá-Teixeira, 2004). Recently, Martinelli *et al.* (2017) mentioned additional specimens of *Luangwa* sp. from the Vale Verde (municipality of Vale Verde) and Bom Retiro area (municipality of Candelária), from the *Dinodontosaurus* AZ. Hence, specimens ascribed to *Luangwa* in the Bortolin site corroborate this record, within the *Dinodontosaurus* AZ, with a precise stratigraphic location. *Luangwa* was also recovered in the late Middle Triassic of the upper portion of the Omingonde Formation (Otiwarongo Basin, of Namibia), and the Ntawere Formation (Luangwa Basin, of Zambia) (*e.g.* Kemp, 1980; Abdala & Smith, 2009), making this taxon biostratigraphically relevant. The *Dinodontosaurus* AZ shares with the upper part of Ntawere Formation only the presence of *Luangwa* (Brink, 1963; Kemp, 1980; Abdala & Sá-Teixeira, 2004). On the other hand, it shares with the upper part of the upper Omingonde Formation, Namibia, besides the record of *Luangwa*, the presence of the probainognathians *Chiniquodon* and *Aleodon*, and the dicynodont *Stahleckeria potens* (Abdala & Sá-Teixeira, 2004; Abdala & Smith, 2009; Martinelli *et al.*, 2017). The *Dinodontosaurus* AZ is classically correlated and considered coeval with the Argentinean Chañares Formation, sharing the presence of the traversodontid *Massetognathus*, the probainognathian *Chiniquodon* and the dicynodont *Dinodontosaurus* (Barberena, 1977; Schultz *et al.*, 2000; Langer *et al.*, 2007). The faunal similarities at the generic level between the Brazilian *Dinodontosaurus* AZ and the aforementioned African and Argentinean formations permit a direct correlation between different Middle to Late Triassic Gondwanan units (*e.g.* Langer *et al.*, 2007; Abdala & Ribeiro, 2010; Abdala *et al.*, 2013; Martinelli *et al.*, 2017). However, radiometric dates from Chañares Formation indicated an early Carnian age to this unit ( $236.1 \pm 0.6$  Ma; Marsicano *et al.*, 2006). On the other hand, an Anisian age is accepted for the African formations with faunal correlation with the *Dinodontosaurus* AZ (Catuneanu *et al.*, 2005; Abdala & Smith, 2009). Moreover, the Santa Cruz Sequence that overlaps the Pinheiros-Chiniquá Sequence and encompasses the *Santacruzodon* AZ, representing a faunal association younger than *Dinodontosaurus* AZ, was recently radioisotopically dated with a maximum age of  $237 \pm 1.5$  Ma (early Carnian) to the top of this sequence (Philipp *et al.*, 2018). Therefore, the absence of absolute dating in most fossil-bearing beds and, in some cases, the lack of precise stratigraphic control for several specimens hampers more accurate biostratigraphic correlations. For example, co-occurrence of basal traversodontids (*e.g.* *Luangwa*, *Scalenodon*; Abdala & Sá-Teixeira, 2004; Melo *et al.*, 2017) and probainognathians (*e.g.* *Aleodon*; Martinelli *et al.*, 2016, 2017) with more specialized forms (*e.g.* *Massetognathus*; Liu & Abdala, 2014) raises a discussion if the *Dinodontosaurus* AZ possibly

includes more than one faunal assemblage (e.g. Langer *et al.*, 2007; Martinelli *et al.*, 2017). The biostratigraphic scheme for the Chañares Formation, in western Argentina, including radiometric dates and well-documented faunal succession (Marsicano *et al.*, 2016; Ezcurra *et al.*, 2017), also support such assumption. In this Argentinean formation, for example, basal traversodontids and an *Aleodon*-like forms come from the lower faunal association (*Tarjadia* AZ) whereas *Massetognathus* and *Chiniquodon* come from the upper one (*Massetognathus-Chanaresuchus* AZ) (Ezcurra *et al.*, 2017). For the Bortolin site, the occurrence of *Luangwa* together with *Massetognathus*, albeit maybe incongruent, is still inconclusive because the *Massetognathus* specimens from this new site demand further investigation in order to access its taxonomy, including further comparisons with the Brazilian and the Argentinean taxa, *Massetognathus ochagaviae* and *Massetognathus pascuali*, respectively. As a consequence, and based on other contributions (e.g. Martinelli *et al.*, 2017), we can hypothesize that: (i) *Massetognathus* and/or *Luangwa* in Brazil would have a more extended biochron; (ii) the *Massetognathus* genus (and possibly its distinctive species *M. ochagaviae*) from Brazil is older than the Argentinean correlate; and (iii) *Luangwa* in Brazil is younger than the African forms (see Catuneanu *et al.*, 2005; Marsicano *et al.*, 2016; Ezcurra *et al.*, 2017; Martinelli *et al.*, 2017; Philipp *et al.*, 2018). Furthermore, the specimen of *Chiniquodon* sp. here reported also needs further investigation to sharpen its relationships as well as its biostratigraphic significance. In order to address these issues properly, detailed studies of these specimens and further geological studies (including radiometric dating) are needed.

As already stated, the presence of large rauisuchian archosaurs, the dicynodont *Dinodontosaurus*, and the cynodonts *Massetognathus*, *Luangwa* and *Chiniquodon* indicates that the fauna of the Bortolin site is part of the *Dinodontosaurus* AZ (Langer *et al.*, 2007; Martinelli *et al.*, 2017). Also, the occurrence of a large-sized mawsoniid considerably improves the faunal composition of this AZ, being the first record of this group in the Triassic of Brazil. Additionally, it indicates that the sedimentary environment includes large freshwater rivers. Further studies and more detailed descriptions and comparisons of Bortolin site vertebrates certainly bring new information from Middle-Late Triassic assemblages of South America.

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