TAPHONOMY OF THE SOUTH-BRAZILIAN TRIASSIC VERTEBRATES

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ABSTRACT The south-Brazilian Triassic rocks have a rich fossil record. In the Scythtian Sanga do Cabral Formation this record consists mainly of fragmentary amphibians and reptilian bone elements, while articulated material is never found. This peculiar taphonomic mode of occurrence is linked to the depositional system of the Sanga do Cabral Formation, a unit generated under ephemeral, Bijou Creek-like fluvial conditions. In the Ladinian-Carnian Santa Maria Formation dicynodonts, rhynchosaurs, tecodonts, cynodonts and dinosaurs occur under different taphonomic modes, from articulated skeletons to fragmentary remains. The four taphonomic classes of the Santa Maria Formation were generated in an anastomosing fluvial system. Permineralization with calcite results in many disrupted and distorted fossils in the Santa Maria Formation, while the Sanga do Cabral taphocoenosis is well preserved.

Keywords: Taphonomy, Vertebrate, Triassic, Paraná basin, South America

INTRODUCTION The Mesozoic succession of the Paraná Basin in southernmost Brazil has some important occurrences of fossil vertebrates - the amphibians and reptiles of the Triassic Sanga do Cabral and Santa Maria Formations. Although known and studied since the beginning of the century (see summary in Barberena *et al.* 1985), systematic research on vertebrate taphonomy started relatively recently, in the late eighties, when several workers began to focus on biostratinomic and diagenetic aspects of these units (Holz and Barberena 1989, 1994, Schultz *et al.* 1991, Holz 1993, 1995, Holz and Soares 1995, Holz and Schultz 1998, Souto-Ribeiro and Holz 1998). The goal of the present paper is to give an overview on the taphonomy of the reptilian fauna, presenting the latest results of the ongoing research work.

GEOLOGICAL SETTING The Paraná Basin is a large intracratonic basin in southwestern Gondwanaland. It is located at the central-eastern part of the South-American Platform and covers a surface area about 1,700,000 km^2, has a NE-SW elongated shape, and is approximately 1,750 km long and 900 km wide (Fig.1A). Sedimentation began after the Brasiliano Cycle (the Brazilian tectonic equivalent for the formation of Gondwana during Proterozoic) with granitogenic events (610-580 m.y.) and subsequent cooling and thermal subsidence in Cambro-Ordovician times (500-450 m.y.) (Milani *et al.* 1998). These authors divided the Ordovician to Cretaceous fill of the basin into six second-order depositional sequences. The aeolian and fluvial deposits of Sanga do Cabral Formation is the topmost unit of the third sequence of Milani *et al.* (1998), labeled the Gondwana I Supersequence. The fluvial Santa Maria Formation constitutes the fourth sequence of Milani *et al* (1998), the Gondwana II Supersequence, separated from the top of the Gondwana I Supersequence by a hiatus of 20 m.y. The Triassic fossil-bearing rocks occur in a 400 km long outcrop belt located in Rio Grande do Sul, the southernmost Brazilian state (Figs. 1A, 1B).

TAPHONOMY OF THE SANGA DO CABRAL FORMATION fluvial and aeolian sandstone named Sanga do Cabral Formation by Andreis *et al.* (1980) corresponds in part to the Rio Pardo Formation of Delaney and Goñi (1963), to the lowermost portion of the Rosário do Sul Formation of Gamermann (1972) and to the Rosário do Sul Formation *sensu stricto* of Bortoluzzi (1974). The unit is positioned between the Rio do Rasto Formation (Late Permian) and the Passo das Tropas Member of the Santa Maria Formation (Middle Triassic).

The fossil association of Sanga do Cabral Formation corresponds to the local faunas Catuçaba (Brazil) and Água de Los Burros (Argentina) (Barberena *et al.* 1985), and consists of *procolophon* and rhytidostoidea and rhynesuchoidea (amphibian families).

Following Miall's method (1985, 1996), nine main facies were recognized: Gmm, Gcm, Gt and Gp (massive and stratified gravels), and Sp, Sr, Sh, Sl, Ss (coarse/pebbly to fine sandstones). The facies were organized into architectural elements CH (channels), GB (gravel bars), SB (sandy bedforms), DA (downstream accretion macroforms), LA (lateral accretion macroforms), LS (laminated sand sheets) and HO (hollows). The predominance of elements DA/SB and presence of the element HO point to a depositional model characterized by high-energy drainage system, with channels of low to moderate sinuosity (Miall 1996). The expressive presence of the element LS is indicative of model number 12, the Bijou Creek type, related to ephemeral floods, with prevalence of upper flow regime and predominance of sand deposits. (Figure 2).

In the Sanga do Cabral Formation fossil bones are found mainly in gravel lenses consisting of mudstone and carbonate intraclasts of facies Gmm, Gcm, Gt, and Gp.

Bones of different weathering stages underwent mechanical concentration, possibly with pre-fossilization, related to the formation of carbonate soil. The hypothesis that the bones already were fossilized to some degree before deposited in the conglomerates is justified due to the preservation of very fragile portions of bone, such as neural arches.

The concentration of bones occurred during periods of huge floods, according to the depositional model (Fig.2). Drier periods, evidenced by the paleosoil features, may have favored the concentration of animals and caused death of a great number of individuals due to food shortage, weakness or thirst.

Due to the evident reworking of deposits, one must pay attention to the time-averaging factor. It is known that most of the vertebrate taphocoenoses formed in river channels show time averaging of hundreds to some thousands of years (Kidwell and Flessa 1995). In the fluvial facies of the Sanga do Cabral Formation, the taphocoenose may represent mixture of several generations, but it seems that under a paleontological point of view there are no significant age differences. As the taxonomic classification is in process, only after a more complete study we will have adequate data on the time averaging of the Sanga do Cabral taphocoenosis. Observation of thin sections confirms the good preservation of the bones. The interior structure is preserved, the Haversian and Volkmann canals are filled by opaque minerals (probably manganese and iron oxides) and quartz grains. Although the studies are preliminary, it is clear that the diagenetic process of the Sanga do Cabral Formation has been very different from that of the overlying Santa Maria Formation, where displacive calcite has an important role in fossilization (Holz and Schultz 1998). The fossils from Sanga do Cabral Formation did not undergo destructive processes during their fossilization as did most of the Santa Maria Formation, the main process is a simple filling of natural pores of the bone structure (permineralization).

TAPHONOMY OF THE SANTA MARIA FORMATION The Ladinian-Carnian Santa Maria Formation is divided in two members (Fig. 1B). The lower Passo das Tropas member is mostly a sandy and conglomeratic fluvial unit, with plant and fish remains in the finer floodplain facies. The taphonomic aspects of other occurrences have not been studied, mainly due to the relative scarcity of the fossils.

The upper Alemoa Member is characterized by massive or laminated mudstone and spatially restricted sandstone bodies (Figs. 3 A and B). As shown by Fonseca and Scherer (1998), the red massive or laminated mudstones represent the floodplain facies, deposited during intervals of intense rainfall, when the margins of the channels were broken and the sediment-laden river water flooded the alluvial plain. Next to the channels, rapid sedimentation generated sandy crevasse splay deposits. In more distant regions of the floodplains fine

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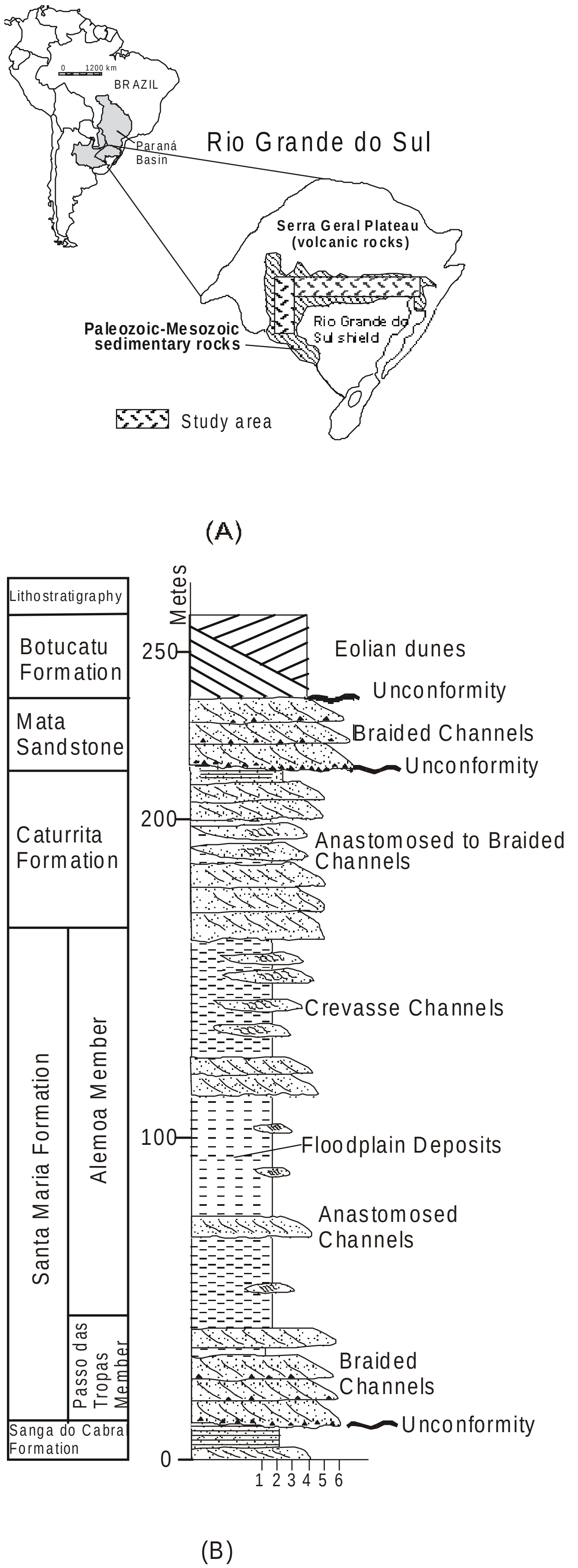


Figure 1 - (A) Geologic setting and location of the studied area, (B) Stratigraphic summary of the studied interval (modified from. Holz and *Scherer 1999*)

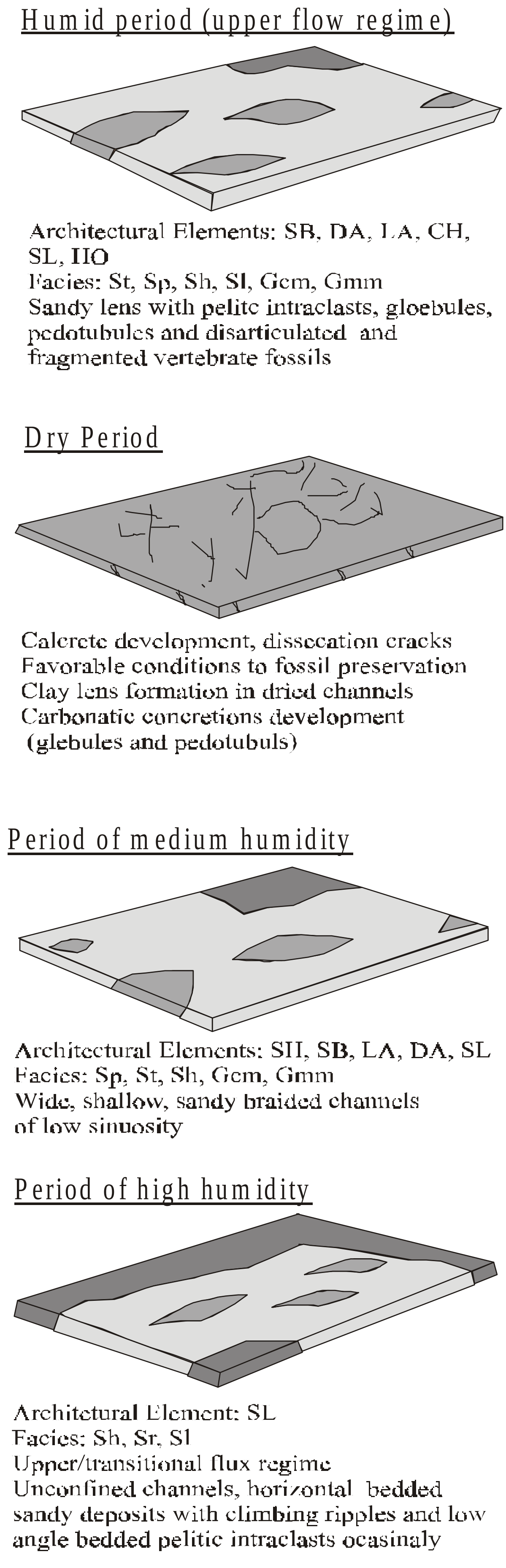


Figure 2 – Depositional model of the Sanga do Cabral Formation

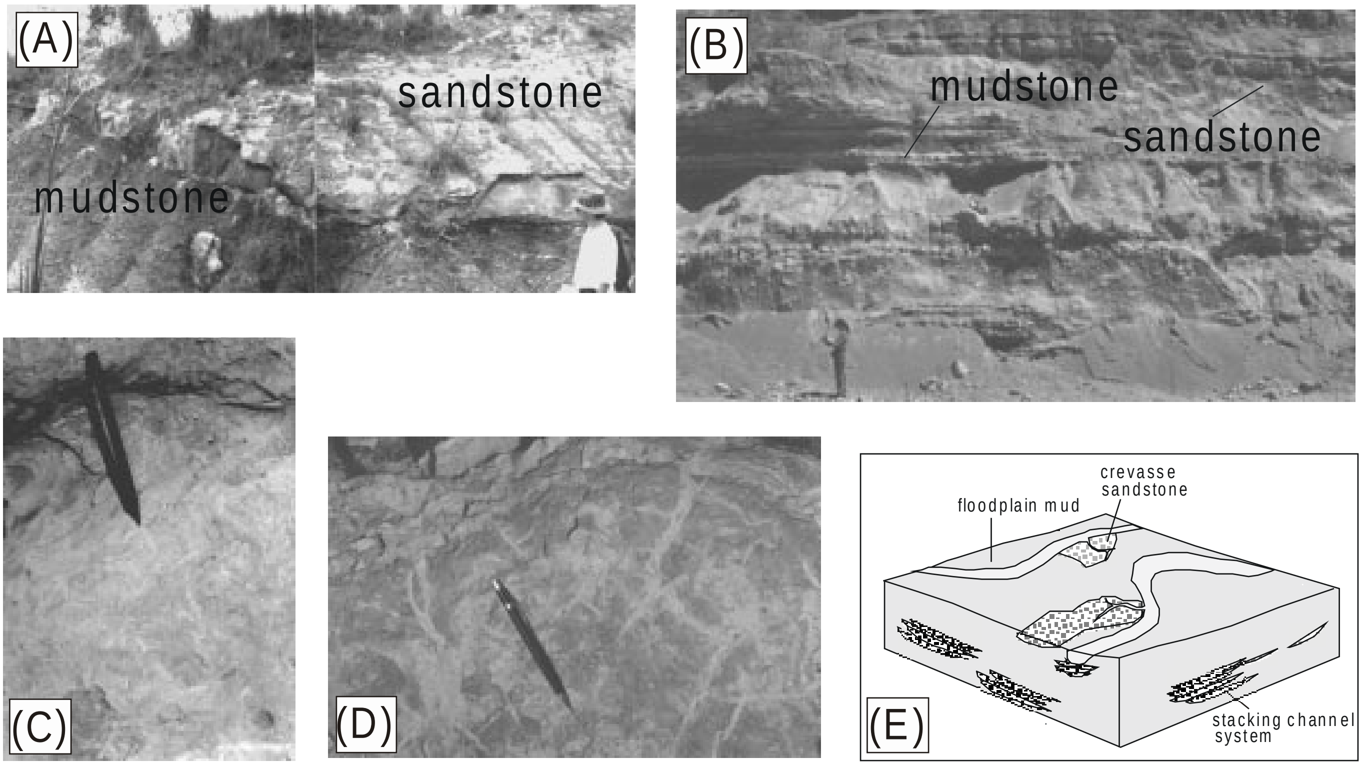


Figure 3 – Facies and depositional model of the Santa Maria Formation: (A) channel-shaped sandstone encapsulated in mudstone, (B) alternation between sandstone and mudstone facies, (C) bioturbation in the mudstone facies, (D) desiccation cracks in the mudstone facies, (E) schematic depositional model of an anastomosing channel system

sediment settled and formed millimeter to centimeter thick layers of mud. During normal "day-by-day" conditions, no net sedimentation took place at the floodplains, as evidenced by bioturbation (Fig. 3C), or exposure evidences like paleosoils and mud cracks (Fig. 3D) described in some outcrops. We agree with Fonseca and Scherer (1998) that this facies framework indicates that the Alemoa Member was mainly deposited in an anastomosing river system (Fig. 3E).

The Alemoa Member has a rich reptilian record, including several forms of tecodonts, cynodonts, rhynchosaurs, dicynodonts and some primitive forms of dinosaurs.

Fossil bones occur in different stages of disarticulation and breakage (from articulated skeletons to isolated and fragmentary material), reflecting different post-mortem/pre-burial periods. (Fig. 4). Fragmentary material is found in the fine sandstone of the crevasse deposits and in the mudstone, while the more preserved and articulated material is found exclusively in the mudstone facies.

As the sedimentation rate decreases with increasing distance from the channel margins, a decrease of the amount of fossil fragments can be expected in this direction. In fact, next the main channels and the crevasse deposits, a larger amount of fragments are found than in the laminated or massive mudstones of the distal floodplain.

The occurrence of articulated skeletons, representing para-autochthonous carcasses of individuals drown during the flooding event, is explained by a particular burial mechanism. The articulated carcasses underwent floating (Schäfer 1972) and stuck in the floodplain mud when the water level fell after the peak of huge innundations (Fig. 4, taphonomic class 1). Subsequent scavenger action, weathering and reworking of the bones generated disarticulated and broken fossil material (Fig. 4, classes 2 to 4), exposed on the floodplain and subject of two possible taphonomic pathways:

- total weathering and destruction, within a period of about 15 or 20 years, based on actualistic observations (Behrensmeyer 1978);
- burial by a huge flooding, which occurred within a certain frequency.

Insofar, the fossiliferous levels correspond to burial events triggered by several consecutive flooding. The bone material available

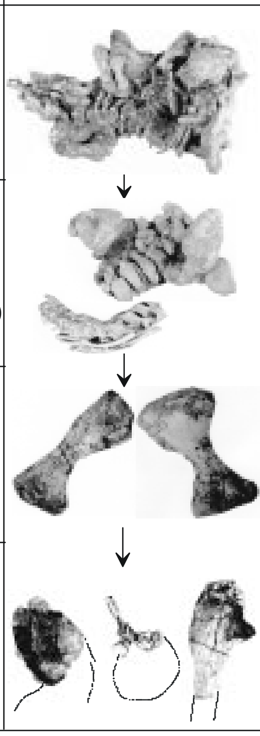
Taphonomic Classes	Disarticulation scheme	Significance P = time span between death and final burial T = taphonomic process
Class 1 (articulated, most complete skeletons)		P = very short, several days T = drifted carcasses, Rapidely buried
Class 2 (articulated segments of columns and limbs)		P = tens of weeks T = carcasses exposed to weathering and biotic action
Class 3 (isolated skull and postcranial elements)		P = tens of weeks up to a few years T = long-time action of weathering and biotic factors like trampling and scavengers
Class 4 (fragmentary skull and postcranial elements)		P = extreme long, close to limit of physical resistance to weathering (15 to 20 years?) T = extreme weathering and biotic action on skeletal remains

Figure 4 – Taphonomic classes and disarticulation process of the Middle Triassic paleoherpetofauna (modified from Holz and *Barberena 1994)*

by the time of the flooding, including bones of recently dead animals, bones of month and year-old carcasses and bones close to the limit of disintegration by weathering, were covered by mud and preserved. (Figure 4)

As discussed by Holz (submitted), the Santa Maria Formation, representing a total time span of approximately 12 m.y., has a representiveness (= comparison between the number of living individuals and the number of fossilized individuals) of about 0,21% This percentage indicates that during more than 99% of the time, no net sedimentation capable to bury and fossilize a bone took place. The normal annual floods as they are observed in present day fluvial systems, were of no paleontological importance, and most of the bone material accumulated on the floodplains underwent the entire cycle of disarticulation until complete weathering. Only during very few times a major flooding event took place, an event capable to mobilize huge amount of sediment, sufficient for burial and preservation of vertebrate remains scattered over the floodplains.

Another important taphonomic aspect concerns time averaging of the taphocoenosis. A taphocoenosis may be the result of a multistory sedimentation and may enclose a huge time interval independent on the thickness of the fossiliferous record. Insofar, the duration of time-averaging is the time span during which the organic remains are accumulated to form a fossiliferous level in the rock record, inclosing the time from the death and burial of the first organic remain to the last one being incorporated to the layer. Huge time averaging is linked to intense reworking, common in proximal marine systems and, in the terrestrial realm, in meandering river systems (Behrensmeyer 1982). Since the depositional system of the South-Brazilian Ladinian-Carnian rocks is interpreted as mainly anastomosing (Fonseca and Scherer 1998), with sinuous but relatively stationary channels, the possibility of significant time averaging of the taphocoenosis is excluded, meaning that paleoecological and evolutionary comparison of different specimens enclosed in the fossiliferous level can be considered.

However, the study of Fonseca and Scherer (1998) detected the presence of point bars in some locations, what is a strong indicative that the meandering channel systems are also present on the Middle Triassic rocks of southernmost Brazil. Fossils found in this deposits may represent a greater time averaging due to the erosion of floodplain deposits as depicted from the facies model of meandering channel systems. The fossil content of these outcrops is under investigation.

Holz and Schultz (1998) present important advances on fossil diagenesis. Skulls and limb bones of reptiles from Meso-Triassic rocks in Southern Brazil show striking morphological and volumetric differences among specimens from the same taxonomic group, and are caused by early calcite cementation. Petrographic analysis of forty thin sections of selected fossil bones demonstrates that the main agent of fossilization was precipitation of calcite and minor hematite in the pores of bones during early burial mineralization. Bone framework is broken and replaced by calcite (+ hematite), beginning in the inner part of the bone (the so-called spongeous bone) and gradually extends into the compact external layers. Destruction of the bone structure appears to have been caused by the force of calcite crystallization, which typically occurs at shallow burial, during initial diagenesis. This process occurs in the vadose zone and requires marked alternating wet and dry seasons, and points to a semi-arid paleoclimate for the South-Brazilian Meso-Triassic, an inference consistent with other paleoclimatic data.

CONCLUSION The taphonomic approach of the South-Brazilian Triassic rocks has shown that the vertebrate fossils are preserved in facies of very different fluvial systems – braided in the Scythian, anastomosed in the Ladinian/Carnian – causing a direct impact on the taphonomic mode of preservation. The pronounced alternations between dry and humid seasons during the Shcityian originated a very fragmentary fossil record, while the more humid conditions of the Middle Triassic led to better preserved fossils, including articulated skeletons. Time averaging is larger in the Early Triassic taphocoenosis of the Sanga do Cabral Formation than in the Santa Maria Formation, but the matter is still under investigation.

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