



## The Tatuí Formation (Early Permian, Paraná Basin), Brazil: Paleontology and Paleoenvironmental Considerations

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### ABSTRACT

The Tatuí Formation, one of the Brazilian Paraná Basin geological units, is developed solely in the State of São Paulo, southeast Brazil. It is studied herein, through outcrops at the eastern border of the basin, which are siltstones and fine sandstones, interbedded with some coarse and conglomeratic sandstones. Published papers on its fossils are sparse, dealing with some groups but not involving the entire association. This paper deals with ichnofossils, arthropods (conchostracans, isopods, and indeterminate crustaceans), plants (pteridophytes and spermatophytes) and fish remains (scales and teeth of Actinopterygii and Sarcopterygii). Foraminifers and sponge spicules were reported in short communications without illustrations and from uncertain stratigraphic positions. The Tatuí Formation paleoenvironmental deposition evolved through three phases. The first contains only the euryhaline fossils in siltstone beds. The second phase is regressive, with continental fossils (conchostracans and plants) in massive or laminated siltstone beds and conglomerates. The third stage is transgressive with hummocky cross – stratification in sandstone and increasing salinity.

*Keywords:* Rock mass classification, Rock slope, Q, RMR, SMR, SQR.

## La Formación Tatuí (Pérmico Temprano, Cuenca del Paraná), Brasil: Consideraciones paleontológicas y paleoambientales

### RESUMEN

La Formación Tatuí es una unidad litoestratigráfica de la Cuenca del Paraná que aflora exclusivamente en el Estado de São Paulo, Brasil. En su borde nororiental está formada por limolitas y areniscas finas que poseen intercalaciones de areniscas gruesas y conglomeráticas. Este trabajo caracterizó en esta formación diversas evidencias de fósiles: huellas, artrópodos (conchostracos, crustáceos isópodos e indeterminados), vegetales (helechos y fanerógamas) y restos de vertebrados (escamas y dientes de Actinopterygii y Sarcopterygii). Foraminíferos y espículas de esponjas fueron reportados en comunicaciones breves, entretanto, sin estar acompañado de ilustraciones y de sus posiciones estratigráficas. Tres fases de deposición permiten reconstruir el paleoambiente de la Formación Tatuí. En la primera fase hay presencia solamente de fósiles eurihalinas en limolitas. En la segunda fase, fósiles continentales (conchostracos y vegetales) que están presentes en camadas limolíticas masivas o laminadas y en conglomerados vinculados a una etapa regresiva. Finalmente, la tercera fase se caracteriza por una etapa transgresiva con la presencia de estratificación cruzada “hummocky” y aumento de la salinidad.

*Palabras clave:* Pérmico, Paleontología, Estratigrafía, Cuenca del Paraná

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## INTRODUCTION

Pennsylvanian – Permian lithostratigraphic units of the Brazilian Paraná Basin are, from the oldest to the youngest: Itararé, Guatá, and the Passa Dois Groups. They are joined in the Gondwana I Supersequence by Milani and Ramos (1998).

The Early Permian Tatuí Formation, studied in this contribution, is chrono-correlated with two formations of the Guatá Group, Rio Bonito, and Palermo, from southern Brazil, and from South Africa, Prince Albert Formation (Milani et al., 2007; Holz et al., 2010; Chahud, 2011).

Fine sandstones, sometimes bearing hummocky cross stratification, and siltstones are the main lithologies of the Tatuí Formation. Coarse and conglomeratic sandstones, locally rather thick, are minor lithologies (Washburne, 1930; Soares, 1972; Massoli, 1980; Fúlfaro et al., 1984; Stevaux et al., 1986; Assine et al., 2003; Holz et al., 2010; Chahud, 2011; Chahud et al., 2012). Most of these contributions dealt with lithostratigraphy and paleoenvironments, but the fossils are recorded in poor communications without descriptions and illustrations.

Thick conglomeratic beds were informally known as the Ibicatu Facies (Soares, 1972). The type section of this facies, now destroyed, was covered by deposits of the Irati. So, this facies was sometimes wrongly allocated to the Irati basal beds (Taquaral Member). The Ibicatu Facies is indeed present at different stratigraphic positions within the Tatuí Formation (Fúlfaro et al., 1984; Stevaux et al., 1986; Assine et al., 2003; Holz et al., 2010; Chahud, 2011).

All known fossiliferous outcrops of the Tatuí Formation are located in the uppermost 10m of the unit (Mezzalira 2000; Chahud, 2011; Chahud et al., 2010a; Chahud et al., 2012). The present contribution stands out from previous investigations by different approaches as to details of fossil taxa, granulometry, depositional evolution, biostratigraphy and paleoenvironments.

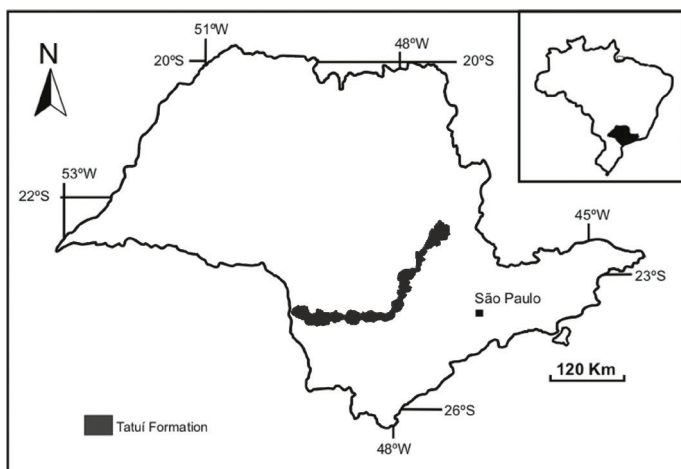


Figure 1. Outcrop belt of the Tatuí Formation in the State of São Paulo.

## TATUÍ LITHOSTRATIGRAPHY

Older researchers considered this formation as essentially made up of two lithologic bodies, recognized by different colors, with a diastem between (Soares, 1972, Fúlfaro et al., 1984).

The lower body, a thick brown – purplish finely laminated siltstone (whitish locally), with interbedded chert-limestone, a few millimeters to 30 cm thick. This lower body is seldom exposed. There are occasional references to foraminifers, without description and illustration (Fúlfaro et al., 1984) and never confirmed by later researchers (Mezzalira and Martins Neto, 1992; Assine et al., 2003; Holz et al., 2010; Chahud, 2011; Chahud et al., 2012).

The second body is gray-greenish to yellow-greenish siltstones and fine sandstones and conglomerates exhibiting rather round clasts with cross-bedding and ripple marks. From angular to rounded chert pebbles are reported. Three lithologies are reported, correlated with the classical lithologic bodies.

The herein described lithologies are the only surely fossiliferous Tatuí beds. They are the following:

### Fine to very fine sandstones with hummocky

These sandstones are well sorted, yellow whitish or greenish, sometimes bearing dots and blots. They mostly lie right under the Irati Formation beds. The outcrops are centimeters to two meters thick, the hummocky cross – beds may reach 0.5m high. Chahud (2007) reported small parallel ripple marks apparently symmetric, striking N20E, less than 0.5cm high, on upper beds of this facies.

Very fine, thinly laminated or massive whitish sandstones, outcrop right under an Irati Formation bed. Sometimes these sandstones acquired a light yellow color, possibly due to weathered pyrite nodules, from the basal Irati bed.

This facies is interbedded with other Tatuí lithologies, discussed below. It is scarcely fossiliferous, small Osteichthyes scales (Ragonha, 1978; Chahud and Petri, 2008a, 2008b, 2009b, 2010b, 2012a, 2012b, 2014) are rarely present. Ichnofossils, right under the Irati bed, were reported (Chahud et al., 2010a)

### Very fine sandstones and siltstones, massive or finely laminated

Defined by very well sorted brownish white, very fine sandstone to siltstone, mostly massive, sometimes parallel or cross laminated. Some lateral variation in granulometry occurs but never over fine sandstones.

Scarcely fossiliferous, these strata contain rare arthropods (conchostracans and indeterminate crustaceans), fish scales and loose remains. The fossils are recognized only in unweathered samples. Occasionally they occur right in sharp contact with the Taquaral Member of the Irati Formation, which are either coarse sandstones or siltstones (Assine et al., 2003; Chahud et al., 2010a; Chahud and Petri 2013a; 2013b).

### Conglomerates

Conglomerate, informally known as the Ibicatu facies since Soares (1972), contains siliceous pebbles one to three centimeters in size, “floating” in a light brown coarse sandstone matrix.

The type locality was a road cut later destroyed by road widening. It was six meters thick, according to Fúlfaro et al. (1984) and Stevaux et al. (1986). Right above, in sharp contact, came deposits of the Taquaral Member of the Irati, reported by these researchers.

The type section had a significant amount of large plant fossils, specimens that reach nearly one meter (Figs. 2 and 3).

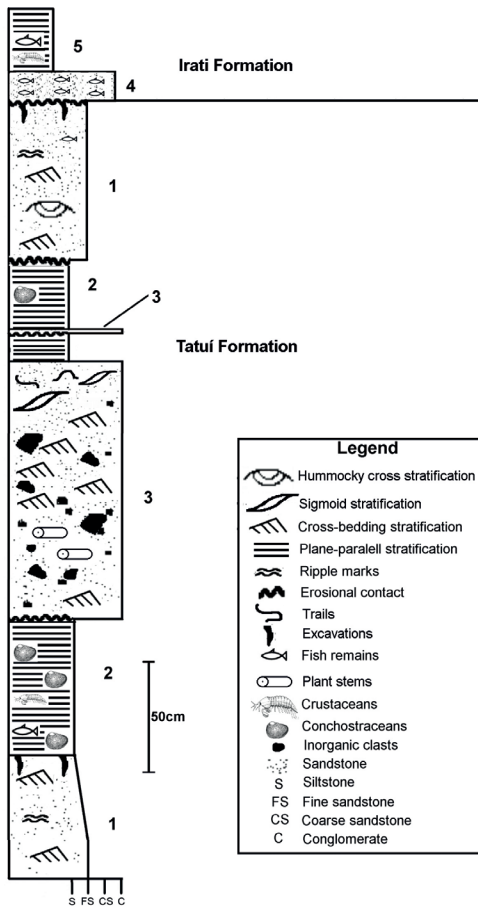
Conglomerates, like the Ibicatu, were reported in other outcrop localities from the State of São Paulo but stratigraphically not in contact with the Irati (Stevaux et al., 1986; Assine et al., 2003; Chahud, 2011; Chahud et al., 2012), with sigmoidal structure, and ichnofossils are present in the upper beds. However, these structures were not present in the type locality (Stevaux et al., 1986).



Figure 2. Fern stem. Ibicatu type locality.

The upper Tatuí Formation, here discussed, is sketched in figure 3. It must be placed in the Late Paleozoic third order sequence of the Tatuí, LPTS-4, of Holz et al. (2010). These authors believe this sequence to be middle Artinskian in age. However, it is possible that the base of Tatuí Formation, not discussed in that paper, might be placed in an older sequence, LPTS3.

The columnar section (fig. 3) was based on center-east outcrops in the State of São Paulo (Stevaux et al., 1986; Assine et al., 2003; Chahud et al., 2010b; Chahud and Petri, 2010b, 2015). Most of the Tatuí outcrops occur in this area.



**Figure 3.** Sketched columnar section of the upper Tatuí Formation as occurring in the State of São Paulo center-east. 1) Fine to very fine sandstones with hummocky; 2) Very fine sandstones and siltstones, massive or finely laminated; 3) Conglomerates; 4-5) Taquaral Member of the Irati Formation: 4) Basal sandy beds; 5) Silty-shale facies

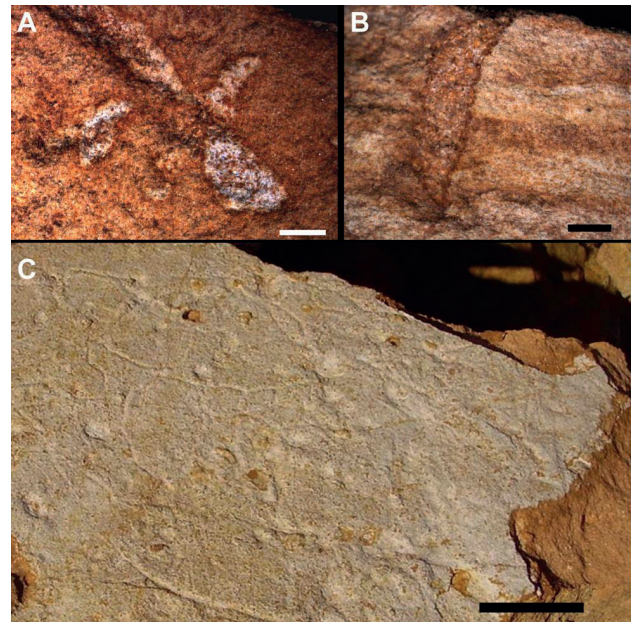
## PALEONTOLOGY

### Ichnofossils

Bioturbated deposits were recorded with two morphotypes in two Tatuí Formation lithologies. The first was described by Chahud et al. (2012) in lithology 1, below deposits interpreted by the authors as representing a freshwater paleoenvironment (lithology 2).

The structures are simple irregular conical excavations, irregular oval or elongate openings lay down in seen both from above and perpendicular to the beds (Fig 4A-B).

Several ichnogenera might be applied to this kind of excavation. It is not a good paleoenvironmental index, present under fresh or salty shallow waters or even subaerial.



**Figure 4.** Ichnofossils. A-B) Excavations in fine sandstones A) Plan view, B) Profile view. Bar-scale 2mm C) trails in coarse sandstone. Bar-scale 40mm.

The second morphotype (Fig. 4C) is seen in poorly sorted sandstone with sigmoidal structure interbedded with silty beds (lithology 3 Fig. 3), observed in outcrop as a lateral extension of the remainder of the destroyed Ibicatu type-locality.

It is a set of horizontal trails of 5mm width with simple ramifications, without preferential direction, many tracks cut perpendicular or askew other trails. There are no spines, paws, claws or any ornamentation, just smooth trails and structureless fill with lithology similar to host rock. The structures are preserved in negative and positive relief, this being the most common.

This ichnofossil might be ascribed to following four ichnogenera, known in the Guatá Group: *Gordia*, *Helminthopsis*, *Palaeophycus* and *Planolites* (Fernandes et al., 2002; Netto et al., 2012)

*Gordia*, *Helminthopsis*, and *Planolites* are widespread and common in three ichnofacies: *Cruziana*, *Mermia*, and *Nereites*. *Palaeophycus* is restricted to the *Cruziana*, is the genus attributed to this ichnofossil. It also appears in the Palermo Formation (Fernandes et al., 2002; Netto, 2000; Netto et al., 2012), partially chrono-correlated to the Tatuí Formation.

Several biogenic perforations occur at the interface Tatuí-Taquaral (lithologies 1 and 4, Fig. 3). Animals that lived at the beginning of Taquaral deposition, right after the final of Tatuí deposition, were responsible for these structures.

### Plant fossils

Only sparse, isolated, fragmented remains of plant fossils in the Tatuí beds have been reported in the literature. The first occurrences of larger and better-preserved specimens came from the Ibicatu conglomerate (Fúlfaro et al., 1984; Assine et al., 2003; Chahud and Petri, 2009a).

These fossils, the largest of the present study, are Pteridophyta and Spermatophyta trunks. The great Pteridophyta fragments of elongate stems (fig. 5A and B), several centimeters long, were investigated by Chahud (2011), who placed them in the genus *Tietea* (Solms-Laubach, 1913), by the shape of the meristeles, similar to those described by Derby (1915) and Tavares (2007), at the Corumbatai Formation, units younger than Tatuí, and also by the absence of the organized meristeles in the central part of the stele, features which exclude the genus *Psaronius*, with well defined and organized meristeles.

Herbst (1987) described similar plants from the Permian of Paraguay, proposing the genus *Tivichapteris*, also with unorganized meristeles and the

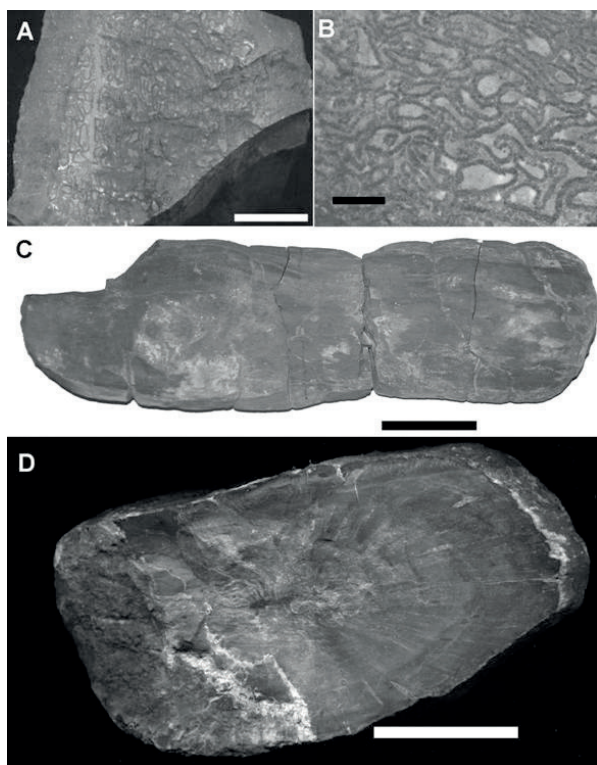


stem center like *Tietea*. The differences between these two genera would be the number of fronds sprouted out from the trunk. The Ibicatu specimens did not preserve them. Tavares et al. (2011), however, argued against the value of the frond differences, which would be caused by the difference of ontogenetic stages, so the priority goes to the name of the genus as *Tietea*.

Another kind of Ibicatu stem, but smaller and apparently less frequent, was attributed to Spermatophyta. It is a gymnospermic cylindrical type (Fig. 5C-D), compact and deformed and irregularly elongate.

The plant fossils were dispersed among the conglomerate with clasts 5mm to 3cm in size. None of the fossils are in “life position”, each laid down horizontally by the current, which direction was registered as E-W for the two kinds of the stems. Previously Stevaux et al. (1986) reckoned a sole N-S direction for the fossils, before the destruction of the outcrop.

Diagenesis acted before final fossilization, mainly through compression by sediment inflow, increasing the fossil widths and internal deformations.



**Figure 5.** Ibicatu stems. A-B) Pterydophyta. A) *Tietea* sp. Bar-scale 10mm. B) Meristele details of *Tietea* sp. Bar-scale 5mm. C-D) Spermaphyta. C) Stem. Bar-scale 50mm D) cross-section. Bar-scale 20mm.

## Arthropods

### Conchostracans

They are preserved as impressions with few external morphological features. Sometimes the umbo is easily seen. The entire outline of growth lines is scarcely observed. No thicknesses neither concave – convex shapes are detected.

The best-preserved specimens allowed distinction of the valves as oval rounded in outline (Fig. 6A and B) similar to both recent and Paleozoic forms (Brito et al., 2000; Ferreira de Oliveira, 2007). However, it is not possible to classify them at the genus level, based only on the features noted above.

A lot of packed conchostracans were reported in a silty laminated bed (Fig. 3) with characteristics of free – settling and absence of traction action (Chahud et al., 2012). These fossils are packed as a “shell bed”, interbedded with others with less numerous fossils. The assemblage concentration changes upward and sideward.

### Other Crustaceans

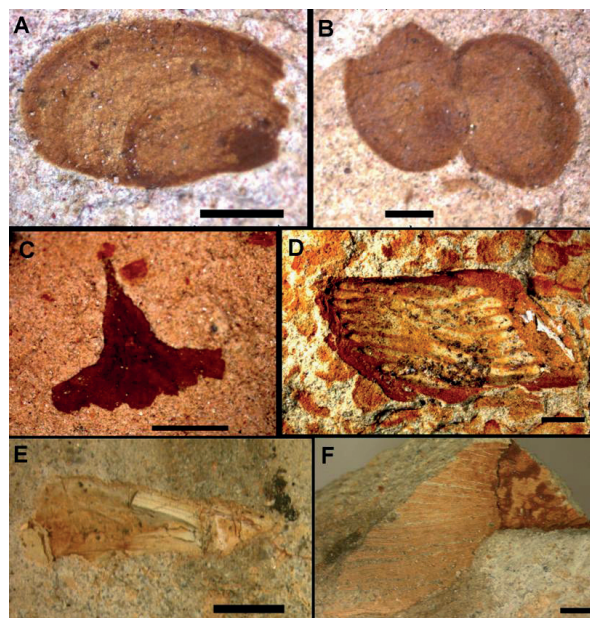
Mezzalira and Martins Neto (1992) are the only researchers to record Crustaceans (no conchostracan) in the Tatuí Formation. The two genera, *Pseudopalaega*, and *Protourda* are rather poorly preserved isopods, associated with fish remains and conchostracans.

Chahud et al. (2012) reported unidentified crustaceans in massive finely laminated sandstones and siltstones (Fig. 6C)

### Paleovertebrates

Some vertebrates are also associated with the conchostracans and others scarcely present in the fine sandstones with hummocky (Ragonha, 1978; Chahud and Petri, 2009c). A unique identification of a semi-articulated fish, Actinopterygii, a kind of Platsomoidea, was reported by Silva Santos (1991). The Mezzalira and Martins Neto (1992)’s crustaceans came from the same outcrop.

The fossils, as a rule, were preserved as scales and loose teeth of the Palaeonisciformes and Coelacanthimorpha, dispersed and fragmented among the matrix (Fig. 6E-F).



**Figure 6.** Tatuí Formation fossils A-B) Conchostracans from the center-east State of São Paulo. Bar-scale 1mm C) Crustacean fragment. Bar-scale 1mm D) Palaeonisciformes scale associated with conchostracans . Bar-scale 5mm E) Fragment of Palaeonisciformes tooth. Bar-scale 2mm. F) Coelacanthimorpha scale. Bar-scale 2mm. E-F) Found out near the contact with Taquaral Member.

### Other fossils

Rare fossils, assigned to the Tatuí beds, were mentioned in papers published before this contribution. Most of them were placed in beds wrongly thought to belong to the Tatuí Formation.

Barbosa and Almeida (1949) and Almeida and Barbosa (1953) reported sponge spicules in beds believed to be Tatuí. They neither described nor illustrated the spicules, furthermore the stratigraphic position of the beds is uncertain.

Three foraminifera genera, *Erlandia*, *Ammodiscus*, and *Hyperamina*, were reported by Fúlvaro et al. (1984) in silty sandstones. These fossils came from the basal beds of the Tatuí, and would be probably a continuation of the conditions of deposition of the upper Itararé Group. Lima et al. (1976) recognized *Ammodiscus* and *Hyperamina* in the Itararé beds.

Cabral Jr. et al. (1988) reported agglutinated foraminifera, ostracods, and acritarchs from core wells from the base and top of a section attributed to the Tatuí. However, the lower cores might belong to the Itararé, and the upper might belong to the base of the Taquaral Member. Cabral Jr. et al. (1988) didn't describe and illustrate them, and only acritarchs were confirmed by Marasco et al. (1993) in the base of the Taquaral Member.

### Conclusions And Paleoenvironmental Considerations

The record of the entire Tatuí Formation fossils are ichnofossils, plant fossils, bones of fishes and arthropods. Only ichnofossils and fishes are reported in more than one lithology (coarse and fine sandstones).

The Tatuí Formation paleoenvironment of deposition evolved through three phases. The first apparently contains only the euryhaline fossils, agglutinated foraminifera mentioned by Fúlfaro et al. (1984). These fossils are common in brackish waters that may be transitional from coastal estuary complex to coastal marine.

Another two phases, from the upper Tatuí, reflect the interplay of two paleoenvironments.

The deposits of the second phase are regressive and continental, with conchostracans dropped downward without further transportation, in a lacustrine deposit, within the siltstones massive or laminated beds (lithology 2, Fig. 3), and large plant stems in the conglomerates (lithology 3, Fig. 3), fluvial deposits.

The third phase is transgressive with hummocky cross – stratification and, probably, increasing salinity, similar to the first stage (lithology one contact with lithology four, Fig. 3).

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