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The most luxuriant and important Permian tropical-subtropical floristic record in the Southern Hemisphere

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Patches of the Northern Tocantins Petrified Forest (NTPF) occur in the Tocantins Fossil Trees Natural Monument (TFTNM) and in its surroundings (Filadelfia, NNE Tocantins, SW Parnaíba Basin). The scenic beauty of this region results from a contrast between two landscape plans: the lower one (Permian) - expressing the top of the Pedra de Fogo Formation or the basal Motuca Formation -, and the upper one (Triassic), formed by the top of the eolian Sambaíba Formation. The fossil plants are associated with alluvial deposits in the base of the Motuca Formation that overlies the restricted marine Pedra de Fogo Formation. The plant material, three-dimensionally preserved as siliceous cellular permineralization, is abundant over the soil surface or embedded in quartz arenites, sometimes in pelitic sediments. The stems commonly reach several meters in length, sometimes more than 10m, with a basal diameter up to 1.20 m. There are distinct tree ferns: Tietea, Psaronius (Psaroniales, the dominant and longer stems), Grammatopteris (Filicales) and Dernbachia (?Filicales). Leaves and petioles related to the stems, Botryopteris (climbing or epiphytic fern), arboreal sphenopsids (e.g., Arthropitys), and different gymnosperm trunks also occur. The exceptional plant preservation allows taphonomic, morphologic, anatomic and ontogenetic studies, in addition to palaeoecologic discussions. The NTPF is interpreted as a tree-fern-dominated wetland Permian flora under warm-humid conditions seasonally variable. It contains key-elements to the comprehension of evolutive relationships among Late Palaeozoic floristic provinces. The TFTNM is an extraordinary geobiological heritage, unique in the world, also presenting archaeological (e.g., petroglyphs), environmental significance, and geo/ecotouristical attractiveness.

Key-words: palaeobotany, fossil tree-ferns, petrified forest, Motuca Formation, Permian, State of Tocantins.

INTRODUCTION

Petrified forests are peculiar areas presenting a large quantity of fossil stems. Commonly, no branches or other plant parts are found connected to them. The plants were buried by siliciclastic sediments or volcanic material, and their cellular tissue impregnated by silica solutions (permineralization). Later, exposed to the weathering and erosion, the fossil stems were partially or totally exhumed, and the trunks were prominently maintained in their growth or depositional position; if fragmented they occur scattered and concentrated on the ground.

From the Devonian onward, dozen of petrified forests have been recorded over the world. In Southern Brazil, Southern Paraná Basin, fossil conifer trunks from the Triassic siliciclastic deposits of São Pedro do Sul and Mata are known (Minello, 1994; Guerra-Sommer *et al.*, 1999; Guerra-Sommer & Scherer, 2002; Pires *et al.*, 2005).

Because of their beauty and scientific significance, many fossil forests became protected areas. More and more state and national monuments and national parks have been created in different countries, mainly in USA and Europe, reflecting the importance of these occurrences for these societies. The *Northern Tocantins Petrified Forest* (NTPF), listed among the world's 31 most beautiful petrified forests (Dernbach, 1996), is one of these natural treasures, and represents the most luxuriant, diverse and important Permian tropical to subtropical floristic record of the Southern Hemisphere. Some of the most significant patches of the NTPF were congregated in the *Tocantins Fossil Trees Natural Monument* – TFTNM. Distant of this entity, other NTPF patches occur in Goiatins, Colinas do Tocantins, and perhaps in the Carolina region, Maranhão State (Fig. 1).

The main goal of this paper is to emphasize the scientific importance of the TFTNM for the Permian tropical-subtropical geohistory in the Southern Hemisphere, in order to include this entity among the most important Brazilian geobiolological sites to be preserved as a natural heritage for the mankind. It presents geological and palaeobotanical data on this area from different authors (*e.g.*, Faria Jr., 1979;

Coimbra & Mussa, 1984; Pinto & Sad, 1986; Herbst, 1999; Dernbach, 1996; Martins, 2000; Dernbach *et al.*, 2002; Robrahn-Gonzáles *et al.*, 2002; Rössler & Noll, 2002; Rössler & Galtier, 2002a,b; 2003; Dias-Brito & Castro, 2005; Rössler, 2006). In addition this contribution presents some new elements to the regional stratigraphic discussion.

The NTPF has been insufficiently investigated by Brazilian scientists. Almost nothing has changed after Mussa & Coimbra (1987, p. 902) pointed out: "…in Brazil (…) since the beginning of the palaeobotanical studies, the searchers, in majority, have been much more concerned in to investigate the Gondwana taphoflora…". In page 906: "…the Paleozoic sequences (…) as those ones of the Parnaíba Basin, are still unexplorated from a palaeobotanical point of view". Recent agreements signed by UNESP - Rio Claro, the Tocantins Government, and the Chemnitz Natural History Museum – Germany will support actions to systematically investigate the NTPF in Brazilian institutions. A great goal is to create a Natural History Museum in Palmas, Tocantins.

This communication also emphasizes that the TFTNM is a mosaic of highly relevant recent ecosystems to be preserved, presenting as well an effective potential to be used in Geology, Palaeontology, Biology and Ecology field education. Due to its scenic beauty the area has geo- and ecotouristical attractiveness. Some archeological finds are aggregating more scientific and cultural value to the TFTNM.

LOCATION

The TFTNM, and its surroundings, is situated in the legal Amazonia, NNE Tocantins State, Filadélfia county, next to the frontier with the Maranhão State. It is located between the lat 7º17'45" and 7º38'34" S, and long 47º35'17" and 48º01'05" W. In its western side is Bielândia, also known in the past as Zé Biel or Venda do Zé Biela. This locality is internationally known as a fossiliferous site. To arrive to the area use the TO-222 road from Araguaína. The TO-010 road and some other secondary roads also can be used to access the NTPF patches.

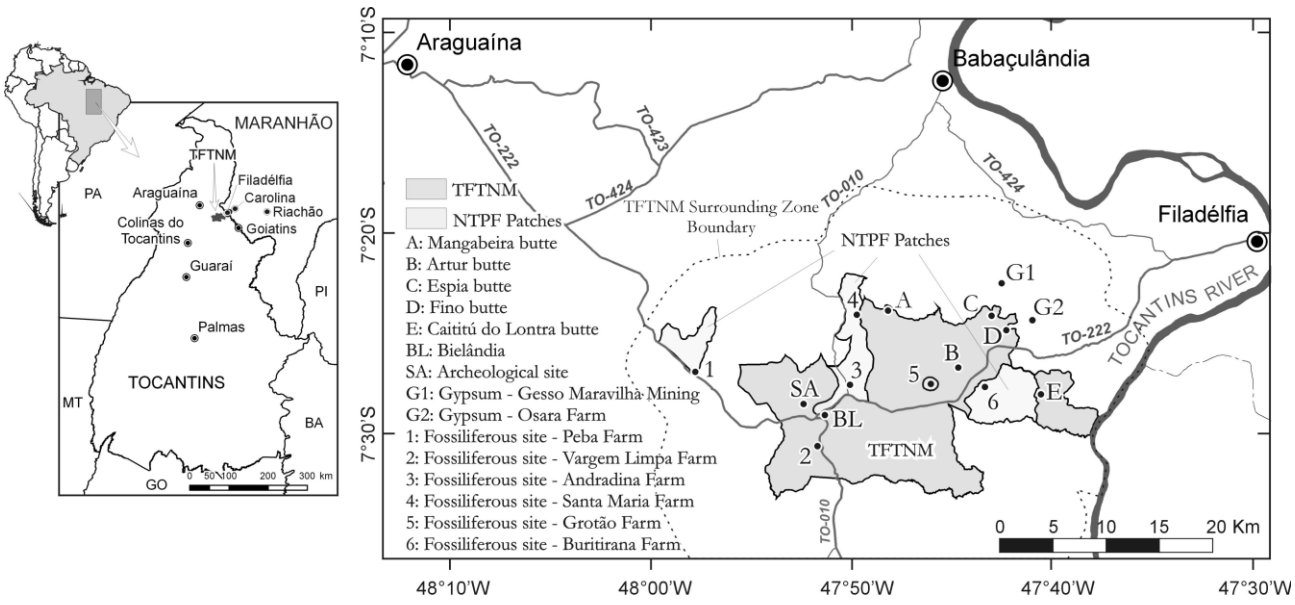

Figure 1 – Location of the Tocantins Fossil Trees Natural Monument (TFTNM) and its surroundings.

SITE DESCRIPTION

Present characteristics

The TFTNM includes natural units interrupted by cattle rising activities and human occupation. It covers an area with approximately 32,000 ha, and is situated in a distinguished region in terms of biodiversity conservation (MMA, 2002). The annual mean temperature is 26,3º C, with maximum and minimum values of 28º and 25.3º C, which are recorded in September and June, respectively. The annual pluvial precipitation reaches 1800 mm. Rains are concentrated from October to April (more than 90% of the total annual mean). From January to March the pluvial precipitation reaches 50% of the total annual mean, while from June to August it is minimum and the air relative humidity reaches 50%. The climatic conditions are variable. In some years the annual pluvial precipitation is lower than 850mm. The ecosystem dynamics is controlled by strong seasonality regarding the hydrologic availability.

The scenic beauty of this region results from a contrast between two landscape plans. The lower one,

situated around 200 and 250m, expresses silex layers in the top of the Pedra de Fogo Formation or silicified sandstones in the base of the Motuca Formation (Pinto & Sad, 1986). The upper one, around 500m (but also occurring in lower altitudes), refers to surfaces or tops of *mesetas* (small "plateaus" with steep edges) formed by Late Permian? Triassic? eolian sandstones. These *mesetas* are present in the eastern side of the TFTNM and correspond to the Sambaíba Formation (Fig. 2). They can be observed from CBERS satellite images.

The area is dominated by a savanna-like vegetation, which is known in Brazil as *cerrado*. It is represented by the rupestrian, typical, and high *cerrado*. Riparian forests containing Amazon elements also occur, and sometimes the palm *Mauritia flexuosa* is dominant. Some small patches of semi-deciduous forests are present too. Perennial or temporary small rivers and creeks compose the drainage net, which has a dendritic or subdentritic pattern. The area is an important biogeographic ecotonous.

Figure 2 – Panoramic view from Santa Maria Farm.

Regional geological context

The TFTNM is situated in the southwestern Parnaíba Basin (also known as Maranhão, Maranhão-Piauí or Meio-Norte Basin), which was a part of the Southern Occidental Pangea (Fig. 3; the arrow indicates the TFTNM position). In this sector of the basin it can be seen horizontal siliciclastics, carbonate and evaporitic layers, which are associated to the Piauí (Late Carboniferous), Pedra de Fogo (Permian), Motuca (Permian), and Sambaíba (Triassic) formations. The latter one – presenting lithological characteristics significantly different from the other ones – is here not interpreted as a part of the Balsas Group as understood by Góes *et al.* (1989; 1992); it reflects a new tectono-stratigraphic cycle in the basin.

The Permian units are particularly focused in this paper. The lower one, Pedra do Fogo Formation, refers to sediments accumulated in marine (shallow restricted milieu) and continental environments, in a context of a warm climate with variations in its humidity; during the marine episodes, when the basin presented negative hydrological balance, carbonate and evaporitic sediments were accumulated (Lima & Leite, 1978; Faria & Truckenbrodt, 1980; Oliveira, 1982; Coimbra, 1983; Góes & Feijó, 1994; Araújo, 2001; Dino *et al.*, 2002). The upper unit, corresponding to the Motuca Formation, was accumulated in continental environments. It includes fluvial, lacustrine and eolian sediments. Episodic marine incursions occurred in its middle phase, when gypsum layers were deposited (Lima & Leite, 1978; Araújo, 2001).

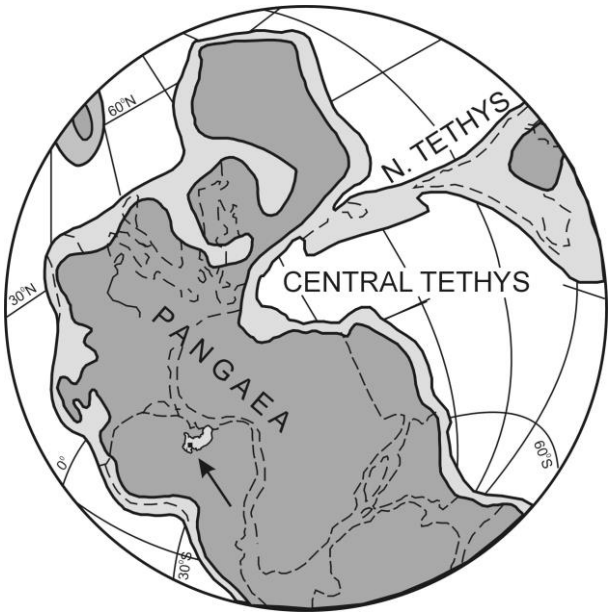

Figure 3 – Parnaíba Basin at the Pangea. Guadalupian geography according to Ross (1995).

There are divergences regarding to the exact chronostratigraphic position of the Pedra de Fogo and Motuca Formation. The divergences are associated with the common occurrence of poorly fossiliferous sedimentary layers, frequently with no fossils or with no good guide-fossils. In addition to the palaeontological data, some regional (mainly regarding to the Amazonas Basin) or long-distance correlations have been used to define the chronostratigraphic position of the Parnaíba Basin's Permian units.

Based on different data and methods of investigation, scientists have suggested a Carboniferous-Permian age for the Pedra de Fogo Formation. Progressively there was a convergence to consider it as a Permian unit, as follow: Early Permian (*e.g.*, Price, 1948; Mesner & Wooldridge, 1964; Barberena, 1972; Cruz *et al.* (1972) *apud* Santos *et al.*, 1984; Góes *et al.*, 1992); Early to Middle Permian (*e.g.*, Lima & Leite, 1978; Faria & Truckenbrodt, 1980; Mussa & Coimbra, 1987; Góes & Feijó, 1994); Late Permian (*e.g.*, Cox & Hutchinson, 1991). Dino *et al.* (2002) presented important palynological data

concerning the Trisidela Member (the upper part of the Pedra de Fogo Formation) and inferred a Late Permian age for the member. However, taking into account the discussion presented by those authors, the arguments for this inference are not completely supportable. Ones could deduce a Kungurian (late Early Permian, according to Menning *et al.*, 2006) to Late Permian age for the mentioned member. Moreover, considering that the Trisidela Member contains palynofloral content highly similar to that one present in the Flowerpot Formation (Oklahoma) – as informed by Dino *et al.* (*op. cit.*) - we suggest a Kungurian age for the upper Pedra de Fogo Formation, seeing that the North American unit is related to this interval, as shown by Lucas (2004). It is important to remark that the cored shale levels studied by Dino *et al.* (*op. cit.*) from the Petrobras well 1-CL-1-MA, which contain abundant pollen, spore grains, and a few acritarchs, are ~ 30m below the stratigraphic level from which there are sandstones with fossil plants (referred classically as *Psaronius*). Moreover, it is inferred that Dino *et al.* (*op. cit.*) studied the uppermost part of the lower Trisidela Member. Both two deductions herein presented result of an analysis of the figures 4 and 2, respectively presented by Pinto & Sad (1986, p. 355) and Dino *et al.* (*op. cit.*, p. 26).

Concerning the Motuca Formation, difficult to date, there are several age assumptions, varying from the Middle Permian to the Triassic, as follow: Middle Permian (Petri & Fúlfaro,1983); Late Permian (Mesner & Wooldridge, 1964; Lima & Leite, 1978; Faria & Truckenbrodt, 1980; Góes & Feijó, 1994); Late Permian-Triassic (Leite & Lima, 1978).

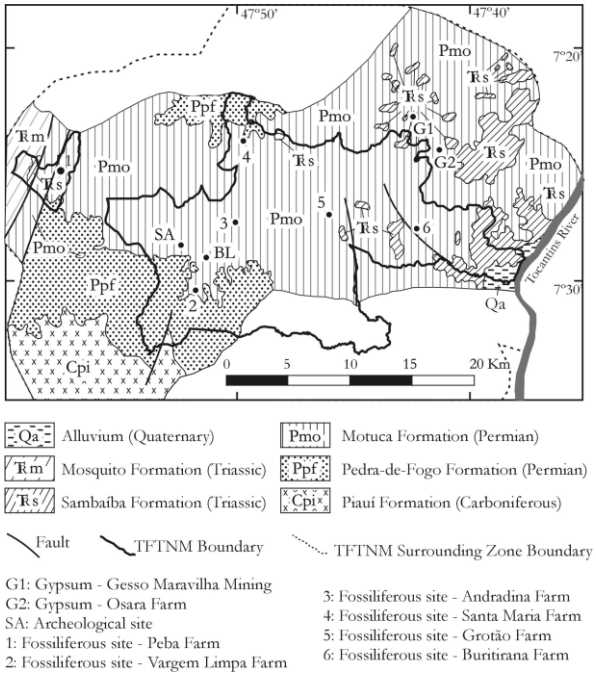

Figure 4 – Geological map of the TFTNM and surroundings (according to Pinto & Sad, 1986).

Local geological context

The Lima & Leite's geological map (1978) presents the area of the TFTNM as dominated by Pedra de Fogo sediments; the Sambaíba Formation and Quaternary deposits occurs as patches. Also on the Coimbra's map (1983), the TFTNM' area is widely dominated by the Pedra de Fogo Formation. However, on the 1:50.000-scale surface geologic map prepared by Pinto & Sad (1986) - specially focusing the region in which is included the Monument and also considering subsurface data - the TFTNM area is shown as bearing every units of the Balsas Group, but clearly being dominated by Motuca sediments. These two latter authors interpreted the non-calciferous reddish or cream fine-grained sandstones - which contain the fossil stems and traditionally considered as Pedra de Fogo Formation - as pertaining to the base of the Motuca Formation. The Figure 4 presents the geologic map of the TFTNM and its surroundings based on Pinto & Sad (1986). Those authors justified their conception on p. 350:

> It was decided to include these rocks into the base of the Motuca Formation mainly based on sedimentological aspects. The top of the Pedra de Fogo Formation contains carbonate rocks apparently accumulated in cyclic deposits (sandstones, siltstones, and calciferous shales alternated with marls layers and silex) presenting plan-parallel stratification in outcrop scale, whereas the above mentioned sandstones [non-calciferous reddish or cream fine-grained sandstones] show medium- thick crossbedding, (…), are silicified on its base, *and contain petrified wood rests*. [our italic].

They wrote on p. 351:

> *In any place it was found* ***Psaronius*** *in carbonate rocks*. [our italic]. Barbosa & Gomes (1957, p. 24) write: 'Finally it should be clarified that one of the authors (F. A. Gomes) working on stratigraphy for six years in Maranhão [State] has only found *Psaronius* in place in shales of the Paleozoic column' top, above the *datum bed*'. The mentioned *datum bed* of these authors is 'a 2 meters thick bank with typical globoid concretions, which are commonly known as *bolachas* that present diameters around 2-4 cm'. These silex concretions are situated at the upper part of the Upper Member [of the Pedra de Fogo Formation].

Faria Jr. (1979, p. 18) writing about fossil plant occurrences from São Bento locality, situated 2 km far from west Morro Pelado, in Serra do Ciriaco, northwestern Bielândia, pointed out: "…***Psaronius*** *in situ is found in the rose-colored and reddish fine-grained crossbedded sandstones, which compose the Motuca Formation walls.*" [our italic]. By occurring close to the Cacundo creek , NW Bielândia, these sandstones were named "Cacunda sandstones" by Sá *et al.* (1979), *apud* Pinto & Sad (1986). They directly overly "…the cream-colored

siltstones of the Upper Member's top of the Pedra do Fogo Formation, the same occurring in other places [in Serra do Ciriaco], as in the Mutum and Mutunzinho hills, where is remarkable the presence of *Psaronius*." (Pinto & Sad, *op. cit*., p.350).

Faria & Truckenbrodt (1980, p. 743), leading with the Pedra de Fogo stratigraphy and petrography, also discussed the relationship between the fossil plants and the lithostratigraphic units, and indicated:

> The fossil woods, including Psaronius [sic], are found associated with siltstones and reddish fine-grained sandstones bearing white patches, which are associated with the uppermost part of the Pedra de Fogo Formation [included into the base of the Motuca Formation by Pinto & Sad, 1986]. It is emphasized that Psaronius [sic] transported to lower topographic levels (…) has caused misunderstandings in mapping works. (…) *it is suggested that the silicified woods also occur into the base of the Motuca Formation* [our italic].

Andreis (in Robrahn-González *et al*., 2002) studied the TFTNM' stratigraphy and described seven columnar sections from outcrops situated in the western and eastern sides of the Monument. He wrote (p.12):

> Comparing the stratigraphic sections descriptions [studied by him] (…) with the established definitions regarding the Pedra de Fogo Formation and its sub-units (Basal Silex, Middle, and Trisidela members, according to Faria & Truckenbrodt, 1980), it is verified that there is no a fair correspondence between them. (…) *the inverse is true if a comparison is made with the upper unit, named Motuca Formation.* [our italic].

TFTNM's stratigraphic sections referring to the Pedra de Fogo and Motuca formations were also investigated by Dias-Brito & Castro (2005). They agreed with Pinto & Sad's criteria to separate the Pedra de Fogo and Motuca formations, also associating the sediments bearing fossil plants to the base of the Motuca Formation. A columnar section of the Pedra de Fogo Formation's upper interval (Fig. 5) revealed six facies associations, from the base to the top. The three lowermost facies are dominantly siliciclastic ones (sandstones, and sandstones/dolomites; pelitic sediments with carbonate and silicified levels; silty-argillaceous sediments), whereas the three uppermost facies are mixed, and dominated by carbonate rocks and silex (marls, dolomite, pelitic layers and silex; calciferous sandstones and limestones; calcilutite and silex). It is assumed a restricted marine origin for the interval (no "signal" of open sea environments), in which the dryness augmented toward the top. In other sections, it was verified the same pattern (*e.g.*, W Bielândia, left side of the TO-222 road, close to UTM 18265x917271 coordinates - dolomitic marls with intraclasts, silicified nodules (silicified oncoids?), and rare ostracods; limestones with silicified intraclasts; Pirarucu River, UTM 2059X91761 - greenish lamite; wavy siltstone intercalated with silex and dolomite passing to a limestone with mud cracks on the top).

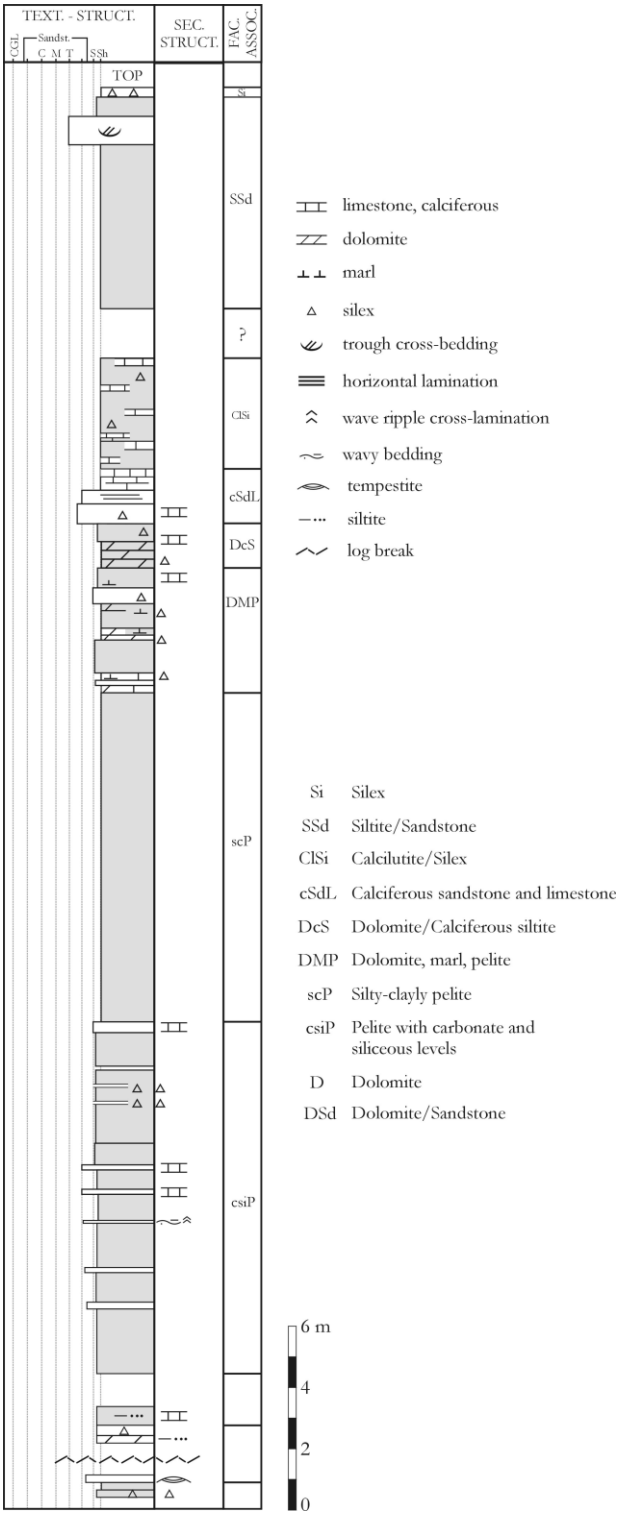

Figure 5 – Stratigraphic section referring to the upper part of the Pedra de Fogo Formation from hill situated in the right side of the TO-222 road (towards Bielândia),7°26'44"S-47°58'08"W, except the lowermost part (Gameleira River, 7°30'58"S-47°57'34"W).

Stratigraphic sections corresponding to the base of the Motuca Formation are presented on Figure 6. These profiles revealed that these rocks are dominated by continental systems (fluvial, deltaic and lacustrine ones), in opposition to the restricted marine nature of the Pedra de Fogo Formation. Crossbedded sandstones from Andradina farm, probably representing fluvial channel facies, indicate paleocurrents toward NE (rarely SE). Some dozen meters from these sandstones, in the same vertical interval, occur paleosoil and probably flood flat facies, in which large fossil stems are found in depositional position.

In the surroundings of the TFTNM, northeastern area (Fig. 4, G1 and G2), there are some gypsum occurrences. These evaporites are banded or nodular. They are probably associated with the middle section of the Motuca Formation, as suggested by Lima & Leite (1978). Considering its palaeoclimatic significance, these rocks should be better investigated regarding its stratigraphic position.

The Northern Tocantins Petrified Forest in the TFTNM

NTPF's patches, largely dominated by tree ferns, crop out in the TFTNM and its surroundings, as already indicated on Figure 1. The most attractive fossiliferous localities are in the Peba, Andradina and Buritirana farms, but those ones located at the Grotão, Santa Maria and Vargem Limpa farms also offer important elements. The sites located at the eastern side of TFTNM are in a better state of preservation. However, all of them are very important and should explorated in future studies. The figures 7, 8 and 9 offer a synthesis of the aspects and elements of the Monument and its surroundings, including fossil plants, outcrop views, rupestrian impressions, and geomorphologic panoramic.

Both the quantity and the size of fossil stems found in the area are remarkable. They are permineralized by silica and three-dimensionally well preserved. Many of them reach more than ten meters, with basal diameter reaching 120 cm. If in depositional position, they are associated with quartz-arenites, shales, and siltstones of the Motuca Formation' lower part. Sometimes big stems with branches are found in para-autochtonous position associated with siltstones, as figured by Rössler (2006, p. 43, Fig. 3d). Due to their weight and resistance to the erosion, the big stems, frequently fragmented, are found scattered on the ground, but maintaining its fossilization orientation (predominantly NE in the Andradina farm, and ESE in the Buritirana farm). Smaller fragments commonly appear concentrated and mixed with silex pieces from the Pedra de Fogo Formation (*e.g.*, in surfaces of the transition Pedra de Fogo – Motuca formations, hillsides, ravines, and creeks). If associated with pelitic sediments the stems are compressed, what is not verified in trunks occurring in sandstones.

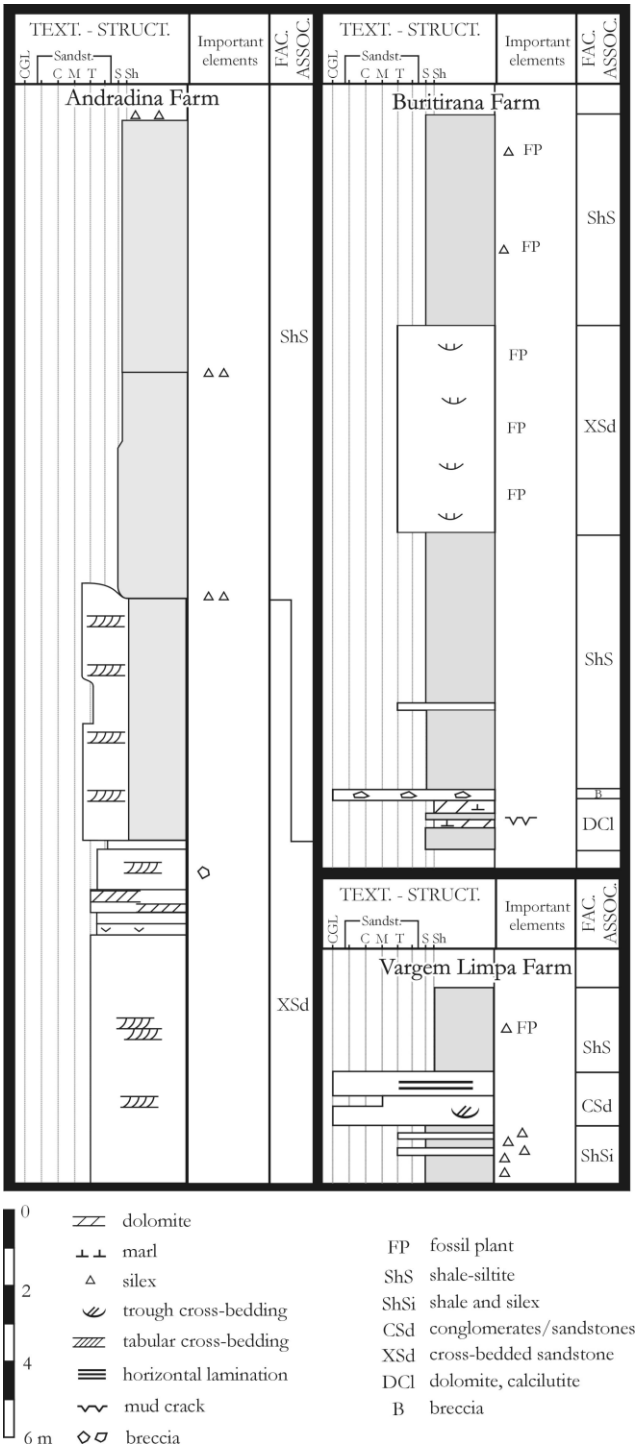

Figure 6 – Stratigraphic sections from Andradina (07°27'19"S - 47°50'21"W), Buritirana(7°27'36"S-47°43'26"W) and Vargem Limpa(7°30'30"S - 47°51'33"W) farms.

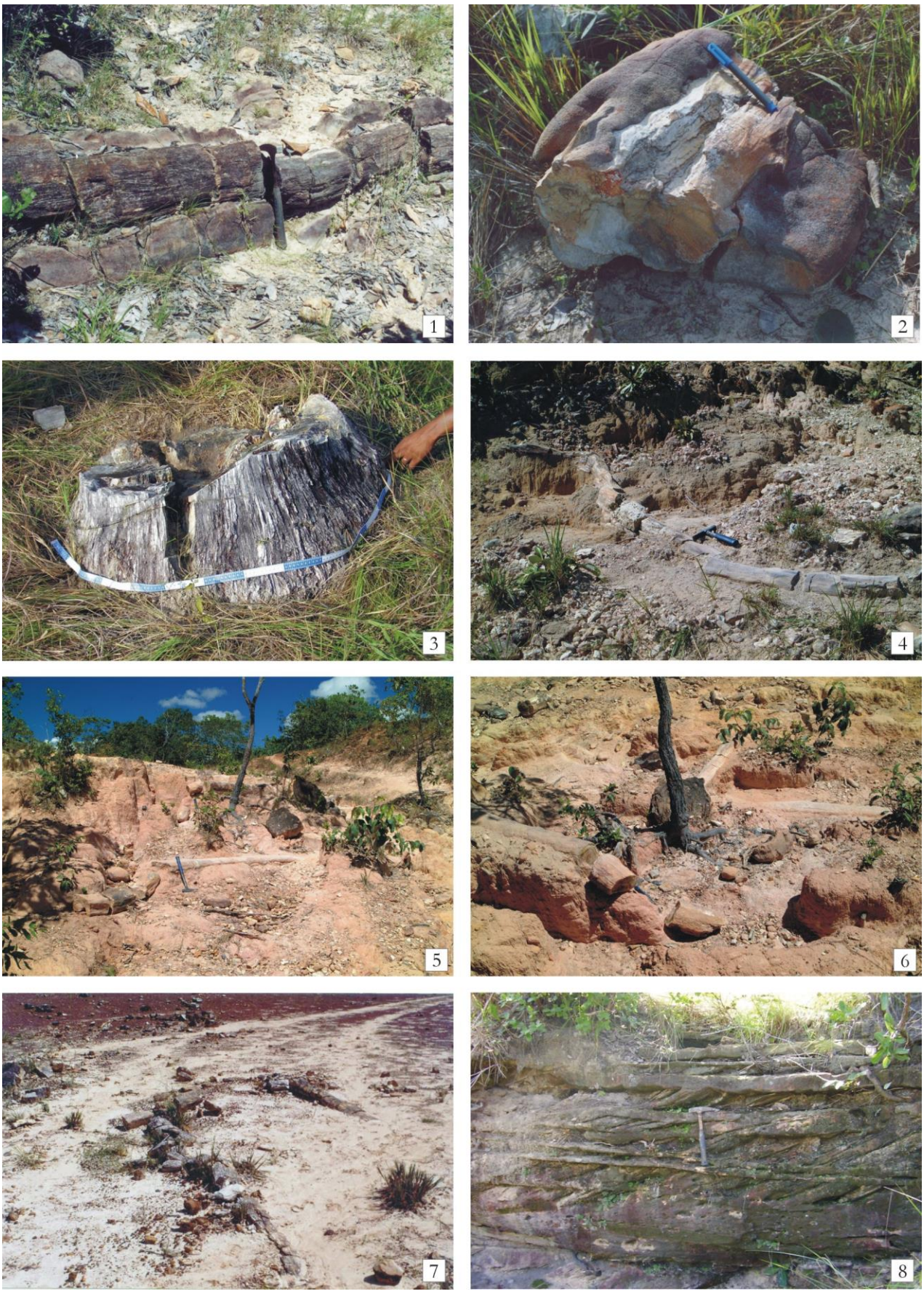

Figure 7 – Outcrops and petrified stems. Motuca Formation. TFTNM and its surroundings. 1. *Tietea singularis;* 2. *Tietea singularis;* 3. basal portion of *Tietea singularis;* 4. *Tietea* deformed; 5. *Tietea singularis;* 6. *Tietea singularis;* 7. *Tietea singularis;* 8. sandstone presenting fluvial channel cross stratification. 1-3: Fazenda Peba; 4-6, 8: Fazenda Andradina; 7: Fazenda Buritirana.

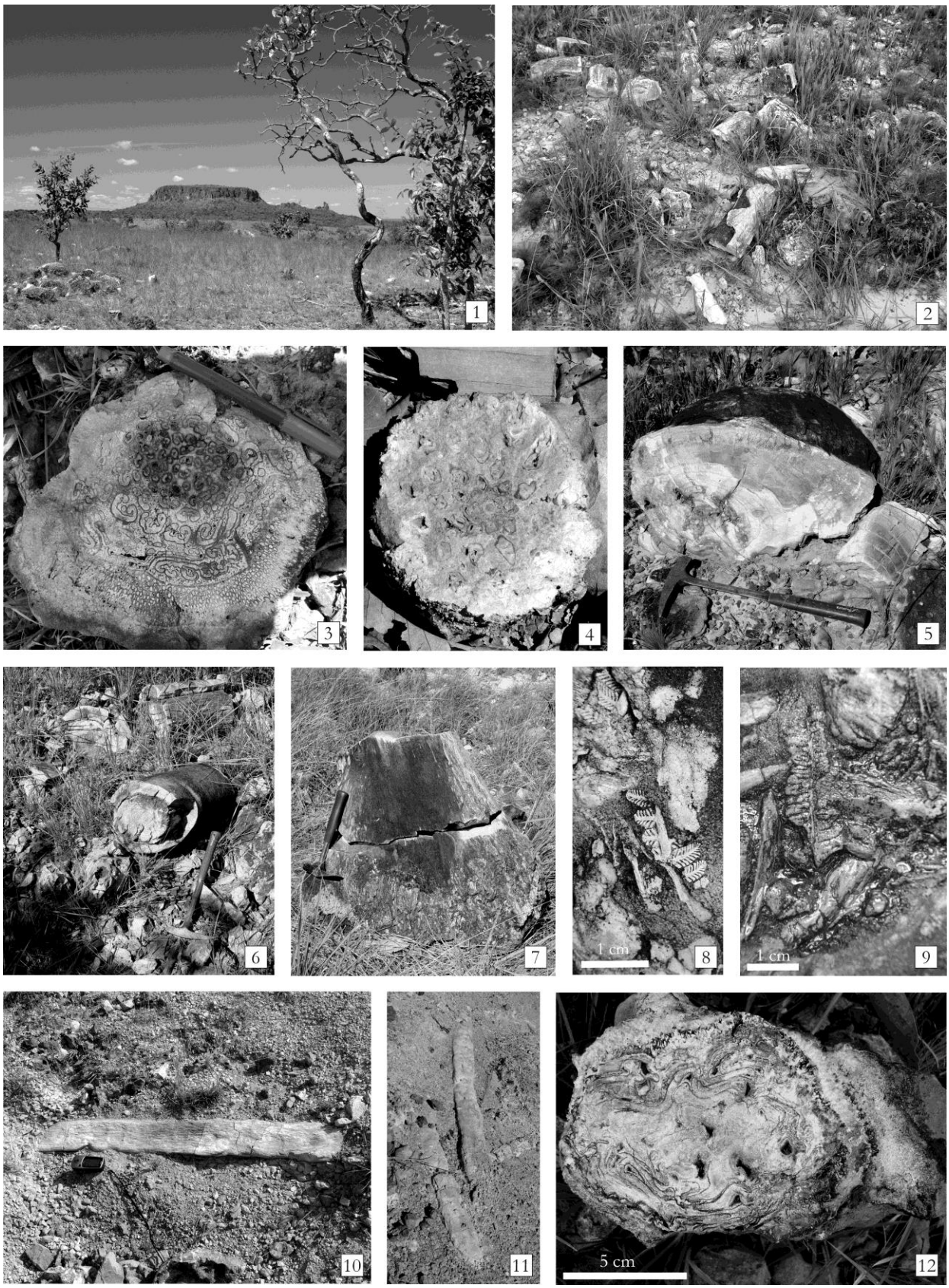

Figure 8 – Outcrops and petrified stems. Motuca Formation. TFTNM. 1. Fazenda Buritirana: Mutuca formation at first plane and, at backgrond, eolic sandstones in hills of the Sambaíbaformation; 2 and 3. *Tietea singularis*. 4. *Grammatopteris freitasii;* 5. *Dadoxylon* sp.; 6. *Tietea singularis;* 7. Basal portion of *Tietea singularis;* 8. *Pecopteris* sp. (sterile pine of samambaia); 9. Fertile pine of samambaia; 10. Distal portion of *Tietea singularis* in mudstone; 11. *Tietea singularis* in mudstone; 12. *Psaronius* sp. 2 a 10, 12: Fazenda Buritirana; 11: Fazenda Vargem Limpa.

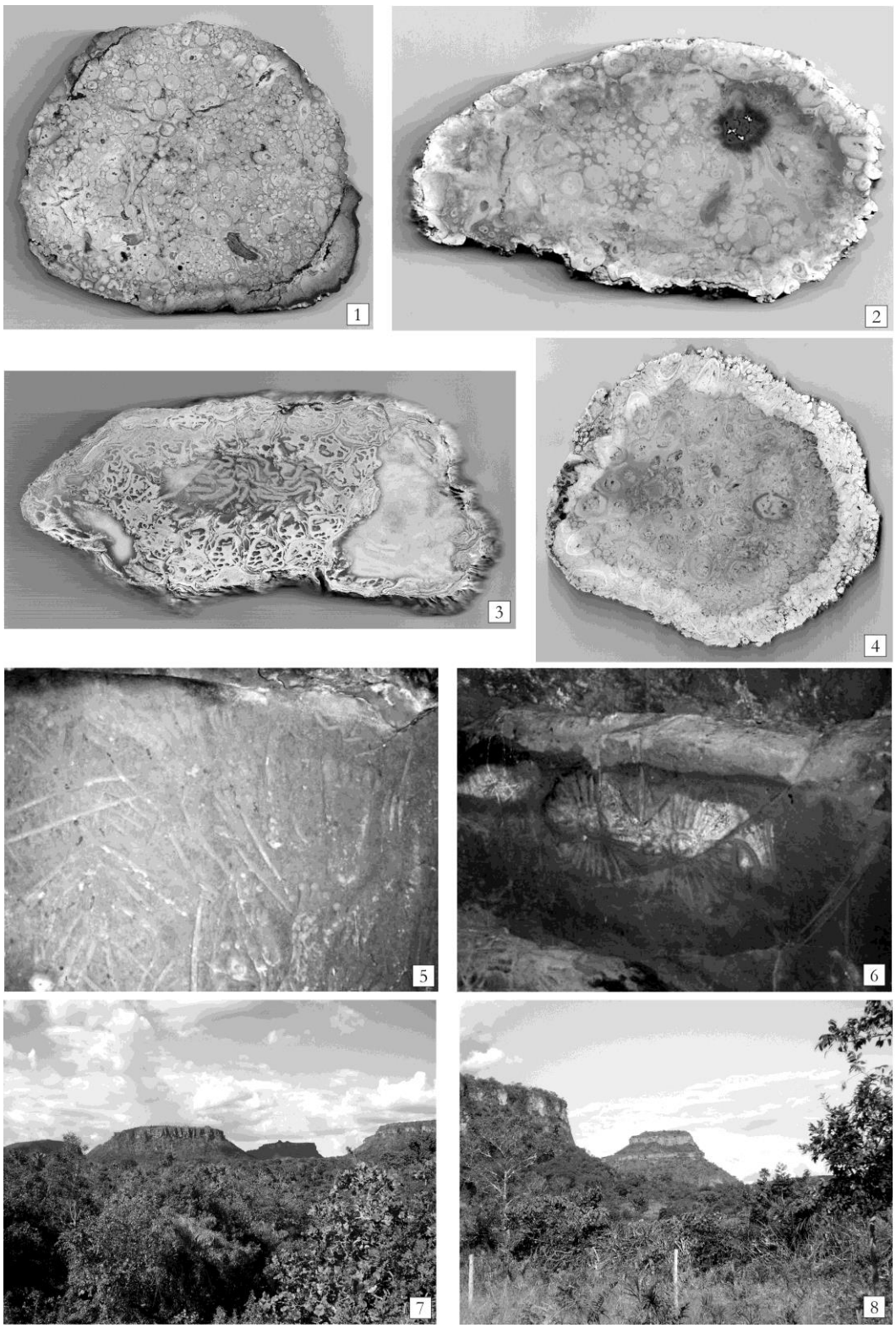

Figure 9 – Fossil plants, rupestrian draws and "mesetas" of the Sambaíba Formation. TFTNM and its surroundings. 1. Transverse section of false trunk showing five cauline members of *Botryopteris nollii* and numerous foliar members of different order and adventitious roots. Specimen MfNC K 5150 (Rössler & Galtier, 2003, pl. VII, fig. 1); 2. Transverse section of false trunk showing two cauline members of *Botryopteris nollii* and many foliar members and roots. Paratype 2, MfNC K 4880 b (Rössler & Galtier, 2003, pl. VI, fig. 1); 3. Transverse section of *Dernbachia brasiliensis*, showing the actinostelic stem surrounded by a mantle of broadly D-shaped petiole bases and adventitious roots. Taphonomic compaction resulted in a crushed trunk portion. Paratype 1, MfNC K 5002 (Rössler & Galtier, 2002b, pl. IV, fig. 1); 4. Transverse section of *Grammatopteris freitasii* from the middle to upper part of the plant showing the central large stem and the concentric zonation of its cortex as well as the root traces departing from proximal abaxial leaf traces. Paratype 4, MfNC K 4893 (Rössler & Galtier, 2002a, pl. VI, fig.1); 5 and 6. Petroglyphs in sandstone cave (Sambaíba Formation?) from Águas Formosas farm. Lat. 07°28'18"S e Long. 48°02"31"W. Altitude: 296m. IPHAN site Filadelfia I (as recorded by Núcleo Tocantinense de Arqueologia - UNITINS); 7 and 8. "Mesetas" of the Sambaíba Formation.

Taking into account the Herbst (1999), Rössler & Galtier (2002a; 2002b; 2003), and Rössler (2006)' studies, the NTPF is represented by a relatively well diversified palaeoflora, which is dominated by psaroneaceous tree ferns, such as *Tietea singularis*, *T. derbyi*, *Psaronius brasiliensis*, and *P. sinuosus* (*Tietea* is the most abundant taxon). According to Rössler (2006), the palaeoflora also include the filicalean tree fern *Grammatopteris freitasii*, the epiphytic filicalean fern *Botryopteris nollii*, the small filicalean (?) tree fern *Dernbachia brasiliensis*, and other hygrophile to mesophile floristic elements (*e.g.*, distinct species of arboreal sphenopsids of the *Arthropitys*-type, permineralized axes of herbaceous sphenopsids, or several coniferophyte trunks, *Dadoxylon*, or cordaitales).

It is important to remark that Coimbra & Mussa (1984) and Mussa & Coimbra (1987) wrote about stems from the "Cacunda sandstones" of the Motuca Formation at NW Bielândia. They noticed the presence of several calamitaleans, introducing the taxa *Arthropitys cacundensis* Mussa (Calamitaceae), *Amyelon bieloi* Mussa (Cordaitaceae), and the genus *Carolinapitys* Mussa with the species *C. maranhensis* Mussa. The latter was described as a gymnosperm with affinities to gondwanic forms and Euro-American Cordaitales, and with pith anatomy plan close to that one shown by *Scleromedulloxylon* from the Autun' Basin, France. They also noticed the presence of *Artisia* pith structures.

From Maranhão State, in the Carolina-Riachão road (around the rotary to Araguaína), fossil plants found in shales, reported as underlying the "Cacunda sandstones", also were described by Mussa & Coimbra (1987). They introduced the genus *Cyclomedulloxylon* with the species *C. parnaibensis* (then considered as a solenoid form typical of the Permian, particularly of the Early and Middle Permian), the species *Cycadoxylon brasiliense* (Pteridospermales, Cycadoxyleae), and the genus *Araguainorachis* with the species *A. simplissima*. The latter refers to a fragment that has, according those authors, a configuration close to that one found in leaf bases of both botryopterid and coenopterid ferns, but also suggesting psaroneaceous petioles. They concluded to assume *A. simplissima* as a rachis or petiole fragment of a pteridophyte or pteridosperm plant. Mussa & Coimbra (*op. cit.*) pointed out (p. 906): "*Therefore, according as new descriptions are presented, it is realized that the Pedra de Fogo floristic association presents a true Nordic affinity, a fact more and more conspicuous.*" [our italic]. It is necessary to study, in detail, the stratigraphic relationship between the Maranhão's fossiliferous occurrence and those ones of the TFTNM, Goiatins, and Colinas do Tocantins. Probably, they are patches of a same petrified forest or palaeobioma. In view of palaeoclimatic discussions, it is also very important to investigate the relationship between the Maranhão fossil plant occurrence and the pollen-bearing shale levels studied by Dino *et al.* (2002).

As previously mentioned, the fossil plants of NTPF were three-dimensionally preserved by siliceous permineralization. The infiltration and impregnation of the silica in the cells and intercellular spaces has formed an inorganic matrix, which supported the plant tissues, and preserve them. As the plants were buried too fast, and then silicified, there was not sufficient time to decompose the material. Due to the quantity of red to purple-coloured ferric constituents, and the completeness of silicification, the fossils generally show clear details of the plant tissues. Nevertheless, the origin of the siliceous permineralization agent is still unclear, although it could be connected with the formation of pedogenic silcrete nodules, which are expressive in some stratigraphic levels (Rössler, 2006). Silica nodules interpreted as silcretes suggest a locally to regionally warm humid setting in areas of very mature soil development (Milnes & Thiry, 1992) or indicate evaporation of water from the silica solution during warm-arid times (Walther, 1993).

Faria Jr. & Truckenbrod (1980, p. 746), discussing the silicification referring to the lower and upper Pedra de Fogo Formation, which is also known as "Silex Formation" (Plummer, 1946), pointed out:

> The plates that compose the intraformational breccias, 'guides' of the upper sequence, would have been formed from amorphous silica precipitation by inorganic processes or due the conversion of sodium hydrated silicate. In both cases it is necessary a restricted environment with intense evaporation and elevated pH (…). The mud cracks and the 'flat pebbles' fragments associated with the intraformational breccias support this origin. Nodules and concretions originated from diagenetic processes, in which the carbonates were substituted. It is not impossible that futures studies link the silex origin with a volcanic activity not yet known for the Permian.

Martins (2000) verified in the trunks a silica almost pure (values of SiO_2 varying between 77,27 and 99,73%), being the impurity represented by Al_2O_3, Fe_2O_3, CaO, Na_2O and TiO_2; transversal and longitudinal sections to the plant structures disclosed, under optical microscopy, granular crystalline, prismatic, and microcrystalline quartz, the calcedonia variety (fibroradial and fringed) being remarkable. According to that author, the permineralization would have occurred under temperatures below 200°C.

Importance and significance of the TFTNM and NTPF

Only a few Palaeozoic petrified forests are known. Compared with the Carboniferous, there is a

considerable decrease in the number of Permian floristic sites over the world. There are few localities deserving be mentioned as a Permian petrified forest. This is the case of the Tocantins Fossil Trees Natural Monument, TFTNM.

Due to the exceptional preservation of the fossil plants and its nature as autochthonous to para-autochthonous material, the Northern Tocantins Petrified Forest, NTPF, can be investigated in several dimensions: anatomy (almost complete plants), taxonomy, taphonomy, biochronostratigraphy, palaecology, palaeophytogeography, stratigraphy, palaeoclimatology and sedimentology. Results from these studies are very important for the geological and palaeobotanical research, in local, regional, and global scales.

On account of its palaeolatitudinal position, between lat 23º and 28º S according to current palaeogeographical reconstructions, the NTPF is the most important Permian tropical-subtropical petrified forest in the Southern Hemisphere. It is a link between the Euro-American and the Austral Gondwana (*Glossopteris* Flora) palaeofloristic provinces. This strategic position has induced geoscientists to reflect about the significance of the NTPF elements and to compare it with some other Late Palaeozoic forests. As mentioned, Coimbra & Mussa (1984) and Mussa & Coimbra (1987) foresaw relationships between the NTPF and the Euro-American tafofloristic province from their finds (*Arthropitys, Amyelon*, *Artisia*-type piths, and psaroniaceous forms). In a more advanced stage, Rössler (2006) compared the famous Early Permian petrified forest of Chemnitz, southeastern Germany, with the NTPF, and concluded:

1. both regions represented tree-fern-dominated, warm humid, seasonally influenced wetland forests [Coimbra & Mussa, 1984, also indicated wetlands as habitat of the NTPF plants due the presence of Calamitaceae and Cordaitaceae];
2. among the Permian forests, these two forests are those ones presenting the most complete stems over the world;
3. given that there is some degree of floristic similarity between the two forests, it would have occurred a large phytogeographic connection between the two areas during the Early Permian. Similar climatic conditions in the mid-Europe and Northern Tocantins, both to comparable distances of the Equator, enabled the establishment of similar megafacies belts.

The Rössler contribuition (*op. cit.*) brought and summarized the following aspects stressing the high palaeobotanical and paleophytogeographic significance of the NTPF:

- the presence of *Grammatopteris*, previously only known from Autun/France and Chemnitz, allowed to know this taxon in much greater detail than before; it can be useful to improve the understanding about the initial evolution of the Osmundaceae, the oldest-known extant fern family;
- *Botryopteris*, a very abundant taxon in Late Carboniferous equatorial wetland forests, is the first botryopterid fern (*B. nollii*) described from the Southern Hemisphere, and represents one of the largest and youngest botryopterids known to date;
- some large and almost complete stems of arborescent sphenophytes (Calamitales, including *Arthropitys*), which were highly successful and flourished in different tropical wetland environments show different types of branching patterns, far more than previously thought. It is necessary to re-evaluate all characters used for calamitales systematics with regard to their taxonomic significance;
- a significant number of plant-plant interactions were detected (*e.g.*, diarch fern roots growing inside a scrambling gymnosperm, the latter growing close to the stele of *Psaronius*; *Psaronius* root growing inside the pith of a gymnosperm; gymnosperm roots growing among adventitious aerial roots of *Grammatopteris* or at the periphery of *Tietea singularis* trunks; *Sphenophyllum* axes growing inside the borings of a calamite or within the marginal root mantle of *Grammatopteris*);
- the finds from Tocantins offer an unique opportunity to characterize in detail the fossil taxa, allowing to establish or support concepts on complete plants in a dimension never imagined possible from other localities;
- edaphical variations in the wetland environments would have controlled the distribution of sub-dominant floristic elements, such as arborescent sphenopsids and different growth forms of gymnosperms;
- regarding the gymnosperms, the finds from Tocantins reveal a somewhat exotic appearance, or sheds new light on the evolution of the morphological and anatomical characters of these plants.

Discussion

From a geoscientific point of view, the TFTNM area has key-elements to the comprehension of the Parnaíba Basin evolution. It is possible to retake discussions on the ages of the Pedra de Fogo and Motuca sediments, and keep open some questions and comments:

a. as the uppermost part of the lower Trisidela Member corresponds to the late Kungurian (late Early Permian), we indicate an age not younger than Early Permian for the Pedra de Fogo Formation. Besides, it is suggested that the lower part of the

Motuca Formation which bears fossil plants are late Kungurian to Middle Permian. The own palaeobotanical characteristics of the FPTS, as indicated by Mussa & Coimbra (1987) and Rössler (2006), suggest that these fossiliferous sediments were accumulated in some phase of this interval;

b. would have the Northern Tocantins petrified forest patches – including that ones from TFTNM and surroundings, Goiatins and Colinas do Tocantins – the same age? Are they coeval or younger than that one reported by Mussa & Coimbra (1987) from Maranhão? How this latter is stratigraphically related to the pollen-bearing shales studied by Dino *et al.* (2002)?

c. a good comprehension of the stratigraphic frame involving the horizons with fossil plants, the palynomorphs-bearing shales, and the gypsum occurrences is essential to the understanding of the regional palaeclimatic evolution. Among the referred horizons, the evaporites would be the youngest ones (middle Motuca), and the shales the oldest ones. However, new stratigraphic studies are necessary to confirm this assumption;

d. until now, interpretations based on palynomorphs and fossil plants are colliding if it is considered the gross sedimentary interval corresponding to the uppermost part of the Pedra de Fogo Formation and the base of the Motuca Formation (*sensu* Pinto & Sad, 1986). While palynological studies suggest a warm and arid to semi-arid climate, the palaeobotanical analysis indicates warm-humid conditions. This apparent conflict will disappear as the stratigraphic investigation progresses. Probably, in a context of warm climate, this interval was marked by climatic oscillation, in which semi-arid conditions (in Pedra de Fogo times) were interrupted by an important humid episode (Lower Motuca). Another scenario, several times observed (*e.g.* Schneider *et al.*, 1984) is imaginable in such a way, that, while a semi-arid regional climate predominated, densely vegetated areas coevally maintained a more humid climate on a local scale;

e. would have existed an expressive phytogeographic barrier between the Parnaíba and the Paraná basins in Permian times? Why only *Tietea* and *Psaronius* are, apparently, the only two common genera in these two basins? Are also these Psaroniales similar at the species level? What is the chronostratigraphic relationship between the deposits containing *Tietea* and *Psaronius* in these basins?

PROTECTION TO THE TFTNM

The *Tocantins Fossil Trees Natural Monument* – TFTNM, which includes important patches of the Northern Tocantins Petrified Forest – NTPF, is legally protected. At the present, this entity is a conservation unit with integral protection, created by the Tocantins State Government by means of the law nº 1179, October, 2000 (D.O. E. 981). Considering that patches of NTPF occur in the surroundings of the TFTNM, a proposal containing a re-definition of the Monument's perimeter (Dias & Reis, 2005) is being analyzed by the Tocantins State entities (SEPLAN and NATURATINS). This re-definition is important to protect other fossiliferous localities (*e.g.*, Peba farm), and to include areas with great scenic beauty, also presenting remarkable importance for the environmental conservation.

In the past, the TFTNM's area - mainly in its western side - was under active illegal exploitation of fossil plants, above all by Pedra de Fogo Mining (www.pedradefogo.com.br). This company acted selling fossils in Brazil and abroad, reaching the North-American and the European market. Bielândia is internationally known as fossiliferous locality, appearing in internet sites as origin of fossil plants on sale. Considering the scientific importance of the material, the Chemnitz Museum acquired pieces from NTPF and initiated an investigation program few years ago. From this initiative new taxonomical entities were described, mainly by Rössler (see references), and a significant progress was made improving the comprehension of the fossil forest. The protection actions to the TFTNM, and the recently signed agreements involving the São Paulo State University –UNESP, the Tocantins State Government, and the Chemnitz Natural History Museum will improve the knowledge concerning the NTPF. Not only the material will be protected, but also systematically studied. The more the knowledge expansion occurs, the more relevant the protected heritage becomes. This is in according with the TFTNM's management plan directives. Actions to create the Tocantins Natural History Museum to lodge and investigate scientific collections, and to divulgate the significance and importance of the Monument would be an excellent strategy to preserve this and other Tocantins's natural heritages. Considering the necessary visibility for the Museum, the access facilities, and its political status indicated Palmas city as location for the Museum. A field research base should be established at the interior of the TFTNM to support study projects and emphasize the importance of the area.

In the management plan for the TFTNM (MRS/OIKOS, 2005) – which has as general goal the protection and conservation of the palaeontological and biological diversities – the following priorities are among those considered more important: to obtain basic scientific knowledge concerning the unit; to expropriate some selected areas; to integrate the unit with the surroundings; to create a physical and human structure to administrate the unit. *The mentioned plan recognizes that the central problem of the TFTNM is still the illegal exploitation of the fossil plants,*

and indicates - as a fundamental action to preserve the heritage - the installation of a rigorous control and inspection program. As specific goals, the plan points out: protection to the palaeobotanical and archaeological sites, and the natural landscapes with outstanding scenic beauty; protection to the botanical, mammalian and birds species menaced to be extincted; preservation and restoration of the natural ecosystems diversity, including creation of ecological passages; to support and stimulate scientific research activities; to promote environmental education and the ecological tourism.

Inasmuch as the TFTNM is an heritage with outstanding scientific and cultural value, extrapolating the national interests, it should receive from the Brazilian authorities and society a special attention. It is a human heritage to be positively preserved.

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