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Note on the paleobiota from the Paleozoic Pimenteiras and Pedra de Fogo formations of the Central Tocantins State, Brazil

Nota sobre a Paleobiota das formações Paleozóicas Pimenteiras e Pedra de Fogo da região Central do Estado do Tocantins, Brasil

Nota sobre Paleobiota del Paleozoico formaciones Pimenteiras y Pedra de Fogo en la región central del estado de Tocantins, Brasil

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Abstract: The central of Tocantins State, northern of Brazil, has an important and diverse biota from the Paleozoic Pimenteiras and Pedra de Fogo formations (Parnaíba Basin). This paper attempts to list the biota known from each geological unit within the Central Tocantins State region using the most recently accepted definition for each formation or higher taxonomic group. The list of fauna and flora from four fossiliferous localities provided here gives a clearer understanding of the stratigraphical distribution of the Pimenteiras and Pedra de Fogo formations.

Key words: Middle Devonian, Late Permian, Parnaíba Basin, fossil biota.

Resumo: A região central do Tocantins, norte do Brasil, possui uma importante e diversificada paleobiota provenientes das formações paleozóicas Pimenteiras e Pedra de Fogo (Bacia do Parnaíba). Este artigo trata-se de uma listagem taxonômica da biota conhecida para cada uma destas unidades, se concentrando na região central do Estado do Tocantins. Este trabalho trata-se de uma listagem da biota conhecida de cada unidade geológicas da região central do Estado do Tocantins onde se usou as definições mais recentes aceitas para cada formação ou grupo superior taxonômico. A listagem de fauna e flora de quatro localidades fossilíferas que aquí apresentamos, dá uma compreensão mais detalhada da distribuição estratigráfica das formações Pimenteiras e Pedra de Fogo.
Palavras-chave: Devoniano Médio, Permiano Superior, Bacia do Parnaíba, biota fossil.

Resumen: La región central de Tocantins, norte de Brasil, una paleobiota importante y diversa de las formaciones paleozoicas Pimenteiras y Pedra de Fogo (Cuenca del Parnaíba). Este trabajo trata es un listagem conocida de la biota de cada unidad geológica de la región central del Estado de Tocantins donde utilizó las últimas definiciones aceptadas para cada entrenamiento o superior grupo taxonómico. Definiciones más recientemente aceptados para cada grupo taxonómico se utilizaron en este estudio. La lista de la fauna y flora cuatro localidades fosilíferas que aquí se presenta, da una comprensión más detallada de la distribución estratigráfica de las formaciones Pimenteiras y Pedra de Fogo.
Palabras clave: Medio Devónico, Pérmico, la Cuenca del Parnaíba, biota fósil.

INTRODUCTION

The Pimenteiras and Pedra de Fogo formations (Parnaíba Basin) of Central Tocantins State, Brazil, contains one of the most diverse Devonian and Permian fossil assemblages represented by invertebrates and paleoichthyofauna in the country (see summary Tab. 1). Fossil-bearing strata of fluvial and eolian lacustrine facies are exposed over an area of 600.000 km² (BRITO, 1981). These same geologic units are exposed in Maranhão and Piauí states, where the fossils ~~they contain~~ are better known than in Tocantins.

Fossil remains in this basin were first discovered in 1977 near Tocantínia municipality, Tocantins State (Pimenteiras Formation). During the last century, few studies of these fossils were made, but important fossil sites were discovered in the northern Tocantins State region. Recently, fieldwork conducted by the Federal University of Tocantins Paleobiology Laboratory at four new fossiliferous localities. Eolian and fluvio-lacustine sediments of the Pedra de Fogo Formation have yielded diverse sharks,

abundant remains of ostheichthyan fishes, large pieces of petrified wood, and invertebrate groups including crinoids, brachiopods, mollusks and ichnofossils of the Pimenteiras Formation (SANTOS; CARVALHO, 2005).

The Best-known vertebrate and plant taxa occur in the Pedra de Fogo Formation. This unit is exposed in central Tocantins, southern Maranhão, and northern Piauí states. In contrast, the Pimenteiras Formation has produced only invertebrate remains and rare records of plants.

The purpose of this paper is to review the fossil content from the Pimenteiras and Pedra de Fogo formations and to report their occurrence to the wider paleontological community. As documented below, highlights of the fossil record of central Tocantins State include a typical Paleozoic biota (from the marine and continental Pimenteiras and Pedra de Fogo formations). We show that many of the late Paleozoic taxa (especially sharks) of the Parnaíba Basin have systematic and paleobiogeographic importance.

METHODS

This research was divided into three methods: (1) a literature synthesis; (2) an annotated bibliography; and, (3) additional references. The scientific reference synthesis and annotated bibliography focus on Central Tocantins State region and on refereed journal publications. Additional references include a selection of citations on geology and paleobiota.

GEOLOGICAL AND PALEONTOLOGICAL SETTING

The Parnaíba Basin (Fig. 1) is an important fossil-bearing location in northern Brazil, with strata ranging in age from the Cambrian to the Lower Cretaceous, includes parts of western Piauí, Maranhão, Ceará and Tocantins states and covers an area of 600 square kilometers (BRITO, 1979).

Goés and Feijo (1994), subdivided this basin into the Silurian Serra Grande Group, the Devonian Canindé Group, the Carboniferous-Triassic Balsas Group, and the Jurassic-Cretaceous Mearim Group. The most fossiliferous strata of the Parnaíba Basin in Tocantins state are represented by the Devonian Pimenteiras (Canindé Group) and the

Permian Pedra de Fogo (Balsas Group) formations (GOÉS; FEIJÓ, 1994), which covered a large area of North-central Tocantins state (Fig. 1).

The Pimenteiras Formation (GOÉS; FEIJÓ, *op cit.*) consists of gray shales and fine-grained sandstones, with abundant invertebrate remains. The lithology consists of shale with intercalating sandstones.

The Pedra de Fogo Formation comprises a westward-thinning series of paralic sandstones interbedded with shales deposited in a costal plain environment with a rich vertebrate fauna and a pteridophyta records.

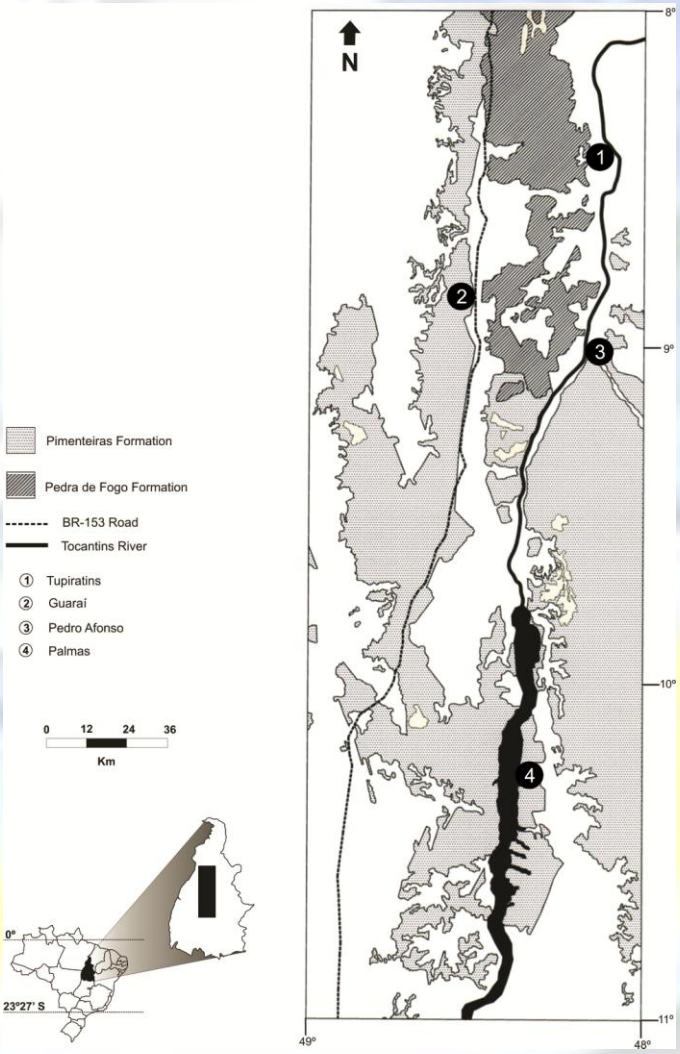

Figure 1 - Distribution of Paleozoic in the Parnaíba Basin and the prolific Tocantins state fossil localities which are discussed in the text.

Pimenteiras Formation

The Pimenteiras Formation is exposed in the Maranhão, Piauí and Tocantins states. Its sediments are marine shales, deposited during warm and humid climatic events (LIMA; LEITE, 1978; SCISLEWSKI *et al.*, 1983). Based primarily on their invertebrate fossil content, the Pimenteiras sediments are considered to have been deposited during the Devonian (BRITO, 1979; AGOSTINHO *et al.*, 2004). According to Scislewski *et al.* (1983), the Pimenteiras Formation (Fig. 1) consists predominantly of shales with frequent occurrences of micaceous siltstone, and is topped by 2 m of black clay shales in the Miranorte and Tocantínia area. Siderites and calcareous concretions are common in the middle and upper divisions of the section.

The marine origin of the Pimenteiras Formation is inferred from its invertebrate fossil content. The unit was most likely deposited in a neritic marine shelf environment (BRITO, 1979). According to Lima and Leite (1978) the fining upward sequence and the change of fauna in the different intervals in the outcrop indicate a transgressive phase in a shallow-water marine environment. According to Goés and Feijó (1994), this unit shows gradual changes in the environment, with a possible variation in coastline.

Their fossil records are featured by a diverse fauna of marine invertebrates, that include brachiopods, trilobites, ostracods, bivalves, gastropods, hyolithids, and tentaculids (FONSECA, 2004), together with elasmobranches and plants (*e.g.* MAISEY; MELO, 2005; GRAHN *et al.*, 2006). In Central Tocantins State, this fossiliferous Devonian succession is mainly exposed in Miranorte, Tocantínia and Palmas municipalities. In case of Miranorte and Tocantínia outcrops, invertebrates records are represented by the ichnofossils *Bifungites* isp., *Nereites missouriensis* Weller, 1899, *Rusophycus polonica* Seilacher, 1970, and *Trichophycus* isp. The occurrence of ichnotaxa like *Neiretes*, *Rusophycus* and *Trichophycus* represent the first devonian known record in Brazil (CORREIA *et al.*, 2004). ~~In~~ Palmas has yielded fossil record typical of the Pimenteiras formation [abundant calyx plate, colunmals and pluricolunmals of crinoids, brachiopods and mollusk~~s~~ shells, together with conulariids and tentaculitids (see tab 1)]. Recently, new outcrops have been discovered, and increased significantly the geographical distribution of marine invertebrates in Central Tocantins State. In two sites of Santa Tereza, Queiroz *et al* (2013) pointed the presence of three brachiopods like *Australocoelia palmata* (Morris and Sharpe, 1846), *Australospirifer iheringi* (Kaiser, 1990) and *Tropidoleptus carinatus* (Conrad, 1839), columns of crinoids assigned to *Exaesiodiscus* and valves of indeterminate bivalvia mollusks.

Pedra de Fogo Formation

This formation is mainly exposed in northern Tocantins (Fig. 1), Maranhão, and Piauí states. Lithologically, these strata are composed of freshwater limestones, sandstones, and based conglomerate, all cemented by carbonate (BRITO, 1981). The Pedra de Fogo Formation is up to 189 m thick (PETRI; FÚLFARO, 1988). According to Dino *et al.* (2002), it is divided into three subunits which from base to top are: Silex Basal, Middle and Trisidela members (FARIA JR; TRUCKENBRODT, 1980). The Silex Basal Member is composed of grey, brown siltsones and shales interbedded by dolomitic banks, sparse siliceous concretions, and fine sandstones. The Middle Member is composed of sandstone and siltstone with carbonate and the top of this subunit is composed by shale intercalated with silex and intraformational breccia.

The fossiliferous Trisidela Member is composed of fluvial channel grey dolomitic banks interbedded with siltstones and calcareous shales or marls with silicified concretions. Sandstones are common. A remarkable fossil discovery in this unit are chondrichthyan diversity described by Silva Santos (1946, 1990, 1994), like fin spines of 'ctenacanthid' and teeth of 'xenacanthid' sharks; teeth of eugeneodontids and petalodontids. There were also found temnospondils remains; dipnoan tooth plates; scales and skull bones of coelacanthids and palaeoniscoids; and petrified pteridophites (*e.g.* COX; HUTCHINSON, 1991; SANTOS; CARVALHO, 2005; TOLEDO; BERTINI, 2005; DIAS-BRITO *et al.*, 2007).

The fossiliferous early Late Permian deposits of Central Tocantins State are mainly located in the municipalities of Guarai, Pedro Afonso and Tupiratins. These areas contain a fossil record typical of the Pedra de Fogo formation. A new locality in Guarai has yielded abundant ctenacanth finespines and 'cladodont' teeth which are recently described by Richter (2008).There are also abundant scales and skeletal material of actinistia and actinopterigyan fishes (ALVES, 2010a and b). Together with this diverse fish assemblage large pieces of petrified wood of the fossil pterydophytes have been found. In Pedro Afonso and Tupiratins a petrified forest is also preserved, where *Psaronius* and unidentified gymnosperms are ~~found~~ dispersed.

Age of fossil-bearing sediments in the Central Tocantins State region

The Devonian age of the Pimenteiras Formation was regarded by Brito (1979) on the basis of similarities between invertebrate of the Pimenteiras and Ponta Grossa (Paraná Basin) formations (crinoids, trilobites, brachiopods). In addition, an integrated study of chitinozoan and miospore zonation realized by Grahn *et al. (*2006) suggested the fossil bearing interval to middle Eifelian-early Famennian (Middle Devonian).

The fossil-bearing Pedra de Fogo Formation yields the famous amphibian labyrinthodont *Prionosuchus plumieri* Price, 1948, and palynomorphs, ostracods, sharks and fishes (BARBERENA, 1972; RICHTER, 2008; ALVES *et al.*, 2008; TOLEDO; BERTINI, 2005; DIAS-BRITO *et al.*, 2007). The age of these deposits, based on the mentioned fossil is probably Permian age by Barberena (1972) and Rößler and Galtier (2002a,b). Despite the importance of this fossil assemblage, the age of this fossil-bearing interval is not completely settled. Lima and Leite (1978) and Dias-Brito *et al*. (2007) assumed it to be the Early/Middle Permian based on sporomorphs, paleoflora (*Psaronius*) and paleoichthyofauna. Recently Dino *et al*. (2002) obtained the Late Permian age to Pedra de Fogo Formation based on the palyno-assemblage content and we used this age here.

Fossiliferous localities within the Central Tocantins State

Four Late Permian fossiliferous localities within the Central Tocantins State are recognized in this work (Fig. 1, Table 1).

Locality 1 (one site): Tupiratins. Horizon: Pedra de Fogo Formation, Trisidela Member. Lithology: the Pedra de Fogo Formation fossil content originates from localities 1, 2 and 3 in the Central Tocantins State area (Fig. 1); these sediments are represented by light-gray to dark-gray, massive, cherty limestone. In the Trisidela beds, bear white limestone and dolomite in middle part, yellowish-white, fine to medium-grained, trough cross-bedded, massive sandstone interbedded with lesser amounts of gray to white-gray (Fig. 2). Age: Late Permian (DINO *et at.*, 2002). Fossil content: *Psaronius* and indeterminate gymnosperms (Table 1).

Locality 2 (two sites): Guarai. Horizon: Pedra de Fogo Formation, Trisidela Member. Lithology: Pedra de Fogo Formation (see lithology description of Locality 1) (Fig. 2). Age:

Late Permian (DINO *et at.*, 2002). Fossil content: Chondrichthyes indet., Ctenacanthidae indet., 'cladodont' indet., Actinistia indet., Paleoniscidae indet., Pteridophyta indet. (Table 1).

Locality 3 (one site): Pedro Afonso. Horizon: Pedra de Fogo Formation, Trisidela Member. Lithology: Pedra de Fogo Formation (see lithology description of Locality 1). Age: Late Permian (DINO *et at.*, 2002). Fossil content: *Psaronius*. (Table 1).

Locality 4 (three sites): Palmas. Horizon: Pimenteiras Formation. Lithology: these sediments are represented by medium- to dark-gray and olive-gray shale that is commonly carbonaceous, interbedded with silty shale, brown sandstone (Fig. 1). Age: Middle Devonian (BRITO, 1979; AGOSTINHO *et al*., 2004). Fossil content: *Laudonomphalus* cf. *tuberosus* (Yeltysheva, 1961), *Exaesiodiscus dimerocrinosus* Scchеffler *et al*, 2011, *Monstrocrinus incognitus* Scheffler *et al*, 2011 and Orthida indet.; *Montsenetes carolinae* Fonseca, 2004, *Australocoelia palmate* (Morrris and Sharpe, 1846), *Mucrospirifer pedroanus* (Rathbun, 1874), *Amphigenia* cf. *elongates* (Vanuxem, 1842), *Tropidoleptus caninatus* (Conrad, 1939) and Orthida brachipods; shells of gastropods; tentaculitids and Conulariids indetermites (Table 1).

Figure 2 - Lithologic profile and Geologic chart. Generalized lithologic profile of the Pimenteiras and Pedra de Fogo formations from Central Tocantins State region. Simplified stratigraphic columns of the Pimenteiras and Pedra de Fogo formations (Paranaíba Basin). Shaded unities represent known fossil-bearing from Central Tocantins State. (Adapted from GOÉS *et al.*, 1990 and DINO *et al.*, 2002).

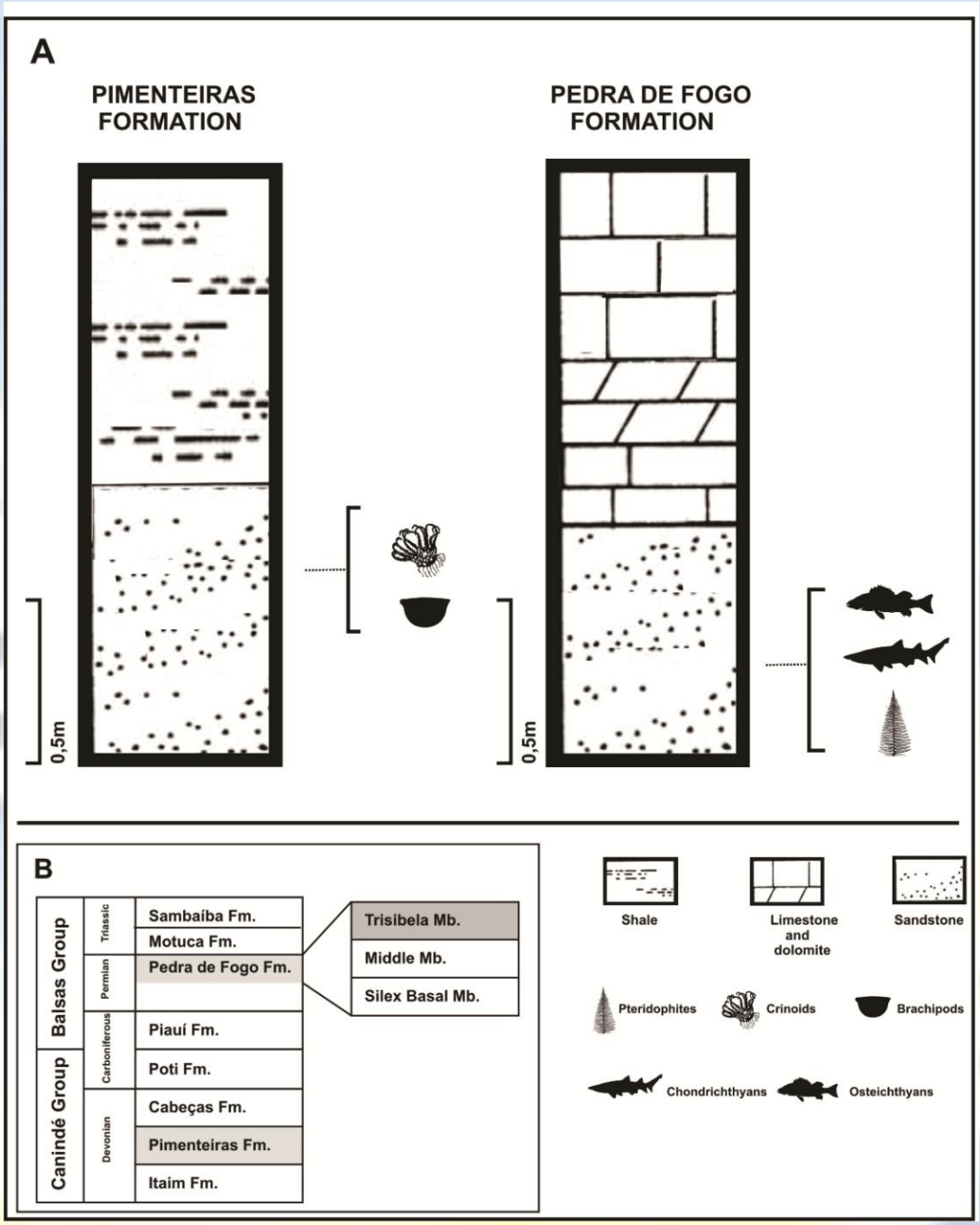

Table 1 - Fossil biota from the Parnaíba Basin (Pimenteiras and Pedra de Fogo formations), Central Tocantins state. **GS1**, Guaraí site 1, **GS2,** Guaraí site 2, **TUP**, Tupiratins site, **PAF**, Pedro Afonso site, **ECS**, Estância Cantilena site (Palmas), **FE2**, Fazenda Encantada II site (Palmas), **MTS**, "Mirante" Taquaruçu site (Palmas),**FBH**, Fazenda Belo Horizonte site (Palmas).

Geologic Unit	Taxa	Locality	Reference
Pedra de Fogo Fm	Ctenacanthidae indet.	GS1 and GS2	Richter (2008)
	Glikmanius indet.	GS1 and GS2	Richter (2008)
	Actinistia indet.	GS1 and GS2	Alves (2010a and b)
	Paleoniscidae indet.	GS1 and GS2	Alves (2010a and b)
	Pteridophyta indet.	GS2	Richter (2008)
	Psaronius	TUP	Lima and Leite (1978)
	Gimnospermas indet.	TUP	Lima and Leite (1978)
	Psaronius	PAF	Campos and Campos (1975)
Pimenteiras Fm	*Exaesiodiscus dimericrinosus*	ECS and MSJ	Scheffler *et al.* (2011)
	Monstrocrinus incognitus	FE2	Scheffler *et al.* (2011)
	Laudonomphalus cf. *tuberosus*	ECS and MTS	Scheffler *et al.* (2011)
	Laudonomphalus cf. *regularis*	ECS, MTS	Scheffler *et al.* (2011)
	Orthida indet.	ECS, FBH	Rodrigues da Silva and Candeiro (2013)
	Montsenetes carolinae	FE2 and ECS	Mendes (2008)
	Australocoelia palmata	FE2	Mendes (2008)
	Mucrospirifer pedroanus	FE2 and ECS	Mendes (2008)
	Amphigenia cf. *elongata*	FE2	Mendes (2008)
	Tropidoleptus carinatus	FE2	Mendes (2008)
	Gastropoda indet.	MTS, ECS and FE2	Scheffler *et al.* (2011)
	Conulariida indet.	MTS, ECS and FE2	Scheffler *et al.* (2011)
	Tentaculites indet.	MTS, ECS and FE2	Scheffler *et al.* (2011)
	Bivalvia indet.	MTS, ECS and FE2	Scheffler *et al.* (2011)
	Ichnofossil indet.	FBH	Agostinho *et al*. (2004)

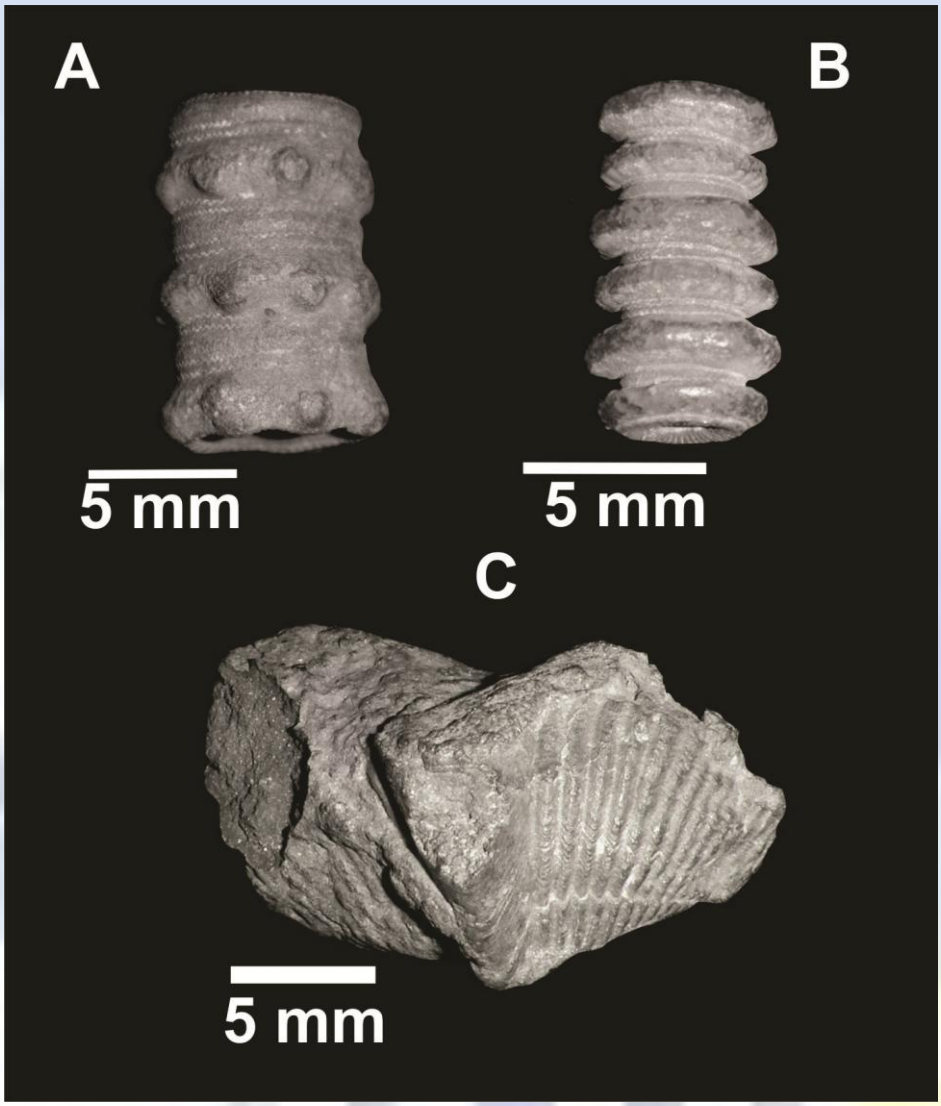

Figure 3 - Invertebrates from Devonian Pimenteiras Formation in the municipality of Palmas, Tocantins State. **A,** Pluricolumnals of *Laudonomphalus* cf. *tuberosus* (UFT-0304); **B,** Pluricolumnals of *Laudonomphalus* cf. *regularis* (UFT-0408); **C,** fragmentary external mold of *Mucrospirifer pedroanus* **(**UFT-329**).**

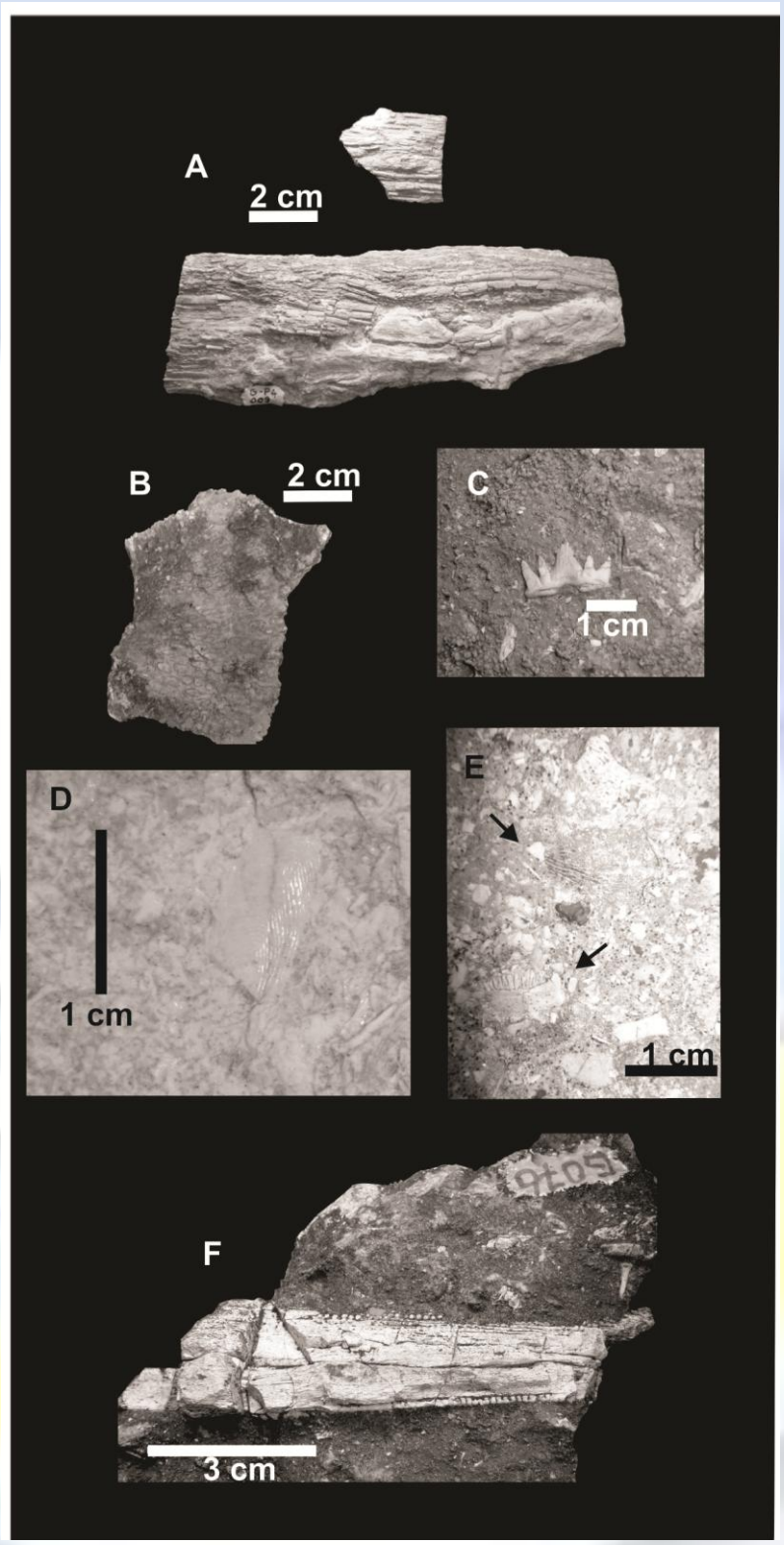

Figure 4 – Plant and chondrichthyan remains from Permian Pedra de Fogo Formation in the municipality of Guaraí, Tocantins State. **A,** Longituginal view of *Psaronius* wood (G-P4009)**; B,** Cross section of *Psaronius* wood **(**G-p4010**), C,** pentacuspid tooth of ?*Glikmanius* indet. **(**G-110**); D,** ganoid scales of Paleoniscidae indet**. (**G-040**)**; **E**, pectoral fin, ?jaw and bones remains of osteichthyan indet. (G-168); **F**, dorsal fin spines of Ctenacanthidae indet. (G-076).

DISCUSSION

The fossil record of invertebrates and vertebrates in the central part of Tocantins from the Pimenteiras and Pedra de Fogo formations have been recognized since the early XIX Century. The fossil pteridophyte *Psaronius brasiliensis* was collected in 1817 and 1920 by the botanist Martius and described by Brongniart (1872), and was the first fossil plant from the Parnaíba Basin to be described (DOLIANITI, 1948).

Although the diversity of brachiopods and crinoids from the Pimenteiras Formation and sharks from the Pedra de Fogo Formation is well known, these beds also yield an impressive and important array of pteridophytes, osteichthyan and actinopterigyan fishes (Fig. 3, 4; Table 1), and ichnofossils (SANTOS; CARVALHO, 2005). Temnospondyl amphibians have not yet been recorded from Tocantins state, but have been reported from the Pedra de Fogo Formation in Maranhão State. Whereas the literature on the systematics and taxonomy of invertebrates and vertebrates from the Pimenteiras and Pedra de Fogo Formation is significant, there have been relatively few paleontologic studies made in central Tocantins state. In contrast, the fossil content of these same rock units in Maranhão and Piauí states is better known.

From the Pimenteiras and Pedra de Fogo formations in Guarai, chondrichthyans are most abundant in the Pedra de Fogo Formation, a prolific fossil-producing unit that has yielded several taxa of Late Permian age. On average, a new shark site has been found in the Pedra de Fogo Formation each year since 2004. No other Paleozoic unit in Tocantins has yielded as many sharks. Alves *et al*. (2008) attributed this abundance of sharks in the Pedra de Fogo Formation to a unique combination of depositional parameters within a marine to continental environment, which have been reported based on geological and faunal evidence. A marine community of sharks, i.e. ctenachanthid and ‘cladodont’ (Table 1) along with freshwater taxa are known from the Trisibela Member (Pedra de Fogo) of the Tocantins (RITCHTER, 2008; ALVES *et al.*, 2008), and the others chondrichthyans Silva Santos (1946, 1991, 1994). The fish taxa represent benthonic conditions where climate was warm. Such an admixture of epicontinental sea and non-marine elements was explained by RICHTER (2008) on the basis of the presence of chondrichthyans in the Pedra de Fogo Formation, from where certain fishes could make frequent upstream incursions. This biota represents a mixture of both marine and continental depositional systems from the Late Paleozoic history of Pangaea.

CONCLUSION

The Paleozoic Parnaíba Basin of central Tocantins state contains two of the most productive invertebrate and vertebrate-bearing formations from the Parnaíba Basin. Researchers have scoured the Pimenteiras and Pedra de Fogo Formations for fossils since the early years of the 19th Century, and have discovered and described a wide array of 14 invertebrates, four vertebrates and two plants taxa. The numerous bone beds preserved within these two formations provide important clues to the Paleozoic biota of northern Brazil. The list of known fauna from the Pimenteiras and Pedra de Fogo formations includes marine crinoids, brachiopods, sharks, coelacanths and paleoniscids and continental pteridophytes and gimnosperms Pangean taxa.

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