Sponge spicules as proxy in Upper Quaternary lake deposits near Cianorte (PR): a tentative correlation with lakes of Central-Southern Brazil (NW Paraná and SE Mato Grosso do Sul

Espículas de esponjas como proxy em depósitos de lagoa do Quaternário Superior próximo a Cianorte, PR – uma tentativa de correlação com lagoas do Centro-Sul do Brasil (NO do Paraná e SE do Mato Grosso do Sul)

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Abstract

Researchers recognize the use of bio-proxy in Quaternary paleo environment reconstruction for more than 50 years. Among the bio-indicators, pollens and spores are, by far, the most used palynomorphs, followed by diatoms. However, oxidizing conditions can destroy and leach organic material. In such cases, sponge spicules, with siliceous skeleton, resist geochemist weathering and diagenesis, preserving in the sediment. This paper proposes an experimental correlation between sponge analyses obtained from lakes sediment in the NW Paraná and SE Mato Grosso do Sul States, Brazil, in a pioneering attempt of paleoclimatic data integration for the south-central Brazil. The structures used to identify the sponges were megascleres, microscleres and gemmoscleres. Both short- and long-distance correlations were satisfactory. Although a temporal and genetic correlation between lakes of NW Paraná and SE Mato Grosso do Sul lakes has been observed, their hydrological functioning was different.

Key-words: sponge spicules, palinology, continental Quaternary, lake paleolimnology, Paraná State

Resumo

O uso de *bio-proxy* na reconstrução climática de paleoambientes é reconhecido por pesquisadores do Quaternário há mais de 50 anos. Entre os bio-indicadores, provavelmente pólens e esporos são, de longe, os mais utilizados além de palinomorfos, seguidos por diatomáceas. Com tudo, tais indicadores são facilmente destruídos pela oxidação. Espículas de esponjas, por seu esqueleto silicoso, resistem ao desgaste geoquímico, preservando-se no sedimento. Este artigo propõe uma correlação experimental de análise paleoambiental a partir de dados de esponjas obtidos de sedimentos de lagoas isoladas no NO do Paraná e sua comparação com lagoas no SE do Mato Grosso do Sul e na confluência dos rios Paraná e Ivaí numa tentativa pioneira de integração de dados paleoclimáticos para o Centro-Sul do Brasil. As estruturas utilizadas para identificação das esponjas foram megascleras, microscleras e gemoscleras. A comparação dos resultados entre as lagoas foi satisfatória. Ampla diversidade de espécies esponjas foi encontrada na Lagoa Fazenda PR, típicas dos ambientes mais secos com mudanças sazonais. Nas lagoas Seca foram encontradas megascleras de *Metania spinata* e fragmentos de gemoscleras de *Dosilia pydanieli* que indicam ambiente com oscilação de condições de umidade.

Palavras-chave: espículas de esponja, palinologia, Quaternário continental, paleolomnologia de lagos, Estado do Paraná

Introduction

Brazilian South-central landscapes were strongly modified by the Quaternary climatic changes. Only during the Last Glacial Maximum, this huge area suffered intensive alterations in the vegetation cover, with changes of the "Cerrado" (Brazilian savanna) and pluvial forest (Absy *et al.* 1989, Ledru 1993, Van der Hammen *et al.* 1992, Thomaz & Thorp 1995), and in rivers and lakes hydrology (Stevaux *et al.* 1997). In addition, in dryer periods, the intensive action of wind, formed small dune fields and deflation pans (Latrubesse *et al.* 2005, Barreto 1996, Parolin & Stevaux 2001).

Researchers recognize the use of bio-proxy in Quaternary paleoenvironments reconstruction for more than 50 years. Among the bio-indicators, probably pollen and spores are by far, the most used palynomorphes followed by diatoms frustules (Bell & Walker 1992). The problem with the first two is

their preservation in oxidizing environment. Under this condition, organic material is destroyed and leached. The siliceous composition of the freshwater sponge skeleton (Pennak 1953) has greater resistance to weathering, favoring its preservation in sediments (Volkmer-Ribeiro & Motta, 1995, Volkmer-Ribeiro & Turcq 1995). This fact increases the potential of using of sponge spicules in continental and marine tropical sediments. Sponges are animals strongly related with their habitat and unlike the pollen and spores, are considered good indicators of local environments (i.e. lake). Because their wide dispersion, pollens offer data about the composition of regional vegetation and thus paleoclimate inferences. The sponges, due to their high sensibility to environmental conditions give important information on water quality, temperature and flow of a specific environment. Many studies presented significant results with sponge spicules in Quaternary sediments in various locations in Brazil, especially in lake sediments in the southwest of Minas Gerais and south of Mato Grosso do Sul (Volkmer-Ribeiro & Motta 1995, Silva 2004, Parolin *et al.* 2008), in Catalão, Goiás (Machado 2009, Machado *et al.* 2012), in the Pantanal wetlands (Kurten *et al.* 2013) and in northwestern Paraná (Guerreiro *et al.* 2013).

This paper proposes a tentative correlation of paleoenvironmental sponge spicules analysis obtained from sediments of the isolated lakes in the NW Paraná State (Fazenda and Seca Lakes). A regional correlation is also attempted with the data from peaty and lakes sediments of the Taquarussu Unit in southeastern Mato Grosso do Sul State (Parolin 2006, Parolin *et al.* 2006) and lakes sediments of northwesthern Paraná (Guerreiro *et al.* 2013) (figure 1).

Geomorphological and Quanternary Background Information

There are three types of lakes in the region that comprising northwest of the Paraná State and the southeastern of the Mato Grosso do Sul State. Sedimentary archives of these lakes preserved important records of paleoclimatic changes since Late Pleistocene to Late Holocene. The first type includes lakes associated with Paraná and Ivaí Rivers floodplains, formed by the abandoned channels and meanders cut-off. Most of these lake sediments are Late Holocene in age, younger than 3 ky BP (Bubena 2006). The second type is associated with pseudo-karst features in Pleistocene sediments of the Taquarussu Unit (Stevaux 1994), which generated hundreds of small shallow lakes, ponds and dry depressions, wich can be interconnect by superficial channels. The oldest sediment of these lakes reached Late Pleistocene (Stevaux 1994, Parolin 2006, Parolin *et al.* 2006, Guerreiro *et al.* 2003). Linda, Samambaia, Dos 32, Milharal and Coceira are lakes of type two (figure 1). Many of this lakes were artificially drained for agricultural purposes and lost their limnologic characteristics.

The third type are isolated shallow lakes (depth <2 m) that cover soils formed by the decomposition of basaltic rocks of the Paraná Basin between 300 and 500 m a.s.l. These types include the Seca and Fazenda Lakes. This study is based in sediments of the second and third types (figure 1).

The Quaternary paleoclimatic changes modified the regional landscape by alternating dry and wet phase since the Late Pleistocene. Data for Quaternary changes studies made in the area came from fluvial terraces and lacustrine deposits on both banks of Paraná River (Jabur 1992, Stevaux 1994, Parolin 2006, Guerreiro 2011), confluence of the Ivaí and Paraná Rivers (Santos 1997, Santos *et al.* 2008, Morais *et al.* 2016) and isolated lakes in basaltic rocks of Paraná Basin (Fernandes 2008).

Four events of climatic changes were recognized by Stevaux (1993, 1994) in the Upper Paraná River area with regional correspondence in other places in South America (Iriondo 1990, Iriondo & Garcia 1993), in which two dry phases were alternated for two wet episodes with important transformations in the landscape scenery:

a) *First dry event*: Palinological and sedimentary data indicate occurrence of semiarid arid climate and flash-flood discharges age MIS 2, around the Last Glacial Maximum;

b) *First humid event*: This event is defined between the limit Pleistocene-Holocene with a peak of humidity around 8000-7000 y BP (Climatic Optimum). Deposits associated to this events are found in the flood plain of the Paraná River and in some intervals in lake deposits. The increase in rainfall produced large discharges in this river with a vertical incision of the ancient surface generating 10 m high terraces over the present water level. Similar conditions were recognized in many others fluvial systems in south central of Brazil (Stevaux *et al.* 1997, Salgado-Labouriau 2004).

c) *Second dry event*: A short dry event occurred in the Middle-Late Holocene between 3500 to 1500 y BP. Although not so strong, the aridity in this event was recognized by the changes in palinological records, lower content of organic matter and small dune field formation (with dunes up to 10 m height) in the SE of the Mato Grosso do Sul State (Parolin & Stevaux 2004). This dryer event was also identified by Iriondo (1990) in NW Argentine, and in the Rio Grande do Sul State (Brazil) by Kröhling & Iriondo (1988).

d) *Second humid event*: Rain forest expansion from the valleys and increasing of precipitation after 1500 y BP to the present day was assumed with establishment of the modern landscape.

Fazenda and Seca are shallow lakes (~1.5 m depth) with a circular morphology with approximately 108 and 86 m², respectively (figure 2). Seca Lake is practically a swamp with dry portions covered by grassy vegetation. Both lakes are situated in private preservation areas and surrounded by remaining of Mata Atlantica rain forest. Following the intensive deforestation since the 1950's

for commercial timber exploration and latterly coffee plantation, the area suffered an expressive change in vegetal covering. Only 3% of the original forest remaining in a few fragments surrounding by extensive soybean and sugarcane plantations (IPARDES 2002). The regional climate is subtropical mesothermic, with mean temperature varying from 18° to 22°C, annual rainfall of 1443 mm with a well- defined dry season in the winter (Nimer 1989, Andrade 2003).

Methods

Cores were extracted by Livingstone (Colinvaux *et al.* 1999) and vibro-coring (Martin, Flexor & Suguio 1995), processed and described at the Palynology and Paleobotany Laboratory at the Gurarulhos University, São Paulo State and at the Laboratório de Estudos Paleoambientais da Faculdade Estadual de Ciências e Letras de Campo Mourão (Lepafe), Paraná State. ^{14}C samples were processed in Beta Analytic Inc., Miami, USA.

The samples for spicules analysis were processed according to Volkmer (1999, 1995), Volkmer-Ribeiro & Turcq (1996). Four slides were prepared from each sediment sample and were analyzed and photographed under microscope. The slide collection is deposited at Lepafe.

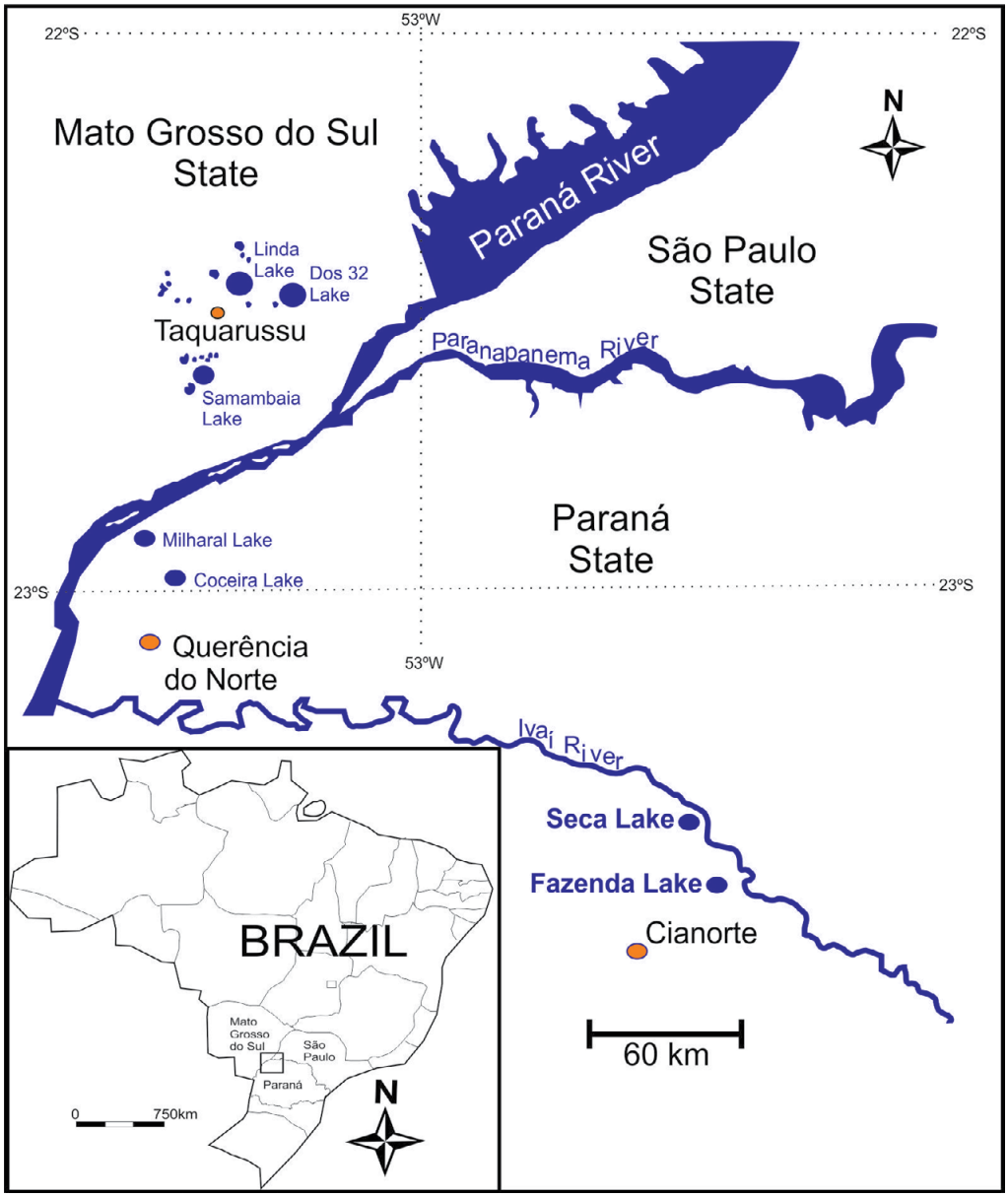

Figure 1. Location map of study areas.

The sponge spicules were identified by the collection and bibliography available at Lepafe. The specific identification keys and spicule nomenclature were provided by Volkmer-Ribeiro & Pauls (2000) and included:

megascleres: spicules that integrate the sponge skeletal network; *microscleres:*

smaller spicules that are mingled in the sponge skeleton; and *gemmoscleres:* spicules that cover the *gemmules* and which ultimately define families, genera and species in freshwater sponges. For the quantification of spicules, 35 transects counting was performed on two slides for each depth (table 1).

Table 1 - Estimates used to score spicules

Number of spicules	Condition
≤ 50	Very rare
51-150	Rare
150-500	Common
≥500	Abundant

1. Results

a) *Sedimentary analysis and chronology*:

Cores obtained in Fazenda and Seca Lakes reached 1.00 and 2.60 m depth, respectively, with relatively similar stratigraphy. They are formed by clayey deposits in the lower section with an increasing of organic matter content to the top (figure 2). Fazenda Lake' sediments have low content of organic material present only (5%) in the upper 0.30 m, while in the Seca Lake organic sediment appears in the base with 3 – 5%, increasing to 11 to 13% in the upper 0.80 m. The Seca lake deposits present sedimentation rate of 0.12 $mm.y^{-1}$ for all interval, while the Fazenda Lake has values ten times less varying from 0.01 to 0.03 $mm.y^{-1}$ in the base increasing to the same value of Seca Lake up to the top (Fernandes 2008).

^{14}C dates reach Late Pleistocene ages in the lower part for both cores: 19.85 ka BP to the Seca Lake and 13.20 ka BP to Fazenda Lake. The middle section of the Fazenda Lake was dated Lower to Middle Holocene (8.39 ka BP e 6.71 ka BP) while the base of upper section belongs to the Upper Holocene (2.18 ka BP).

b) *Sponge analysis:*

Fazenda Lake core presented more diversity and detailed content of sponge spicules. This is the best core for pollens, sponge spicules and datable material. Four species of sponges were identified sediments of both cores, including *Dosilia pydanieli* (Volkmer-Ribeiro 1992), *Tubella variabilis* (Bonetto & Ezcurra de Drago 1973), *Heterorotula fistula* (Volkmer & Motta 1995) and *Metania spinata* (Carter 1881). All these species has similar environmental preferences and tolerance for seasonal environmental changes (Volkmer-Ribeiro 1992). *D. pydanieli* current lives encrusted on submersed logs and leaves available in shallow, shaded (by trees), lacustrine environments with seasonal dry season. This species is found from the extreme northern Brazil (Roraima State) up to Southtern Brazil (Paraná State) (Volkmer-Ribeiro 1992, Rezende 2010). *M. spinata* leaves in small lakes occupies the lake environment as a whole (bottom to water surface); *T. variabilis* lives under leaves or branches or underwater in shaded sites in lentic environment. It occurs from Roraima to Entre Rios Province in Argentina (Bonetto & Ezcurra de Drago 1973).

According to Volkmer-Ribeiro & Motta (1995), the species *H. fistula* also indicates lentic environment in spite of any living specimen has not ever found in present lakes. Its description in literature is based in remains found in Quaternary lake sediments. Parolin *et al.* (2007) point out that this sponge is found in seasonal drought lakes common in the Brazilian Cerrado or even in more arid climate (like BWh in the Köppen's classification, 1936).

According the sponge content and ^{14}C ages, three intervals could be defined in the Fazenda Lake core (figure 3, table 2):

- Late Pleistocene – 1.00 to 0.80m: With an age of 13,160 ± 60 y. BP, This interval presents a very low quantity (~0.1%) of sponge spicules;
- Early to Late Holocene – 0.80 to 0.35m: This interval is dated 8.390 ± 50 y BP in its base to 6.710 ± 50 y BP to 2.180 ± 40 y BP in its top. It presents the higher concentrations of gemoscleres of *D. pydanieli*, *H. fistula*, *T. variabilis*. *No* microscleres were found in this interval;
- Late Holocene – 0.35 to 0,00m, after 2.180 ± 40 y BP: In this interval the occurrence of *D. pydanieli* gemoscleres and *H.*
- *fistula*, *T. variabilis* decreases with increasing of microscleras.

Using the same criterions, three intervals could be defined in the Seca Lake (figure 3, tab. 2):

- Late Plesitocene – 180 to 100 cm dated 19.850±180 y BP. There, are rare megasclere fragments, very rare occurrence of microscleres and rare occurrence of *D. pydanieli* and *M. spinata* gemoscleres.
- Holocene (?) – 100 to 50 cm. Very rare presence of spicule fragments and total absence of the other structures. Age estimative was made by sedimentary rates in similar lithology in the core.

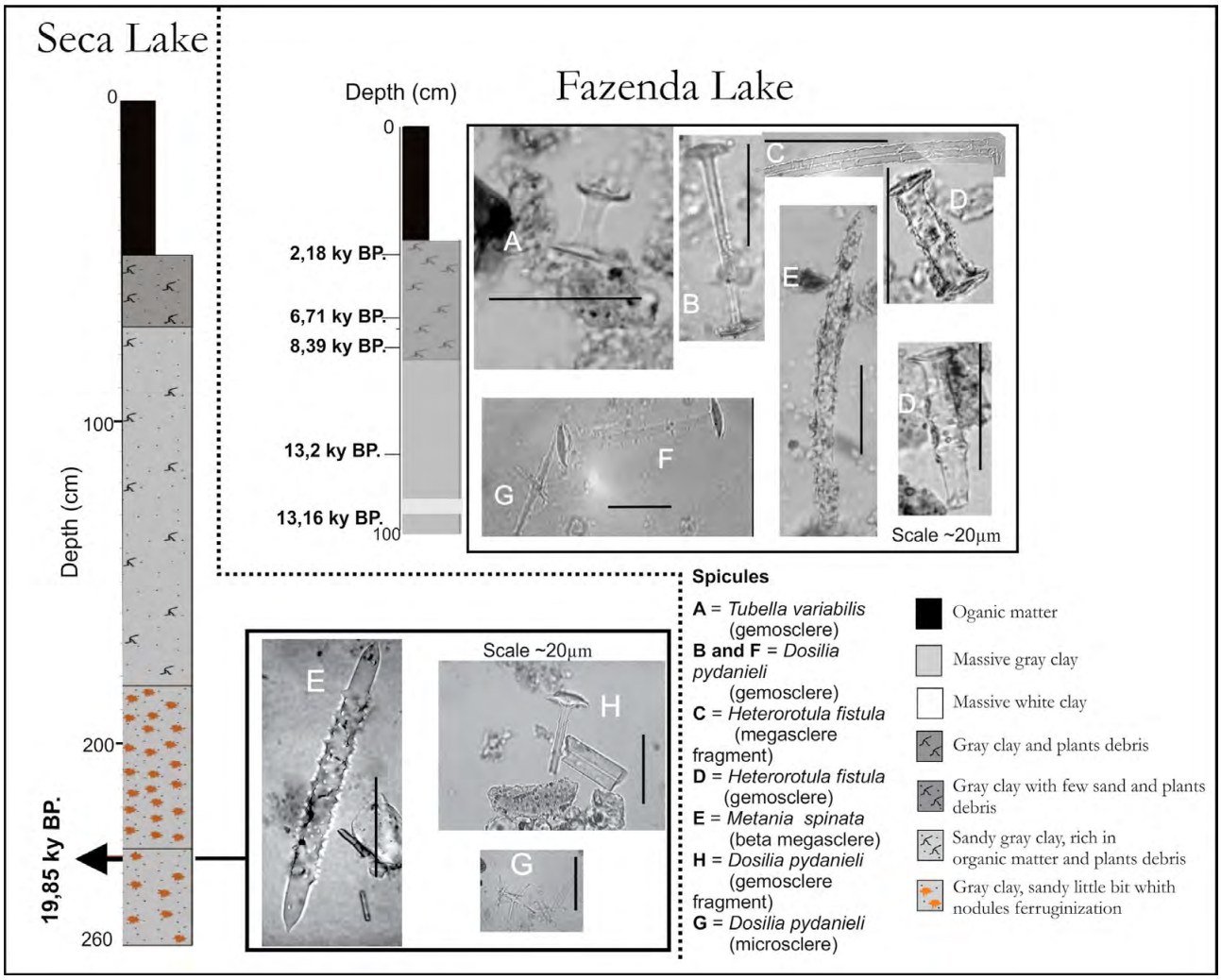

Figure 2. Core description, ^{14}C dates and sponge spicules for Seca and Fazenda Lakes.

Table 2 . Results, dating, spicules counting, detected species and environmental condition.

^{14}C age (depth in cm)	Depth (cm)	Fragments of spicules	Megascleres	Microscleres	Gemoscleres	Species	Observations
Fazenda Lake							
2,180 (35)	0/35	+++	+++	+++	+++	Dosilia pydanieli Trochospongilla variabilis	longer residence time of water
	30/35	+++	+++	+++	++		
6.710 (48)	35/45	+	+	Θ	Θ	Dosilia pydanieli	very short residence time of water
8.390 (55)	45/60	+	+	Θ	Ø		
	60/70	++	++	+	Θ	Tubella variabilis	little residence time of water
	70/80	++	++	+	+	Heterorotula fistula	
13.200 (80)	80/95	++	++	+	+	Dosilia pydanieli	
13.160 (100)	95/100	+	Θ	Ø	Ø	-	very short residence time of water
Seca Lake							
	0/50	++	++	Θ	Θ	-	little residence time of water
	50/100	Θ	Ø	Ø	Ø	-	very short residence time of water
	100/180	+	+	Ø	Θ	Metania spinata Dosilia pydanieli	
19,850 (189)	180/260	+	+	Ø	Ø	Metania spinata	

+++ Abundant; ++ Common; + Rare; Θ Very Rare; Ø Absent

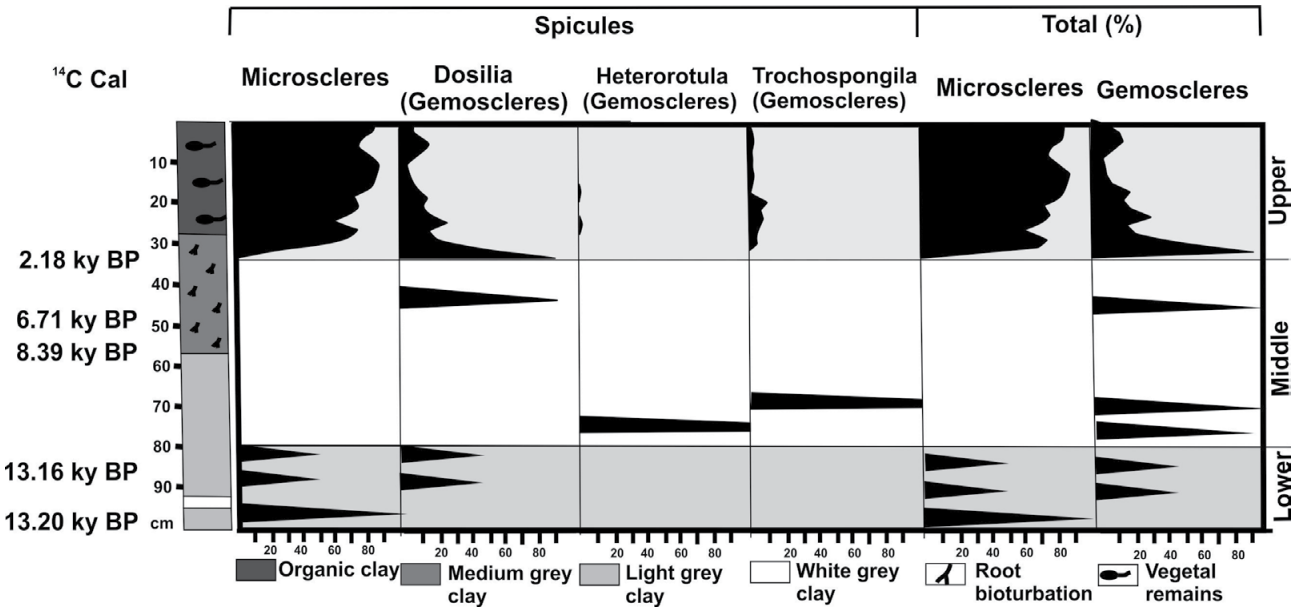

Figure 3. Sponge species found in Fazenda Lagoa sediments.

Discussion

The increasing upward on grey to black color in the Fazenda Lake sediments suggests a few-drained environment (lake or swamp) permanently submerse (Farrell 1987). The same situation is observed in Dos 32 Lake in Taquarussu, MS (Parolin 2006). The organic content is relatively low in the core base (1.20 – 1.40 m) and increases up to 13 a 15% in the upper interval. In opposition, the yellowish colors of Seca Lake sediments were originated in an intensive oxidizing environment with periods of total absence of water. Once the both lakes are under the same climatic conditions, it is supposed a different hydrological regime for Seca Lake.

Although not sufficient study, it is possible that water table is this lake would have presented a more instable behavior, with strong oscillation during the year. This fact has been observed in other lakes in the area (Stevaux 1993).

Sedimentation rates in both Fazenda and Seca Lakes are relatively lower compared with those found in the Dos Trinta e Dois Lake, where Parolin (2006) estimated values about ten to hundred times higher (1.6 mm.y^{-1} against 0.12 to 0.03 mm,y^{-1} in Seca and Fazenda Lakes).

The explication for this fact probably concerns with vegetation cover and geological basement in both sites. While in the NW Paraná lakes, the vegetation was constituted of rain forest over red clayey soil, in in the Mato Grasso do Sul, lakes were surrounded by fine to very fine sand soil covered by open vegetation (Cerrado vegetation).

Under this situation, wind could have strong influence as sediment transport agent. Stevaux (1993) observed this fact studying lake sedimentation in this area. Stevaux (1994, 2000) pointed out that the Second Dry Period in the middle Holocene was not sufficient strong in order to change drastically the vegetation cover, however, areas with sandy soil experienced a more effective reduction in vegetal cover sufficient to allow wind blow transportation. This situation improved sedimentation rates in lakes of this area. In true, Stevaux (1993, 1994) described floating grain sand in muddy matrix in lake sediment of Linda and Piranhas Lakes in SE Mato Grosso do Sul State.

According to pollen studies made by Fernandes (2008), it is possible to assume that during the Lower Holocene the Fazenda Lake was submitted to large water level oscillation very unfavorable to lake development. This fact corroborates with low content of pollens in the same basal interval (Fernandes 2008). This fact confirms the results in sponge analysis presented in this paper.

Environment changed since the Middle Holocene (^{14}C 2.180 ± 40y BP), when the lake water volume increased and an enrichment in species diversity with abundance of whole and fragments of *D. pydanieli*, *H. fistula* and *M. spinata* megascleres and gemoscleres. These conditions allowed the established of a spongofacies in the sense Parolin *et al.* (2008). The presence moderate presence of *M. spinata,* could indicate environment permanently submerse, although subjected water level variations.

Pollen data in the upper interval of Fazenda Lake core indicates a high production of algae and aquatic vegetation, with the increasing on tree pollen elements, typical of riparian vegetation (Fernandes, 2008). The increasing on sedimentation rate in this context suggests more expressive hydrological conditions – high rainfall and more effective flow of sediment to the lake. This interpretation corroborates with that based on sponge analysis.

The occurrence of Araucaria pollen around 500y BP and a reduction in microscleres:gemoscleres ratio (0.9 to 0.70) is interpreted as the area was under a short period of cooling. In true, this cold period is identified with the Little Ice Age. It is the first time that the LIA is identified in this huge area of Central Brazil.

In the Seca Lake, fragments of megascleres beta of *M. spinata* and whole gemoscleres of *D. pydanieli* suggest shallow water for relatively long time. In present environments, the alternation of drought and water in the lake favours the increasing on water turbity (Parolin 2006). In true, in Seca Lake, the drought-water hydrodynamic, with shallow water for a long period suggests an environment with high content of suspend sediment very unfavorable to sponge developing.

Sponge studies carried out by Parolin (2006) and Parolin *et al.* (2007, 2008) showed that SE Mato Grosso do Sul area suffered expressive climatic changes since the Last Glacial Maximum. Alternations of rainy and dry period extending up to the Holocene. The present humid climate is suggested by those authors as occurring since 4.300y BP, what corroborates with data found in Fazenda Lake, suggested by the presence of *Dosilia pydaniel* and *Metania spinata* (table 3).

Table 3. Comparison between sponges of the lakes of NW Paraná (Seca and Fazenda Lakes) with SE Mato Grosso do Sul (Linda, Samambaia and Dos 32 Lakes)

Lakes	State	Species found	Environmental interpretation	Methods/ Age y BP/ depth (cm)
*Linda	MS	- *Dosila pydanieli* - *Heterorotula fistula*	Characteristic of low water environments	TL/26300/190 TL/24600/132 TL/18760/82
*Dos 32	MS	- *Heterorotula fistula* - *Dosila pydanieli* - *Tubella variabilis*	Characteristic of lentic water body in Cerrado environment	Core 1 TL/19600/95 TL/11200/22 Core 2 TL/22200/140 TL/18700/87
*Samambaia	MS	- *Corvospongila secki* - *Metania spinata* - *Dosila pydanieli* - *Heterorotula fistula* - *Oncosclera petricola* - *Radiospongilla amazonensis*	Characteristic of lotic environments	Core 1 TL/17600/181 TL/46040/132 TL/4360/94 Core 2 TL/32740/248 TL/25980/210 TL/8700/168 TL/5600/75
Coceira**	PR	- *Dosilia pydanieli* - *Radiospongilla amazonensis* - *Metania spinata*	Chracaterisitc of lentic anvironment	TL/26900/5.000
Milharal**	PR	- *D. pydanieli* - *R. amazonensis*	Chracaterisitc of lentic anvironment	TL/20600/4.800
Fazenda	PR	- *Heterorotula fistula* - *Dosila pydanieli* - *Heterorotula fistula* - *Oncosclera petricola* - *Radiospongilla amazonensis* - *Metania spinata* - *Dosila pydanieli*	Charcteristic of lentic and lotic environmets	^{14}C/13200/80 ^{14}C/8390/55 ^{14}C/6710/48 ^{14}C/2180/28
Seca	PR	- *Metania spinata*	Chracaterisitc of lentic anvironment	^{14}C/19850/240

*Parolin *et al.* (2006); **Guerreiro *et al.* (2013).

Conclusion

The comparison between data from sponge and pollen analysis presented in this paper is satisfactory. The gemulation reduction occurred at the same time of an increasing on pollens, algae and other aquatic vegetation occurrence. However, it is important to note that the paleo-environmental information provides by the sponges have a local approach and refers mainly to the lake hydrology and water quality. On the other hand, information from pollen analysis has a regional scope as pollen grains came from different places. The greatest diversity of species found in the Fazenda Lake, such as *Dosilia pydanieli*, *Heterorotula fistula Metania spinata* and *Tubella variabilis*, suggests drier environment, with tolerance to seasonal changes.

In the Seca Lake were found rare megascleras fragments of the *Metania spinata* and gemoscleras fragments of *Dosilia pydanieli.* According to the environmental behavior of these species, it is possible the interpretation of an environment subject to drought, probably due to short periods of moisture oscillation in the Holocene.

The results the two lakes compared to those obtained by Parolin (2006) in the SE Mato Grosso do Sul State's lakes Taquarussu, MS show that many species are common in both regions. Most of the species are related to seasonal dry environments. However, in the sponges found in Mato Grosso do Sul State have greater diversity, suggesting lakes with fluvial flood pulses influence. Differently, the NW Paraná lakes

obtained their water supply from the ground water and from the rain.

Both short- as long-istance correlations (between Seca and Fazenda Lakesoa Farm and between Mato Grosso do Sul Lakes) showed satisfactory, allowing observing a genetic and temporal relation among them. The use of sponge as a proxy for reconstruction of Quaternary environments can be a strong tool when associated to pollen analysis and a supported chronological data.

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