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SPONGE SPICULES IN PEATY SEDIMENTS AS PALEOENVIRONMENTAL INDICATORS OF THE HOLOCENE IN THE UPPER PARANÁ RIVER, BRAZIL

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ABSTRACT – The presence of freshwater sponge spicules was analyzed in samples of peaty sediments obtained in two vibro-cores from the Taquarussu region (22º30'S, 52º20'W, Mato Grosso do Sul State, Brazil) . Four samples were dated by 14C method as 11,570±80 years BP (depth 240 cm), 9,710 ± 80 years BP (depth 220 cm), 4,610 ± 70 years BP (depth 130 cm) and 4,010 ± 80 years BP (depth 29-35 cm). The freshwater sponges detected were *Heterorotula fistula* Volkmer-Ribeiro & Motta, 1995, *Radiospongilla amazonensis* Volkmer-Ribeiro & Maciel, 1983, *Corvospongilla seckti* Bonetto & Ezcurra de Drago, 1966 and *Trochospongilla repens* Hinde, 1888. The first two species are typical of lentic environments and the other two of lotic habitats. These two pairs of species are found in alternating throughout the length of core 2, indicating flooding pulses, which may be responsible for the peat formation and accumulation along the river Esperança marginal embayments during the Holocene. There is also evidence of a wetter period between 4,610 and 4,010 years BP. The results corroborate the palynological studies previously produced for the region. This is the first dated fossil record of *Heterorotula fistula* and *Trochospongilla repens*.

Key words: freshwater sponges, siliceous spicules, flood pulse, Holocene, peaty deposits.

RESUMO – Foi analisada a presença de espículas de esponjas de água doce em amostras de sedimentos turfosos obtidas em duas perfurações com “vibro-core” na região de Taquarussu (Mato Grosso do Sul, Brasil, 22º36'S, 52º20'W). Quatro datações pelo método do ^{14}C obtiveram os seguintes resultados: 11.570 ± 80 anos AP (240 cm profundidade), 9.710 ± 80 anos AP (220 cm profundidade), 4.610 ± 70 anos AP (130 cm profundidade) e 4.010 ± 80 anos AP (29-35 cm profundidade). As espécies de esponjas detectadas foram *Heterorotula fistula* Volkmer-Ribeiro & Motta, 1995, *Radiospongilla amazonensis* Volkmer-Ribeiro & Maciel, 1983, *Corvospongilla seckti* Bonetto & Ezcurra de Drago, 1966 e *Trochospongilla repens* Hinde, 1888. As duas primeiras espécies são típicas de ambientes lênticos e as duas últimas de ambientes lóticos. As alternâncias desses dois pares de espécies na coluna sedimentar indicam pulsos de inundação na planície do rio Esperança, responsáveis pela acumulação e formação da turfa ao longo das baias marginais desde o início do Holoceno. Também verificou-se a existência de um período mais úmido entre 4.610 and 4.010 anos AP. Os resultados confirmam os estudos palinológicos já produzidos para a região. Esse constitui o primeiro registro fóssil datado para *Heterorotula fistula* e *Trochospongilla repens*.

Palavras-chaves: Esponjas de água doce, espículas silicosas, pulsos de inundação, Holoceno, depósitos turfosos.

INTRODUCTION

An extreme change in the Paraná River hydrology occurred around 8,000 years BP, when, during a wet climatic phase, the increased force of the river cut the channel deeper transforming the former floodplain into a terrace 10 m above the river bed (Fazenda Boa Vista Terrace) and a new floodplain began to be constructed around 6,000 years BP (Figure 1a) (Stevaux & Santos, 1998). In the Taquarussu area (Mato Grosso do Sul State), this terrace is in general covered by fluvial lake and eolian sandy deposits with localized peat deposits in the floodplain of the Esperança River, a small drainage that crosses the area (Parolin & Stevaux, 2001, 2004, in press; Parolin *et al.*, 2006). For the purpose of hydrological and paleoenvironmental analysis of the area, three sediment cores were collected across the Esperança river floodplain (Figures 1b and 2). In two of those cores freshwater sponge spicules were common.

Continental sponge spicules are useful tools in paleoenvironmental and paleolimnological reconstructions, particularly when considering continental sediments deposited in aquatic environments (Harrison *et al*., 1979; Hall & Herrmann, 1980; Harrison, 1988; Sifeddine *et al*., 1994; Cordeiro *et al.*, 1997; Turcq *et al.*, 1998; Cândido *et al.*, 2000; Gaiser *et al.*, 2004; Volkmer-Ribeiro *et al.*, 2006). Accordingly, the spicules found in the two upper sample cores across Esperança river were used to provide a paleoenvironmental reconstruction of the peaty deposits and make a comparison with a previous hypothesis for the area (Parolin *et al*., 2006).

STUDY AREA

The recovered sediments were retrieved from the Fazenda Boa Vista Terrace, in the floodplain of the Esperança River (22º36'34"S and 53º11'49"W), near the right bank of the Upper Paraná River, near the town of Taquarussu (Mato Grosso do Sul State), Southwestern Brazil (Figures 1, 2). The area presents 5 to 10 m high hills identified by Parolin & Stevaux (2001, 2004, in press) as Middle Holocene dunes. These paleodunes are cut by the Esperança River resulting in a wide swampy floodplain and floodbays with peat deposits (Figure 2). The base of the terrace deposits was dated by Stevaux & Santos (1998) as 42,500±1,700 years BP. Santos & Stevaux (2000) suggested that these terrace deposits were formed by gravelly deposits of the Paraná River during a semi-arid period when the river developed a braided pattern with a predominance of flash floods. This system acquired a sandy anastomosed, low energy pattern, at the Pleistocene-Holocene boundary. During the Holocene terrace deposits were re-worked by fluvial and eolian activities. This terrace can be geomorphologically divided into three units (Figure 1A): a) *Higher Fazenda Boa Vista Unit* **-** defined by a 200 to 10,000 m strip within the ancient dune field; b) *Lower Fazenda Boa Vista Unit* – defined as an incised surface in the former unit with scars and the remains of a sandy drainage network, c) *Fazenda Boa Vista Fan Unit* – corresponds to the last unit covered by an inactive alluvial fan formed by the Esperança and Baile Rivers.

The regional Late Pleistocene and Holocene climate was defined by (Parolin & Stevaux, 2001, 2004). Stevaux (1994, 2000), who identified four main phases: a) *Dry phase* at the end of the Pleistocene related to the Last Glacial Maximum; b) *Humid phase* early to middle Holocene; c) A short dry phase between 3,500 to 1,500 years BP; and d) The present humid phase since 1,500

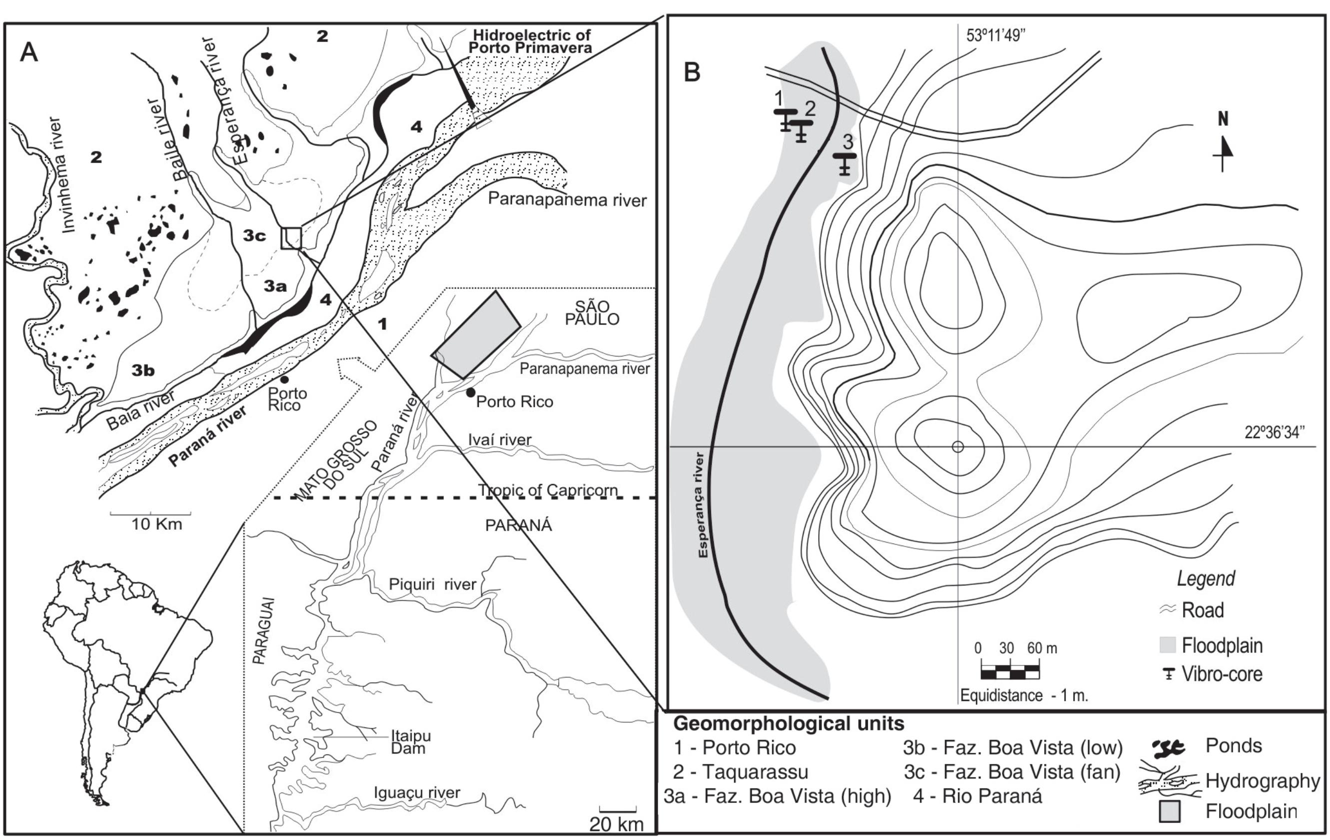

Figure 1. Location map of study with geomorphological units (A) and topographic detail of a paleodune with the location of the cores (B) (modified from Parolin & Stevaux, 2001; Stevaux, 1993).

Figure 2. Image of satellite of the studied area with limits (full white line) of the flood plain of Esperança river. The stippled white lines indicate the floodbays with peat deposits (modified from Google Earth®).

years BP. In a recent paper Parolin *et al.,* (2006) suggest that the short dry phase started around 4,500 years BP, with mobilization of the terrace sand by wind activity and dune formation.

The present climate is humid tropical, with a mean annual temperature of 24ºC and annual rainfall between 1,250 and 1,500 mm. Precipitation is not well distributed throughout the year and with maximum rainfall in the summer and minimum in the winter (Nimer, 1989).

METHODS

The work was based on the geomorphological maps of Stevaux (1993) and Parolin & Stevaux (2001), aerial photographs (1:60.000, 1966), topographic charts of Loanda (SF-22-Y-A-V, 1:100,000 and SF 22-Y-A, 1:250,000), satellite images from Google Earth® software, and topographic field surveys. Three vibro-cores (Martin & Flexor, 1989) were extracted from the floodplain of the Esperança River (Figures 1, 2, 3). Four samples were dated by ^{14}C, (two by BETA ANALYTIC and two by the Center of Nuclear energy in Agriculture/University of São Paulo) and another four samples were dated using thermoluminescence (by the College of Technology of São Paulo FATEC). The longer cores, 2 and 3, were submitted to short spaced sampling for sponge spicules to provide species determination and paleoenvironmental correlation, based on the known habitats of each species (core two at depths of 10, 30, 60, 82, 90, 100, 125, 190, 200, 220 cm and core three at depths of 142, 150, 180, 195 cm). The sediments were processed according to Volkmer-Ribeiro & Turcq (1996). The resulting siliceous material was suspended in water, placed on microscopic slides, dried, Entellan mounted and permanently sealed with cover slips. Four such slides were prepared from each sediment sample for microscopic examination and photography. The slide collection is deposited at the Laboratory of Paleoenvironment of the Fecilcam (Lepafe) under catalog number LEFAPE 01/2006 and LEFAPE 02/2006 (Figures 4 and 5).

The sponge spicules were identified by the second author based on her considerable experience with South American freshwater sponge taxonomy. The rich slide collection and bibliography available at Museu de Ciências Naturais of Fundação Zoobotânica do Rio Grande do Sul (MCN- FZB) was used in the comparison process. 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

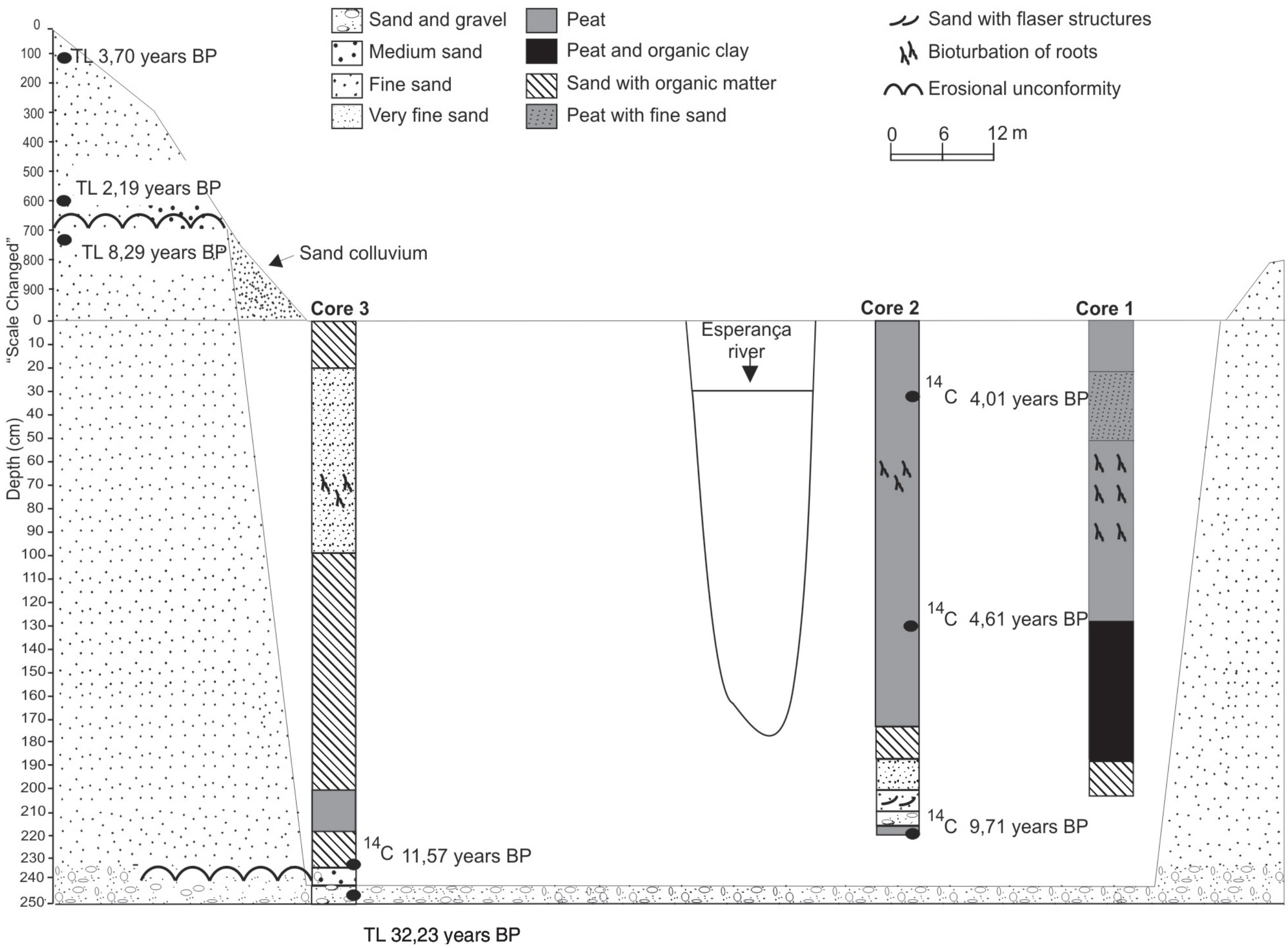

Figure 3. Core profiles with litology, absolute ages and position in relation to the paleodune (adapted from Parolin *et al*., 2006).

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.

RESULTS

Chronology

The paleodune (Figure 3) was dated at TL 2,100±200 (depth 70 cm), 3,700 ± 370 (depth 120 cm) and 8,290 ± 600 (depth 680 cm) years BP (Parolin & Stevaux, 2001, 2004, in press). The Esperança River floodplain peat deposits obtained with core 3 presented (^{14}C) ages 11,570±80 (depth 240 cm), 9,710±80 (depth 220 cm), 4,610±70 (depth 130 cm) and 4,010±80 (depth 30 cm) years BP. The sandy gravel at the base of core 3 reached (TL) 35,230±2.200 years BP (Figure 3).

Sedimentary sequences

The sedimentary analysis of core 2 (Figure 4) showed 6 depositional sequences: (a) peat (between 220 to 218 cm and 173 to 0 cm; (b) sand and pebbles between 218 to 210 cm; (c) fine sand with flaser structures between 210 to 211 cm; (d) very fine sand between 211 to 188 cm; (e) sand with organic matter between 188 to 173 cm and (f) peat between 173 to 0 cm, with bioturbation by roots (110 to 90 cm and 80 to 60 cm). Seven sedimentary sequences were detected in Core 3 from top to bottom (Figure 5): a) sand and pebbles between 240 to 232 cm; b) fine sand between 232 to 228 cm; c) sand with organic matter between 228 to 209 cm, 173 to 96 cm and 19 to 0 cm; d) peat between 209 to 173 cm and e) fine sand between 96 to 19 cm, in this sequence there is root bioturbation (80 to 60 cm).

Spicule analysis

Large amounts of spicule fragments were seen in core 2 at depths of 60, 90, 140, 190 and 220 cm (Figure 4 and Table 1). The presence of gemmoscleres and microscleres made it possible to specifically identify the freshwater sponge species present in almost all the sedimentary sequences (at depths 60, 82, 90, 100, 140,180,190, 220 cm). The identified taxa were: *Heterorotula fistula* Volkmer-Ribeiro & Motta, 1995 (at depths 60, 90, 100, 140, 190, 220 cm); *Corvospongilla*

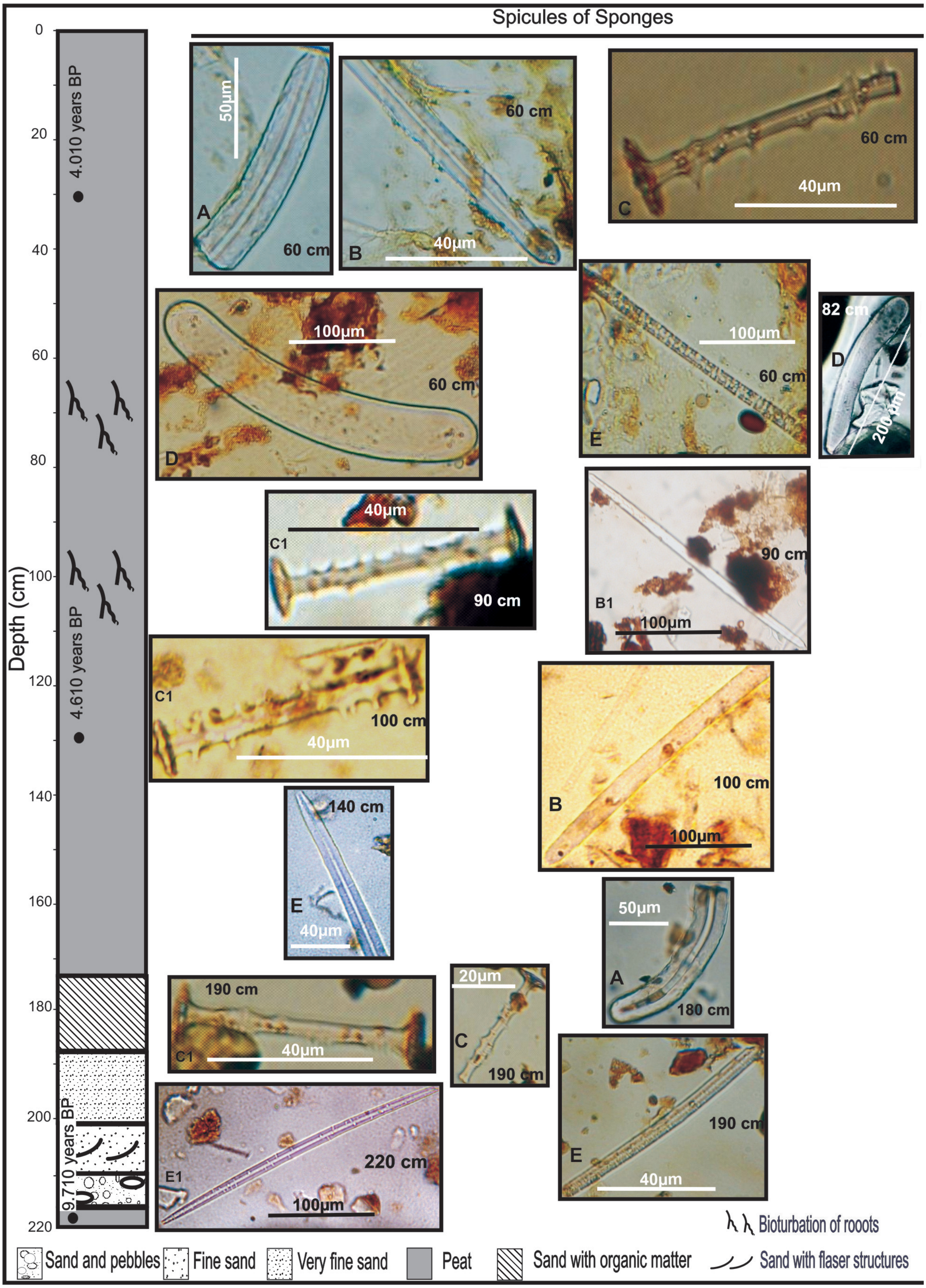

Figure 4. Sedimentary sequences of core 2 with spicule microphotographs: **A**, megasclere fragment of *Corvospongilla seckti*; **B**, fragment of megasclere of *Radiospongilla amazonensis*; **B1**, young megasclere of *Radiospongilla amazonensis*; **C**, fragment of long gemmosclere of *Heterorotula fistula*; **C1**, a long gemmosclere of *Heterorotula fistula*; **D**, megascleres of *Trochospongilla repens*; **E**, megasclere of *Heterorotula fistula*; **E1**, young megasclere of *Heterorotula fistula*.

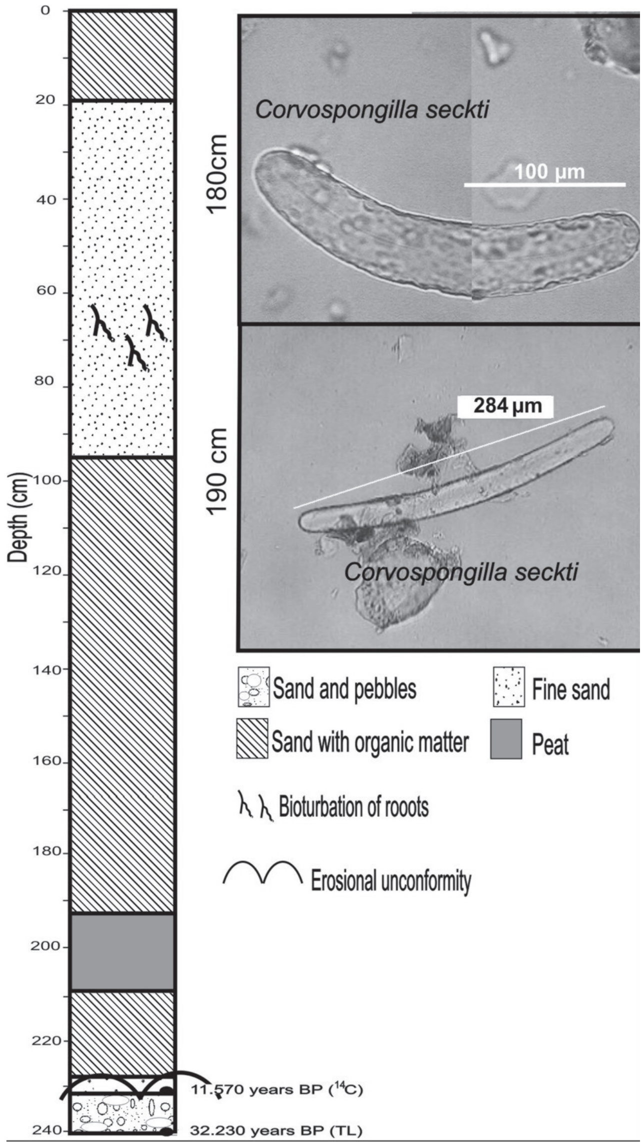

Figure 5. Sedimentary sequences of core 3 and microphotographs of identified of sponge spicules (190 cm).

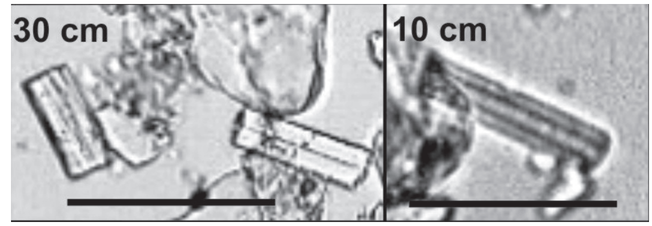

Figure 6. Spicule fragments of sedimentary sequences of core 2, at 30 and 10 cm depths. Scale bar = 20 µm.

seckti Bonetto & Ezcurra de Drago, 1966 (depths 60, 180 cm); *Trochospongilla repens* Hinde, 1888 (at depths 60, 82 cm); gemmosclere and megasclere fragments of *Radiospongilla amazonensis* Volkmer-Ribeiro & Maciel, 1983 (at depths 60, 90 and 100 cm). At 60 cm entire megascleres of *C. seckti* were detected (Figure 4). There were scanty spicule remains in core 3 (Figure 5), however megascleres of *C. seckti* were again detected at 180 and 190 cm. The sediment chronology provides the first dated record of *H. fistula* (^{14}C) at 9,710 years BP, and for *Trochospongilla repens* (^{14}C) at 4,010 and 4,610 years BP.

DISCUSSION

The occurrence of a drier climate than the present one during the Holocene has been identified elsewhere in central-southern Brazil by many authors (Barbosa *et al*., 1990; Van der Hammen, 1991; Thomas & Thorp, 1995; Ledru, 1993; Ledru *et al.,* 1996; Stevaux, 2000 as example). In the upper catchment region of the Paraná River this dry period was determined by Jabur (1992) and Stevaux (1993, 1994, 2000) at between 3,500 and 1,500 years BP, followed by a humid period from 1,500 years BP. Iriondo & Kröhling (1995) and Iriondo *et al.* (1997) suggested that for northeast Argentina this dry period coincided with remobilization of the "*loess pampeano*", which was deposited during dry periods of the Pleistocene. Stevaux & Santos (1998) put forth the hypothesis that this same dry event reached the Taquarussu region. Kramer & Stevaux (1999), Stevaux (2000) and Parolin & Stevaux (2001, 2004, in press) identified an erosive hiatus of about 9 years BP (between 3,000 to 12,000 years BP) in the depositional sequence of the Taquarussu region and attributed it to intensive eolical activity *ca*. 3,000 years BP. Paleosols studied by Barczyczyn (2001), Barczyczyn *et al.* (2001), Medeanic & Stevaux (2003) and Stevaux *et al.* (in press) in the same region also present evidence of a drier climate ending around 1,700 years BP.

Parolin *et al.* (2006) identified a prevalence of herbaceous vegetation (Asteraceae, Ciperaceae and Poaceae) during the Holocene, with the restricted occurrence of arboreal and arbustive vegetation (Fabaceae, Palmaceae and Apocinaceae). These authors believe that the first humid phase, which occurred in the region between 7,500 and 3,500 years BP, was not as intense as elsewhere in central-south Brazil or at least, the short dry period of the Holocene had begun earlier in the study area (around 4,610 years BP). This fact would seem to agree well with the formation of the field dune and eolian activity detected by Parolin & Stevaux (2001, 2004, in press).

The occurrence of charcoal fragments in core 2, from 230 to 190 cm depth suggests that the arboreal and arbustive vegetation was concentrated along the water bodies at that time (Parolin *et al.,* 2006). Spicules of the sponge *Heterorotula fistula* were detected at this same depth. Volkmer-Ribeiro & Motta (1995) reported the occurrence of *H. fistula* gemmoscleres in the spongillite deposits at the Lagoa dos Datos pond, close to the town of Conceição das Alagoas (Minas Gerais State), south-western Brazil. These authors suggested that the genus *Heterorotula* was, at the time, restricted to dry environments in Australia and New Zealand. Volkmer-Ribeiro *et al*. (1998) also reported the presence of *H.*

Table 1. Freshwater sponges spicules identified in core 2. Frequency: absence = -, presence = +, abundant = ++.

Depth (cm)	Sponge espicules				
	Fragments	*Heterotula fistula*	*Radisopongilla amazonensis*	*Trochospongilla repens*	*Corvospongilla seckti*
10	+	-	-	-	-
30	+	-	-	-	-
60	+ +	Gemmoscleres fragments	Megascleres	Megascleres	Megasclere fragments
82	+	-	-	Megascleres	-
90	+ +	Gemmoscleres	Megascleres	-	-
100	+	Gemmoscleres	Megascleres	-	-
125	+	-	-	-	-
140	+ +	Megascleres	-	-	-
150	+	-	-	-	-
165	-	-	-	-	-
180	+	-	-	-	Megasclere fragments
190	+ +	Megasclere fragments/ gemmoscleres	-	-	-
200	+	-	-	-	-
220	+ +	Megascleres	-	-	-

fistula in diatomite deposits at the Lagoa Capão da Horta pond, close to the town of Januário Cicco (Rio Grande do Norte State), northeastern Brazil. Accurate observation of the spicules from core 2 show that the megascleres are incompletely formed (Figure 4). This fact, allied to the presence of gemmoscleres is indicative of the short duration of the water periods in a drier climate. This evidence agrees with the climatological picture for the area proposed by Jabur (1992); Stevaux (1993, 1994, 2000); and Parolin & Stevaux (2001, 2004).

Some authors suggest the existence of a drier phase at the begining of the Holocene in central-southern Brazil (Bombim & Klant, 1974; Bombim, 1976; Van der Hammen, 1991; Ledru, 1993; Thomas & Thorp, 1995; Ledru *et al.,* 1996; Behling, 1997). This same climatological phase is proposed for northeastern Argentina (23º to 30º S) by Iriondo & Garcia (1993).

The presence of well preserved megascleres of *C. seckti* in core 3, at depths of 190 and 180 cm (Figure 3), indicates the existence of a lotic environment at that time. Bonetto & Ezcurra de Drago (1970, 1966) found this species on the rocky bed of the Paraná and Uruguay rivers as well as in their smaller tributaries in northern Argentina. Tavares (1994) and Batista *et al.* (2003) registered the occurrence of *C. seckti* on blocks, logs and branches in the channel borders or beds of Amazonian rivers. Megascleres of *C. seckti* are also the predominant spicules in core 2 (180 cm). This sediment sequence correlates well with that of core 3 (depth 200 and 210 cm) identified as a lotic environment subjected to seasonal short flooding periods (Figure 5).

The small amount of sponge spicules in core 2 at depths 165 and 125 cm, allied to the presence of *H. fistula* megascleres suggests the occurrence of very short water residence, leading to the formation of small isolated water bodies along the floodbays of Esperança River. This evidence corroborates the studies of Parolin & Stevaux (2001, 2004, in press) and Parolin *et al.* (2006).

Gemmoscleres of *H. fistula* and well-formed megascleres of *Radiospongilla amazonensis* detected in core 2 between 100 and 90 cm depth (Figure 4), point to an increase in water residence in relation to the previous sequence. *Radiospongilla amazonensis* is an indicator of the peat layers topping the spongillite deposits in western Minas Gerais State (Volkmer-Ribeiro & Motta (1995). Cândido *et al.* (2000) report the occurrence of this species in the early Holocene sandy mud sediments (9,080 to 8,860 years BP) at Lake Caracaranã, in Roraima, Brazil.

The well-preserved, robust megascleras of *T. repens* found in core 2 at a depth of 82 cm, aged (^{14}C) 4,010 and 4,610 years BP, indicate a lotic environment. Bonettto & Ezcurra de Drago (1964) described the occurence of this sponge in the Middle Paraná River (Argentine). De Rosa Barbosa (1984) found it in Ibicuí and Jacuí Rivers in the

State of Rio Grande do Sul, southern Brazil. Volkmer-Ribeiro & Hatanaka (1991) registered the species for the River Tocantins, central Brazil and Batista *et al.* (2003) for the Araguaia River (Tocantins River Basin). All such records support the preference of *T. repens* for rocky substrates at the bottom of turbulent waters.

The sequence where species of sponges characteristic of lentic habitats, such as *R. amazonensis* and *H. fistula* alternate with species of lotic environments (*T. repens* and *C. seckti*) point to flooding pulses favoring the residual formation of satellite lentic environments with peat deposits. This situation was identified in core 2, depth 60 cm (^{14}C) 4,010 and 4,610 years BP and represents a progressive increase in the frequency of flood pulses of the Esperança River (Figure 4) suggesting a probable amelioration of climatological conditions. Parolin *et al.* (2006) described large amounts of pteridophytic and an extreme reduction in xerophytic pollen during this same interval. This climatic amelioration was correlated to the first humid phase defined by Stevaux (1993, 1994) at the Upper Paraná River catchment area.

The presence of fragments of spicules (< 20 µm) between depths of 30 and 10 cm in core 2 (Figures 4 and 6), when compared with other sequences, suggests intense remobilization of channel material by turbulent water flow. This indicates a wetter climate, as proposed in the palynological analysis for this sequence made by Parolin *et al.* (2006).

CONCLUSIONS

Based on the occurence of lentic (*Heterorotula fistula* and *Radiospongilla amazonensis*) and lotic (*C. seckti* and *T. repens*) sponge spicules in sediments recovered at the Esperança River site it is possible to conclude that this river was active during the Holocene with intense periods of flood pulses occurring ca. 4,010 years BP. These flood periods account for the peat formation and the relatively high sedimentary rate of 1.6 mm/year^{-1}. The first sponge species to appear in and characterize the lentic phase was *Heterorotula fistula* at the beginning of the Holocene (9,710 years BP), followed by *Radiospongilla amazonensis* during the Middle Holocene (between 4,010 and 4,610 years BP). The periods of more intensive flooding are clearly demarcated at a depth of 180 cm (cores 3 and 2) firstly by the presence of *Corvospongilla seckti* and then by *Trochospongilla repens* megascleres at depths between 82 and 60 cm (core 2).

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