A high-resolution Holocene record on the Southern Brazilian shelf: paleoenvironmental implications

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ABSTRACT

A high resolution multi-proxy record has been used to determine environmental changes during the Holocene on the southern Brazilian shelf. Present oceanographic conditions reveal wind and freshwater input as determinants of short-term productivity changes in the study area. Thus, magnetic susceptibility and grain size parameter variations, together with proxies of productivity (organic carbon, carbon accumulation rate, Ba, Sr and Ca content, Ba/Al, Ba/Ti and Al/Ti ratios) were analyzed and compared with proxies of redox condition (V/Ti ratio), terrigenous input (Fe/Ca and Ti/Ca ratios) as well as other Element/Ti ratios, in order to evaluate the paleoceanographic and paleoclimatic changes over the period.

Sediment samples were taken every 2 cm along the 506 cm long core and AMS radiocarbon datings were undertaken every 50 cm.

The core covers a time interval of about 7,650 years, with sedimentation rates varying from 0.025 to 0.250 cm.yr^{-1}, which represent time intervals of between 8 and 80 years per sample. There is a clear change in the sedimentation rate at about 2,800 years B.P.

All grain size and elemental results indicate the occurrence of conspicuous changes between 5,200 and 5,000 yr B.P. as well as between 3,000 and 2,800 yrs B.P.. A comparison of our results with palynological information available for the continental areas suggests that the sedimentary changes in this last interval may be correlated with the onset of modern climatic conditions in South America and, especially, with the onset of the Plata Plume Water, a water mass that carries cold, less saline waters towards the north. Minor changes are observed at ca 1,500 years B.P. and are correlated with an increase in atmospheric humidity.

A time series analysis undertaken of the several proxies indicates the occurrence of Sub-Milankovitch cycles which may be compared with those reported for the Northern Hemisphere.

INTRODUCTION

The present oceanographic conditions give the southern Brazilian shelf a privileged status for the study of short-term (seasonal and decadal) changes in the wind-driven currents and freshwater discharge regimes of the Southwestern Atlantic Ocean. In this area, the wind-dependent northward displacement of cold and less saline waters originating in the Río de La Plata and the discharge of the southern Brazilian lagoons (Piola et al., 2000; Piola and Romero, 2004) control the seasonal variation in primary productivity (Ciotti et al., 1995). Sedimentological evidence of the northward displacement of this water flow is to be observed both in the organic and inorganic constituents of the bottom sediments and can be traced as far north as the 24°S parallel (Mahiques et al., 1999; 2004). Also, this northward flow, which was originally attributed to the Malvinas Current, has been used to explain the occurrence of cold water foraminiferal forms on the Southwestern Atlantic Shelf (Stevenson et al., 1998)

Assuming that the Río de La Plata river mouth has undergone only very slight changes in its geographical position over the last 7,500 years (Cavallotto et al., 2004; Violante and Parker, 2004), that the relative sea-level crossed its present height approximately at this time (Mahiques and Souza, 1995) and that later oscillations in the Holocene sea-level were unable to expose significant portions of the shelf (Suguio and Martin, 1978; Angulo et al., 1999), we may assume that middle and late Holocene paleoceanographic changes on the Southwestern Atlantic shelf were mainly dependent on the wind regime and terrigenous input and that millenial variations in the sedimentary pattern may be assumed to have resulted from variations in this wind-driven water mass.

The aim of this work is to identify environmental Holocene changes on the Southwestern Atlantic shelf based on a high-resolution, multi-proxy analysis of a sediment core, sampled from a location in an area of high level of primary productivity, determined by the displacement of the northward flow described above. Paleoproductivity, redox conditions and terrigenous input proxies, together with grain-size and magnetic susceptibility variations were considered so as to permit the analysis of the main temporal changes and variability as well as to correlate with the known climatic changes that affected the South American continent during the Holocene. This work constitutes a first attempt at the utilization of a multiproxy approach in paleoenvironmental studies on the Southwestern Atlantic shelf.

STUDY AREA

The northernmost part of the Southern Brazilian margin is known as the São Paulo Bight, which is an arc-shaped feature extending from 23°S to 28°S (Zembruscki, 1979) (Figure 1).

The ocean floor of the São Paulo Bight shows a rather complex morphology involving channels, canyons, and considerable variations in the slope morphology (Furtado et al. 1996). The shelf break is located at a water depth of approximately 140 meters with the upper slope showing an average gradient of approximately 1:55. On the inner shelf the sedimentation is mainly determined by the Plata Plume Water flow (Möller Jr. et al., under revision) which carries sediments from the Río de La Plata and, to a lesser extent, from the southern Brazilian coastal lagoons (Mahiques *et al.*, 2004). On the middle and outer shelves as well as on the upper slope the sedimentary processes are influenced by the flow of the Brazil Current (BC) along the western Atlantic continental margin (Mahiques et al. 2002, 2004).

The distribution of surface sediments on the Southeastern Brazilian margin was extensively studied during the 70's and is described in the papers of Rocha et al. (1975) and Kowsmann and Costa (1979). In general, the present sea-floor is covered by very fine siliciclastic sands and silts, with variable amounts of clay and calcium carbonate. Coarser sediments and carbonate gravel and boulder facies, found on the outer shelf, represent less than 5% of the present bottom sediments and are generally related to relict sediments, deposited under lower sea-level conditions. More recently, Mahiques et al. (2002, 2004) have re-evaluated the sedimentary characteristics of the Southeastern Brazilian shelf and proposed hydrodynamic models for the sediment deposition in the area.

The displacement of the La Plata Plume over the continental shelf is highly dependent on both river discharge and wind regime. Piola and Romero (2004) report a 1000-km displacement of the plume during the winter season, extending as far north as 27°S, and a retreat to 32°S during summer, associating this variability with the influence of the along-shore wind stress. Also, in a multi-year study, using satellite images, Gonsalez-Silvera et al. (2006) recognized a marked temporal variability of the plume, the most effective northward penetration of the plume occurring under conditions of high river discharge and southerly winds. Under El Niño conditions, characterized by the blockage of the southerly winds, the plume extends southward.

METHODS

A 506-cm piston core was sampled at the coordinates 26°59'16.8"S – 048°04'33.6"W, at a water depth of 60 meters, onboard the R.V. "Prof. W. Besnard". Prior to its opening the core was analyzed for magnetic susceptibility using a Bartington MS2C sensor.

At the laboratory the core was sub-sampled continuously at intervals of 2cm, sub-samples being immediately frozen for further freeze-drying.

Due to the lack of suitable carbonate materials (e.g. foraminifers, mollusks), approximately 7 grams of total sediment at each 50 cm was separated for AMS radiocarbon dating at Beta Analytics. Calibrated ages were calculated using the Calib software, version 5.0.2html, available at http://calib.qub.ac.uk/calib/, with the standard marine correction of 408 years and a regional reservoir effect of $\Delta R=82.0\pm46$, corresponding to the average value of three samples reported by Angulo et al. (2005) to the area, and the Marine04 Calibration Dataset (Hughen et al., 2004).

Grain-size analysis was performed in a Malvern Mastersizer 2000, on decarbonated samples.

Organic carbon was determined in a LECO CNS2000 analyzer. Approximately 200 mg of dry sediment of each sample was treated with 10% hydrochloric acid in order to remove calcium carbonate, and then freeze-dried and analyzed. LECO soil standards and blanks were analyzed as controls for each set of 30 samples. Organic carbon accumulation rate (${}_{org}C$ AR), in $g.cm^{-2}.kyr^{-1}$, was calculated in accordance with the formula described in Grant and Dickens (2002):

$$(\underline{{}_{org}C\ AR}) = (\underline{\%\ {}_{org}C}))/100 * SR * DBD*1000$$

where SR is the sedimentation rate ($cm.yr^{-1}$) obtained from the age model and DBD is the dry bulk density ($g.cm^{-3}$), calculated from:

$$DBD = (1-\square/100)*\square_s$$

where $\square$ is the wet porosity and $\square_s$ is the density of the sediment particles, previously determined as 2.35 $g.cm^{-3}$. The wet porosity ($\square$) was calculated using the formula proposed by Clifton et al. (1995):

$$\square = [(W/100)*\square_s] / \{[(W/100)*\square_s]+ [1- (W/100)]*\square_w\}$$

where W is the water content (in weight %), $\square_s$ the density of the sediment particles, i.e. 2.35 $g.cm^{-3}$, and $\square_w$ the density of the pore water, assumed to be 1.0 $g.cm^{-3}$.

Elemental analysis (Al, B, Ba, Ca, Cr, Fe, Mg, Mn, Sr, Ti, V) was performed using the ICP-OES technique. Approximately 1 g of dry sediment was digested with 10 mL of 1:1 HNO_3 at 95°C for 15 minutes. After cooling, another 5 mL of concentrated HNO_3 was added and the solution heated for 30 minutes. This second procedure was repeated until the digestion of the sample was complete. 2 mL of water and 3 mL of 30% H_2O_2 were added under heating until the elimination of the organic matter was complete. The solution was then filtered through a Whatman 41 filter and 10 mL of concentrated HCl was added to the digestate. Finally the solution was filtered again in a Whatman 41 filter and the filtrate was collected in a 100 mL volumetric flask. The volume was completed and the solution analysed in a Perkin Elmer Model 2100 DV ICP-OES. Measurement precision for all elements was better than 5%. Method accuracy was obtained by analysing certified sediment (HR1) and conformed by joining proficiency promoted by RTC, NELAP (National Environmental Laboratory Accreditation Programme) accredited.

RESULTS AND DISCUSSION

Age Mode and, Sedimentation Rates

Table 1 presents the results of radiocarbon datings. There was no age inversion in the radiocarbon datings.

The establishment of a reliable model for depth-age relationships is a key question for all the studies involving sediment accumulation and has been recently criticized by Telford et al. (2004). A basic assumption determined by these latter authors is that age-depth models are only meaningful and useful when established using calibrated radiocarbon ages. In order to evaluate the effect of the age-depth models on the values of sedimentation rates and, consequently, sediment accumulation, we tested several interpolation procedures (polynomial, linear interpolation between radiocarbon values, cubic spline and mixed effect). Polynomial, linear interpolation and cubic spline models were calculated using the DepthAge software, developed by Louis Maher Jr. and available at the INQUA file boutique at http://www.geology.wisc.edu/~maher/inqua.html (last accessed December 15, 2006) . The mixed-effect model was calculated by means of the Cagedepth and Cagenew functions as described by Heegard et al. (2005) and available at http://www.uib.no/bot/qeprg/Age-depth.htm (last accessed January 3, 2007).

As stated by Grant and Dickens (2002), the linear interpolation leads to artificial sedimentation rate values, and, in our case, there was no significant difference among the 4th order polynomial, cubic spline and mixed effect estimates, with a correlation coefficient higher than 0.999. Nevertheless, due to the possibility of a better error estimation in this last model, we chose the mixed-effect procedure for the depth-age modelling.

The core covers an age range of 7,650 years with sedimentation rates varying from 0.025 to 0.250 $cm.yr^{-1}$, which represent a time interval of between 8 and 80 years for each sample, the main changes having occurred at around 3,000 yr B.P (Figures 2 and 3). The changes in sedimentation rates observed in this study seem dramatic for such a short time period. Nevertheless, this has already been verified in other shelf and upper slope areas. Knies (2005) observed changes in sedimentation rates by a factor of 12 between the Holocene and older layers in shelf sediments off northern Norway. The same behavior has been observed for an equivalent period on the shelf off NE Iceland (Andresen et al. 2005).

Grain size

Almost all of the parameters show a pattern of three time intervals, with transitions occurring between 5,200 and 5,000 yrs B.P. and 3,000 and 2,800 yrs B.P.

This pattern is reflected in the grain-size (Figure 3). From the base to ca. 5,200 yrs B.P., sediments are essentially composed of sandy silts, with clay content varying from 5 to 10% and sands ranging from 20% to 40%. A progressive increase in the silt content, followed by diminishing sand (10 to 25%) values is found from this date up to 3,000 yrs B.P. Finally, after this age, the grain size remains approximately constant, as observed by the mean diameter and silt content, this latter corresponding to more than 80% of the grain size distribution.

Terrigenous input and redox proxies and other Element/Ti ratios (Figure 3)

Terrigenous input has been evaluated through the use of the magnetic susceptibility values and Fe/Ca and Ti/Ca ratios (Arz et al., 1998). There is an expected significant correlation (R=0.82) between the Fe/Ca and Ti/Ca ratios, with a much smaller but significant correlation between magnetic susceptibility and those elemental ratios. As a rule, terrigenous input, as defined by the Fe/Ca and Ti/Ca ratios, follows a pattern which is similar to that observed in the grain size, with the occurrence of three phases in the time interval considered. Higher terrigenous input appears to have occurred during the Late Holocene.

The vanadium content and, specifically, the V/Ti ratio has been used as a proxy for the redox condition (Moreno et al., 2004). Together with Cr/Ti, B/Ti, Mg/Ti and Mn/Ti ratios, they all exhibit the same three-phase division stated above, with a highly significant correlation among these ratios and sedimentation rate.

Productivity proxies (Figures 4 and 5)

Barium is one of the most widely used proxies for estimating paleoproductivity (Dymond et al., 1992; Paytan et al., 1996). Nevertheless, the number of its adepts (Jacot Des Combes, 1999; 2005; Calvert and Fontugne, 2001; Pfeifer et al., 2001; Prakash Babu et al., 2002; Wei et al., 2003) is as large as is the number of its detractors (Averyt and Paytan, 2004; Anderson and Winckler, 2005; Mora and Martinez, 2005) for its use as a reliable indicator of variations in productivity over time. The problems reported are related to the impossibility of calculating Ba_{xs} values from the Ba/Al ratios (Kasten et al., 2001; Moreno et al., 2004), either due to the reactivity of the aluminium, to its use as a "normalizing" element, to the absence of regional Ba/Al background values, or even to inconsistencies in the algorithms used for the productivity estimates.

Averyt and Paytan (2004), indicate discrepancies in the results obtained from the different parameters related to the barium content, as well as to the Al accumulation rate and Al/Ti ratio. In a more general analysis, Anderson and Winckler (2005) criticize the utilization of the Ba/Ti and Al/Ti ratios which may be influenced by the spatial and temporal variability in the Ti flux. According to the authors, the dissolution of $CaCO_3$ during the Holocene might be responsible for the increase in the concentrations of barite as well as for the excess in aluminium, which might raise difficulties regarding the utilization of these proxies in paleoproductivity estimates. Also, Pattan et al. (2003), studying glacial-interglacial variations in the southeastern Arabian Sea, indicate that the Al/Ti ratio cannot be used as a reliable paleoproductivity proxy.

Concerning our data the following questions must be addressed:

1) May we use Al as a reliable normalizer element? Murray and Leinen (1996), analysing samples from the Equatorial Pacific, reported anomalous values in the Al/Ti ratio, related to the non-terrigenous character of the aluminium. In order to evaluate this aspect of our samples, we plotted Al vs Ti, assuming that this last element is exclusively terrigenous and non-reactive (Figure 4a). The correlation may be considered statistically significant (0.797). Nevertheless, when we compare the Ba content, as well as Ba/Al, Ba/Ti and Ba/Ca ratios, with the organic carbon and carbon accumulation rate (Figures 4b to 4i), the Ba/Al plots exhibit the smallest values of correlation, despite being statistically significant. Further, it is worth noting that several plots, such as Ba vs. ${}_{org}C$ showed a dispersion which is not explicable by a linear equation, but probably only by a polynomial or exponential equation. Actually, there is a clear temporal dependence in the relationship between Ba and Ba-related parameters with ${}_{org}C$ and carbon accumulation rate.

2) May we calculate Ba_{xs}? None of our Ba/Al values is greater than 0.0075, which may be considered as a terrigenous background value (Taylor and McLennan, 1985) or even higher than 0.0028, found by Klump et al. (2000) in the Chilean continental margin surface sediments. Hence, and due to the lack of regional background values for Ba/Al, the determination of Ba_{xs} and the calculation of paleoproductivity is somewhat deficient. Nevertheless, it is possible, at least, to compare data qualitatively in order to establish temporal changes in productivity.

As observed in almost all of the other parameters, the paleoproductivity proxies exhibit a temporal variation characterized by two main changes at the intervals 5,200-5,000 and 3,000-2,800 years B.P. From the base of the core to 5,200-5,000 years B.P. organic carbon and carbon accumulation rates, as well as Ba, Al and Ca exhibit their lowest values. The interval between 5,000 and 3,000 years is characterized by low but increasing values in organic carbon and carbon accumulation rate. The Ba/Ti and Ba/Ca ratios show their lowest values in this interval, indicating a correspondingly lower productivity period during the Holocene in the area. There was a significant increase in productivity after 3,000 years B.P., as shown by the behavior of organic carbon, carbon accumulation rate, barium, aluminium and other Ba and Al ratios. This increase coincides with the increase of the terrigenous input and sedimentation rate in the area.

Climatic changes

As a rule we observe important environmental variations during the Holocene, not only in the productivity but also in the terrigenous input and shelf dynamics. Some events are very well marked, the break in the depositional process prior to and after the transition of 3,000-2,800 years B.P. being the most conspicuous. The causes of the oscillations observed along the core may be analysed from the point of view of the climatic variability affecting South America, the main factor of which is the wind regime (Ledru et al., 1996, 1998; Behling, 1997, 1998; Gaiero et al., 2004; Gilli et al., 2005).

Ledru et al. (1996), in a description of the climatic variability of the last 55,000 years in Southeast Brazil, describe the occurrence of a drier and warmer period, between 7,000 and 4,000 years B.P., followed by a subsequent increase in moisture, as a consequence of oscillations in the position of the Inter Tropical Convergence Zone (ITCZ). In a more detailed paper, Ledru et al. (1998) describe a persistent increase in moisture, from 7,000 years B.P. up to the present, by virtue of changes in the wind regime, dominated by the advance of polar masses. The role played by the wind has also been stressed by Behling (1997, 1998), who described the northward advance of the *Araucaria* forests, from 2,850 years B.P. to the present, resulting from the intensification of the wind regime, increase in moisture and decrease in atmospheric temperature.

It is thus, in view of the modern controls of the productivity on the shelf, that our results permit us to infer paleoclimatic changes, associated with the wind regime and continental input. As a rule, the period of lower productivity corresponds to the interval between 5,200 and 3,000 years, which may be compared with the lower humidity values on the continent as well as weaker winds over the South American continent. The increase in moisture and the intensification of the southerly winds, as related by the authors above, led to an environmental change in the shelf regime, with a consequent increase in sedimentation rates, productivity and terrigenous input. Oscillations occurred after 3,000 years, as shown by the decrease in several parameters at ca 1,500 yrs B.P., which also agree with the paleoclimatic inferences set out by Behling (1997).

Time Series Analysis

The occurrence of cycles in the Holocene climate and ocean circulation has been reported by Bond et al. (1997), who identified a 1,470±500-year periodicity in the North Atlantic surface winds and hydrography. This cyclicity, which has been attributed to solar activity, has also been lately identified in other parts of the world, thus giving it a global character (Russell and Johnson, 2005).

More recently this single-dominant period cyclicity has been questioned by Clemens (2005), who indicated the occurrence of two stronger spectral peaks, at 1,667 and 1,190 years. The author suggests that millenial variability is determined by nonlinear interactions (heterodyning) between centennial periodicities due to solar activity.

In order to evaluate the occurrence of cycles in the sedimentation of the study area a time series analysis (Lomb periodogram) was undertaken with the aid of the software PAST (Hammer et al., 2001). Prior to analysis the data were detrended in order to remove the effect of very low frequencies (e.g. periods longer than the time span) on the results. Also, in order to reduce noise, a Principal Component Analysis (PCA) was performed with the standardized values including all of the elements, and the Axis-1 (83% of the total variance) scores were submited to spectral analysis. Axis-1 corresponds mainly to the input of Fe and Al, which may be assumed that the terrigenous input is the most important factor in the variability of the system.

An example of the results is shown in Figure 6 and the significant frequencies ($p <= 0.05$) for each parameter are presented in Table 2 with the highest peak highlighted.

The spectrograms for most of the elements as well as for the PCA scores show five main periodicities:

a) 3,880 to 6,700 years, accounting for the low frequency oscillations. These periods are too long compared with the time series for them to give reliable information concerning periodicity;

b) 2,360 to 2,820 years (centered at 2,680 yr B.P., according to the PCA analysis), observed at its highest power in Cr, Fe, magnetic susceptibility, sedimentation rate and PCA Axis-1 score. This cycle may be compared with the 2,750-year cycle observed both in the GISP-2 ice core and Santa Barbara Basin sediment core (Nederbragt and Thurow, 2005);

c) 1,600 to 1,910 years (centered at 1,848 yr B.P.), as identified in Mg. This cycle is found in most of the elements but we cannot assume that this cycle corresponds to the 1,470±500 year-cycle of Bond et al. (1997; 2001). On the other hand, Clemens (2005) observes a conspicuous 1,667 year-cycle in the records of Hulu Cave and GRIP;

d) 1,220 to 1,310 years (centered at 1,276 yr B.P.), found to be the most powerful cycle in Al distribution. We may not discard this as the second harmonic for the 2,360-2,820 year-cycle. It may also be compared with the 1,160-1,190 year-cycle reported by Clemens (2005), for the GRIP and Hulu Cave $\delta^{18}O$ records;

e) 880 to 1,030 years (centered at 1,030 yr B.P.), as observed in Sr, Ti and V. This cycle may be compared with the 1,000-year cyclicity reported for thermohaline circulation (Chapman and Shackleton, 2000), GISP-2 $\delta^{18}O$ and atmospheric $\Delta^{14}C$ (Nederbragt and Thurow, 2005) and North America temperatures (Viau et al., 2006), among others. This cycle is still maintained on several parameters (Axis-1 of the PCA, B, Sr, Mn and Ti) when the periodogram is executed for the most recent interval, i.e. coretop to 3,000 yrs B.P.

CONCLUSIONS

A high-resolution Holocene multiproxy record obtained for the first time on the Southwestern Atlantic shelf allowed us to recognize the main changes in the wind and La Plata river discharge. Two transitions, at 5,200-

5,000 and 3,000-2,800 yrs B.P. mark the boundaries of three time intervals with different sedimentary characteristics, related to environmental changes.

The interval between 5,200 and 3,000 yrs B.P. marks the period of lowest terrigenous input and productivity, which may be associated with the weakening of southerly winds and a decrease in humidity in South America, as confirmed previously in the palynological record for the continent.

The period after 3,000 yrs B.P. marks the highest terrigenous input and productivity, corresponding to the establishment of the modern conditions of wind and river discharge. At least one interval of the weakening of the climatic conditions could be observed in this period.

The time series analysis allowed us to recognize four significant cycles, which may be compared with the cyclicity described by several other authors, mainly in the northern hemisphere. The significant cycles centered on 2,680, 1,848, 1,276 and 1,030 found in the spectrograms of several parameters are comparable to those of GISP-2, GRIP, Hulu Cave, Santa Barbara basin, $\Delta^{14}C$ and North American temperatures.

Despite their significant correlation with ${}_{org}C$ and carbon accumulation rates, the utilization of Ba and Ba-related ratios as proxies for productivity have only been used qualitatively by the present authors. Regional studies are needed in order for us to be able to understand of the background terrigenous values of barium and, consequently, Ba_{xs}, better.

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CAPTIONS

Figure 1. Location of the core analysed in this paper. Seismic line represents a cross-shore chirp (2-8 kHz) profile, showing the bathymetric position of the core sampled. The strong sub-superficial reflector corresponds to the surface developed during the sea-level retreat after Isotope Stage 5e.

Figure 2. Age-Depth model, based on 11 AMS radiocarbon dating. Interpolation has been obtained with the mixed-effect model as described in Heegard et al. (2005)

Figure 3. Along-core variation in sedimentation rates, grain-size, terrigenous input and redox proxies and other Element/Ti ratios.

Figure 4. Dispersion plots of A) Al vs. Ti; B) Ba vs. ${}_{org}C$; C) Ba vs. carbon accumulation rate; D) Ba/Al vs. ${}_{org}C$; E) Ba/Al vs. carbon accumulation rate; F) Ba/Ti vs. ${}_{org}C$; G) Ba/Ti vs. carbon accumulation rate; H) Ba/Ca vs. ${}_{org}C$ and I) Ba/Ca vs. carbon accumulation rate. Statistically significant values ($p<0.05$) of Pearson Correlation Coefficient are pointed.

Figure 5. Along-core variations in organic Carbon (${}_{org}C$), total Nitrogen (${}_{tot}N$), C/N ratio, carbon accumulation rate (C.A.R.), Al, Ba, Ca and Sr contents, and Ba/Al, Ba/Ca, Ba/Ti and Al/Ti ratios.

Figure 6. A) Lomb periodogram of the detrended values of Axis 1 Factor Score (83% of the total variance) obtained by a Principal Component Analysis, using elemental values as data source; B) Sinusoidal fit on the same data, using the 2,680, 1,848, 1,276 and 1,030-year cycles.

Table 1. Results of AMS radiocarbon datings in the organic matter of selected samples. Calibrated ages were calculated using a SW Atlantic reservoir effect ($\Delta R=87$, $U=46$), using data from www.calib.org (accessed June 15th, 2006).

Table 2. Significant frequencies obtained in the Lomb Periodogram, for each parameter analysed. Highest peaks of each parameter are highlighted.

Depth	Conventional radiocarbon age (yr B.P.)	Error	δ13C (‰ PDB)	Calibrated radiocarbon age (yr B.P.)
0-2	1410	40	-19.6	855
50-52	1680	40	-19.8	1155
98-100	2080	50	-19.8	1565
148-150	2560	50	-20.3	2125
198-200	2750	40	-20.9	2370
248-250	3090	50	-20.6	2780
298-300	3230	50	-20.2	2930
352-354	3770	40	-19.6	3595
398-400	4490	40	-19.9	4545
448-450	5340	40	-20.3	5625
504-506	7290	40	-20.4	7665

Table1

Al	**Ba**	**B**	**Ca**	**Cr**	**Fe**	**Mg**	**Mn**	**Sr**	**Ti**	**V**	**Sus**	**C**	**S**	**Median**	**Sed Rate**	**Axi 1 PC sco**
6700	**6700**			6700	6700	6700	**6700**			6700						667
		5960														
			5360					5360								
												4180	**3880**	**4520**		
2550	2680	2820		**2550**	**2680**	2550	2680	2550	3150	2550	**2820**				**2360**	**268**
1790	1850			1850	1850	**1910**	1850	1790		1790		1600				185
1280	1280	1250		1310	1280				1220	1250						128
1050	1030	1030	870	1030	1030			**880**	**1010**	**1030**						103

Table 2