

MIOCENE LITHOLOGICAL, FORAMINIFERAL AND PALYNOLOGICAL DATA FROM THE BELVERDE BOREHOLE (PORTUGAL)

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ABSTRACT

Preliminary data on lithostratigraphy and biostratigraphy of the Belverde borehole (http://www.dct.fct.unl.pt/Sondagem/Sondagem/coluna/index_col.html) is presented. The borehole attained 619,77 m of depth, crossing 130 m of Plio-Pleistocene and 460 m of Miocene deposits. Main lithologies are fine sands, marls and biocalcarenes. A coral reef was recognized in the lower part of the borehole (530-585 m). Gamma ray, neutrons and sonic diagraphies were obtained. Eight ⁸⁷Sr/⁸⁶Sr isotopic ages (H. Elderfield, Cambridge University) and the presence of some of the main planktonic foraminifera markers were used to establish the chronostratigraphic framework. Planktonic spikes are related to the major transgressions of the Lower Tagus Basin (LTB): M. Burdigalian (sample Belv 459; 446 m), L. Serravallian (Belv 76; 244 m) and L. Tortonian (Belv 51, 202 m). Benthic assemblages are dominated by *Ammonia*, *Elphidium* and *Nonion*. Spores suggest a mild and humid climate during the uppermost Burdigalian to the Tortonian. Pollen is scarce. Thirty dinoflagellates taxa (26 Gonyaulacoids and 4 Peridinioids) have been identified, indicating coastal to shallow marine environments. In the uppermost Burdigalian to the Tortonian the presence of peridinioids and scarce acritarchs suggest influence of inshore to brackish environments. Several ⁸⁷Sr/⁸⁶Sr ages obtained by H. Elderfield (Cambridge University) fit well with the biostratigraphy for the Lower an Middle Miocene, but values given by Howarth and Mearthur (1997) are closer to the Upper Miocene biostratigraphic data.

Key words: Belverde borehole, Lower Tagus Basin, Portugal, Miocene, biostratigraphy, palynology, ⁸⁷Sr/⁸⁶Sr ages.

RESUMEN

En este trabajo se presentan los datos preliminares (litoestratigráficos y bioestratigráficos) obtenidos del análisis del sondeo de Belverde (http://www.dct.fct.unl.pt/Sondagem/Sondagem/coluna/index_col.html). Este sondeo alcanzó los 619,77 m de profundidad, atravesando 130 m de depósitos plio-pleistocenos y 460 m de depósitos miocenos. Las litologías encontradas se corresponden con arenas de grano fino, limos y biocalcarenes. En la parte inferior de la perforación (530-585 m) se reconoció un nivel de corales. Se realizaron estudios de Rayos Gamma, neutrones y diagrafías acústicas. Para el establecimiento del marco cronoestratigráfico se usaron ocho edades de ⁸⁷Sr/⁸⁶Sr, junto con foraminíferos planctónicos. La abundancia de foraminíferos plactónicos se relaciona con las principales transgresiones de la cuenca del Bajo Tajo (LTB): Burdigaliense medio (ejemplo, Belverde 459 a 446 m), Serravaliense inferior (ejemplo, Belverde 76 a 244 m) y Tortoniense inferior (ejemplo 51 a 202 m). *Ammonia*, *Elphidium* y *Nonion* son dominantes en las asociaciones bentónicas. Las esporas sugieren que desde el Burdigaliense hasta el Tortoniense predominó un clima suave y húmedo. El polen encontrado es escaso. Se han podido identificar 30 grupos taxónomicos (26 Gonyaulacoides y 4 Peridinioides) que indican ambientes

costeros a marinos. La presencia de peridinioides y acritarcos escasos sugieren influencia de ambientes costeros salobres en el tramo Burdigaliense-Tortonense. Las edades obtenidas en la relación $^{87}\text{Sr}/^{86}\text{Sr}$ por H. Elderfield (*Cambridge University*) se encuadran bien con la bioestratigrafía en el Mioceno Inferior a Medio, mientras que para el Mioceno Superior las edades propuestas por Howarth y McArthur (1997) se correlacionan mejor con los datos de foraminíferos planctónicos.

Palabras Claves: sondeo de Belverde, Cuenca del Bajo Tajo, Portugal, Mioceno, bioestratigrafía, palinología, edades de $^{87}\text{Sr}/^{86}\text{Sr}$.

INTRODUCTION

The Lower Tagus Basin (LTB) presents a rather complete marine and continental Cenozoic sedimentary record. It has been the object of scientific research for a long time, namely since Teodoro de Almeida's "Recreação Filozofica" (1762). Several geologic and paleontologic studies followed during the 19th century, either by foreign (D. Sharpe, W. Sowerby, W.-L. von Eschwege, etc) or Portuguese researchers (José Bonifácio de Andrada e Silva, A. Vandelli, F. Pereira da Costa and others, with a special reference to J. C. Berkeley Cotter, in the early 20th century). Also relevant were the works of Paul Choffat and Georges Zbyszewski.

Concerning the Neogene, it allows a good knowledge of the stratigraphy, paleontology, geochemistry and paleoclimates. Namely for the Miocene, direct correlation between marine and continental biomarkers can be obtained. Further relevancy is added by its peculiar geographic situation on the interface between the western Atlantic and mediterranean domains, and in some way influenced by the North American margin. An impressive volume of multidisciplinary data is presently available (Pais, 2004, Fig. 2, in this volume). Among others, the contribution of the PRAXIS XXI Project "Neogénico da margem atlântica da Ibéria e transformações globais" must be stressed (Antunes *et al.*, 1996, 1999).

Until now, studies have been based on outcropping units although not representing the total infill of the Lower Tagus Basin. In order to get the most continuous record of the Miocene deposits a new research project (POCTI/32345/CTA/2000) was proposed. The aim of this project was to make a borehole with continuous sampling through Neogene reaching the topmost Paleogene, drilled on the inner region of the Lower Tagus gulf but still in the area of Atlantic influence.

LOCATION

The drilling location was selected from seismic profiles, in order to allow the extrapolation of the results to the inner regions of the basin by following the main reflectors. The chosen location was at Belverde (Península de Setúbal, coordinates: 38° 35' 54,1" N; 9° 8' 24,7" W).

MATERIALS AND METHODS

Drilling work took place from 21st March to the end of December 2001.

Four hundred samples were collected for micropaleontological, palynological and clay minerals studies. Samples for foraminiferal study were disaggregated with a H_2O_2 solution, and washed in a 125 μm sieve. Preparation of samples for palynological study followed standard procedures with wet sieving through 150 μm sieve onto a 25 μm . The fraction containing palynomorphs was separated using Zn_2Cl heavy-liquid. The residues were mounted in glycerin jelly.

Natural gamma ray, neutron-neutron, temperature and geophysical logs were made. The Geothermal gradient log was calculated after temperature log. SP, SPR and sonic logs were obtained for two small sections in upper and lower parts of the Miocene deposits.

LITHOLOGY AND PALAEOLOGY

The borehole reached 619,77 m. It crossed 130,31 m of Plio-Pleistocene continental deposits, 460 m of Miocene (mainly marine deposits; including marsh ones). In the lower part of the borehole (530-585 m), a coral reef was recognised. This coral reef overlays red continental conglomeratic deposits probably representing the Benfica Group historically supposed to be of Paleogene age.

Miocene (from 130 m to 590 m) main lithologies are fine sands, marls and biocalcarenes. In the lower part, marly limestones prevail while sands become predominant in the upper part. Marls are abundant in the Middle Burdigalian and Lower Serravallian.

Mica is present, except in the lower part of the borehole (Aquitania). Sediments are strongly micaceous in the Upper Burdigalian and from Middle Serravallian to Lower Tortonian. After Langhian biotite becomes much more frequent.

Coal fragments are present in lower part (Aquitania and Burdigalian) but almost inexistent in the upper part (Langhian to Tortonian).

Macrofossils are frequent along the borehole, but they are absent from 175 m to 193 m (Tortonian) and in the Upper Aquitania (515-528 m).

A coral reef was recognized in the lower part of the borehole (530-585 m). Corals are also present in the Burdigalian (458-480 m) and Langhian (275-308 m).

Algae are frequent, increasing after the Middle Burdigalian.

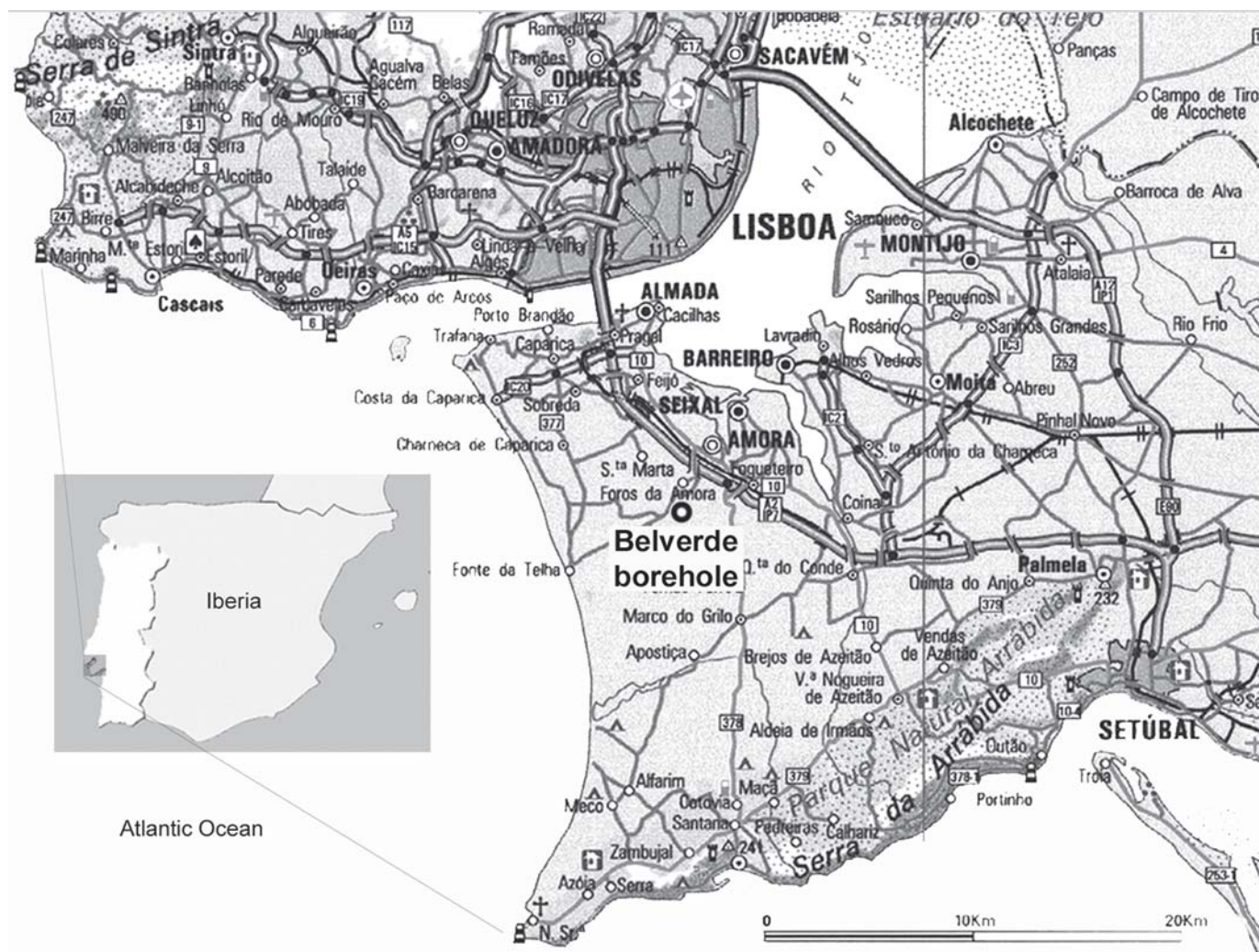


Figure 1. Location of Belverde borehole.

DIAGRAPHIES (Fig. 2)

Sonic logs (and, generically, neutron logs) reflect sediments porosity, being the higher acoustic velocities often related with compact/massive levels (as siltstones and/or limestones and rather fossiliferous marly layers) and smaller values with porous ones (silty sandstones, fossiliferous and with scarce clay content levels and biocalcarenites). As indicative, we obtained the mean values of 2000-3000 m/s to the higher velocities, and 5000-8000 m/s to the lowest ones.

Concerning gamma ray logs, the spikes of radiation can be correlated with marly layers often fossiliferous and micaceous (presence of radioactive micas). Minimum values of gamma ray can be correlated to the boundaries of depositional sequences previously defined for the Lower Tagus Basin (Antunes *et al.*, 1999, 2000; Pais *et al.*, 2002). A correlation between gamma ray cycles and depositional sequences is presented in Fig. 2.

BIOSTRATIGRAPHY (Fig. 3)

Planktonic foraminifera spikes are related to the major transgressions of the Lower Tagus Basin (LTB): Middle Burdigalian (sample Belv 459; 446 m), Lower Serravallian (Belv 76; 244 m) and Lower Tortonian (Belv 51, 202 m) (Legoinha *et al.*, 2002).

In the marls at 440-453 m, *Globigerinoides altapertura*, *Globigerinoides subquadratus* and *Globorotalia acrostoma* were found indicating the Burdigalian (N6). These sediments are related to the Lower Miocene main transgression of the LTB.

Globigerinoides bisphericus (Belv 161, 342 m) allow correlation to the Upper Burdigalian (N7).

Praeorbulina transitoria (Belv 134, 311 m) and *Praeorbulina glomerata* (Belv 104, 278m) occur in the Langhian (N8).

First occurrence of *Orbulina universa* (Belv 96, 267 m) was used to place the Langhian/Serravallian boundary (N9). *Globorotalia scitula* and *Globorotalia periphero-*

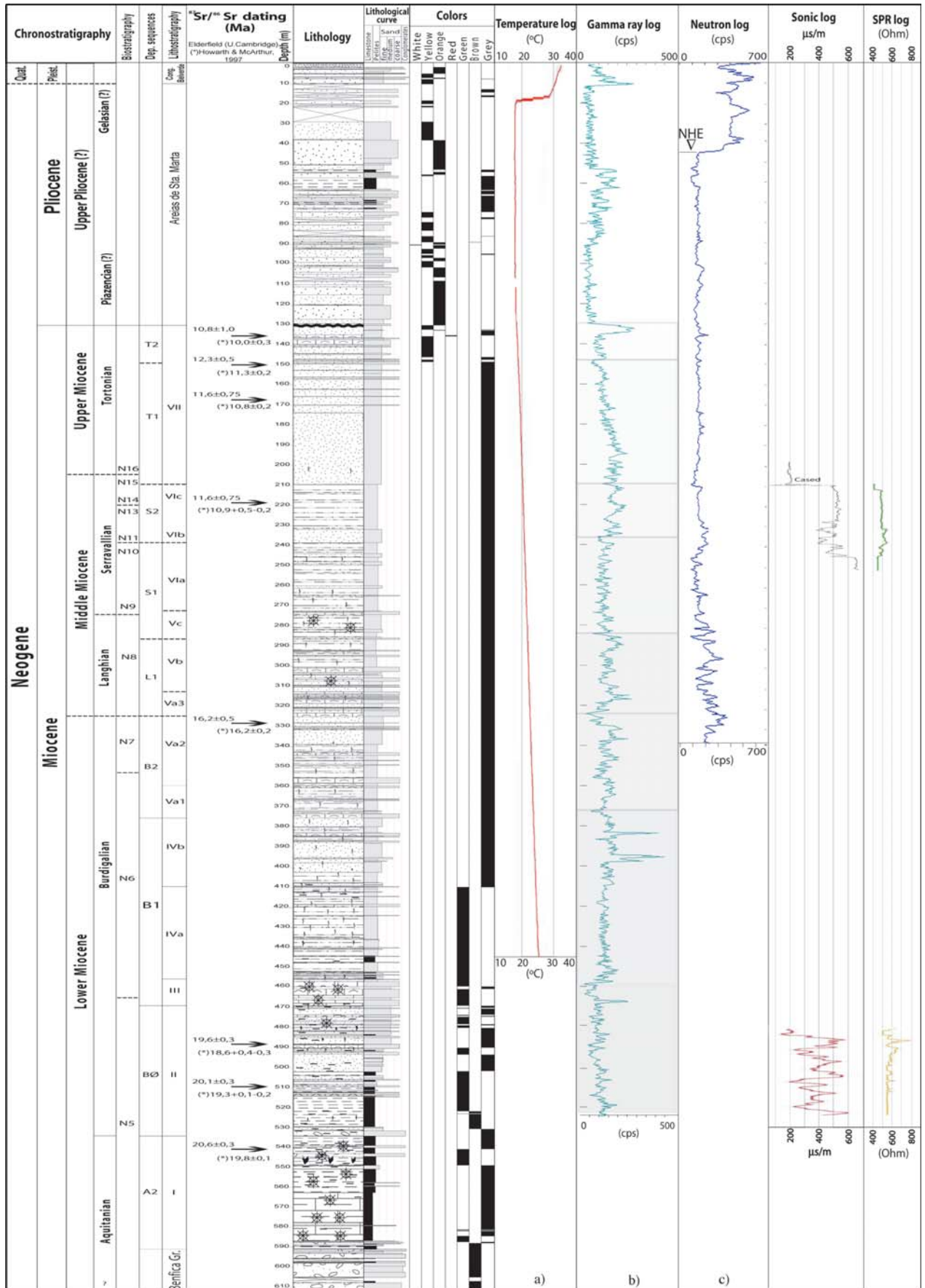


Figure 2. Lithology, diagraphies, depositional sequences and chronostratigraphical framework of the Belverde borehole.

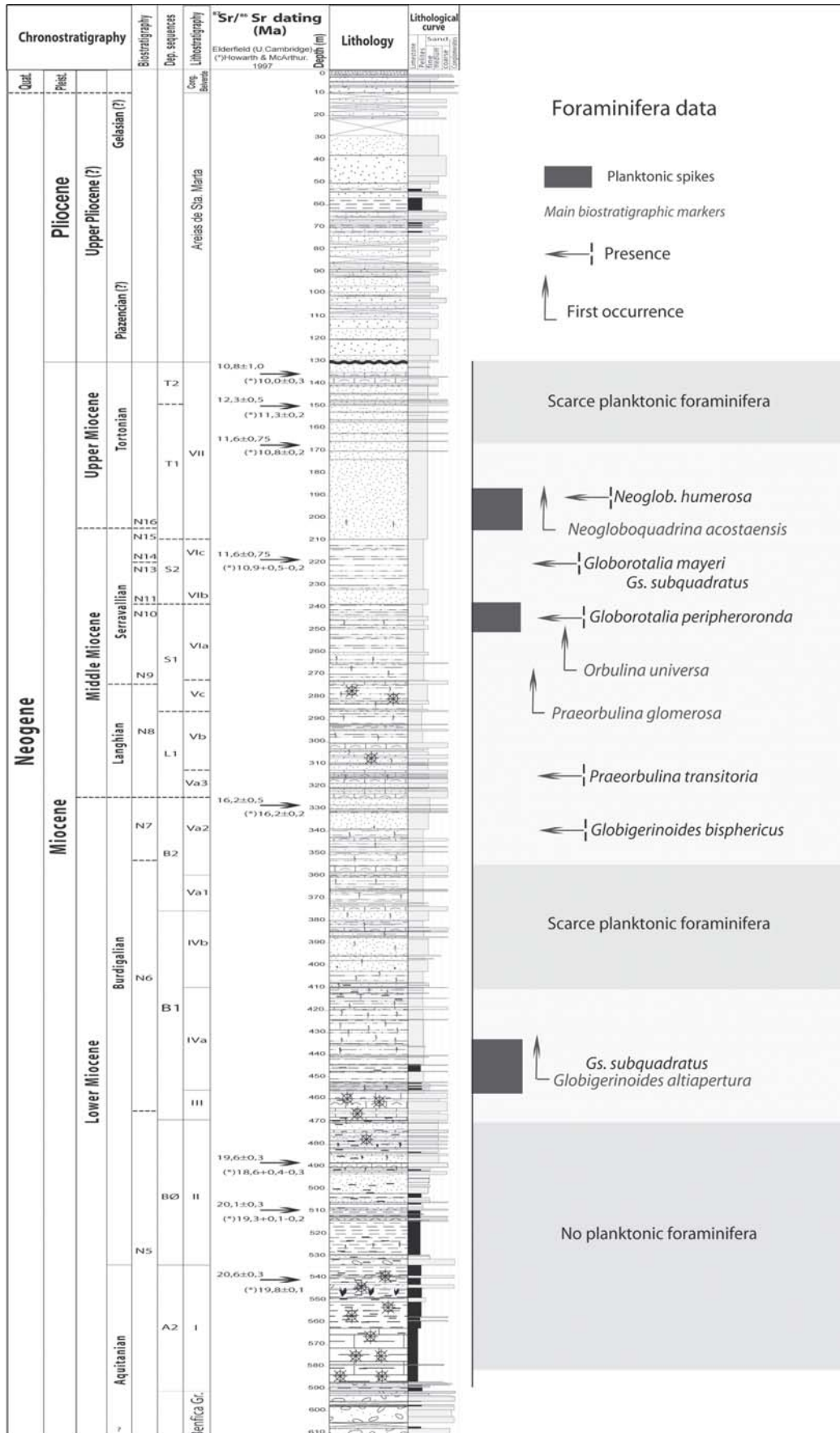


Figure 3. Biostratigraphy of the Belverde borehole based on planktonic foraminifera and ⁸⁷Sr/⁸⁶Sr ages.

ronda (\leq N10) are present (Belv 76, 244 m). *Uvigerina* is frequent. These sediments are related to the Serravallian main transgression of the LTB.

Globigerinoides subquadratus, *Globorotalia mayeri*, *G. menardii* and *Orbulina universa* occur in the interval from Belv 61 (218 m) to Belv 70 (235 m) characterizing N11 to N13 (Serravallian).

Neogloboquadrina acostaensis is frequent above Belv 55 (207 m) pointing out to the Tortonian (N16); *Neogloboquadrina humerosa* is present in Belv 45.

Planktonic foraminifera are abundant and well preserved from Belv 55 to Belv 45 (210 m to 190 m), suggesting a maximum of depth related to the Lower Tortonian transgression of the LTB. Planktonic foraminifera are scarce in the upper 50 m of the Miocene succession, indicating less influence of the sea.

BENTHONIC FORAMINIFERA

In the lower part of the borehole planktonic foraminifera are scarce or absent (460 to 595 m). *Ammonia*, *Elphidium* and *Nonion* are predominant in the benthic assemblages. *Amphistegina* and *Cibicides* occur sporadically. Fragmented shells, brown due to limonitisation are frequent in some samples. Abundant miliolids occur in a few samples from 530 to 550 m.

In some levels benthic shells appear abraded and/or recrystallized. At Belv 13 (143 m) benthic foraminifera are scarce. *Ammonia* and *Nonion* constitute all the assemblage of the uppermost samples.

PALYNOLOGY (Fig. 4)

Concerning palynomorphs, 15 samples were selected (table 1).

Belv 1 and 7 are almost sterile (Tortonian). In Belv 387 (Aquitanian), 329, 292, 237 (Lower Tortonian) and Belv 32 (Middle Tortonian) the palynomorphs are scarce (<100 forms). They are abundant (250-1660 forms) in the other samples. Dinoflagellates are predominant over spores/pollen in Belv 187, 120 and 54. In Pa1, Belv 83, 68, 42, 32 and 17 spores/pollen prevail.

Spores (Sphagnaceae, Anthocerotaceae, Ricciaceae, Selaginellaceae, Pteridaceae) suggest a mild and humid climate (Belv 187, 120, 83, 68, 54, 42, 32, 17 — uppermost Burdigalian to uppermost Tortonian). Pinaceae are abundant in the samples of Middle and Upper Miocene but, in Belv 387, 329, 237, 7 and Pa1, it is very scarce. Ephedraceae is scarce (Pa1, Belv 187, 120, 17). Angiosperm arboreal pollen are scarce ($n < 6$). Non arboreal pollen occur in all samples except Belv 329, 7 and 1; they are represented during uppermost Burdigalian (Pa1, Belv

Series	Stages	Samples (Belv)	Depth (m)
Miocene	Tortonian	1	130,35
		7	135,66
		17	146,59
		32	162,18
		42	179,51
	Serravallian	54	205,86
		68	231,88
	Langhian	83	251,28
		120	295,58
	Burdigalian	187	370,55
		237	460,85
		292	481,15
		329	520,62
	Aquitanian	387	580,60
		Pa1	595,97

Table 1. Palynological samples.

187), Middle (Belv 120, 83, 68) and Upper Miocene (Belv 54, 17). Acritarchs are few ($n < 4$); only *Cyclopsiella granosa* and *Pterospermella* sp. occur in Upper Miocene (Belv 292, 187, 54, 42): Peridinioids occur in the uppermost Burdigalian (Belv 187), Middle (Belv 120, 83, 68) and Upper Miocene (Belv 54, 42, 32, 17); only *Selenopemphix* and *Trinovantedinium* are present.

Twenty-six gonyaulacoids taxa have been identified; they are particularly frequent in the Upper Burdigalian (Belv 187), Langhian (Belv 120), Lower Serravallian (Belv 83) and Lower Tortonian (Belv 54); they can be correlated to the main transgressions of the LTB. They are absent in Belv 237, 7 and Pa1; in other samples they are scarce ($n < 50$). During Upper Burdigalian, *Polysphaeridium zoharyi*, *Systematophora placacantha*, *Lingulodinium* sp., *Operculodinium israelianum* and *Spiniferites ramosus* are represented. In the Langhian, *Apteodinium australiense* is very abundant; *Lingulodinium* sp., *Polysphaeridium* sp. and *S. ramosus* are common. In the Serravallian, *Spiniferites/Achomosphaera*, *Hystricosphaeropsis obscura*, *Lingulodinium machaerophorum* and *Operculodinium israelianum* are frequent. During Tortonian *Lingulodinium machaerophorum*, *Homotryblum vallum*, *Spiniferites/Achomosphaera*, *S. pseudofurcatus* and *Operculodinium israelianum* are common.

ISOTOPIC AGES (Fig 2, 3)

$^{87}\text{Sr}/^{86}\text{Sr}$ age of eight mollusc shells, collected in the bottom, middle and upper part of the miocene succession, were obtained by H. Elderfield (Cambridge University). In the Lower and Middle Miocene the ages agree quite

well with the biostratigraphy, but for the Upper Miocene the ages given by the Howarth and McArthur's table (1997) fit better with the biostratigraphic data.

CONCLUSIONS

Belverde borehole (Pais *et al.*, 2002) with a length of 620 m, crossed 130 m of Plio-Pleistocene and 460 m of Miocene deposits. Classical lithostratigraphic units (Cotter, 1956) established for Lisbon region were recognized.

Planktonic biozones N6, N7, N8, N9, N10, N11-13 and N16 were identified.

The oldest Miocene depositional sequence known in Lisbon (SD A1) seems not to be represented in the Belverde Borehole. On the other hand, the youngest Miocene sediments from the borehole gave *Neogloboquadrina acostaensis* and *Neogloboquadrina humerosa*, which were not known in the outcrops.

The relative abundance of dinoflagellate cysts indicates a fluctuating marginal littoral to shallow marine depositional environments during the late Burdigalian through Tortonian. The presence of peridinioids (and scarce acritarchs) in some samples of the Upper Miocene (Belv 54, 42, 17) suggests an inshore to brackish environment (Sousa and Pais, 2002).

Minimum values of gamma ray fit well with the boundaries of depositional sequences previously defined for the Lower Tagus Basin (Antunes *et al.*, 1999, 2000; Pais *et al.*, 2002). A correspondence between depositional sequences and natural gamma ray cycles was established.

⁸⁷Sr / ⁸⁶Sr ages obtained by H. Elderfield (Cambridge University) fit well with the biostratigraphy for the Lower and Middle Miocene. For the Upper Miocene values given by Howarth and McArthur's table (1997) are closer to the biostratigraphic interpretation.

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