

High resolution stratigraphy and miocene facies correlation in Lisbon and Setúbal Peninsula (Lower Tagus basin, Portugal)

M. Telles Antunes⁽¹⁾, P. Legoinha⁽²⁾, P. Proença Cunha⁽³⁾ & J. Pais⁽⁴⁾

Work supported by "Praxis XXI 2/2.1/CTA/106/94" and by "POCTI/32 345/CTA/2000 Projects (FCT).

1 - Academia das Ciências de Lisboa, Centro de Estudos Geológicos (JNICT), Faculdade de Ciências e Tecnologia, Quinta da Torre, P-2825-114 Caparica, Portugal; mta@mail.fct.unl.pt;

2 - Centro de Estudos Geológicos (JNICT), Faculdade de Ciências e Tecnologia, Quinta da Torre, P-2825-114 Caparica, Portugal; pal@mail.fct.unl.pt;

3 - Centro de Geociências, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Largo Marquês de Pombal, Coimbra; cunha@ci.uc.pt;

4 - Centro de Estudos Geológicos (JNICT), Faculdade de Ciências e Tecnologia, Quinta da Torre, P-2825-114 Caparica, Portugal; jjp@mail.fct.unl.pt

ABSTRACT

Key words: Sequential stratigraphy; Miocene; Lower Tagus Basin; Lisbon; Setúbal Peninsula; Portugal.

Correlation between facies associations (marine, estuarine and distal fluvial environments) and unconformities, observed between Foz da Fonte (SW of Setúbal Peninsula) and Santa Iria da Azóia (NE of Lisbon) are presented. The precise definition of the marine-continental facies relationships improved very much the chronology of the depositional sequence boundaries. Tectonic and eustatic controls are discussed on the basis of subsidence rates' variation.

RESUMO

Palavras chave: Estratigrafia sequencial; Miocénico; Bacia do Baixo Tejo; Lisboa; Península de Setúbal; Portugal.

Apresenta-se correlação entre associações de fácies (ambientes marinhos, estuarinos e fluviais distais) e descontinuidades sedimentares desde Foz da Fonte (a SW da Península de Setúbal) até Santa Iria da Azóia (a NE de Lisboa). A definição precisa da interdigitação entre fácies marinhas e continentais permitiu precisar a cronologia dos limites das sequências deposicionais. Discute-se a influência dos controlos tectónico e eustático na geração de espaço de acomodação com base na análise das variações da subsidência.

INTRODUCTION

The Lower Tagus basin is situated in the western margin of the Iberian plate. It presents an NE-SW alignment. Its almost siliciclastic neogene infilling shows several sedimentary unconformities. The most important are angular unconformities related to tectonic events associated to the geodynamic evolution of the Iberian plate.

The Lisbon and Setúbal Peninsula areas belong to the distal part of the Lower Tagus basin where the predominant estuarine sedimentation passes westwards to an oceanic one (Antunes *et al.*, 1987; Cunha, 1992a; Cunha 1992b; Pena dos Reis *et al.*, 1992; Barbosa, 1995).

The Miocene (Aquitanian to Early Tortonian) succession is bounded by angular unconformities. It reflects a compressive context related to the Betic collision. Basin's depocenter is placed in the Setúbal Peninsula where thickness attains about 900 m.

Several logs allow high resolution correlations between marine and continental levels dated by planktic forams, mammals, and/or isotopic ages (K/Ar-glaucónites; Sr isotopes). Small and large mammals give precise datation for fluvial/estuarine beds. Palaeontologic wealth — dinoflagellates, palinofossils, nannoplankton, algae, plant macroremains, forams, ostracods and other crustaceans, molluscs, echinoderms, fish, reptiles, mammals — as well

as Oxygen and Carbon isotopic studies provide a huge amount of information on palaeogeographic and palaeobiogeographic reconstructions.

Antunes *et al.* (1973) defined sedimentary cycles in the Lisbon region based on the successive unit's transgressive/regressive character. Antunes & Pais (1993) made correlations with Almada (Setúbal Peninsula) and with the inland part of the basin (Ribatejo); seven transgressive events alternating with six regressive ones were recognized.

Research on the Setúbal Peninsula (Sen *et al.*, 1992; Legoinha, 1993; Antunes *et al.*, 1995; Antunes *et al.*, 1996) improved the biostratigraphic knowledge of some units (presenting correlation difficulties because of facies differences from Lisbon region).

The integration of all lithologic, biostratigraphic (first and last occurrence of significant groups/species of forams and mammals) and isotope (K/Ar e $^{87}\text{Sr}/^{86}\text{Sr}$) dating allowed the chronostratigraphic framework from Lower Tagus basin Miocene series, as well as the characterization of eight depositional sequences (Antunes *et al.*, 1999).

Analysis and interpretation of outcrops and boreholes (Fig.1) from the Lisbon-Setúbal Peninsula area (Cotter, 1950; Choffat, 1956; Antunes & Torquato, 1969; Antunes *et al.*, 1996a; 1996b; 1998; 1999; Sen *et al.*, 1992) are presented. Taking into account the previously defined depositional sequences, we present a detailed correlation

scheme between facies and discontinuities, as well as a palaeoenvironmental interpretation. Lateral and vertical thickness changes are discussed.

FACIES ASSOCIATIONS

Lithology, sedimentary structures, palaeontologic contents and sedimentary discontinuities were used to characterize facies (marine, estuarine and fluvatile). Correlations from Foz da Fonte (SW, in the Setúbal Peninsula) to Santa Iria da Azóia (NE, Lisbon) are shown (Figs 2 and 3).

Vertical and lateral facies' shifts were used to interpret the sea level changes and to characterize transgressive-regressive cycles of different scale order. The eustatic changes could be registered because of the continuous regional subsidence.

The thickness of the Miocene succession increases from Foz da Fonte-Ribeira da Lage sector (about 85m) to Charneca (more than 494m). It diminishes from there to Santa Iria da Azóia (about 162m; Choffat, 1956). In the southwestern and central sectors of the concerned area an alternance between marly limestones and marls predominates. In the NE sector detrital sedimentation predominates in result of the fluvatile influx.

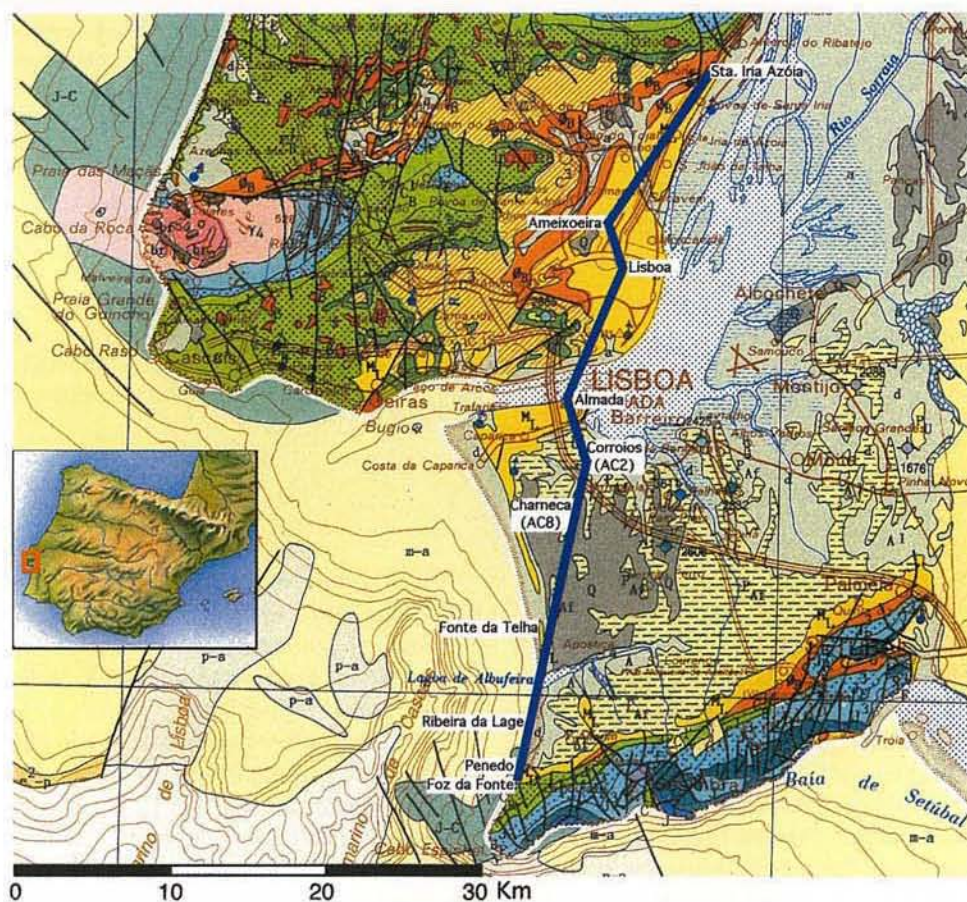


Fig. 1 - Localização dos cortes geológicos, das sondagens e do perfil interpretativo.

Facies associations and sedimentary environments are as follows:

- Af1 - infralittoral to circalittoral (conglomerates/glaucinite sands and sandy marls with planktic forams);
- Af2 - littoral to estuarine, infratidal (biocalcarenes and marls, with molluscs);
- Af3 - tidal flats (silts, often with abundant organic matter);
- Af4 - delta/estuary channels and bars (bioclastic, fine to middle sandstones);
- Af5 - distal fluvial (coarse to middle grained sandstones and clays, with plant and mammal remains).

DEPOSITIONAL SEQUENCES AND THE CHRONOLOGY OF DISCONTINUITIES

For each log, sea-level changes were interpreted on sedimentological characteristics and palaeontologic contents. Transgressive/regressive cycles were correlated between all the studied stratigraphic columns. Ten main cycles have been recognized and named by depositional sequences (SD). As the result of better correlation data obtained now, the previous sequence SD-A is divided in SD-A1 and SD-A2 as well as the SD-T in SD-T1 and SD-T2. The last two have not been sufficiently characterized because of the poor exposition and the scarce biostratigraphic markers (Figs 3 and 4).

Integrating all the available data, and their precise stratigraphic position in each sequence, discontinuities between depositional sequences are dated as follows:

- SD-A1, D1 - 23 Ma;
- SD-A2, D2 - 21 Ma;
- SD-B0, D3 - 20 Ma;
- SD-B1, D4 - 19 Ma;
- SD-B2, D5 - 17,8 Ma;
- SD-L1, D6 - 17 Ma;

- SD-S1, D7 - 15,3 Ma;
- SD-S2, D8 - 12,7 Ma;
- SD-T1, D9 - 11,6 Ma;
- SD-T2, D10 - 9,5 Ma.

A correspondence with 3rd order eustatic cycles (Haq *et al.*, 1987) is presented (Table 1). Sequences SD A1, A2, B2, L1, S1 and T1 seem to correspond to 3rd order eustatic cycles. Sequences SD-B0, SD-B1 concern the same eustatic cycle (TB2.1), while SD-S2 corresponds to two (TB2.5 and TB2.6) cycles. In some sequences (SD-L1, SD-S1 and SD-S2) lower order cycles can be recognized.

As Antunes *et al.* (1996) had referred, discrepancies between the basin's maximum flooding events and the eustatic maxima (Haq *et al.*, 1987) may be related to local changes on subsidence (and/or inaccurate correlation between different chrono and biostratigraphic scales).

SUBSIDENCE ANALYSIS

A ready approach to the subsidence rate (Table 2) for each depositional sequence was obtained by dividing thickness by the age span between the upper and lower discontinuity boundaries. Backstripping was not calculated; this was regarded as irrelevant due to the succession's weak burial.

Sedimentation begins in the Lisbon area. This area is the only one where the SD-A1 sequence has been recognized. Subsidence rate increases everywhere till B1 (Fig.4). After a general decrease during SD-B2, subsidence increases between Corroios and Lisbon (SD-L1). Subsidence rate increases again in the Ribeira da Lage-Charneca region (SD-S2).

The thickness of depositional sequences changes laterally very much. Migration of the depocenter also is significant. The A2, B0 and B1 sequences depocenters are in Almada and Charneca. The B2 depocenter is confined to Charneca. In sequences L1 and S1 the depocenter is located at Corroios; in sequence S2 it returns to Charneca.

Chronostratigraphy	3 rd ord. Cycles	Depos. Seq.
Tortonian	TB3.2	T2?
	TB3.1	T1
Serravallian	TB2.6	S2
	TB2.5	
	TB2.4	S1
Langhian	TB2.3	L1
Burdigalian	TB2.2	B2
	TB2.1	B1
Aquitania		BØ
	TB1.5	A2
	TB1.4	A1

Table 1 - 3rd order cycles (Haq *et al.*, 1987) and depositional sequences in the distal part of the Lower Tagus Basin.

Dep. Seq	FF-RL	CH-AC8	Corr-AC2	AL	Li	Am	SIA
A1	0	0	0	0	19,5	0	0
A2	0	38	18	46	17	0	6
B0	12	48	30	37	20	16	14
B1	25,8	93,3	83,3	92,5	53,3	51,7	43,3
B2	7,1	45,7	27,1	21,4	19,3	21,4	11,4
L1	0	34,5	56,4	13,6	32,7		25,5
S1	1,2	32,3	46,2	13,8	12,3		6,9
S2	29	70,9	38,2	12,7	10,9		10,9
T1	8,6	15,2	15,2	10,5	17,1		7,6
T2				26	32		

Table 2 – Subsidence rate (m/Ma) for each depositional sequence on studied logs (FF- Foz da Fonte; RL - Ribeira da Lage; CH - Charneca; AC8 - Corroios; AL - Almada; Li - Lisboa; Am - Ameixoeira; SIA - Santa Iria da Azoia). Dark blue colour stresses the greatest subsidence rate for each depositional sequence.

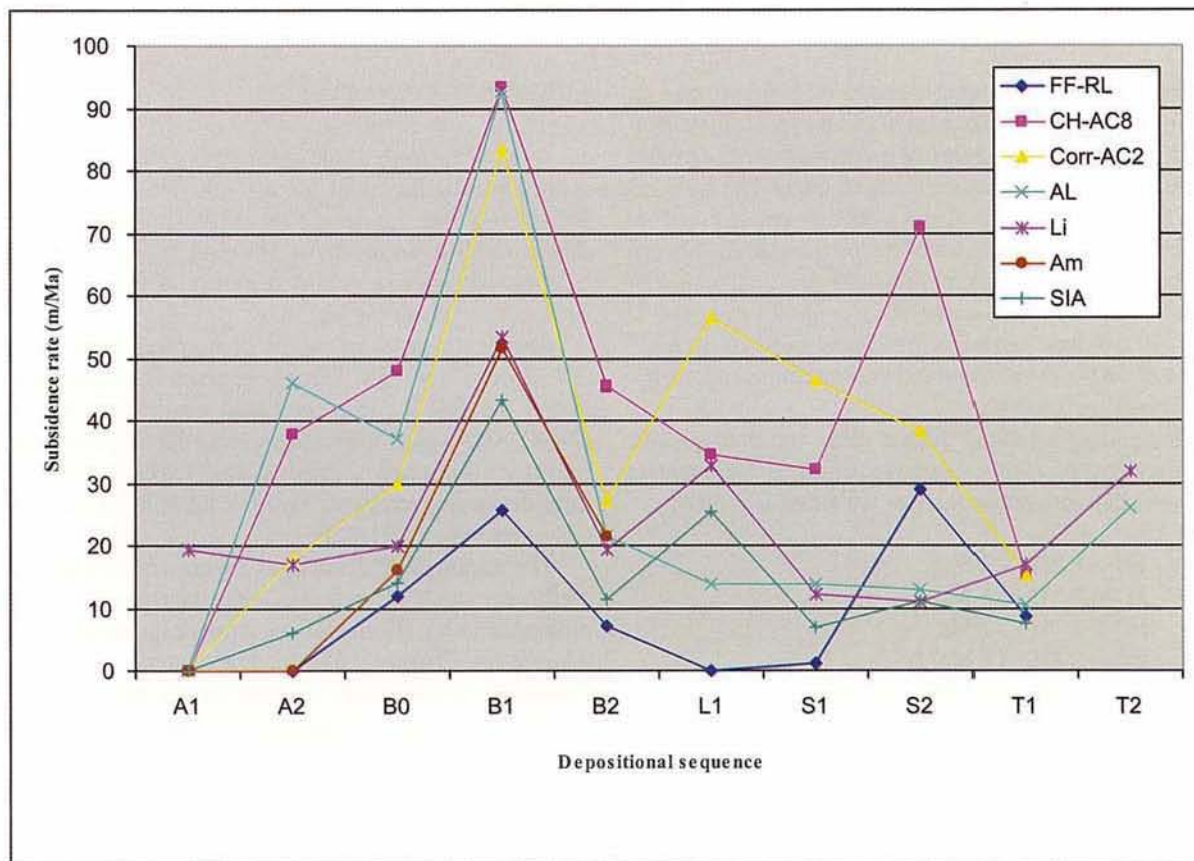


Fig. 4 – Subsidence rate (m/Ma) for the studied logs (FF- Foz da Fonte; RL - Ribeira da Lage; CH - Charneca; AC8 - Corroios; AL - Almada; Li - Lisboa; Am - Ameixoeira; SIA - Santa Iria da Azoia).

T1 and T2 sequences (T2 restricted to a narrow area between Fonte da Telha and Lisboa) show greater subsidence rate in Lisbon.

In a regional compressive context between the area to the North of Lisbon and the Arrábida chain (defining a large syncline with continuous subsidence) depocenter migration results from block's tectonics. Northwards migration of the depocenter between B2 and L1 is a consequence of a tectonic event (about 17 Ma). This event originated an angular unconformity that may be seen at Portinho da Arrábida (Pais *et al.*, 1991; Antunes *et al.*, 1995).

CONCLUSIONS

- Correlation of facies associations and depositional sequences in several Miocene logs (outcrops and boreholes) from Lisbon and Setúbal Peninsula has been achieved.
- Vertical and lateral facies changes of the Aquitanian to Tortonian depositional sequences have been characterized in detail. Redefinition of the previous SD-A and SD-T sequences is proposed.

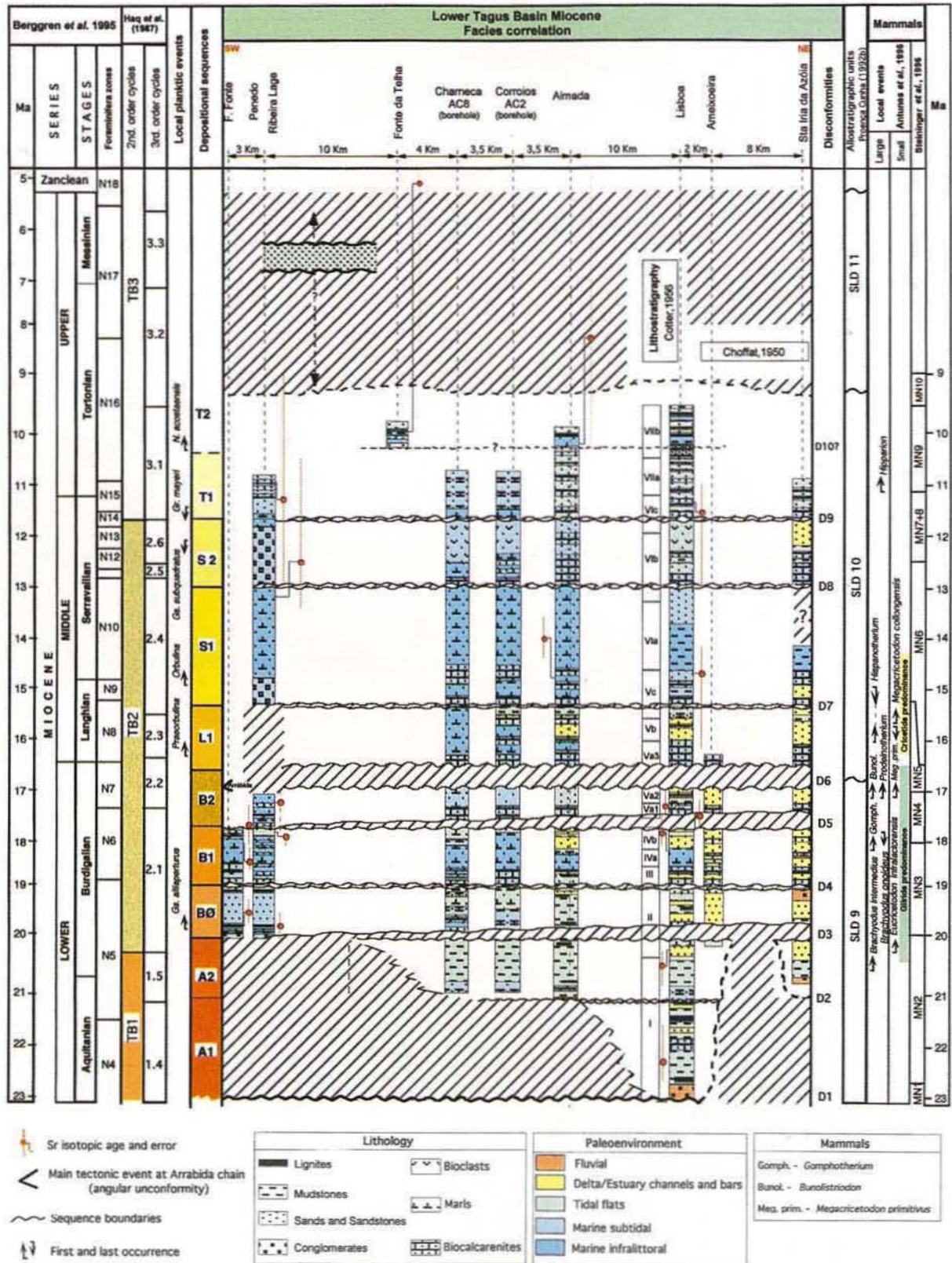


Fig. 3 - Stratigraphic framework of the Miocene from the distal part of the Lower Tagus Basin (Lisbon and Setúbal Peninsula).

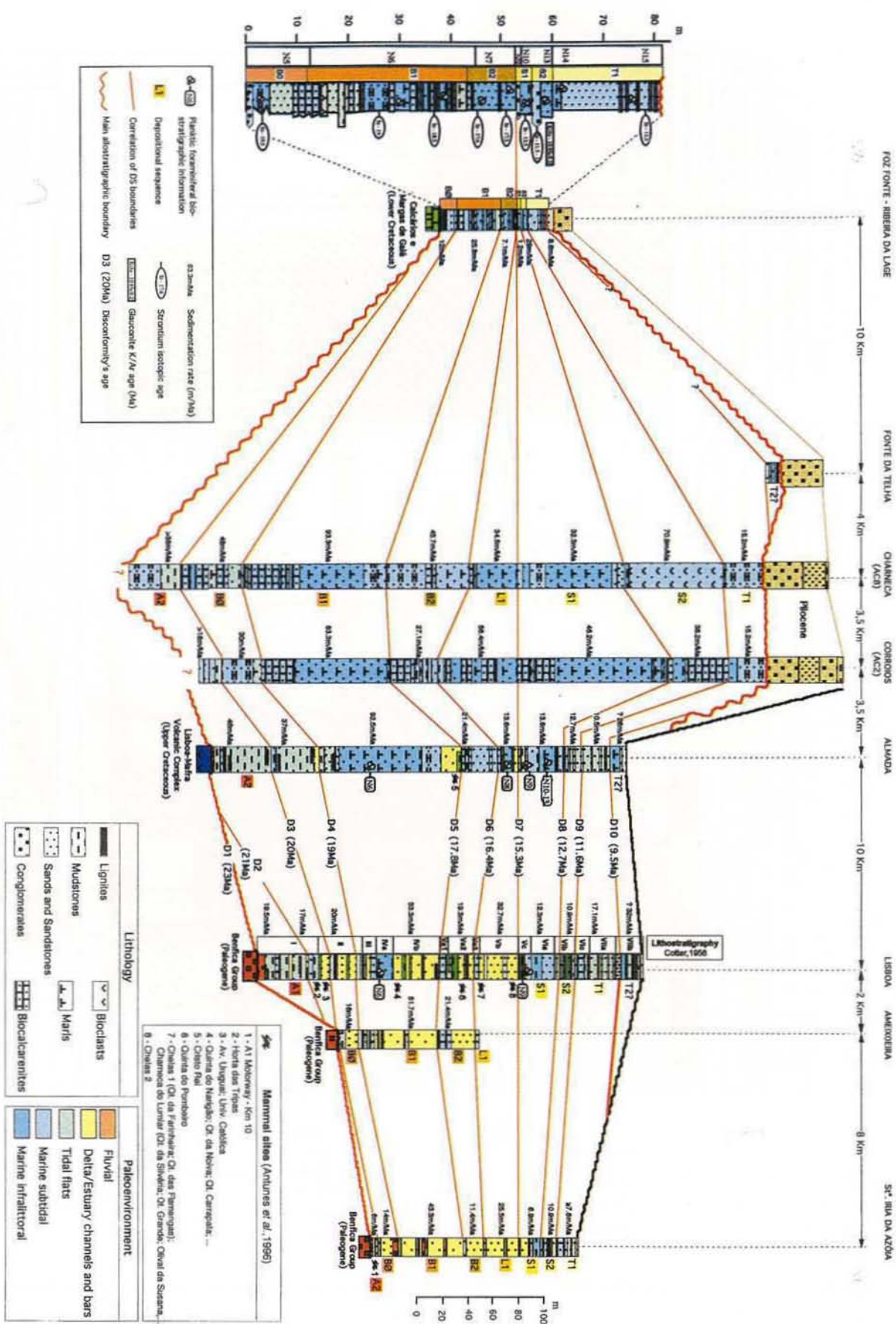


Fig. 4 - Correlation chart between sections and boreholes from Foz da Fonte/Ribeira da Lage (Setúbal Peninsula) to Lisbon region.

- A chronostratigraphic framework of the facies, depositional sequences and corresponding boundaries is presented. Sequence depositional (SD) boundaries (D) are aged (Ma) as follows:
 - Aquitanian: D1 - 23 Ma (beginning of Miocene sedimentation);
 - Aquitanian: D2 - 21 Ma (SDA1-SDA2);
 - Burdigalian: D3 - 20 Ma (SDA2-SDB0);
 - Burdigalian: D4 - 19 Ma (SDB0-SDB1);
 - Burdigalian: D5 - 17,8 Ma (SDB1-SDB2);
 - Burdigalian/Langhian : D6 - 16,4 Ma (SDB2-SDL1);
 - Langhian: D7 - 15,3 Ma (SDL1-SDS1);
 - Serravallian: D8 - 12,7 Ma (SDS1-SDS2);
 - Serravallian: D9 - 11,6 Ma (SDS2-SDT1);
 - Tortonian: D10 - 9,5 Ma (SDT1-SDT2).
- Local subsidence rates have been quantified in the Foz da Fonte - Ribeira da Lage, Charneca, Corroios, Almada, Lisboa, Ameixoeira and Santa Iria da Azoia sectors.
- Analysis of the sedimentary and palaeontological contents and isotopic dating provides an improved assessment of the influence of tectonics, eustatism and sedimentary supply in the generation of the accommodation space.
- In a regional NW-SE compressive context, the Albufeira syncline had continuous subsidence; that allowed eustatic changes of diverse order to be recognized.
- Depocenter migration and facies changes suggest that tectonic blocks subsided at different rates.

REFERENCES

- Antunes, M. T.; Civis, J.; González-Delgado, J.A.; Legoinha, P.; Nascimento, A. & Pais, J. (1996a) - Miocene stable isotopes ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$), biostratigraphy and environments in the southern limb of Albufeira syncline (Setúbal Peninsula, Portugal). *Geogaceta*, Madrid, 21: 21-24.
- Antunes, M. T.; Civis, J.; González-Delgado, J.A.; Legoinha, P.; Nascimento, A. & Pais, J. (1998a) - Lower Miocene stable isotopes ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$), biostratigraphy and environments in the Foz da Fonte and Penedo sections (Setúbal Peninsula, Portugal). *Geogaceta*, Madrid, 23: 7-10.
- Antunes, M.T.; Elderfield, H.; Legoinha, P. & Pais, J. (1995) - Datações isotópicas com Sr do Miocénico do flanco Sul da Serra da Arrábida. *Com. Inst. Geol. e Mineiro*, Lisboa, 81: 73-78.
- Antunes, M. T.; Elderfield, H.; Legoinha, P.; Nascimento, A. & Pais, J. (1998b) - A Stratigraphic framework for the Miocene from the Lower Tagus Basin (Lisbon, Setúbal Peninsula, Portugal). Depositional sequences, biostratigraphy and isotopic ages. Proceedings of the 2d RCANS Congress (1997). *Bol. Soc. Geol. España*, Madrid 12 (1): 3-15.
- Antunes, M. T., Ginsburg, L., Torquato, J. R. & Ubaldo, M.L. (1973) - Âges des couches à mammifères de la basse vallée du Tage (Portugal) et de la Loire moyenne (France). *C. R. Acad. Sc. Paris*, 277: 2313-2316.
- Antunes, M.T.; Legoinha, P.; Nascimento, A. & Pais, J. (1996b) - The evolution of the lower Tagus basin (Lisbon and Setúbal Peninsula, Portugal) from Lower to early Middle Miocene. *Géologie de la France*, B.R.G.M., 6: 59-77.
- Antunes, M.T.; Legoinha, P.; Pais, J. & Nascimento, A. (1995a) - Biostratigrafia e paleoambientes do Miocénico do flanco Sul do sinclinal de Albufeira (Península de Setúbal). *Museu e Laboratório Mineralógico e Geológico*, Porto, Memória 4: 25-28.
- Antunes, M.T.; Legoinha, P.; Pais, J. & Nascimento, A. (1995b) - Evolução da Bacia do Baixo Tejo (Lisboa e Península de Setúbal, Portugal) no Burdigaliano e Langhiano. *Museu e Laboratório Mineralógico e Geológico*, Porto, Memória 4: 19-23.
- Antunes, M. T. & Pais, J. (1983) - Climate during Miocene in Portugal and its evolution. Interim Colloquium. *Paleobiologie Continentale*, Montpellier, XIV(2) (1984): 75-89.
- Antunes, M.T. & Pais, J. (1993) - The Neogene of Portugal. *Ciências da Terra (UNL)*, 12: 7-22.
- Antunes, M.T.; Pais, J.; Balbino, A.; Mein, P. & Aguilar, J.P. (1999) - The Cristo Rei section (Lower Miocene). Distal fluvial environments in a marine series, plants, vertebrates and other evidence, age. *Ciências da Terra (UNL)*, 13: 141-155.
- Antunes, M.T.; Pais, J. & Legoinha, P. (1992) - Excursion A. Neogene deposits of Lisboa and Setúbal peninsula. *Ciências da Terra (UNL)*, número especial II: 29-35.
- Antunes, M. T. & Torquato, J.R. (1969) - Notes sur la Géologie et la Paléontologie du Miocène de Lisbonne. VI - La coupe de Quinta da Silvéria (Helvétien Vb et Vc): stratigraphie et évolution morphologique. *Bol. Soc. Geol. Portugal*, Lisboa, XVII: 1-30.
- Barbosa, B. P. (1995) - Alostratigrafia e Litostratigrafia das unidades continentais da Bacia Terciária do Baixo Tejo. Relações com o eustatismo e a tectónica. Dissertação de doutoramento na Univ. Lisboa, 253 p.
- Choffat, P. (1950) - Géologie du Cenozoïque du Portugal. *Com. Serv. Geol. Portugal*, Lisboa, XXX, suplemento, 183 p.

- Cotter, J.C.B. (1956) - O Miocénico marinho de Lisboa. *Comun. Serv. Geol. Portugal*, Lisboa, XXXVI, suplemento, 170 p.
- Cunha, P. Proença (1992a) - Estratigrafia e sedimentologia dos depósitos do Cretácico superior e Terciário de Portugal central, a leste de Coimbra. *Dissertação de Doutoramento*, Universidade de Coimbra, 262 p.
- Cunha, P. Proença (1992b) - Establishment of unconformity-bounded sequences in the cenozoic record of the western iberian margin and synthesis of the tectonic and sedimentary evolution in central Portugal during Neogene. *First Congress R.C.A.N.S.*, Lisboa, Abstracts: 33-35.
- Haq, B. U., Hardenbol, J. & Vail, P. R. (1987) - Chronology of fluctuating sea levels since the Triassic. *Science*, 235: 1156-1166.
- Legoinha, P. (1993) - Miocénico da Península de Setúbal (faixa ocidental a sul da Lagoa de Albufeira). Foraminíferos, biostratigrafia e paleoambientes. *Diss. Provas de Aptidão Pedagógica e Capacidade Científica, Dep. Ciências da Terra, FCT, UNL*, 78 p. (unpublished).
- Pais, J.; Legoinha, P. & Kullberg J. C. (1991) - Novos elementos acerca do Neogénico do Portinho da Arrábida (Serra da Arrábida)- *III Congresso Nacional de Geologia*, Coimbra:122.
- Pena dos Reis, R.; Cunha, P. Proença; Barbosa, B. P.; Antunes, M. T. & Pais, J. (1992) - Mainly continental Miocene and Pliocene deposits from Lower Tagus and Mondego Tertiary basins. *Ciências da Terra (UNL)*, nº especial II, Lisboa: 37-56.
- Sen, S., Antunes, M. T., Pais, J. & Legoinha, P. (1992) - Bio and magnetostratigraphy of two Lower Miocene sections, Tagus basin (Portugal). *Ciências da Terra (UNL)*, Lisboa, 11: 173-184.