Controls on vertical changes of alluvial system character. The «grés belasianos» unit – Cretaceous of the Lusitanian Basin (Central Portugal)

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ABSTRACT

The «grés belasianos» unit represents alluvial siliciclastic sediments deposited during late Aptian to Cenomanian times in the Lusitanian Basin, on the western margin of the Iberian plate. Two fining-upward successions have been identified in the unit by studies of vertical changes of lithofacies associations in the northern part of the basin. The lower fining-upward succession corresponds to deposits of coalescent wet alluvial fans, changing to a braidplain with local sinuosity. The upper succession records the transition from high slope braidplains with increasing sinuosity to fluvial-dominated deltaic deposits. Considering the available biostratigraphic data, the allocyclic controls on vertical changes of lithofacies associations is discussed. It was inferred that the climate or a basin margin uplift were not the main control on system character changes. Furthermore, evidence in the offshore suggests that sea-level changes probably had a major influence.

We believe that the onset of seafloor spreading in the Galician western margin and Bay of Biscay during upper Aptian to middle Albian have caused sea-level variations in the Lusitanian Basin, related to the thermal and isostatic adjustments. A relationship was admitted between the eustatic curves of Haq *et al.* (1988) and the North Atlantic (Iberia included) geodynamic evolution. In the unit studied, the lower fining-upward succession probably corresponds to the supercycle LZB-4 and the upper fining-upward succession to UZA-1 and part of the UZA-2 of Haq *et al.* (1988).

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Key words: Lusitanian Basin, Cretaceous, fining-upward successions, allocyclic controls.

RESUMEN

La unidad «grés belasianos» consiste en depósitos aluviales de edad Aptiense superior a Cenomaniense, sedimentados en la Cuenca Lusitana, en la margen oeste de la placa Ibérica. El análisis de la variación vertical de asociaciones de facies en la unidad ha permitido identificar dos macrosecuencias positivas, tendencia confirmada por sondeos. La macrosecuencia inferior comprende las asociaciones interpretadas como depósitos de abanicos aluviales húmedos pasando a sistemas fluviales trenzados con sinuosidad local. En la macrosecuencia superior, los sistemas fluviales gradan a deltas con dominio fluvial. Considerando los datos bioestratigráficos, se discuten los controles alocíclicos responsables por la organización vertical de las associaciones de facies, deduciendose estabilidad en la tectónica del margen de la cuenca y en el clima. Este hecho sugiere que los factores primordiales en los cambios de las condiciones sedimentarias definidoras de ambas macrosecuensias, han sido las fluctuaciones del nivel de base.

El comienzo de la expansión oceánica en el margen occidental de Galicia y en el Golfo de Vizcaya (Aptiense superior-Albiense medio), pudo haber causado variaciones relativas en el nivel del mar de la Cuenca Lusitana, debido al ajuste isostático y térmico. Admitiendo que existe relación entre las curvas eustaticas de Haq *et al.* (1988) y la evolución geodinámica del Atlántico Norte (incluyendo Iberia), se deduce la correspondencia entre la macrosecuencia inferior y el superciclo LZB-4, mientras que la superior corresponderia al UZA-1 y parte del UZA-2.

Palabras clave: Cuenca Lusitana, Cretácico, macrosecuencias, controles sedimentarios.

1. INTRODUCTION

The «grés belasianos» is the lowermost unit of the Cretaceous in the Lusitanian Basin north of Nazaré (Fig. 1), and it extends all over the basin. The unit consists of a siliciclastic alluvial succession of Aptian to Cenomanian age, outcropping in the western margin of Portugal. It is equivalent to the Upper Almargem Sandstones defined in the south of the basin (Choffat, 1900; Rey, 1972), called Almargem formation by Wilson (1988).

The detailed study of outcrops in several areas north of Nazaré allowed the identification of two fining-upward successions in this unit. The purpose

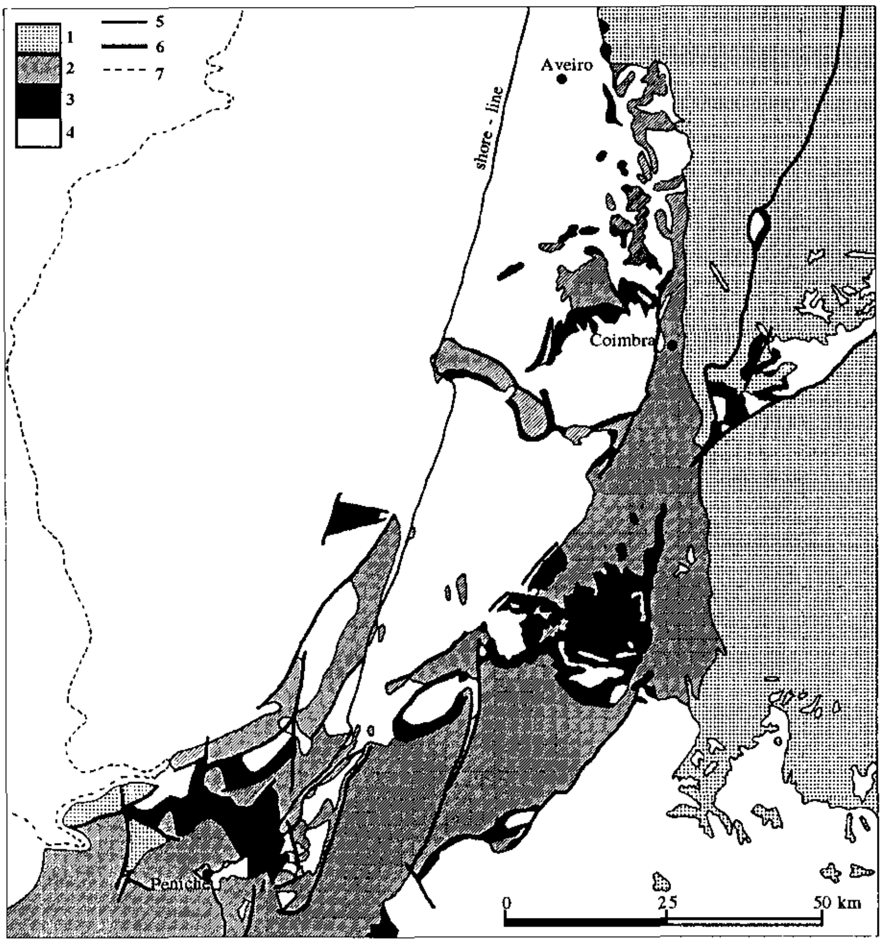
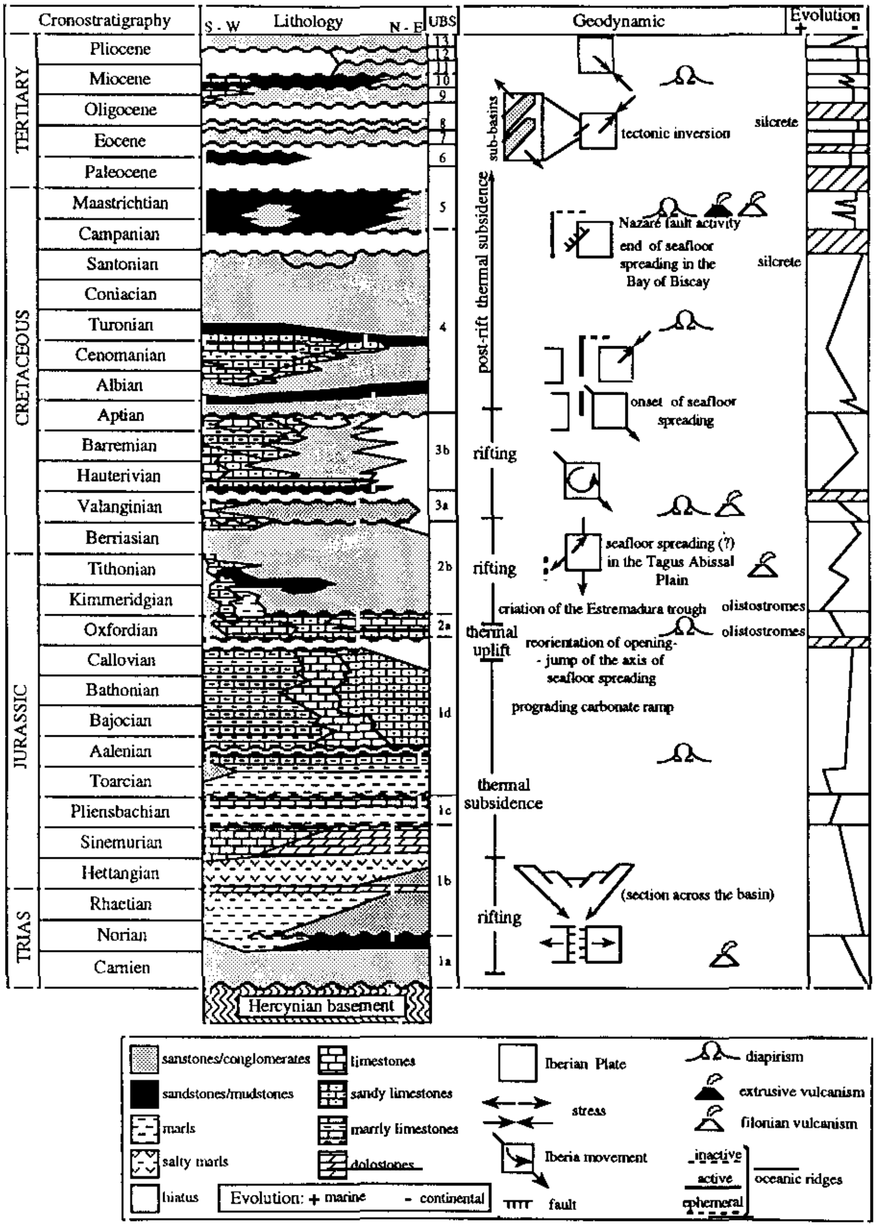


Fig. 1.–Geological sketch of the onshore part of the Lusitanian basin and adjacent continental shelf, north of Peniche (simplified from Boillot & Mougenot, 1978). 1: basement. 2: Mesozoic pre-«grés belasianos». 3: «grés belasianos». 4: post-«grés belasianos» record. 5: geological limits. 6: main faults. 7: 1000 m isobath (geology at West not represented).

Fig. 1.–Esquema geológico de la Cuenca Lusitana, al norte de Peniche (simplificada de Boillot & Mougenot, 1978). 1: basamento. 2: Mesozoico anterior a los «grés belasianos». 3: «grés belasianos». 4: sedimentos posteriores a los «grés belasianos». 5: límites geológicos. 6: fallas principales. 7: isobata de los 1000m (geologia al Oeste no representada).


Cronostratigraphy
S - W Lithology N - E
UBS
Geodynamic
Evolution
+ -
TERTIARY
Pliocene
Miocene
Oligocene
Eocene
Paleocene
CRETACEOUS
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
JURASSIC
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
TRIAS
Rhaetian
Norian
Carnien
Hercynian basement
13
12
11
10
9
8
7
6
5
4
3b
3a
2b
2a
1d
1c
1b
1a
sub-basins
tectonic inversion
silcrete
post-rift thermal subsidence
Nazaré fault activity
end of seafloor spreading in the Bay of Biscay
silcrete
onset of seafloor spreading
rifting
seafloor spreading (?) in the Tagus Abissal Plain
rifting
criation of the Estremadura trough
olistostromes
olistostromes
thermal uplift
reorientation of opening- - jump of the axis of seafloor spreading
prograding carbonate ramp
thermal subsidence
(section across the basin)
rifting
sanstones/conglomerates
sandstones/mudstones
marls
salty marls
hiatus
limestones
sandy limestones
marly limestones
dolostones
Evolution: + marine - continental
Iberian Plate
stress
Iberia movement
fault
diapirism
extrusive vulcanism
filonian vulcanism
inactive
active
ephemeral
oceanic ridges

of this paper is to present and discuss the relationships between the evolution of sedimentological features and paleoenvironmental interpretations against allocyclic controls of deposition, such as climate, tectonism and eustasy.

2. GEOLOGICAL SETTING

The Pangea supercontinent breakup led to the opening of the Atlantic through a succession of northward jumps of the spreading axis of the seafloor and to the closure of Tethys (Ziegler, 1982; Uchupi, 1988; Mougenot, 1989). The Lusitanian Basin extends in a North-South trend between hercynian basement blocks, bounded by NNW-SSE and NE-SW late hercynian orogenic strike-slip faults (Hiscott *et al.*, 1990). The Mesozoic sedimentary infill reflects the geodynamic evolution of North Atlantic (Fig. 2), and several unconformity-bounded sequences with basinwide distribution were recognized (Wilson, 1988; Wilson *et al.*, 1990; Cunha, 1992), related to four main structural stages:

– Upper Triassic-Calovian, with continental deposition being followed by Lower and Middle Jurassic carbonates representing the regional sag of the basin during thermal relaxation (Hiscott *et al.*, 1990).

– Middle Oxfordian-Berriasian, composed of lacustrine and shallow marine carbonates followed by terrigenous facies that correspond to high rates of basement subsidence, with creation of sub-basins by block faulting and halokinetic activity (Guéry, Montenat & Vachard, 1986; Wilson *et al.*, 1990).

– Valanginian-lower Aptian, occurring only south of Nazaré, characterizes a rifting event showing relatively little variation in thickness and facies between the blocks defined in the previous cycle. The marine carbonates in the depocenter are laterally equivalent of marginal fluvial facies (Rey, 1972, 1982, 1985).

– In the upper Aptian – lower Campanian structural stage, the main tectonic controls were the Atlantic extension and the opening of the Bay of Biscay. The stage begins with important diastrophic activity correspon-

Fig. 2.–Summary of the Mesozoic lithological framework in the onshore part of the Lusitanian basin (Pena dos Reis *et al.*, 1993, modified from Pena dos Reis *et al.*, 1992). Note the several unconformity-bounded sequences (UBS) in the sedimentary record of the Basin.

Fig. 2.–Columna estratigráfica sintética de las litologias del Mesozoico de la Cuenca Lusitana, en la área emergida en la actualidad (Pena dos Reis *et al.*, 1993, modificado de Pena dos Reis *et al.*, 1992). Se presentan las secuencias limitadas por discontinuidades (UBS).

ding to the uplift of the Berlenga horst system (western border of the basin) and the Hesperian Massif and an important enlargement of the sedimentation area. At the NE domain of the Basin, coalescent wet alluvial fans draining to SW (the «grés belasianos» unit and other regional denominations; Fig. 1) change progressively to transitional systems and to a carbonate platform. At the SW domain of the Basin (Berlenga horst), also exists a drainage to the east. An important fall of the sea level succeeds the long term Albian-Cenomanian transgression resulting in progradation and latter incision of the depositional systems. The top of the sedimentary record is regionally marked by an important silcrete, testifying weathering during a long hiatus in sedimentation and tectonic stability (Pena dos Reis & Cunha, 1989a).

– The upper Campanian-Maastrichtian distensive phase is marked by volcanic and sub-volcanic episodes and diapiric and non-diapiric diastrophic events. The record consists of quartzarenites and red mudstones, interpreted as a meandering fluvial system draining to NW, changing distally to transitional and marine environments; the diapiric reactivation built up alluvial fans, in which calcareous conglomerates and mudstones were accumulated (Pena dos Reis, 1983; Pena dos Reis & Cunha, 1989b; Cunha, 1992).

3. DEFINITION, LIMITS AND BIOSTRATIGRAPHY OF THE «GRÉS BELASIANOS» UNIT

3.1. Definition and limits

In the area north of Peniche (Fig. 1), the «grés belasianos» lies in angular unconformity over Mesozoic deposits and the hercynian basement. The unit presents 65 m at the eastern basin border, approximately 300 m in the Nazaré area, 440 m at the offshore borehole Faneca – 1 and a diminishing thickness towards the western border (Berlengas horst system). However, shows relatively little thickness variation along the axis of the northern part of the basin (NNW-SSE).

It can be inferred that the base is approximately synchronous in the meso-cenozoic west margin of Portugal, dating from the late Aptian (Dinis & Trincão, *in press*).The top of the «grés belasianos» is marked by the lithologic change to the marine carbonate deposits of the Alcabideche and Alcântara formations (Wilson, 1988) and to the micaceous Choisa Sandstones (Pena dos Reis & Cunha, 1989) in the eastern border. The upper limit is clearly

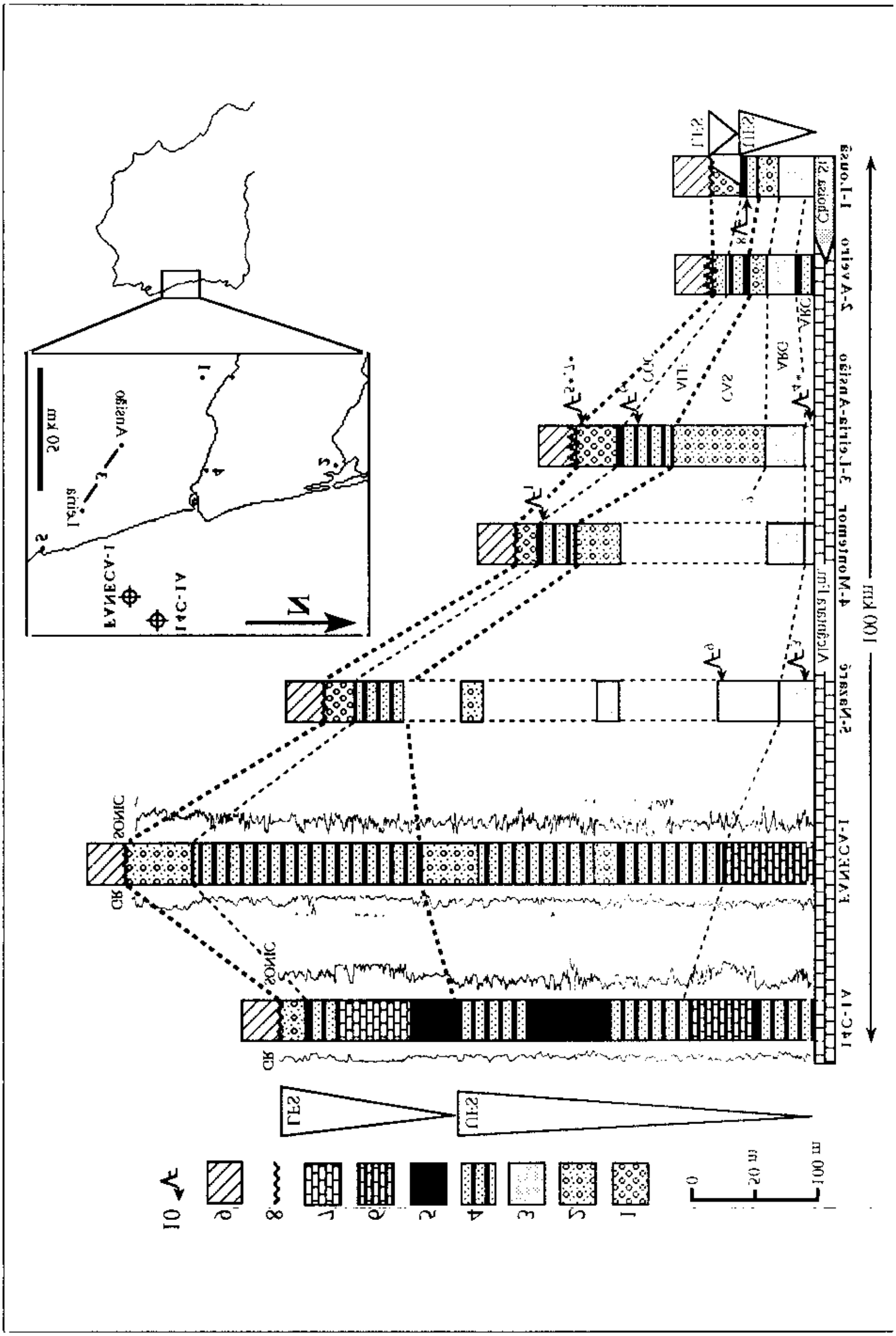
NUM.	*REFERENCE*	*LOCATION*	*AGE*	*UNIT*	*TYPE*
1	Teixeira (1952)	Arnal-Leiria	probably Aptian	ALF	M
2	Groot & Groot (1962)	óbidos Lagoon	Albian	CAS-ALF ?	P
3	Moron (1981)	Nazaré - cliff top	probable middle Cenomanian	ARC	P
4	Moron (1981)	Buarcos	early to middle Cenomanian	ARC	P
5	Pais & Reyre (1981)	Buarcos	Aptian	CGC ?	P, M
6	Pais & Trincão (1983)	Almas do Juncal - Montemor-o-Velho	late Aptian	ALF	P
7	Trincão (1986)	Grada - Coimbra	Aptian	CGC base	P
8	Trincão *et al.* (1989) (revised by Dinis & Trincão, *in press*)	Papanata - Lousã	near Aptian-Albian limit	ALF	P
9	Trincão *et al.* (1991)	Nazaré cliff base	middle to late Albian	ARG upper part	P

TABLE 1.—Biostratigraphic data available in the studied zone concerning the «grés belasianos» unit, based on the paleobotanic al content. Unit referes to «grés belasianos» sub-units/lithofacies associations: CGC-Calvaria conglomerates; ALF-Famalicão sandstones and mudstones; CAS-Salgueira conglomerates and sandstones; ARG-Gondemaria sandstones; ARC- Calvaria sandstones. Type M refers to vegetal macrorremains and type P to palynomorphs.

TABLA 1.—Datos biostratigráficos disponibles en los «grés belasianos» de la región estudiada. Las unidades de referencia son sub-unidades/asociaciones de facies: CGC-conglomerados de Calvaria; ALF-areniscas y lutitas de Famalicão; CAS-conglomerados y areniscas de Salgueira; ARG-areniscas de Gondemaria; ARC-areniscas de Caldelas. El tipo M se refiere a macrorestos vegetales y el tipo P a palinomorfos.

diachronous (middle Albian to upper Cenomanian; Berthou, 1984), onlapping along the basin axis from SSW to NNE. The point of maximum landward position of the shore-line is represented in the Leiria-Ansião region by the *Anorthopygus michelini* level of the albian-cenomanian carbonates (Soares, 1972; Berthou, 1984), and probably by the carbonaceous levels at the base of the Choisa Sandstones in the Lousã-Arganil region (Pena dos Reis & Cunha, 1989).

The unit belongs to the «A» megasequence of Corrochano & Pena dos Reis (1986), comprising also the overlying Alcabideche and Alcântara for-



mations up to the maximum of the cenomanian transgression, showing a vertical evolution with positive trend.

3.2. BIOSTRATIGRAPHICAL DATA

The age attributions are based in palynological and plant macroremains studies. In the considered zone, the available biostratigraphical data are presented in Table 1. The stratigraphic position of each level in the unit is presented in Fig. 3.

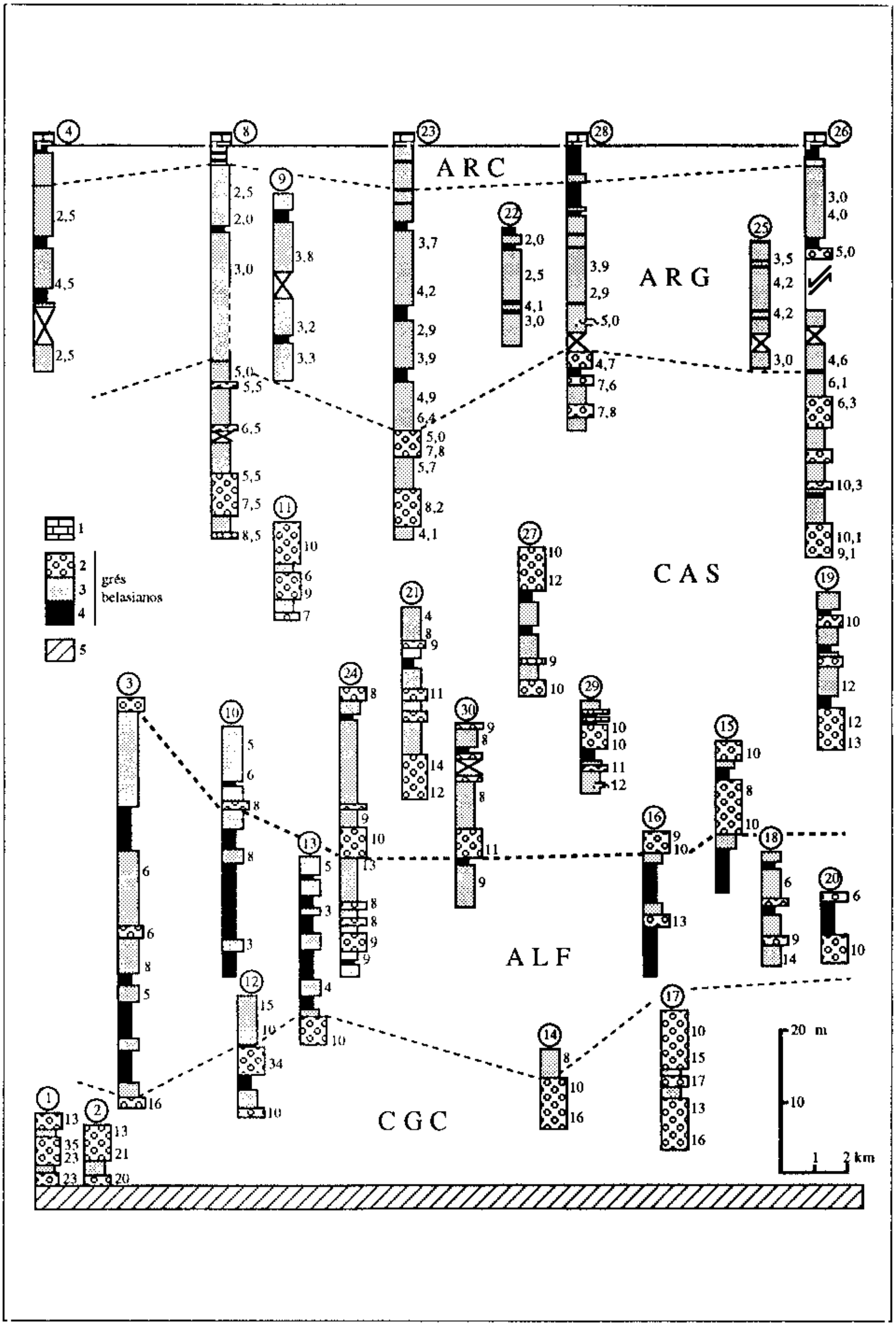
Other biostratigraphical statements in the southern part of the basin, which are in agreement with the aforementioned, are presented by Teixeira (1948), Groot & Groot (1962), Rey (1972), Medus & Berthou (1980), Berthou, Hasenboehler & Moron (1981), Hasenboehler (1981), Berthou & Leereveld (1986, 1990) and Trincão (1990).

4. VERTICAL SUCCESSION AND INTERPRETATION OF LITHOFACIES ASSOCIATIONS

The field study and borehole data of the unit in several areas of Central Portugal allowed the execution of synthetic sections (Fig. 3), revealing two fining-upward successions. The Aveiro section is based on data from the hydrogeological drill JK4 located at the Cacia village. The 14C-1A and FANECA-1 logs (Neste Oil, 1991) correspond to hydrocarbon exploration wells. In the Leiria-Ansião region the detailed study of 40 vertical logs (900 m) using the lithofacies code of Miall (1985), and architectural elements analysis in selected panels (Miall, 1985), allows the definition and in-

Fig. 3.–Synthetic sections of the «grés belasianos» and respective positions. LFS-lower fining-upward succession. UFS-upper fining-upward succession. 1: conglomerates. 2: conglomerates and sandstones. 3: sandstones. 4: sandstones and mudstones. 5: mudstones. 6: mudstones and limestones. 7: limestones. 8: angular unconformity. 9: pre-«grés belasianos». 10: position of paleobotanical samples, *-projected from near locations (see Table 1).

Fig. 3.–Situación y perfiles estratigráficos sintéticos de los «grés belasianos». LFS-macrosecuencia inferior. UFS-macrosecuencia superior. 1: conglomerados. 2: conglomerados y areniscas. 3: areniscas. 4: areniscas y lutitas. 5: lutitas. 6: lutitas y calizas. 7: calizas. 8: discordancia angular. 9: pre-«grés belasianos». 10: posición de los yacimientos paleobotanicos, *-proyectados de posiciones cercanas
(ver Tabla 1).


ARC
ARG
CAS
ALF
CGC
1
2
3
4
5
grés belasianos
20 m
10
1
2 km

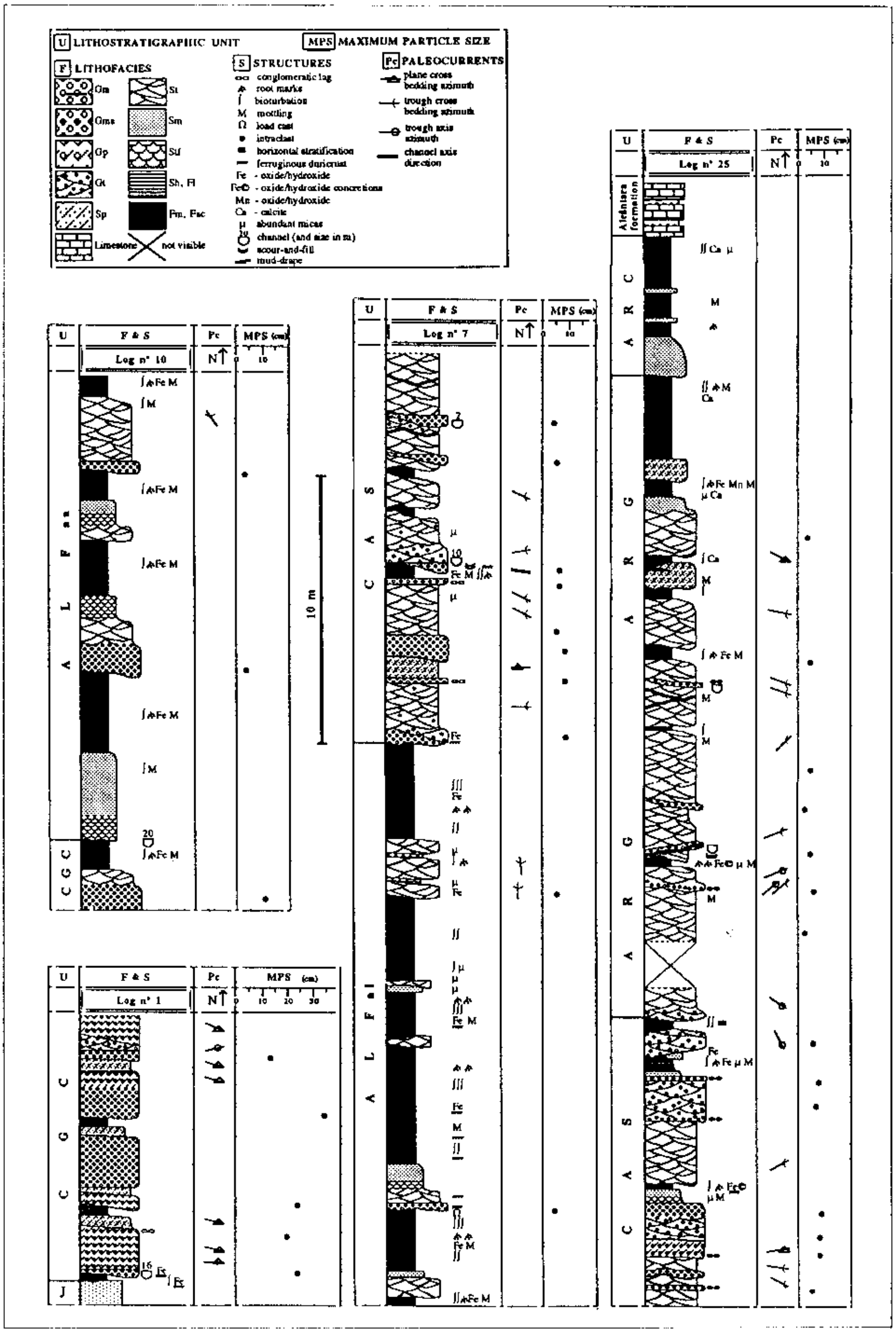
terpretation of five informal lithostratigraphic units (Dinis & Pena dos Reis, 1989; Dinis, 1990, *in press*). Correlation of lithofacies logs in this region, showing the lithostratigraphic units are presented in Fig. 4, and some detailed examples in Fig. 5. These units corresponds to lithofacies associations and are used here as references.

4.1. THE LOWER FINING-UPWARD SUCCESSION

The lower fining-upward succession (LFS) is defined by the transition from the Calvaria conglomerates to the Famalicão sandstones and mudstones. The Calvaria conglomerates are composed mainly of Gm facies accumulated in longitudinal bars, with significant amounts of St, Gt, Gp and Fm (Table 2). In the Famalicão sandstones and mudstones of the Leiria-Ansião region, strips of different lithofacies associations were identified, controlled by subsidence compensation caused by salt withdrawal into the Vermoil diapir (Dinis & Pena dos Reis, 1990). The position over the diapir corresponds to a mudstone association whereas the marginal strips are enriched in sandstones. The sandstone association is dominated by St facies corresponding to fields of sinuous-crested dunes, with minor conglomeratic content (Gt, Gms, Gp and Gm) organized in longitudinal and transverse bars. The mudstone association is dominated by Fsc and Fm, with an important proportion of St and almost complete absence of conglomerates. The dominant morphologic elements deduced from lithossomes are floodplain with crevasses and channels frequently revealing cutoff. Locally it is possible to identify lateral accretion sigmoidal forms in heterolithic mudstone/sandstone facies.

Fig. 4.—Correlation of vertical lithofacies logs in the Leiria-Ansião region, showing the lithostra tigraphic sub-units (lithofacies associations) of the «grés belasianos». CGC: Calvaria conglomerates. ALF: Famalicão sandstones and mudstones. CAS: Salgueira conglomerates and sandstones. ARG: Gondemaria sandstones. ARC: Caldelas sandstones. Numbers inside circles correspond to logs located in Fig. 7. Numbers at logs side corresponds to Maximum Particle Size (MPS). 1: Alcântara Fm. 2: conglomerate. 3: sandstone. 4: mudstone. 5: underlying units.

Fig. 4.—Correlación de perfiles estratigráficos ilustrativos de las sub-unidades (associaciones de facies) en los «grés belasianos» de la región de Leiria-Ansião. CGC: conglomerados de Calvaria. ALF: areniscas y lutitas de Famalicão. CAS: conglomerados y areniscas de Salgueira. ARG: areniscas de Gondemaria. ARC: areniscas de Caldelas. Los números encerrados en círculos corresponden a las columnas localizadas en la Fig. 7; los números al lado de las columnas corresponden al centil (MPS). 1: Fm. Alcântara. 2: conglomerado. 3: arenisca. 4: lutita. 5: unidades infrayacentes.


U LITHOSTRATIGRAPHIC UNIT
MPS MAXIMUM PARTICLE SIZE
F LITHOFACIES
Gm
Gms
Gp
Gt
Sp
Limestone
St
Sm
Sr
Sh, Fl
Fm, Fsc
not visible
S STRUCTURES
conglomeratic lag
root marks
bioturbation
M mottling
load cast
intraclast
horizontal stratification
ferruginous duricrust
Fe - oxide/hydroxide
Fe - oxide/hydroxide concretions
Mn - oxide/hydroxide
Ca - calcite
μ abundant micas
channel (and size in m)
scour-and-fill
mud-drape
Pc PALEOCURRENTS
plane cross bedding azimuth
trough cross bedding azimuth
trough axis azimuth
channel axis direction
U
F & S
Pc
MPS (cm)
Log n° 10
Log n° 7
Log n° 1
Log n° 25
10 m

FACIES	*CGC*	*ALF*	*ALF*	*ALF*	*CAS*	*ARG*	*ARC*	*TOTAL*
Gm	29.5	6.4	2.6	4.1	10.1	2.3	–	11.9
Gms	1.4	8.5	2.5	5.0	2.9	0.4	–	2.5
Gt	11.8	10.3	2.4	5.7	16.3	3.4	–	9.9
Gp	15.0	6.3	0.6	2.9	8.8	0.8	–	7.3
Gtotal	57.8	31.5	8.1	17.6	38.1	6.8	–	31.5
St	23.7	56.9	28.0	39.8	45.7	45.4	27.8	38.3
Sp	7.5	–	–	–	5.7	19.7	114.8	7.7
Stf	0.8	2.2	4.8	3.7	2.1	4.0	12.6	2.8
Sh	1.2	0.8	1.4	1.2	0.5	0.3	0.7	0.8
Sm	0.4	0.7	6.7	4.3	1.1	7.9	24.8	3.6
Stotal	33.6	60.6	40.9	49.0	55.1	77.4	80.7	53.2
Fm	7.1	5.3	20.5	14.3	5.9	15.0	13.7	10.1
Fsc	1.1	2.5	30.5	19.1	0.5	0.7	5.2	5.1
Fl	0.4	–	–	–	0.4	0.1	0.4	0.1
Ftotal	8.6	7.8	51.0	33.3	6.8	15.8	19.3	15.3
Total	100.0	99.9	100.0	99.9	100.0	100.0	100.0	100.0

TABLE 2.–Lithofacies (%) by sub-unit (facies associations). Facies code of Miall (1985), except Stf - trough cross-bedded fine sandstone. In ALF: AA - sandstone association; AL - mudstone association.

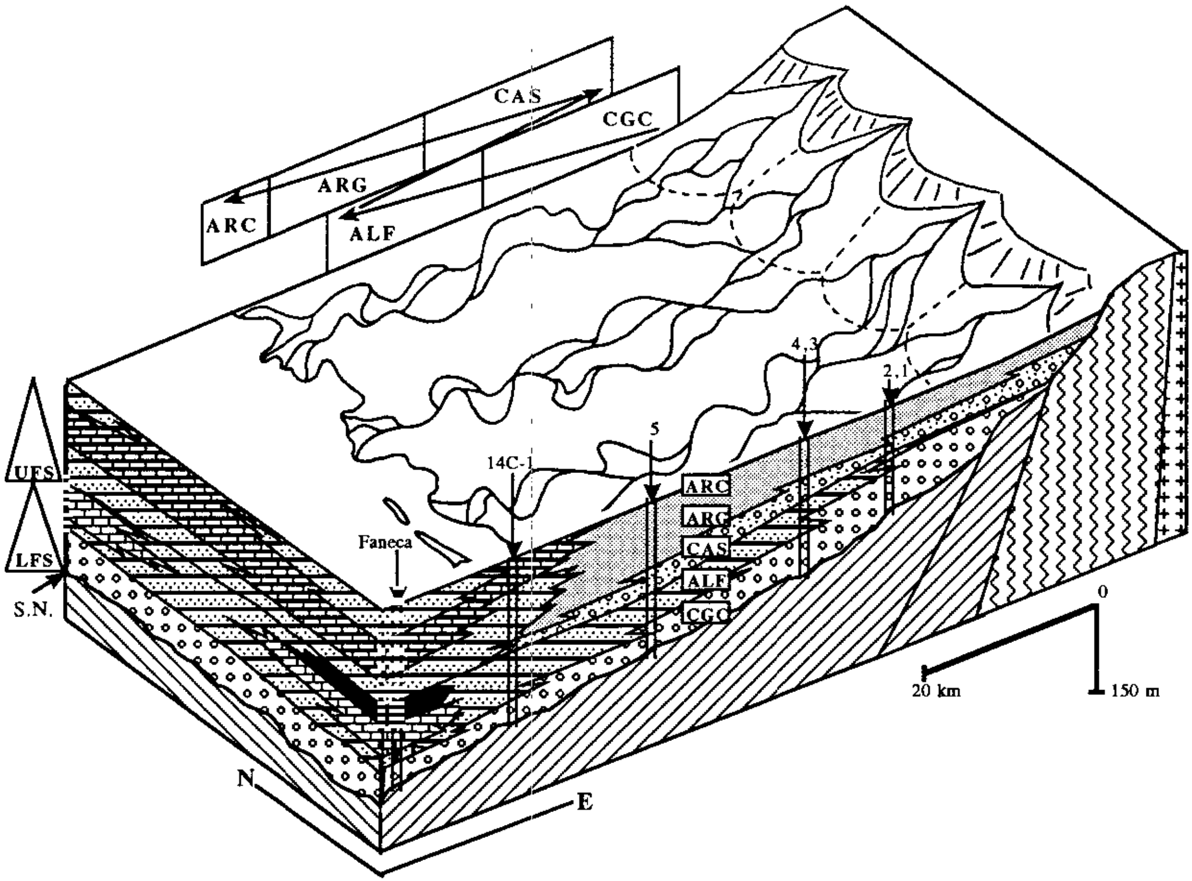
TABLA 2.–Porcentage de las litofacies en cada sub-unidad. Código de facies de Miall (1985), excepto Stf - areniscas finas con estratificación cruzada en surco. En ALF: SA - associación arenosa; AL - associación lutítica.

This fining-upward succession is considered as the change from deposition in coalescent wet alluvial fans to deposition in a braidplain with local sinuosity (Fig. 6).

4.2. THE UPPER FINING-UPWARD SUCCESSION

In the upper succession (UFS), the Salgueira conglomerates and sandstones consist of facies Gt, Gm and Gp alternating with the dominant St. Channel infill by fields of sinuous crested dunes separated by longitudinal and

Fig. 5.–Examples of vertical lithofacies logs in the «grés belasianos». For location, see Fig. 7.
Fig. 5.–Ejemplos de perfiles estratigráficos de los «grés belasianos». Localización en la Fig. 7.


CAS
CGC
ARG
ARC
ALF
4.3
2.1
5
14C-1
UFS
LFS
S.N.
Faneca
ARC
ARG
CAS
ALF
CGC
0
20 km
150 m
N
E

transverse conglomeratic bars, sometimes with lateral accretion, are the interpreted physiographic features. This architectural style is characteristic of conglomeratic high slope braidplains with moderate sinuosity. This unit grades upward to the Gondemaria sandstones, corresponding to a similar environment but with a lower slope gradient (Fig. 6) as inferred from the lithofacies assemblages and rock-body geometry. Gm conglomerates forming lags of large channels (> 30 m wide) are succeeded by sinuous crested dunes. Gp and Sp correspond to frequent straight-crested bars and periodic bed-forms; Fm and Sm occur in lateral accretion morphologies and sheet bodies deposited in crevasse and floodplain.

The overlying Caldelas sandstones consist of St, Sm and Sp lithofacies interbedding with Fm and Fsc. These facies are very mud-rich turning difficult the clear observation of architectural elements; however, it is possible to infer an organization in heterolithic bodies, frequently with large scale and low angle internal bed-contacts, or sigmoidal sandstone bodies. This thin unit (less then 10% of the «grés belasianos» total thickness) is interpreted as a fluvial-dominated deltaic deposit (Fig. 6) that grades to the marine carbonate deposits of the Alcabideche and Alcântara formations.

The paleocurrent directions in the «grés belasianos» vary between west and southwestward in the studied region (Fig. 7), revealing drainage from the hercynian basement, transverse to the basin axis (Rey, 1972; Dinis, 1990; Cunha, 1992).

5. POSSIBLE CONTROLS ON SEDIMENTATION

The unit is a depositional response to the onset of oceanic opening and beginning of oceanic crust formation in the Atlantic sector near the Lusitanian Basin, north of the Tagus abyssal plain, during the early Aptian (Fig. 8) (Masson & Miles, 1984, 1986; Keen *et al.*, 1987; Mougenot, 1989; Hiscott *et al.*, 1990; Wilson *et al.*, 1990), leading to thermal uplift of the margin (Vanney & Mougenot, 1981; Rey, 1982; Malod, 1987; Wilson, 1988) and forms the base of the post-rift sequence.

Fig. 6.—Depositional sedimentary environment interpreted for the «grés belasianos». Indicated the sub-units (facies associations) and the progradational/retrogradational/progradational cycle. S.N.: Neocomian Surface. For location of logs and legend see Fig. 3.

Fig. 6.—Modelo interpretativo para los «grés belasianos». Se indicadan las sub-unidades (asociaciones de facies) y el ciclo de progradación/retrogradación/progradación. S.N.: Superficie Neocomiense. Para localización de las columnas y leyenda, ver Fig. 3.

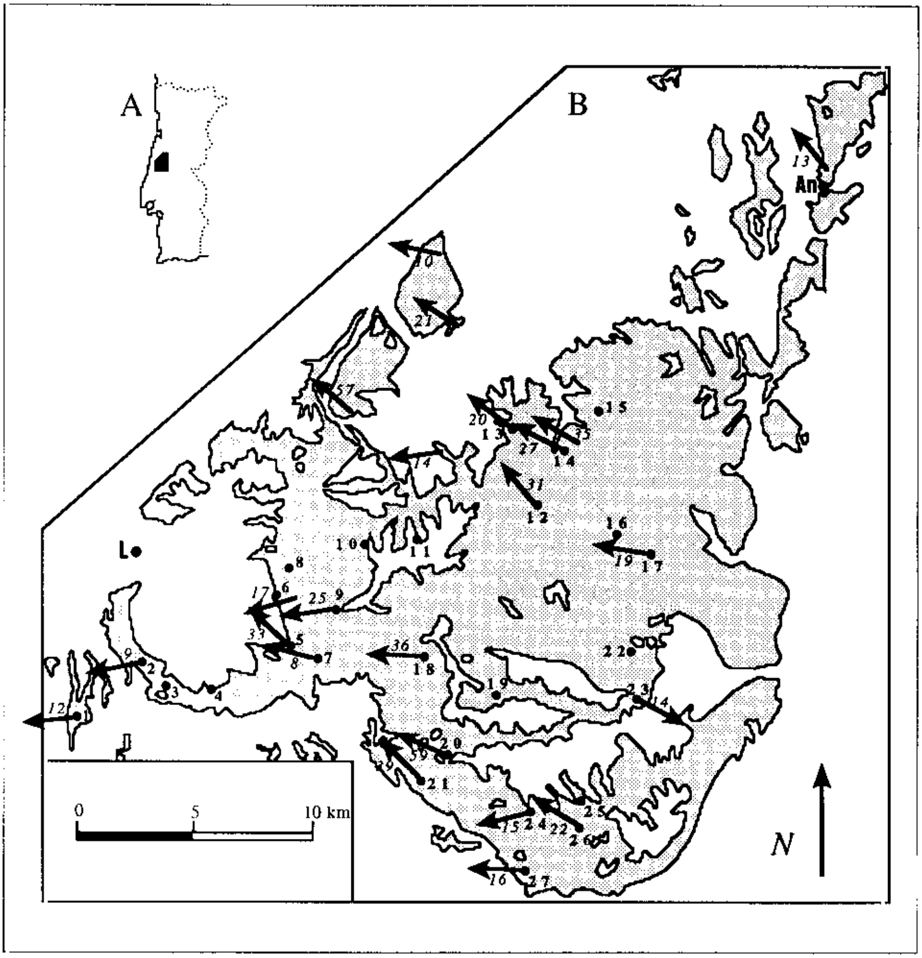


Fig. 7.–A: Location of B. B: Paleocurrent data of the «grés belasianos» in the Leiria (L)-Ansião (An) region. *N*º: number of readings of each mean-vector; the number in bold corresponds to the location of the logs presented in Figs. 4 and 5.

Fig. 7.–A: localización de B. B: Distribución de paleocorrientes de los «grés belasianos» en la región Leiria (L)-Ansio (An). *N.º*: número de medidas para cada vector-medio; el n.º en negrita corresponde a la posición de las columnas de las Figs. 4 y 5.

The comparison of paleobathymetric curves of different basins (Scott, Frost & Shaffer, 1988), including the Lusitanian, recognizes an intra-Aptian hiatus suggesting a widespread major sea-level drop, about 116 Ma. This event corresponds to the base of supercycle LZB-4 of Haq, Hardenbol & Vail (1987). The combined effect of thermal uplift in the regions surrounding the rift and a sudden eustatic fall allow the synchronous onset of a high energy sedimentation in a large area of the basin.

The positive evolution of the upper Aptian – Cenomanian megasequence of the Lusitanian Basin can be explained by several allocyclic controls (Berthou, 1984; Rey, 1985; Pena dos Reis & Cunha, 1989a; Dinis, 1990): 1) reduction of postrift thermal subsidence rate as the basin moves away from the ocean spreading axis, a typical situation of passive margins (Miall, 1984), 2) the long-term eustatic rise during Albian and Cenomanian (Haq *et al.*, 1988), 3) the basin infill and diminishing sediment supply associated with hinterland erosional lowering (Berthou, Blanc & Chamley, 1982; Riba, 1989).

Bearing in mind the passive nature of the basin margin, worldwide acting parameters such as climate changes and eustasy are relevant in the following analysis of depositional controls within the unit. Thus, the available data of nearest basins (during Aptian to Cenomanian) are considered.

Despite the difficulty of recognizing the value of erosional surfaces in alluvial deposits, considering the regional data we suggest that the boundary between the fining-upward successions is a sixth-order surface (Miall, 1988), eventually caused by a general incision of the system. From the presented biostratigraphic data and the stratigraphic position with respect to the unit thickness, it is possible to conclude that the limit between the two considered successions is located near the Aptian-Albian limit.

At a regional level, towards more distal basin positions, considering the relative thickness of the unit, the limit between the fining-upward successions occupies increasingly lower positions, and the contrast between the successions sharpens (Fig. 3).

5.1. Climate

It can be inferred that during the Aptian to Cenomanian the temperature distribution was quite equable in the Earth, with reduced meridional temperature gradient but with important variations between littoral and continental interiors (Barron, 1983; Sloan & Barron, 1990). The widespread occurrence of bauxite deposits in the Aptian suggests warm and humid conditions in large areas (Ager, 1981; Chamley & Debrabant, 1984; Combes, 1984; Nikolov, 1987). The climate of the Iberian plate was subtropical, probably with high rates of rainfall (Rey, 1972; Berthou, 1973; Vanney & Mougenot, 1981; Berthou *et al.* 1982; Rat, 1982; Dinis, 1990; Gomes, 1991), at least in the coastal areas (Barron, William & Thomson, 1989).

Climatic changes may be recorded by vertical changes in clay composition, pedogenetic evolution, paleobotanical elements and sedimentologic parameters such as lithofacies and architecture (Schumm, 1981; Gordon & Bridge; 1987; Kraus, 1987).

In the studied sediments no evidence of significant modifications on the paleoclimatic evaluation parameters was found, namely in the unit clays distribution, with a dominance of kaolinite, small amounts of illite and an increase in smectite (mainly montmorillonite) content at the top (Berthou *et al.*, 1982; Carvalho *et al.*, 1982; Rocha, 1989; Dinis, 1990; Gomes, 1991). Also the paleopedogenic signal shows little variation throughout the unit in the onshore studied region. The overbank facies shows a low maturity degree (Kraus, 1987), presenting red, purple and blue mottling, rubefaction and some times intense root and burrow bioturbation (Dinis, 1990).

Thus, we suggest that climate was not the main control in the definition of two finning-upward successions in the «grés belasianos», due to the lack of evidence in the unit and the admitted slow and gradational change of the climate during the middle of the Cretaceous.

5.2. Tectonics

The geodynamic setting (Fig. 8) during the Aptian and Albian, indicates that the Iberian plate was submitted to a stress regime provoked mainly by the separation between Iberia and Newfoundland and the opening of the Bay of Biscay. Several authors suggest that the seafloor spreading propagated northward along the Iberian margin in discrete pulses (Boillot & Malod, 1988; Mougenot, 1989; Srivastava *et al.*, 1990), bifurcating eastward to the Bay of Biscay branch in the triple point at the northwest corner of the plate (Fig. 8). The opening is cut by several transverse fractures, inducing a ridge jump mechanism.

In the northward extensions of the Lusitanian Basin, the Oporto Basin (Graciansky *et al.*, 1978) and the west Galicia margin (Boillot & Malod, 1988), the «breakup» unconformity is of latest Aptian age, reflecting the onset of seafloor spreading in the segment of the rift bordering those basins. The M0 magnetic anomaly, considered of early Aptian age (Kent & Gradstein, 1985; Haq & Van Eysinga, 1987) is represented in the west margin of Iberia just south of the Galicia margin and disappears at latitude 41.5°. This means that the onset of spreading is slightly younger than M0 (Malod & Mauffret, 1990; Sibuet & Collete, 1991).

One important question is the relative influence of the Bay of Biscay opening in the Lusitanian Basin, since intraplate stress might induce tectonic uplift of the margin or variations in basinfloor subsidence. Seafloor spreading in this segment started in latest Aptian or early Albian times (Boillot & Malod, 1988; Mougenot, 1989; Malod & Mauffret, 1990; Sibuet & Collete, 1991). However, we suggest that during the Aptian and Albian the induction created by the transtensive stress in the northern margin of the Iberian plate was minor in the Lusitanian Basin, due to the almost perpendicular orientation between the stress and the main fractures of the basin. Nevertheless, the anti-clockwise rotation of the plate might create a tension pattern more complex than a purely extensional rifting, as suggested by Sibuet & Collete (1991).

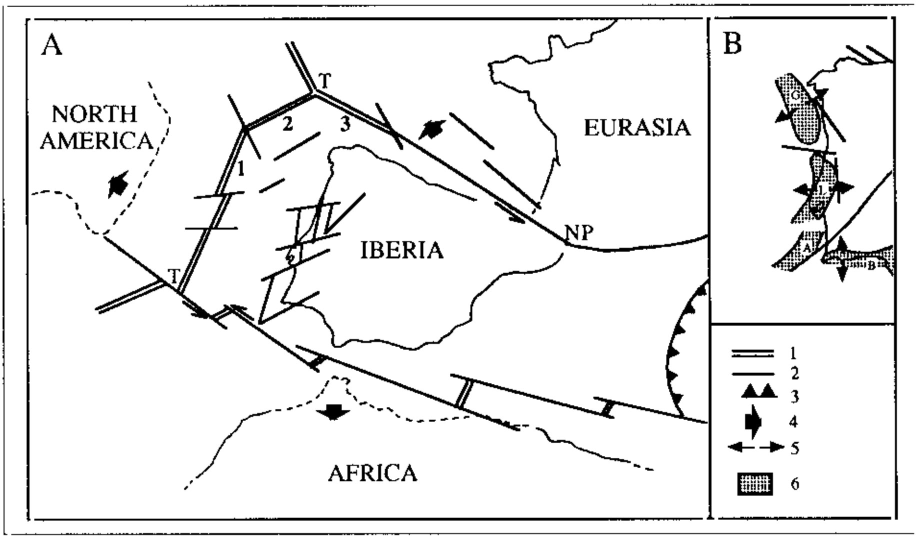


Fig. 8.—A: Reconstitution of the Iberian plate position during the onset of the ridge segments 1 to 3 (Aptian and early Albian). Legend: 1: ridge. 2: transform. 3: subduction. 4: relative direction of plate movement. 5: basin extention direction. 6: basins. T: triple junction. NP, north-pyrenian fault. B: Mesozoic basins (A: Alentejo. B: Betic. L: Lusitanian. G: Oporto-Galice).
Fig. 8.—A: Reconstrucción de la posición de la placa Ibérica durante el emplazamiento de la expasión oceánica (Aptiense y Albiense inferior). Leyenda: 1: eje del «rift». 2: falla transformante. 3: subducción. 4: dirección del movimiento relativo de las placas. 5: dirección de extensión de la cuenca. 6: cuencas. T: punto triple. NP: Accidente Noribérico. B: Cuencas mesozóicas (A: Alentejo. B: Bética. L: Lusitana. G: Oporto-Galicia).

Direct evidence of tectonic activity in the unit were not found, namely sin-sedimentary faulting or great changes in thickness at close range. However, low intensity halokinetic activity was inferred in the Famalicão sandstones and mudstones of the Leiria-Ansião region, leading to the acceptance of a slightly distensive context. Moreover, despite the vertical change in facies ratios (lithofacies associations), the straight evolution of the «grés belasianos» maximum particle size (MPS) indicates that it is unlikely that important basin margin uplift occured. This statement is based on the assumed capability of tectonic transpressive movements that creates uplift, to generate more and/or larger clasts. Also the increase in smectite content in the Lusitanian Basin throughout the Albian and the Cenomanian might reveal continued lowering of relief over a long period in a tectonic quiet period (Berthou *et al.*, 1982).

5.3. SEA-LEVEL CHANGES

The base of the unit at the 14C-1A well is interpreted as a proximal streamflood facies association underlying a shallow marine carbonate/siliciclastic association, and the overlying sediments were interpreted as a distal fluvial to transitional siliciclastic system (Neste Oil, 1991). This vertical succession indicates a relative sea-level rise and fall cycle, and we propose the correlation (Fig. 3 and 6) of the marine carbonate levels with the Famalicão sandstones and mudstones. This is consistent with the existence of symmetrical ripples (wave-generated) in this unit at Nazaré, the single observation in outcrop of probable marine influence, with the exception of the Caldelas sandstones.

Cretaceous series have been drilled at the DSDP 398 well, located south of the Vigo Seamount (150 km WNW of 14C-1A), north branch of the western margin of the Lusitanian Basin (Berlenga horst). Analyzing the palynological content, Taugourdeau-Lantz *et al.* (1982) suggested a transgressive movement during middle and upper Aptian, reaching its maximum near the Aptian-Albian boundary. Also in the lower to middle Albian near Lisbon a regressive second order ecosequence was identified by Cugny (1988).

In order to evaluate the nature and extension the upper Aptian to lower Albian sea-level rise and subsequent drop, work carried out in nearby basins is considered. Correia, Prates & Berthou (1982) point out an upper Aptian transgression in the Algarve Basin (south portuguese margin). According to García-Mondéjar & Robador (1987), the sea-level drops recorded during upper Aptian and lower Albian in the Vasco-Cantabrian coast were in part of eustatic nature. The transgression during upper Aptian to lower Albian, and the subsequent regression in the middle Albian in two domains of the Betic Chain resulted from eustatic changes (García-Hernández *et al.*, 1982). In the Anglo-Paris Basin, within a context considered tectonicaly stable, Amedro (1992) established eleven eustatic controlled depositional sequences; the age attribution was based in ammonites and the most important sequence limit placed in the Aptian-Albian boundary. Using seismic data, Olsson (1991) divided the nonmarine Lower Cretaceous of the passive margin of New Jersey (U.S.A.) in sequences and recognizeed the same unconformity.

Comparison of sea-level changes in the Lower Cretaceous of seven basins of northwest Europe was carried out by Ruffel (1991). Despite some limitation in precision dating, it is clear a widespread earliest Aptian regression followed by transgressive conditions, and a European regression at the Aptian - Albian limit. The same author fits this sea-level fall with the type 1 unconformity that separates the LZB-4 e UZA-1 supercycles of Haq *et al.* (1988) (Fig. 9).

Independent of it nature, becomes clear from the aforementioned that a sea-level rise and fall cycle happened in the basins surrounding the Lusitanian Basin during Aptian and early Albian, reaching the maximum near the Aptian-Albian boundary.

6. DISCUSSION ON CONTROLLING FACTORS INTERPLAY

6.1. RELATIONSHIP BETWEEN SEA-LEVEL AND SYSTEM CHARACTER CHANGES

The vertical transition from the Calvaria conglomerates to the Famalicão sandstones and mudstones records the gradual change to more distal conditions and a system slope decrease, marked by increasing sinuosity of channels and decrease in sediment size, proportion and amalgamation of channel-belt deposits and braid-index (Gordon & Bridge, 1987). The sixth-order surface (Miall, 1988) that separates the two finning-upward successions reflects a sudden energy and slope increase, resulting in clear sediment coarsening and onset of higher gradient systems.

Sea-level fluctuations, inducing variations in topographic and freatic gradients, can influence the depositional systems characteristics within continental domains of perioceanic basins (Gordon & Bridge, 1987; Rust *et al.*, 1987; Jervey, 1988; Aubrey, 1989; Leckie, Fox & Tarnocai, 1989; Rust & Gibling, 1990, Posamentier *et al.*, 1992). Such modifications are recorded in sequential trends, discontinuities (erosional or non-depositional), depositional rates and architecture.

During the rise of base-level, the increase of accommodation (apparent subsidence) increases the channel to overbank deposits ratio (Gordon & Bridge, 1987). An augment in muddy sedimentation leads to a channel stabilization and a higher sinuosity index (Schumm, 1981; Rust *et al.*, 1987; Rust & Gibling, 1990). This effect explains the vertical evolution of the lower finning-upward succession.

The subsequent drop, admitted to be rapid and deep (type 1, according

Haq *et al.*, 1988), took place in a basin in which the admitted physiography was a gently sloping plain, due to the presumed infill of the depocenter axis. If the sea-level fall was faster than the subsidence, incision might have occurred (Aubrey, 1989) and/or a readjustment of channel geometry and stream pattern (Posamentier *et al.*, 1992). In such conditions, the adaptation of the longitudinal profile of the alluvial systems (Posamentier *et al.*, 1992) is recorded in the studied region by the seaward progradation of the proximal coarse part (Hunt & Tucker, 1992). This mechanism could explain the transition between the two finning-upward successions (Fig. 6).

6.2. NATURE OF SEA-LEVEL CHANGES

The discussion about the origin of sea-level changes is of capital importance and is focused in the eustatic versus tectonic poles. However, the acceptance of eustatic nature in sea-level changes implies the recognition of the event synchrony in independent basins, which is beyond the scope of this paper. Hence, we accept the eustatic curve of Haq *et al.* (1988) as a comparison term and basis for discussion.

We admit the influence of the seafloor spreading onset in the Oporto Basin plus west Galicia margin, and Bay of Biscay on the Lusitanian Basin. It is relevant that the assigned age to the onset in those segments is compatible with the biostratigraphic data available for the lower part of the «grés belasianos» unit (late Aptian to early Albian), where the more pronounced vertical changes of system character occurs. It can be assumed that thermal and isostatic uplift related to (one at least) these separation episodes, was sufficient to generate a decrease of subsidence or even a slight uplift on the Lusitanian Basin floor near the Aptian-Albian boundary, reflected in a relative sea-level drop.

As pointed out by Chadwick, Livermore & Penn (1989) and Hiscott *et al.* (1990), there are many similarities between basins surrounding North Atlantic due to near-synchronous geodynamic pulses of continental breakup. Cloetingh *et al.* (1989) stated that the second and third-order eustatic cycles of Haq *et al.* (1988) appear to be related to timing and patterns of sea-seafloor spreading. The accumulation of intraplate stress and its sudden liberation, can explain eustasy and the main features of tectonic behavior of many basins. The erosive unconformities are related to events of continental separation, generated at the basin peripheries by an isostatic uplifting rebound and thermal uplift. Even if this mechanism cannot producc global sea-level changes, is relevant for our purposes that the curves of Haq *et al.* (1988) are biased toward the North Atlantic basins data (Cloetingh *et al.*, 1989). Hiscott *et al.* (1990) consider that sea-level variations recorded in six basins of North Atlantic, including the Lusitanian Basin, are responses to the ocean opening.

6.3. Depositional Sequences

The recognition of depositional sequences results from the identification and interpretation of genetically related depositional systems and bounding unconformities (Van Wagoner *et al.*, 1988). In the presented case, the application of such methodology is difficult due to the i) long distance between location of the data; ii) minor contrast between cycles in continental facies and, mainly, iii) lack of data from genetically related marine or transition systems. However, the cyclicity proposed here can be related to the cycles of Haq *et al.* (1988) in timing and in admitted genesis and, so, compared to depositional sequences.

The best fit between age and nature of the studied deposits, the age constrains for geodynamic pulses of western and northwestern Iberia breakup and the sea-level (eustatic ?) curves of Haq *et al.* (1988) is presented in the Fig. 9.

Other cycles of relative sea-level changes might have induced responses on system character during the deposition of the «grés belasianos», but are

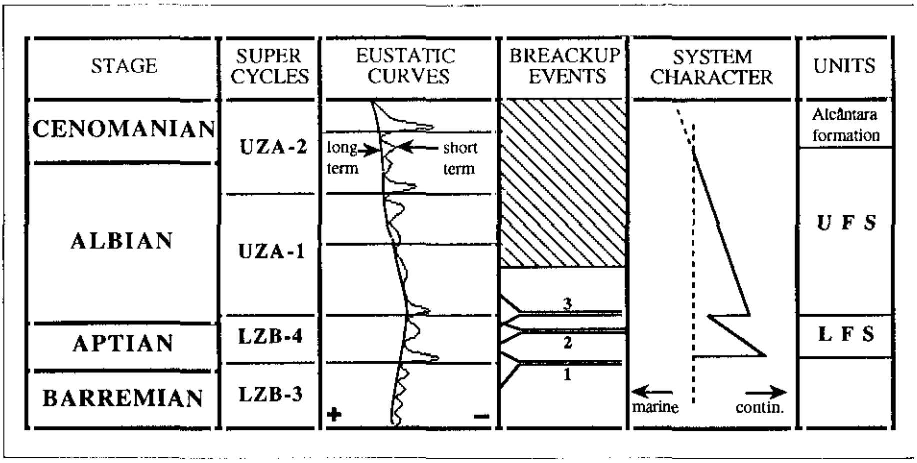


Fig. 9.—Comparison between the «grés belasianos» vertical evolution, eustatic fluctuations and breackup events (1: northern part of the Lusitanian Basin, 2: western Galicia margin, 3: Bay of Biscay. Cf. Fig. 8). Eustatic curves and supercycles after Haq *et al.* (1987).

Fig. 9.—Comparación entre y las macrosecuencias definidas en los «grés belasianos», variaciones eustáticas y episodios de apertura oceánica (1: sector norte de la Cuenca Lusitana. 2: margen occidental de Galicia. 3: Golfo de Vizcaya. Cf. Fig. 8). Curvas eustáticas y superciclos según Haq *et al.* (1987).

not clearly observed in the more proximal part. Considering the concepts of sequence stratigraphy for clastic deposition in passive margins (Jervey, 1988; Posamentier, Jervey & Vail, 1988) it is possible that the upper fining-upward succession includes two depositional sequences. In fact, other cycles may be recognized in the unit or equivalents, namely those pointed out by Taugourdeau-Lantz *et al.* (1982) and Cugny (1988). In the 14C-1A and Faneca-1 wells (Fig. 3), and the Leiria-Ansião region (Figs. 3 and 4) it is possible that the upper third part of the unit constitutes another finning-upward succession. This is consistent with the data of Olsson (1991) from the New Jersey coast and Amedro (1992) from the Anglo-Paris Basin.

7. SUMMARY AND CONCLUSIONS

The sedimentological and lithostratigraphical study concerning the «grés belasianos» unit in the northern part of the Lusitanian Basin has allowed the definition of two finning-upward successions. The lower fining-upward succession (LFS) corresponds to the deposition in coalescent wet alluvial fans, changing to a braidplain with local sinuosity. The upper succession (UFS), records the transition from high slope braidplains with increasing sinuosity to fluvial-dominated deltaic deposits (Fig. 6).

The lack of evidence of climate variations in the unit suggests that this was not the main control for the system character change. This is consistent with the admitted slow and gradational change of the climate during the middle of the Cretaceous.

We admit that pulses of continental breakup had a regional influence in sea-level. This leads to the hypothesis that during upper Aptian to middle Albian the Lusitanian Basin underwent an indirect influence of the onset of seafloor spreading in the Galician western margin and Bay of Biscay. In this context, we can infer that large scale cyclicity within the «grés Belasianos» unit –the two finning-upward successions– was probably caused by sea-level variations related to the thermal and isostatic adjustments. It must be stressed that the relationship established between the eustatic curves of Haq *et al.* (1988) and the North Atlantic geodynamic evolution is based on the admitted data bias of the former and intraplate stress capability to influence widespread sea-level changes. Even if those cycles could not be considered eustatic, they can be used as reference for the sea-level variations in the North Atlantic margins.

Despite the poor age constrains for the unit and the geodynamic events considered, the proposed correlation of sea-level (tectono-eustatic ?) and sedimentological cyclicity is consistent. In conclusion, LFS probably corresponds to the supercycle LZB-4 and UFS to UZA-1 and part of the UZA-2 of Haq *et al.* (1988). Further studies will provide the biostratigraphical and sedimentological data needed to the detailed correlation between continental, transitional and marine deposits, in order to confirm the proposition and identify the system tracts.

Nevertheless, several questions remain open for further discussion, namely:

1. The detailed age of the «grés belasianos» all over the vertical and lateral extent of the unit.
2. The influence induced by the onset of seafloor spreading in the Galician western margin and Bay of Biscay, as well as the plate rotation, in the Lusitanian Basin.
3. The relationship between those tectonic pulses and widespread (possibly eustatic) sea-level changes, specially the compilation of Haq *et al.* (1988).

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