

# MESOZOIC DEVELOPMENT OF THE LUSITANIAN BASIN, PORTUGAL

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## ABSTRACT

The Mesozoic of the Lusitanian Basin comprises four unconformity bounded sequences which may be related to events in the evolution of the North Atlantic.

(1) *Triassic - Callovian*. Triassic red fluviatile siliciclastics are capped by Hettangian evaporites which subsequently influenced the manner in which reactivation of Hercynian basement faults affected the cover of younger sediments. Where they were thick, halokinetic structures formed, but where they were thin, extensional faults developed. The Triassic and Hettangian sediments accumulated in grabens and half grabens, but later lower and middle Jurassic sediments blanketed the basin and exhibit relatively simple facies geometries. These features are consistent with deposition during thermal relaxation of the crust following Triassic rifting.

(2) *Middle Oxfordian-Berriasian*. A basinwide hiatus, over which latest Callovian and lower Oxfordian sediments are missing, is overlain by lacustrine carbonates. These are succeeded by up to 1500 m of marine carbonate, within which facies distributions indicate contemporaneous movement of salt structures and faults. The base of the Kimmeridgian is marked by an influx of siliciclastic sands over much of the basin, and such sediments dominate the succession in the north and east of the basin, but are replaced south westwards by carbonates. The Kimmeridgian - Berriasian interval is up to 4 km thick.

(3) *Valanginian-Lower Aptian*; (4) *Upper Aptian - Turonian*. These sequences show a similar facies distribution to that seen at the end of the previous sequence. Both are relatively thin in contrast to thick sequences of this age drilled off Galicia Bank and Vigo Seamount.

Sequence 1 is typical of rift-related successions encountered in most North Atlantic margin basins. Rapid subsidence and syn-sedimentary fault and halokinetic movements characteristic of Sequence 2 suggest a rifting episode that heralded a pre-Aptian phase of ocean opening to the southwest of the Basin. Sequences 3 and 4 may be equated to syn- and post-rift sequences drilled on the subsided northwestern Iberian margin, but they do not show comparable rates of subsidence. The contrasting subsidence histories of the two sectors of the western Iberian margin are consistent with a change from a lower to an upper plate boundary configuration southwards across the Nazaré Fault.

**Key words:** Atlantic margin, Mesozoic basin development, Portugal; post rift sediments, pre rift sediments, upper and lower plate boundaries.

## RESUMEN

Contrariamente a lo ocurrido en el margen vascocantábrico, el margen occidental de Portugal (Cuenca Lusitana), no desarrolló una importante cuña de sedimentos progradantes propia de la etapa de deriva ni sufrió una fase tectónica compresiva. La Cuenca Lusitana representa por lo tanto una oportunidad única para estudiar afloamientos de sedimentos de las etapas "sin-rift" y "pre-rift" y conseguir así un modelo de la constitución de otros márgenes del Atlántico Norte solamente accesibles mediante sismica y sondeos.

En la sucesión mesozoica de dicha cuenca se encuentran cuatro secuencias limitadas por discordancias: (1) Triásico superior - Calloviano superior; (2) Oxfordiano medio - Berriasiense; (3) Valanginiense - Aptiense inferior, y (4) Aptiense superior - Turoniano (ver fig. 4).

Durante el Triásico y Jurásico inferior, los movimientos de las fracturas del basamento hercíniano produjeron fosas y semifosas que fueron llenadas con sedimentos clásticos y evaporitas. Es probable que las áreas en que hoy día se encuentran los diapiros salinos fueran originalmente los lugares de depósito de potentes secuencias evaporíticas que tenía lugar en las fosas. Las intrusiones salinas probablemente fueron desencadenadas por la reactivación de las fallas del basamento durante el Jurásico superior y el Cretácico inferior (causada por el adelgazamiento cortical y quizás por acción de movimientos de desgarre). La fracturación se transmitió a la corteza mesozoica allí donde las evaporitas tenían menos espesor.

El relleno progresivo de las fosas triásicas, unido a la subsidencia térmica de la corteza que siguió a su estiramiento, así como el ascenso global del nivel del mar, dio lugar a que en la cuenca se desarrollaran unas condiciones

más uniformes durante el intervalo Sinemuriense-Calloviano, con excepción de la elevación local en el Toarcense de un "horst" del basamento, en el margen occidental de la misma. Durante el Jurásico medio tuvo lugar el desarrollo de carbonatos de mayor energía probablemente debido a un descenso global del nivel del mar, pudiendo haber tenido lugar entonces movimientos halocinéticos poco importantes.

Durante el Calloviano terminal-Oxfordiano basal, tuvo lugar una importante interrupción sedimentaria de alcance regional, asociada a menudo con superficies kársticas, sobre la que reposan sedimentos carbonatados bituminosos lagunares, perimareales y de lagos alcalinos que indican la existencia de una importante somerización con respecto a los medios relativamente profundos del Calloviano. El Oxfordiano superior muestra un importante episodio de depósito de carbonatos marinos, con dos tipos de construcciones, unos sobre bloques fracturados y los otros en relación con el ascenso de estructuras salinas. Los primeros son relativamente delgados (200-500 m), tienen grandes variaciones de facies, dominando las micritas sobre "grainstones" y "packstones". Los segundos son más potentes (500-1.000 m o más), con pocas variaciones laterales de facies e importantes secuencias de "grainstones" y "packstones" (fig. 6). El Kimmeridgiense inferior se caracterizó por una repentina entrada de sedimentos siliciclasticos con velocidades de sedimentación aceleradas (llegando en algunas subcuenca a 1 cm/100 años) y diapirismo y fracturación sinsedimentarias. Esta actividad tectónica cesó a fines del Kimmeridgiense inferior, con progradación hacia el sur de un complejo de talud siliciclastico de 500 m. de espesor (fig. 7).

El intervalo desde el Kimmeridgiense superior hasta el final de Cretácico no suele presentar espesores superiores a 1 km, siendo menos aparente la influencia de la fracturación y el diapirismo en la sedimentación y en la distribución de la subsidencia, por lo que en la cuenca se volvió a una distribución de facies relativamente simple. En el golfo situado al oeste de Lisboa se depositaron sobre todo sedimentos carbonatados de origen marino somero que muestran digitaciones hacia el norte y hacia el este con sedimentos terrígenos fluviales (figs. 5 y 5C).

Los acontecimientos tectónicos al norte y al oeste de Iberia no fueron totalmente sincrónicos. Mientras que la subsidencia del margen continental desde Oporto hacia el norte durante el Cretácico inferior es comparable a la que tuvo lugar en Norte de España, en la Cuenca Lusitana tuvo lugar una importante fracturación en el Kimmeridgiense inferior que puede haber sido precursora de una fase pre-Aptiana de apertura oceánica hacia el sudoeste de la misma.

La diferencia entre el desarrollo de la subsidencia de los dos sectores del margen ibérico occidental puede ser explicada aplicando el modelo de falla de "detachment" de Lister *et al.*, (1986). La Cuenca Lusitana, en la que no existe una espesa secuencia post-rift es característica de una placa superior, mientras que la subsidencia en la plataforma situada hacia el norte evidencia una situación de placa inferior.

**Palabras claves:** Margen atlántico, evolución de la cuenca mesozoica, Portugal, sedimentos postrift, sedimentos prerift, discontinuidades, subsidencia, paleogeografía.

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## 1. INTRODUCTION

During the Mesozoic, the Iberian plate was situated in a focal position between the Atlantic Ocean and Tethys. Although extensional structures dominate the fabric of the western Iberian margin, they were overprinted to varying degrees by Pyrenean and Betic compressional events.

Like the Asturias and Basque-Cantabrian basins in northern Spain, the Lusitanian Basin of Portugal provides an opportunity to study pre-rift and syn-rift sedimentary sequences which in other North Atlantic Mesozoic marginal basins can only be studied by seismic methods and drilling (Wilson, 1987). Unlike the Basque-Cantabrian area, the Lusitanian Basin lacks thick post-rift sequence, and though it suffered compressional tectonics during the Tertiary, these did not produce crustal shortening on the scale of that seen in northern Spain. Therefore the Basin provides a unique opportunity to study pre-rift and syn-rift sediments using a combination of outcrop, borehole and seismic data.

The Lusitanian Basin extends at least 250 km to the north of Lisbon, and its onshore area totals 23000 km<sup>2</sup>. It is bounded to the east by Hercynian basement rocks which are cut by strike-slip faults showing predo-

minantly NE-SW and NNE-SSW trends. The western offshore boundary of the Basin is marked by a series of basement horsts, one of which is exposed on the Berlenda and Farilhões Islands (fig. 3). To the north of these islands, the western boundary of the Basin is not clearly defined. It is possible that the Lusitanian Basin is connected northwards to Mesozoic basins situated offshore between the narrow continental shelf, and Porto and Vigo Seamounts and Galicia Bank (fig. 1).

The stratigraphy of the Lusitanian Basin records two rifting events which are characterised by red siliciclastic fluvial sediments. The first, late Triassic rifting phase is common to all North Atlantic margin basins, and it did not herald ocean opening. The second late Jurassic rifting episode is significantly older than syn-rift sediments drilled off Galicia Bank, and those of North Spain where Atlantic opening commenced in the Aptian (fig. 1).

This paper reviews some of the major structural and stratigraphic features of the Lusitanian Basin and suggests that crustal thinning did not occur synchronously along the entire margin of western Iberia. The significance of the thin post-rift sequence and associated magmatic activity is discussed in the context of models of crustal thinning.

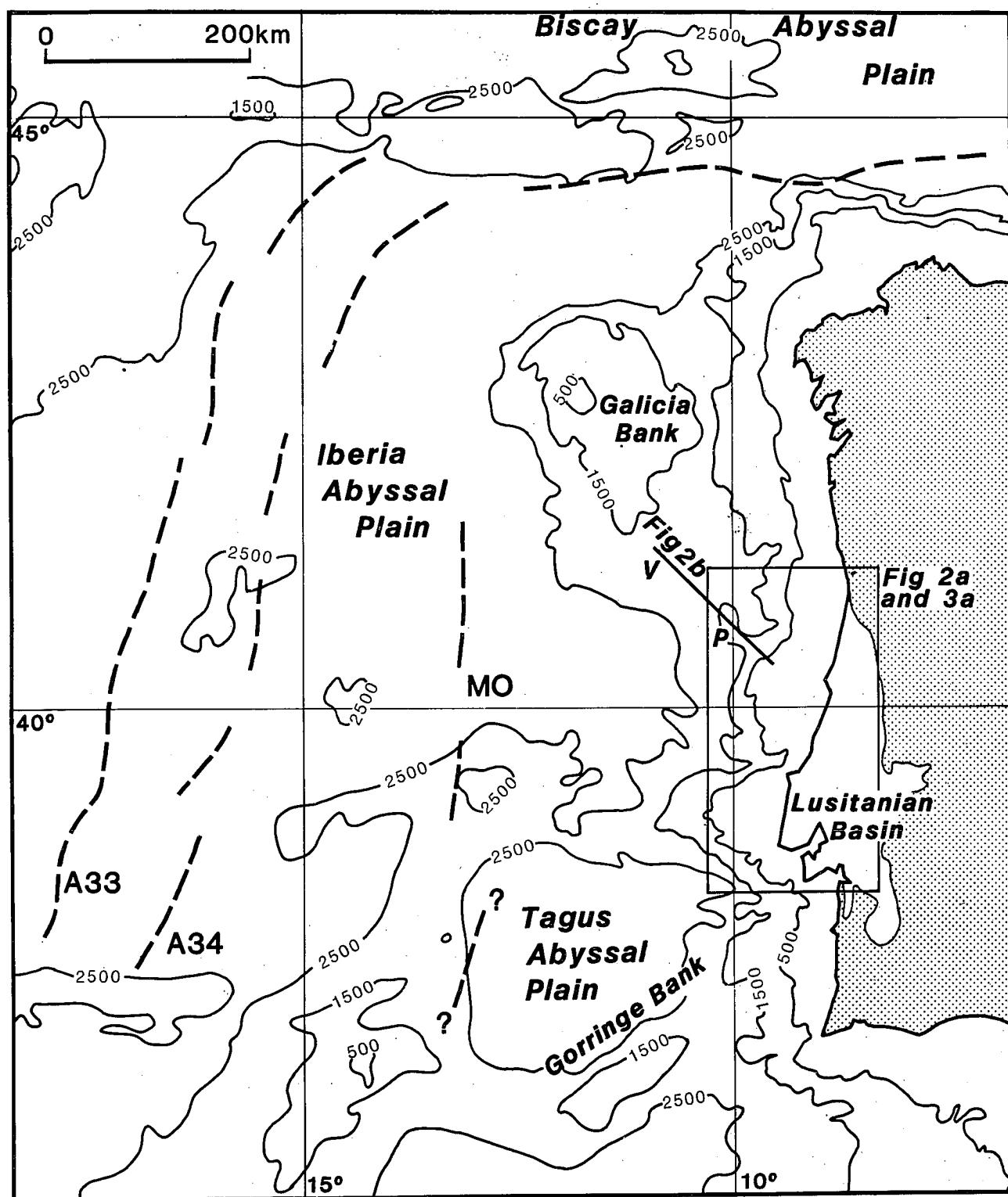


Fig. 1.—The Atlantic margin west of Iberia (simplified and modified from Boillot and Malod, this volume). The northwestern part of the margin, bounded by Galicia Bank, Vigo Seamount (V) and Porto Seamount (P), subsided rapidly during the later part of the Early Cretaceous due to crustal thinning. Anomaly MO indicates that ocean floor spreading began in the Aptian (Boillot and Malod, 1988), whereas the anomaly indicated by a question mark may indicate earlier spreading to the southwest of the Lusitanian Basin (see Uchupi, 1988 fig. 4). Anomalies A33 and A34 are respectively Santonian and Campanian in age.

Fig. 1.—Margen atlántico occidental de Iberia (simplificado y modificado de Boillot y Malod, 1988). La parte noroeste del margen, limitada por el Banco de Galicia, el "seamount" de Vigo y el "seamount" de Oporto, muestra una rápida subsidencia hacia el final del Eoceno inferior debido a un adelgazamiento de la corteza. La anomalía MO indica que la expansión del océano se inició en el Aptiense (Boillot y Malod, 1988), mientras que la anomalía marcada con una interrogante puede indicar la expansión inicial al suroeste de la cuenca lusitana (ver Uchupi, 1988, fig. 4). Las anomalías A33 y A34 son de edad Santoniense y Campaniense, respectivamente.

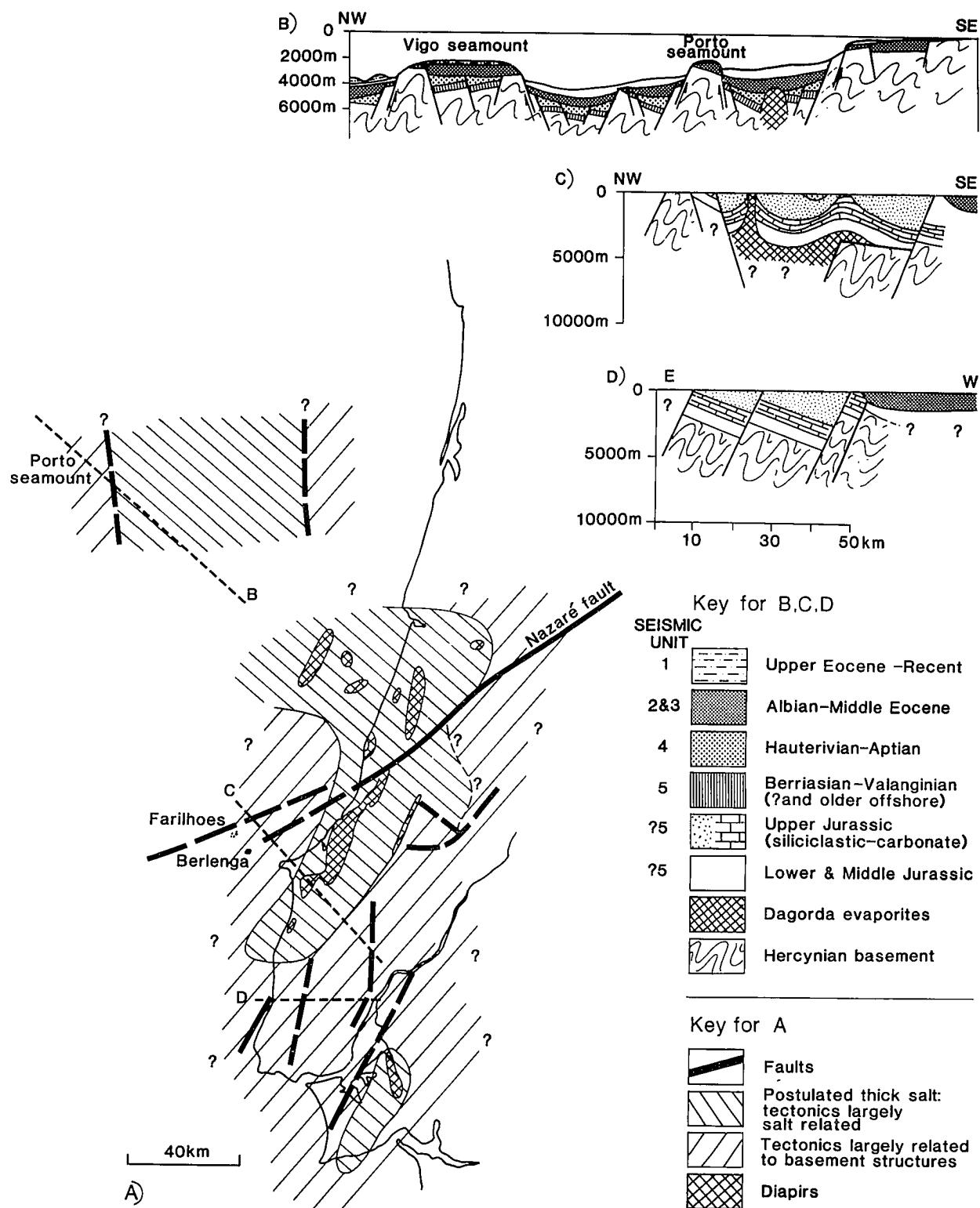


Fig. 2.—The principal structural features of the Lusitanian Basin and adjacent offshore areas. A. Sketch map showing the distribution of halokinetic and fault structures. The two contrasting tectonic styles are considered to be controlled by the thickness of evaporites in the Dagorda formation. Where it was thick, reactivation of Hercynian basement faults triggered the migration of salt, but where the Dagorda was thin, the faults propagated into younger sediments. B, C and D: sketches showing structure styles. B is based on seismic data and is from Mougenot *et al.* (1984); this section is also located on fig. 1. C and D are based on outcrop and seismic data.

Fig. 2.—Rasgos estructurales de la Cuenca Lusitana y áreas marinas adyacentes. A.—Mapa esquemático en el que se muestra la distribución de las estructuras halocinéticas y las fallas. Los dos estilos tectónicos diferentes que se observan están controlados por las variaciones en el espesor de las evaporitas de la Formación Dagorda. Allí donde esta formación tiene gran espesor la reactivación de las fallas del basamento produjo la migración de la sal, mientras que donde era poco potente las fallas afectaron a toda la cobertura. B, C y D.—Secciones esquemáticas mostrando el estilo estructural. La sección B se basa en datos sísmicos y ha sido tomada de Mougenot *et al.*, (1984); la localización de esta sección se indica en la fig. 1. Los cortes C y D se basan en datos tanto de geología superficial como de perfiles sísmicos.

## 2. STRUCTURE

The Tectonic Map of Portugal (Ribeiro *et al.*, 1972) shows that the Lusitanian Basin has a relatively simple geometry. It depicts a Mesozoic basin trending NNE-SSW, with a width of about 100 km and a length of some 250 km, in which just over 4 km of sediment accumulated. In the southern part of the basin, modern seismic data has revealed that this picture is oversimplified, for a number of sub-basins can be recognised. These sub-basins were particularly active during the late Jurassic (Wilson, 1979; Guéry *et al.*, 1986). One of them, the Bombarral sub-basin, is flanked by diapiric structures, and subsided largely due to salt withdrawal, whereas the Arruda and Turcifal sub-basins developed as half-grabens.

The Lusitanian Basin exhibits two tectonic styles: one dominated by halokinetic structures, and the other by faulting (fig. 2). These structures show a dominant NNE-SSW orientation, plus a minor NE-SW trend, both of which mirror the trends of Hercynian basement faults. The spacing of the structures, at between 15 and 25 km, is very similar to that seen offshore, such as to the west of Galicia Bank (see Boillot and Malod, 1988, fig. 3). It is probable that the distribution of halokinetic and fault structures was controlled by the depositional thickness of Hettangian evaporites of the Dagorda formation. Where this formation was thick, diapiric structures developed over reactivated Hercynian basement faults, but where it was thin or absent, the faults propagated into the cover of younger sediments.

Zbyszewski's (1959) perceptive conclusions concerning the origin of the diapiric structures of the Lusitanian Basin is confirmed by 1980's seismic data. He postulated that diapiric structures developed over normal faults in the Hercynian basement, which had previously controlled the depositional thickness of the Dagorda evaporites (see fig. 3D). This relationship has been described more recently by Jenyon (1985) in the Zechstein of the southern North Sea. He showed examples of salt pillows developing over regions where the Zechstein thins over buried fault scarps. Although seismic data is not good beneath the top evaporite interval in Portugal, a similar situation probably exists along the Torres Vedras - Montejunto anticline, which separates the Bombarral sub-basin (beneath which thick Dagorda evaporites occur) from the Arruda sub-basin, under which drilling and seismic data have proved only thin evaporites. The anticline developed as a salt pillow during late Jurassic times as demonstrated by onlapping and thinning of formations towards the axis of the structure (see fig. 3E) and apart from the effects of Tertiary compressional movements, is very similar to the fault-scarp related structures described by Jenyon (*op. cit.*). Elsewhere in the basin, piercement structures are common, the biggest of which is the long (35 km) and relatively narrow (up to 7 km) Caldas da Rainha diapir (Zbyszewski 1969, Guéry *et al.*, 1986). All these structures have been modified by Tertiary, probably Miocene, compressional movements, which, in view of the

flower-like geometry of the faulting (fig. 3E), probably had a strike-slip origin.

Major normal faults bounding the Arruda and Turcifal sub-basins can be seen on seismic sections (fig. 3B). Most of the normal movement occurred during the late Jurassic, and perhaps in the early Cretaceous. Tertiary compressional movements reactivated the structures (fig. 3C).

Figs. 3C and D summarise the nature of the two tectonic styles displayed in the Lusitanian Basin. Similar features have been observed offshore (fig. 2B), where significant early Cretaceous extension occurred (Mougenot *et al.*, 1984, 1986; Mauffret and Montadert 1987) and resulted in subsidence of the offshore areas beyond the present day continental shelf to approximately the depths observed today. Like the onshore structures, those offshore were reactivated by probable strike-slip related compressional events during the Tertiary. These movements caused the uplift of both basement blocks tilted during the Mesozoic (Porto and Vasco de Gamma Seamounts) and a sedimentary basin (Vigo Seamount) (Boillot and Malod, this volume).

The southern limit of the region of major Cretaceous crustal subsidence is the Nazaré Fault, which has led many workers to suggest that it may be a transform feature. However, no significant thickness or facies changes appear to occur across it in the onshore part of the Basin.

## 3. STRATIGRAPHY

Fig. 4 summarises the Mesozoic succession in the southern part of the Lusitanian Basin. It uses an informal nomenclature currently under discussion which aims to rationalise the confused mixture of biostratigraphic and lithostratigraphic terms used in previous literature describing the succession. Earlier in this paper, two influxes of siliciclastics related to late Triassic and late Jurassic rifting were highlighted. Closer inspection of fig. 4 reveals four sequences bounded by major unconformities:

- 1 Upper Triassic-Upper Callovian
2. Middle Oxfordian-Berriasian
3. Valanginian-Lower Aptian
4. Upper Aptian-Turonian

The key features of these sequences are discussed below, with special emphasis on the second, which is the thickest and displays the greatest range of depositional environments.

### 3.1. Upper Triassic-Upper Callovian

Fault movements along Hercynian basement faults resulted in the formation of grabens or half grabens which were filled by red fluvial siliciclastics of the Silves formation (Palain, 1976, 1979). These are succeeded by the evaporitic Dagorda formation which, also probably accumulated in fault bounded basins. However, the overlying lower and middle Jurassic formations

show no rapid thickness variations at outcrop or on seismic sections. The lower Jurassic shows a general northward thickening trend, superimposed on which is an axial zone of thickening approximately coincident with the present day coastline (Wright and Wilson, 1984, fig. 1) indicating regional sag of the basin during thermal relaxation of the crust that was thinned during Triassic rifting. Deposition of the Coimbra, Brenha and Candeiros formations occurred over an westerly dipping gentle slope in the onshore part of the Lusitanian Basin (fig. 5A). The absence of significant amounts of siliciclastic sands in these formations suggests that carbonate deposition probably extended far into the interior of Iberia. The Coimbra and Candeiros formations show carbonate facies indicative of an westerly dipping ramp (Watkinson, personal communication), with barrier system ooid grainstones separating lagoonal and peritidal facies in the east from deeper water micritic limestone and shale facies of the Brenha formation to the west. The limestone-shale alternations within the Brenha formation were formed either as the O<sub>2</sub>-H<sub>2</sub>S interface fluctuated between a location beneath the sediment surface to within the water column (Wright and Wilson, 1984, fig. 5), or as fine grained peloidal turbiditic influxes interrupting the deposition of mixed sili-

ciclastic carbonate muds. During the Toarcian and Aalenian, the presence at Peniche of a 300 m sequence of resedimented carbonates, derived from the NW (Wright and Wilson, 1984) indicate that the western horst system was active at this time. Guéry *et al.*, (1986) suggested that diapiric structures began to influence carbonate facies distribution during middle Jurassic times. They also suggested that tectonic uplift of the eastern part of the basin resulted in the deposition of shallower water limestones of the Candeiros formation, but relative sea-level changes affecting a westward tilted ramp could have had the same effect.

### 3.2. Middle Oxfordian-Berriasian

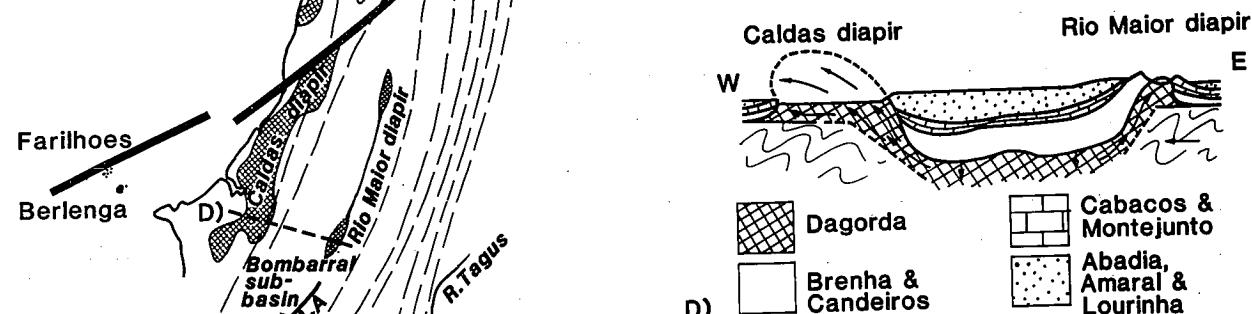
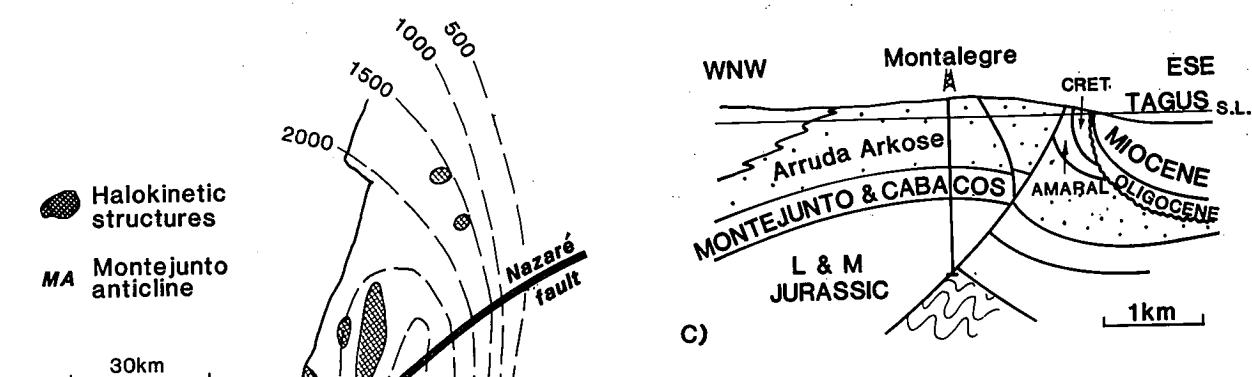
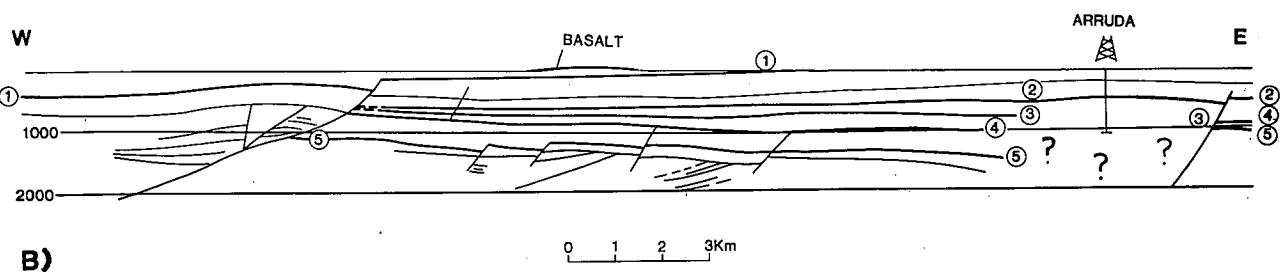
This succession is underlain by a basin-wide hiatus extending from the latest Callovian, usually the *lamberti* zone (Wilson, 1979) to the end of the early Oxfordian. The middle Oxfordian Cabaços formation is often underlain by karstified surfaces. Lacustrine carbonates dominate the Cabaços formation (Wright and Wilson, 1985), which is overlain by marine carbonates of the Montejunto formation. Two types of carbonate build-up occur in the latter formation, and these were deposited in two distinct tectonic settings (Ellis and Wil-

Fig. 3.—Structural features of the southern part of the Lusitanian Basin.

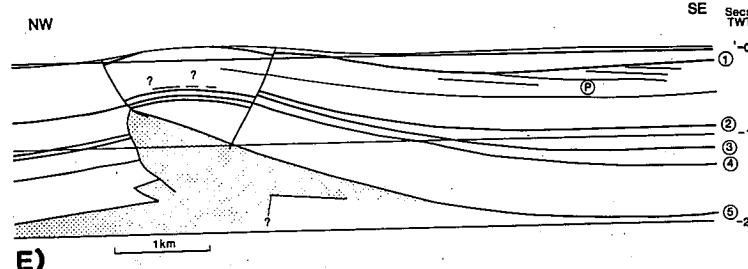
- A.—Sketch map showing the distribution of halokinetic structures, and major sub-basins in the southern part of the Lusitanian Basin. The isopachytes for the Mesozoic plus Tertiary sediment thicknesses are taken from the Tectonic Map of Portugal (Ribeiro *et al.*, 1972); in the light of modern seismic data, it can be seen this pattern is clearly oversimplified, for the sub-basins are not revealed by it (cf. figs. 3B and 7B). The location of the sections B, D and E are shown as dashed lines.
- B.—East-west section across the Arruda sub-basin from 1981 seismic data, showing its origin as a half-graben (for location, see fig. 2A). Numbers refer to seismic reflectors as follows: 1.—Amaral formation; 2.—Top Montejunto formation; 3.—Anhydrite interval within Cabaços formation; 4.—Top Middle Jurassic; 5.—Top Dagorda formation. Significant movement of the fault blocks during the late Jurassic is indicated by westward thinning of strata of this age. The area immediately to the west of the Vila Franca de Xira Fault is difficult to interpret. The Aruda Well failed to reach Oxfordian carbonates after drilling 2 200 m of Lower Kimmeridgian arkosic gravels and coarse sands which show amalgamated sand facies characteristic of submarine fans. [Carvalho (personal communication, 1981) suggested that the Arruda borehole failed to penetrate Oxfordian carbonates because they were eroded by a submarine canyon. However, as such a canyon system cannot be traced on seismic section to a break in slope, it is more likely that the anomalously thick siliciclastic sequence at Arruda was either caused by contemporaneous fault movement, or more likely by lateral facies changes during the Oxfordian towards the Vila Franca de Xira Fault].
- C.—Example of Tertiary reverse movement on the Vila Franca de Xira Fault (from Chameau, 1962).
- D.—Zbyszewski's (1959) hypothetical section across the Bombarral sub-basin showing salt structures developing above basement faults.
- E.—Sketch section across the Montejunto Anticline based on seismic data (numbers refer to seismic reflectors itemised in B). The structure developed initially as a salt pillow rising during the late Jurassic (as indicated by thinning and onlapping) above a fault in the basement. Tertiary transpression produced the present day reversed flower structure.

Fig. 3.—Rasgos estructurales de la parte meridional de la Cuenca Lusitana.

- A.—Mapa esquemático en el que se muestra la distribución de las estructuras halocinéticas, en la parte meridional de la Cuenca Lusitana. La isocapas corresponden al conjunto Mesozoico y Cenozoico y han sido tomadas del mapa tectónico de Portugal (Ribeiro *et al.*, 1972); los datos sísmicos modernos muestran que estas curvas corresponden a una simplificación excesiva. La localización de las secciones B, C, D y E se marca con líneas discontinuas.
- B.—Sección este-oeste atravesando la subcuenca de Arruda elaborada a partir de datos sísmicos de 1981, en la que se muestra su estructura de semifosas. Los números corresponden a los siguientes reflectores sísmicos: 1.—Formación Amaral. 2.—Techo de la formación Montejunto. 3.—Tramo de anhidrita dentro de la Formación Cabaços. 4.—Techo del Jurásico medio. 5.—Techo de la Formación Dagorda. El adelgazamiento hacia el oeste de los materiales del Jurásico superior indica un significativo movimiento de bloques fallados durante esta época. El área localizada inmediatamente al oeste de la Falla de Vila Franca de Xira presenta especial dificultad de interpretación. El sondeo de Arruda llegó hasta materiales carbonáticos del Oxfordense después de atravesar 2.200 m. de gravas arcósicas y arenas gruesas del Kimmeridgiense inferior, con amalgamaciones y otros rasgos característicos de abanicos submarinos.
- C.—Ejemplo de movimiento inverso de la Falla de Vila Franca de Xira en el Terciario según Chameau (1962).
- D.—Sección hipotética a través de la subcuenca de Bombarral mostrando el desarrollo de las estructuras salinas sobre las fallas de basamento, según Zbyszewski (1959).
- E.—Sección esquemática a través del Anticlinal de Montejunto basada en datos sísmicos (los números corresponden a los mismos reflectores sísmicos de B). La estructura se inicia en el Jurásico superior como una almohadilla de sal (como indica el adelgazamiento y solapamiento de las unidades) sobre una falla del basamento. La transpresión terciaria produjo la actual estructura.



A)



son, 1986, see fig. 6). Buildups that were deposited in the vicinity of diapiric structures are relatively thick (500-1000 m or more) sequences of *Solenopora* rich grainstones and packstones with little lateral facies variation. In contrast, buildups that developed over tilted fault blocks show great lateral facies variation, from hemipelagic muds to peritidal fenestral carbonates; these buildups are relatively thin (200-500 m) and mud dominated. The second type of build-up is exposed to the northeast of Montejunto anticline, on the eastern side of the Arruda basin north of Vila Franca de Xira (Leinfelder, in press) and in the subsurface on the south side of the Tagus estuary. The grainstone buildups occur on the northwestern flank of the Bombarral sub-basin. The Caldas salt wall was active at this time and had a major effect on facies distributions (Wilson 1979, Guéry *et al.*, 1986), separating the grainstone buildups to the southeast from bivalve rich quartzose peloidal packstones with a lagoonal aspect which occurs to the northwest (fig. 5B).

The latest Oxfordian and earliest Kimmeridgian was marked by a sudden influx of siliciclastic sediments over the entire basin (Wilson, 1979). This influx was accompanied by a significant increase in subsidence rates in the Arruda sub-basin, where 2200 m of arkosic gravels and coarse sands were deposited in a fan system spreading westwards from the Vila Franca de Xira fault (fig. 7). In the Montejunto area, the Oxfordian-Kimmeridgian event is marked by the partial exposure of the Oxfordian carbonate build up and resedimentation of shallow water carbonate clasts into the deeper parts of the basin to form the Tojiera member of the Abadia formation. Shallow water carbonate sedimentation continued in the platform interior into the middle Kimmeridgian, while, according to Guéry (1984) the Montejunto buildup continued to supply carbonate debris from a fault scarp on its western margin into the Portlandian.

The Abadia formation is dominated by shales and fine silts with subsidiary sand units. Its upper 500 m is expressed on seismic sections as southward dipping clinoforms indicating a prograding slope system. This interpretation was also reached on the basis of sedimen-

tological data by Ellwood (1987) who interpreted the overlying thin ooid grainstone dominated Amaral formation as a shelf deposit capping the siliciclastic slope system. The thickness of the clinoform part of the Abadia formation appears to be unaffected by the Vila Franca de Xira Fault and the Torres Vedras-Montejunto anticline, although it does thin against the Vimeiro Lourinha salt cored anticline (see fig. 7). Thus structures that were very active during the early part of the Kimmeridgian became dormant for a significant time, although they did influence the thickness of the overlying fluvial Lourinhã formation.

Around the Sintra granite (which is late Cretaceous in age) a carbonate slope system characterised by debris flow deposits, and capped by low energy carbonates (Ellis, 1984), is exposed and comprises the Ramalhão, Mem Martins and Farta Paõ formations.

From the middle Kimmeridgian onwards, the complex facies distribution pattern of the Oxfordian and earliest Kimmeridgian was replaced by a simple configuration in which fluvial siliciclastics were replaced southwards by shallow marine marls and limestones.

### 3.3. Valanginian-Lower Aptian and Upper Aptian-Turonian

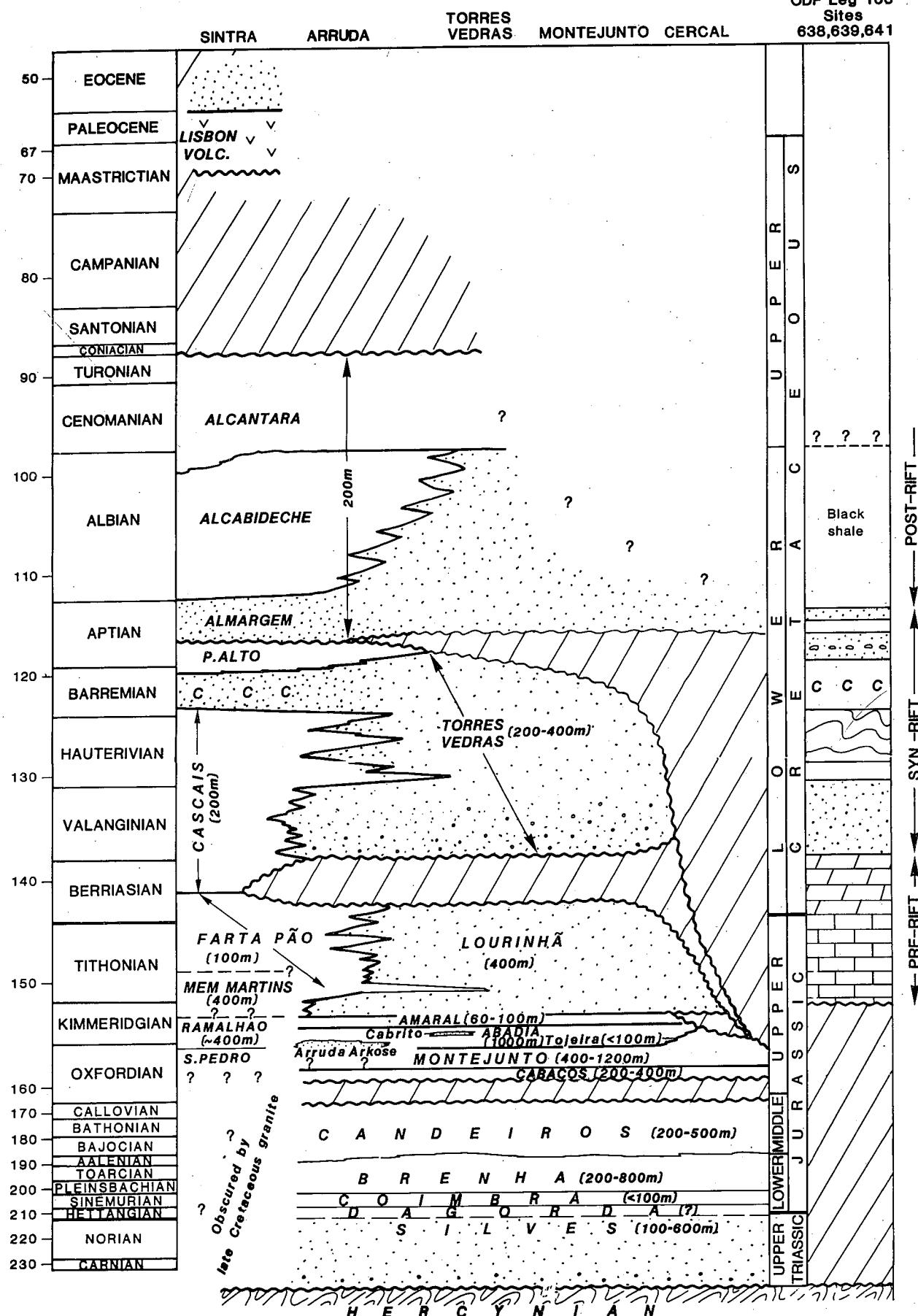
These two sequences are considered together because they both exhibit similar facies distributions, with fluvial siliciclastics in the north being replaced southwards by marine marls and rudist limestones (see figs. 4 and 5). Although the range of facies present is comparable to that present in the Basque-Cantabrian area, with the exception that there are no re-sedimented and deep-water sediments, both sequences are very thin - a mere two to three hundred metres compared to the several kilometre thicknesses exhibited by their counterparts in northern Spain.

The unconformities at the base of the two sequences increase in magnitude at the eastern margin of the Lusitanian Basin (Rey, 1972), suggesting continued movement along basin boundary faults. Likewise, diapiric structures continued to develop, as shown by the Torres Vedras formation resting on Dagorda evaporites at

Fig. 4.—Summary of the Mesozoic lithostratigraphy of the southern part of the Lusitanian Basin, and the succession drilled during ODP Leg 103 (see Boillot, and Malod, 1988, fig. 6). Note the change in scale of time at base of the Oxfordian and the top of the Cretaceous. The time scale used is that of Kent and Gradstein (1985) For the Lusitanian Basin, only the occurrence of siliciclastic sediments is indicated by stipple; all the other formations are argillaceous or carbonaceous in character, and are described briefly in the text. The ODP summary uses conventional lithological symbols. CCC indicate significant condensed sequences of Barremian age at both locations. Note the four unconformity-bound sequences that occur in the Lusitanian Basin, namely: (1) Upper Triassic - Upper Callovian; (2) Middle Oxfordian - Berriasian; (3) Valanginian - Lower Aptian and (4) Upper Aptian - Turonian. The location of places shown at the top of the diagram are given on fig. 3, with the exception of Cercal, which is situated at the northern end of the Montejunto Anticline.

Fig. 4.—Cuadro de las unidades litoestratigráficas de la parte meridional de la Cuenca Lusitana, y sección del sondeo realizado en el Leg. 103 del ODP (ver Boillot y Malod, 1988, fig. 6). Obsérvese el cambio de escala de tiempo desde la base Oxfordense hasta el final de Cretácico. La escala de tiempo absoluta utilizada es la de Kent y Gradstein (1985). Para la Cuenca Lusitana se marcan con punteado los sedimentos siliciclásticos; el resto de las formaciones son arcillosas o carbonatadas, y se describen brevemente en el texto. Para la sección del sondeo de ODP se utilizan los signos litológicos convencionales. CCC indica notables secuencias condensadas de edad barremiense, en la cuenca y en el sondeo. Obsérvense las cuatro secuencias, limitadas por discontinuidades, que se reconocen en la Cuenca Lusitana, y que corresponden a: 1.—Triásico superior-Calloviano superior. 2.—Oxfordense medio-Berriense. 3.—Valanginiense-Aptiense inferior, y 4.—Aptiense superior-Turoniano. La ubicación de las localidades puede verse en la fig. 3, con excepción de Cercal, la cual se sitúa en el extremo septentrional del Anticlinal de Montejunto.

ODP Leg 103  
Sites  
638, 639, 641



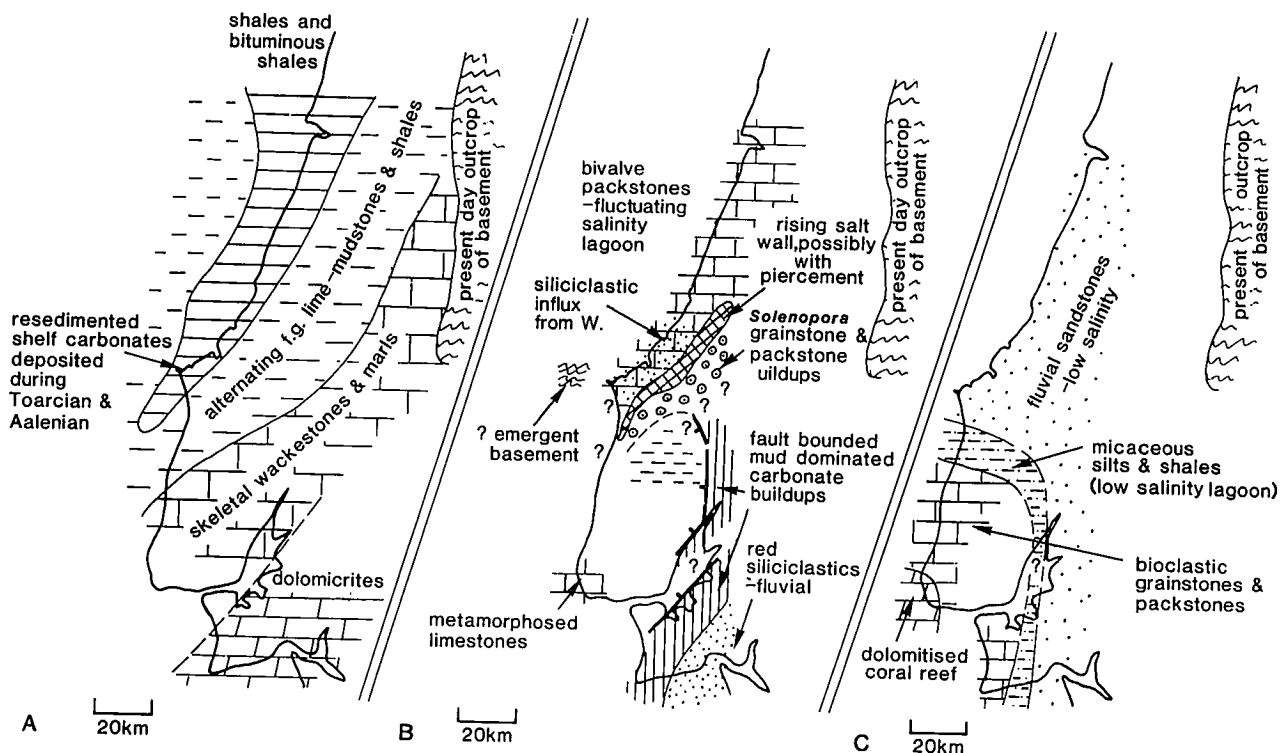


Fig. 5.—Simplified sketch maps showing the distribution of major lithofacies characteristic of three unconformity bound Mesozoic sequences of the Lutitanian Basin.

A.—*Pliensbachian* (from Wilson and Exton, 1979). Note the eastward deepening in the onshore part of the Basin indicated by the changing lithofacies. To the west, the limestone facies present were probably deposited on the distal part of a carbonate ramp. Global sea-level fall during the Middle Jurasic in shallow environments migrating westwards, so that shelf carbonates of the Candeiros formation were deposited (Watkinson, personal communication).

B.—*Upper Oxfordian* (modified from Wilson, 1979). Facies distribution was controlled by both halokinetic and fault movements, and differentiation into sub-basins had begun (see fig. 3A).

C.—*Hauterivian* (simplified from Rey, 1972). A simple facies distribution returned to the basin in late Tithonian times (Leinfelder, 1987), with a marine embayment to the southwest, and this persisted, albeit with successive regressive and transgressive episodes (see fig. 4), until the Turonian.

Fig. 5.—Mapas de litofacies simplificados para diversas etapas momentos de cada una de las tres primeras secuencias de la Cuenca Lusitana.

A.—*Pliensbaquiense* (según Wilson y Exton, 1979). Obsérvese como la profundización hacia el este de la parte emergida de la cuenca queda indicada por los cambios de litofacies. La bajada global del nivel del mar durante el Jurásico medio produce una somerización que migra hacia el oeste, hasta el punto que se depositan las calizas de plataforma somera de la Formación Candeiros (Watkinson, comunicación personal).

B.—*Oxfordense superior* (modificado de Wilson, 1979). La distribución de las facies estuvo controlada por la halocinesis y los movimientos de fallas, con lo que se produjo la diferenciación en subcuencas (fig. 3A).

C.—*Hauteriviense* (simplificado de Rey 1972). A partir del Tithónico superior se implanta de nuevo una distribución más simple de las facies (Leinfelder, 1987), con el desarrollo de un golfo hacia el suroeste y persiste hasta el Turoniano, aunque con episodios transgresivos y regresivos (ver fig. 4).

several locations offshore between Peniche and Figueira da Foz. However, relative sea-level changes rather than local tectonic movements were probably the major control on facies distributions.

#### 3.4. Igneous activity.

Ribeiro *et al.* (1981), recognised two important phases of igneous activity in the Lusitanian Basin to the north of Lisbon; these occurred only to the south of the Nazaré Fault. The first phase, ranging from Oxfordian to Valanginian in age consists of basalts, teschenites and dibase dykes trending either NNE-SSW or ESE-WNW. The second late Cretaceous episode is manifested by the intrusive complex of Sintra and the basl-

tic extrusives and associated dykes of the Lisbon volcanics.

#### 4. THE LUSITANIAN BASIN AND THE EVOLUTION OF THE WESTERN MARGIN OF IBERIA.

The stratigraphy of pre-, syn- and post rift sediments drilled during ODP Leg 103 is described by Boillot and Malod (*op. cit.*), and summarised on Figure 4. Three of the four sequences described from the Lusitanian Basin were encountered at the drilling sites to the west of Galicia Bank. The Upper Triassic - Callovian sequence was not encountered, but dredge samples

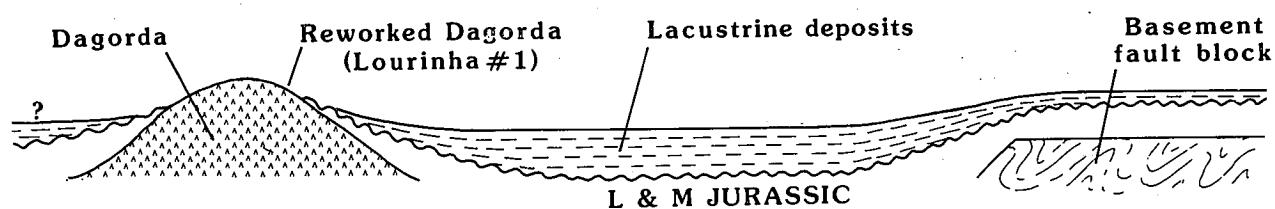
along the fault scarps bounding tilted fault blocks yielded red sandstones similar to those of the Silves formation onshore (Mougenot *et al.*, 1985). Given that Lower and Middle Jurassic sequences in the Lusitanian Basin, Northern Spain, Aquitaine and the Grand Banks are so similar, it would be surprising if they had not been deposited off northwest Iberia. Their absence suggest major erosion over the crests of tilted fault blocks before the deposition of the Tithonian-Berriasian carbonate platforms. They may well be present in basinal areas.

The pre-rift sequence drilled by ODP Leg 103 consists of Tithonian-Berriasian carbonates, with no trace of Oxfordian and Kimmeridgian sediments. However, Mauffret and Montadert (1987) have suggested that the lower part of seismic formation 5 (see fig. 2) may be of this age, in which case some Oxfordian crustal extension and consequent rifting did occur along the entire western Iberian margin. There is no doubt that onshore this interval is the major syn-rift episode of margin evolution and it may have heralded a short period of ocean formation in the Tagus abyssal plain (see Uchu-

NW

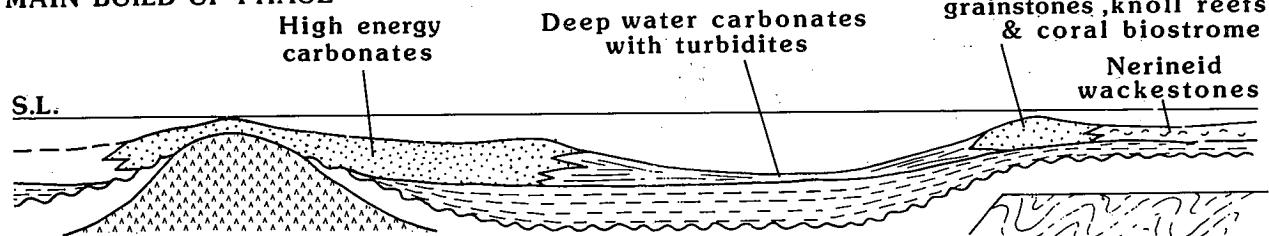
SE

### Middle Oxfordian (Cabacos Fm)



### Upper Oxfordian (Montejunto Fm)

#### MAIN BUILD UP PHASE



### Lower Kimmeridgian (Tojeira Mb & equivalents)

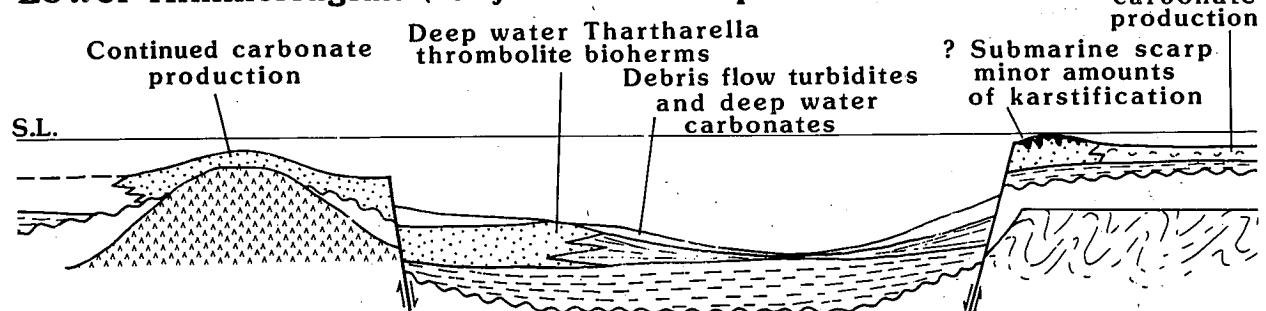


Fig. 6.—Sketch sections (not to scale) showing the tectonic settings of the two types of Oxfordian carbonate buildups of the Lusitanian Basin, and the onset of rifting at the beginning of the Kimmeridgian. The sections are drawn from the southern part of the Caldas da Rainha diapir to the northeastern end of the Torres Vedras - Montejunto anticline (for location of these structures, see figs. 3 and 8).

Fig. 6.—Secciones esquemáticas, sin escala, en las que se muestra el contexto tectónico de los dos tipos diferentes de construcciones carbonatadas en la Cuenca Lusitana, en relación con el inicio del *rifting* en el Kimmeridgiense inferior. La sección abarca desde la parte meridional del diapiro de Caldas da Rainha hasta el extremo septentrional del Anticlinal de Torres Vedras-Montejunto (ver localización de estas estructuras en figs. 3 y 8).

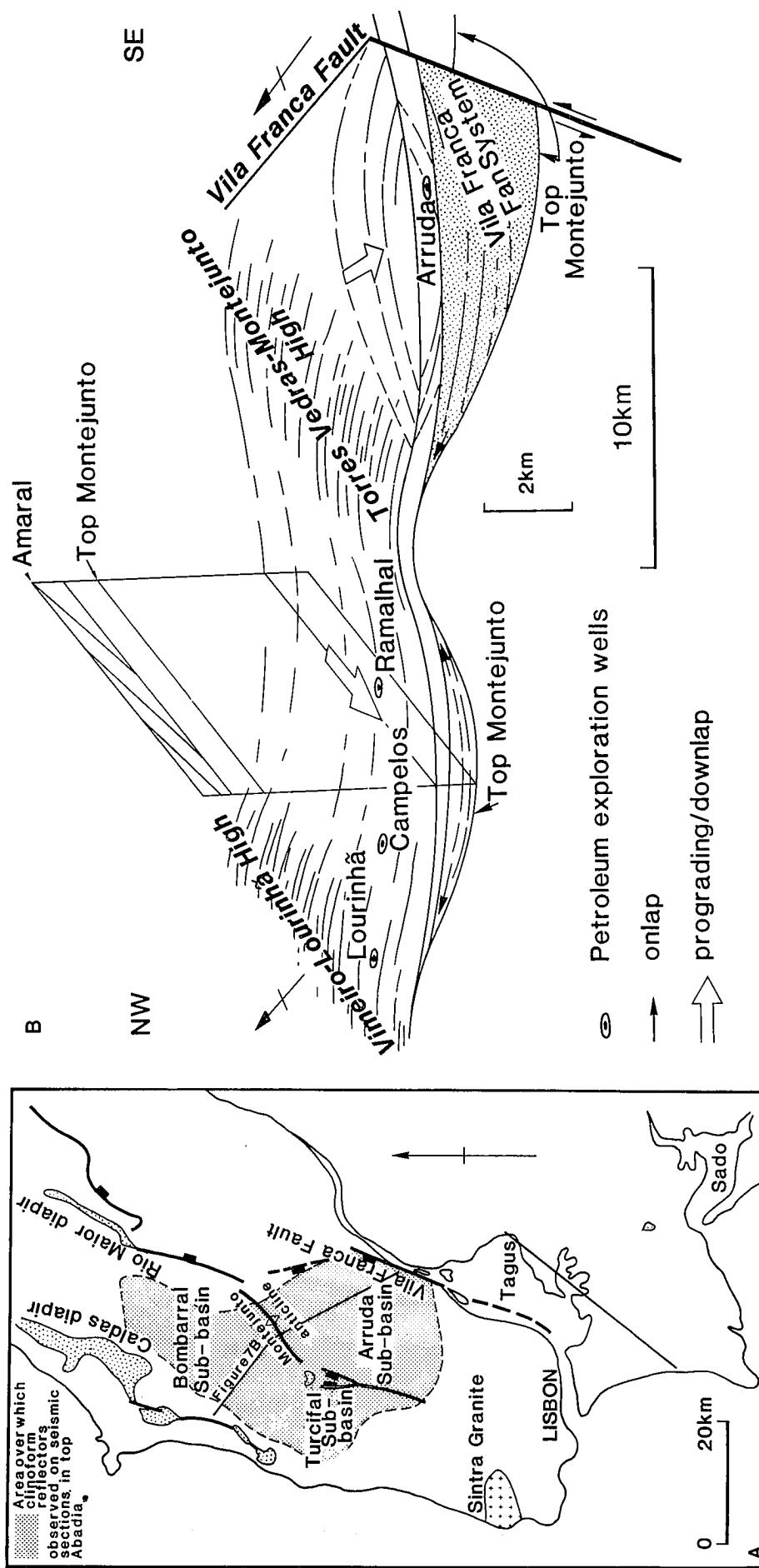


Fig. 7.—Map and sketch cross section illustrating the distribution of slope deposits of the lower Kimmeridgian Abadia formation. A.—Map showing the location of sub-basins in the southern part of the Lusitanian Basin, and the extent on southerly inclined clinoform seismic facies at the top to the Abadia formation. B.—Sketch section (for location, see A) across the Bombarral and Arruda sub-basins showing the nature of the Abadia formation. Note the onlap and thinning onto the Vimeiro-Lourinha and Torres Vedras-Montejunto highs, and the thick (2,000 m) coarse siliciclastics of the Vila Franca fan system. The thickness of the upper clinoform facies is unaffected by the Torres Vedras-Montejunto high and Vila Franca fault, indicating that they were dormant at this time. The latter structure became active once more after the deposition of the Amaral formation.

Fig. 7.—Mapa y corte esquemático en los que se ilustran la distribución de los depósitos de talud del Kimmeridgiense inferior (Formación Abadia). A.—Mapa en el que se indica la localización de las subcuencas en la parte meridional de la Cuenca Lusitana, y la extensión hacia el sur de las facies sísmicas clinoformes del techo de la Formación Abadia. B.—Sección esquemática (ver localización en la fig. A) a través de las subcuencas de Bombarral y Arruda mostrando la naturaleza de la formación Abadia. Observese el solapamiento (*onlap*) y adelgazamiento en los altos de Vimeiro-Lourinha y Torres Vedras-Montejunto, y el gran espesor (2.000 m.) de siliciclasticos gruesos en el sistema del abanico de Vila Franca. El espesor de las facies clinoformes superiores no está afectado por el alto de Torres Vedras-Montejunto y la Falla de Vila Franca, lo que indica que ambos eran inactivos en este tiempo. La estructura vuelve a ser activa antes del depósito de la Formación Amaral.

pi, 1988, fig. 4) that preceded the main phase of Atlantic opening between Iberia and the Grand Banks that commenced in the Aptian. The latest Callovian pre-middle Oxfordian hiatus of the Lusitanian Basin may be related to the Middle Callovian eastward jump in the location of the oceanic ridge of the newly opened southern North Atlantic suggested by Sheridan (1983) (see fig. 8).

The unconformities in the Lusitanian Basin at the base of the Valanginian and in the Aptian are respectively coincident with the onset of rifting and ocean opening documented by ODP Leg 103 results. However, the equivalent onshore sequences were deposited in shallow marine or continental conditions, and are very thin compared to the deep water sediments encountered off Galicia Bank (Boillot and Malod, *op. cit.* and Vigo Seamount (Sibuet and Ryan, 1979).

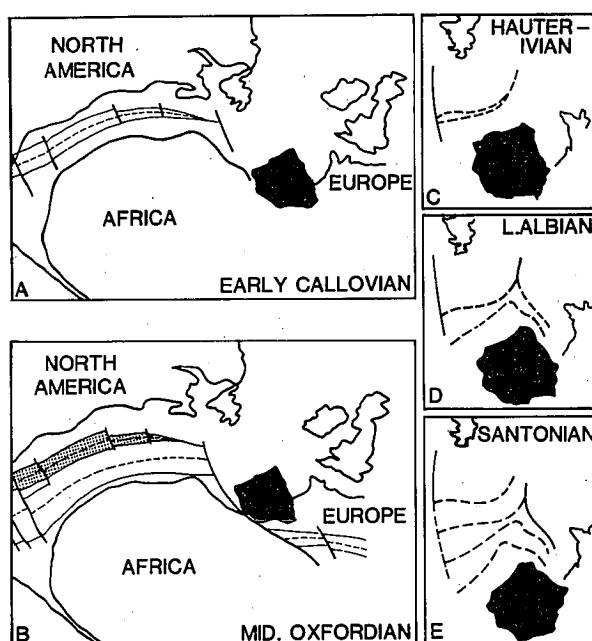


Fig. 8.—Key events in Atlantic opening A and B from Sheridan (1983) and C-E from Masson and Miles (1984). A and B show the jump in the location of the ocean floor spreading axis in the southern North Atlantic.

Fig. 8.—Eventos tectónicos que jalonan la apertura del Atlántico (A y B según Sheridan, 1983 y C-E según Masson y Miles, 1984). A y B muestran el salto del eje de expansión oceánica en la parte meridional del Atlántico norte.

## 5. SUMMARY AND CONCLUSIONS

The tectonic features of the Lusitanian Basin are the result of reactivation of faults in the Hercynian basement and the thickness of the evaporites of the Hetangian Dagorda formation. Where this formation was thin, reactivation of basement faults resulted in their propagation into the overlying Mesozoic sediments, but where it was thin, the development of halokinetic structures was triggered. Variations in the original thicknesses of the evaporite was probably caused by movement along the basement faults.

Four unconformity bounded sequences are recog-

nised in the Mesozoic succession, and may be related to events in the evolution of the North Atlantic ocean.

*Upper Triassic - Upper Callovian:* rifting resulted in the deposition of fluviatile siliciclastics and evaporites in fault bounded basins. Subsequent thermal relaxation of the crust resulted in simple facies distributions, with a general thickening northwards, and towards an axial zone almost coincident with the present day coastline north of Peniche. A carbonate ramp existed on the eastern margin of the basin and the westward shift in the location of the shallower parts of this system in the Middle Jurassic was probably controlled by global sea-level fluctuations.

*Middle Oxfordian - Berriasian:* The uppermost Callovian - Middle Oxfordian hiatus may be related to events in the opening of the southern North Atlantic. Here ocean spreading commenced in the Callovian, to be followed by a southward (eastward in terms of present day continental configurations) jump in the ocean spreading axis in the Oxfordian (see fig. 8). Differentiation of the Basin into sub-basins occurred during the Oxfordian, and marked the onset of rifting, which climaxed during the early Kimmeridgian, when major influxes of basement-derived sediments were deposited. This rifting episode may have heralded a pre-Aptian period of Atlantic opening to the southwest of the Lusitanian Basin.

*Valanginian - Lower Aptian and Upper Aptian - Turonian.* The unconformities at the base of these two sequences are respectively similar in age to the onset of rifting and sea floor spreading to the west of the subsided continental crust to the northwest of Iberia (see fig. 8). However, these intervals are relatively thin in the Lusitanian Basin.

From the review presented above, it is clear that the timing of major rifting events affecting the Lusitanian Basin and the subsided offshore continental crust to the northwest of Iberia was different. This is consistent with Boillot and Malod's (*op. cit.*) suggestion that 'seafloor spreading propagated northward along the west Iberian rift...'. But the evolution of the two areas not only differs in terms of timing of rifting. In the offshore area, rifting was accompanied by major subsidence, and the area continued to subside when rifting had ceased, due to thermal relaxation consequent on the earlier crustal thinning. Why was there no major subsidence following the Oxfordian - Kimmeridgian rifting episode in the Lusitanian Basin? Seismic refraction studies show that the crust is between 25 and 30 km thick beneath the Lusitanian Basin (Mendes-Victor *et al.*, 1980) indicating that no significant thinning occurred. This almost normal crustal thickness, and the absence of subsided continental crust on the oceanward side of the shelf edge beyond the Basin suggest that it may have developed in an upper plate location of the kind envisaged by Lister *et al.*, (1986). The Iberian margin to the north shows features consistent with a lower plate origin. The presence of significant late Jurassic and early Cretaceous igneous activity in the Lusitanian Basin, and its apparent absence north of the Nazaré fault is consistent with this hypothesis.

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