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# 42. MESOZOIC EVOLUTION OF THE LUSITANIAN BASIN: COMPARISON WITH THE ADJACENT MARGIN[1]

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## ABSTRACT

This report presents a description of the tectonic and sedimentary development of the Lusitanian Basin during the Mesozoic, using onshore surface and subsurface data. The timing of events recorded in the Lusitanian Basin is compared with the Mesozoic evolution of the adjacent margin, reconstructed from different surveys, including ODP Leg 103.

## INTRODUCTION

The evolution of the western Iberian margin during the Mesozoic was controlled by the extensional tectonic process that resulted in the opening of the North Atlantic Ocean. Tectonic and sedimentary aspects of this evolution can be approached through various data: the results of numerous marine surveys on the Galicia margin, including Ocean Drilling Program (ODP) Leg 103, and field surveys (surface and subsurface data) of the Lusitanian Basin, which constitutes an emergent part of the margin (Fig. 1).

To date, no synthesis of these two data sets has been attempted for a variety of reasons:

1. Studies dedicated to the Mesozoic structural development of the Lusitanian Basin are locally detailed but not generalized, and much of the data are as yet unpublished.
2. The extensive offshore studies (cited within this report) lack the stratigraphic precision that is possible from onshore investigations; this deficiency is most acute for the initial syn- and pre-rift sequences. Therefore, differences revealed by comparison of the evolution of the two domains may be more apparent than real, owing to scale differences in the various investigation methods. Moreover, the tectonic and sedimentary events recorded in the Lusitanian Basin relate to the oldest stages of the Iberian margin's Mesozoic development, whereas the offshore studies reveal more information about the later stages. Thus, transferring knowledge derived from onshore data to the offshore domain is somewhat difficult.

In this paper, the Mesozoic tectonic and sedimentary history of the Lusitanian Basin is reviewed, based on unpublished data, and compared with information available from the offshore part of the western Iberian margin, including results from ODP Leg 103.

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## LUSITANIAN BASIN AND THE ADJACENT PART OF THE MARGIN: GENERAL FRAMEWORK

### Lusitanian Basin

The Mesozoic formations of the western Iberian margin crop out within the Lusitanian Basin in a narrow coast-parallel strip that extends about 280 km from Ovar, south of Porto, to Sinés, south of Setúbal. These outcrops do not exceed 60 km in width. To the northeast, the Mesozoic Lusitanian Basin rests on basement of the Iberian Meseta. To the southeast, it is covered by the Cenozoic deposits of the Tagus Basin (Figs. 1 and 2). The western border of the Mesozoic Lusitanian Basin is located off the present-day shoreline (Berlengas Block and its northern prolongation, described in the following).

Within the Lusitanian Basin, the faults that record evidence of activity during the Mesozoic extensional phases are of four different trends (Guery, 1984, 1987a; Becquart et al., 1987) (Fig. 2; see also Fig. 5):

1. The most significant faults trend north-northeast (mainly N20°), parallel to the general elongation of the shoreline. The significant halokinetic structures occur along this trend (Caldas da Rainha and Rio Maior; Fig. 2).
2. Faults trending northeast to east-northeast (N40° to N70°, generally facing north) are less numerous. Nevertheless, they were influential (e.g., Nazaré fault).
3. The north-northwest- (approximately N160°) and north-trending faults are present mostly in the central part of the Lusitanian Basin; during the Late Jurassic they formed an important structural trend within the Estremadura trough (e.g., Pragança fault; Guery, 1987b).
4. Faults with a west-northwest trend (N100°–110°) are scattered, but their synsedimentary activity is locally well expressed for the Jurassic.

Occurrences of magmatic rocks (essentially dikes and sills) within Mesozoic and Cenozoic formations are along all of the fault trends (Fig. 2) and indicate that these fractures extend to crustal depths.

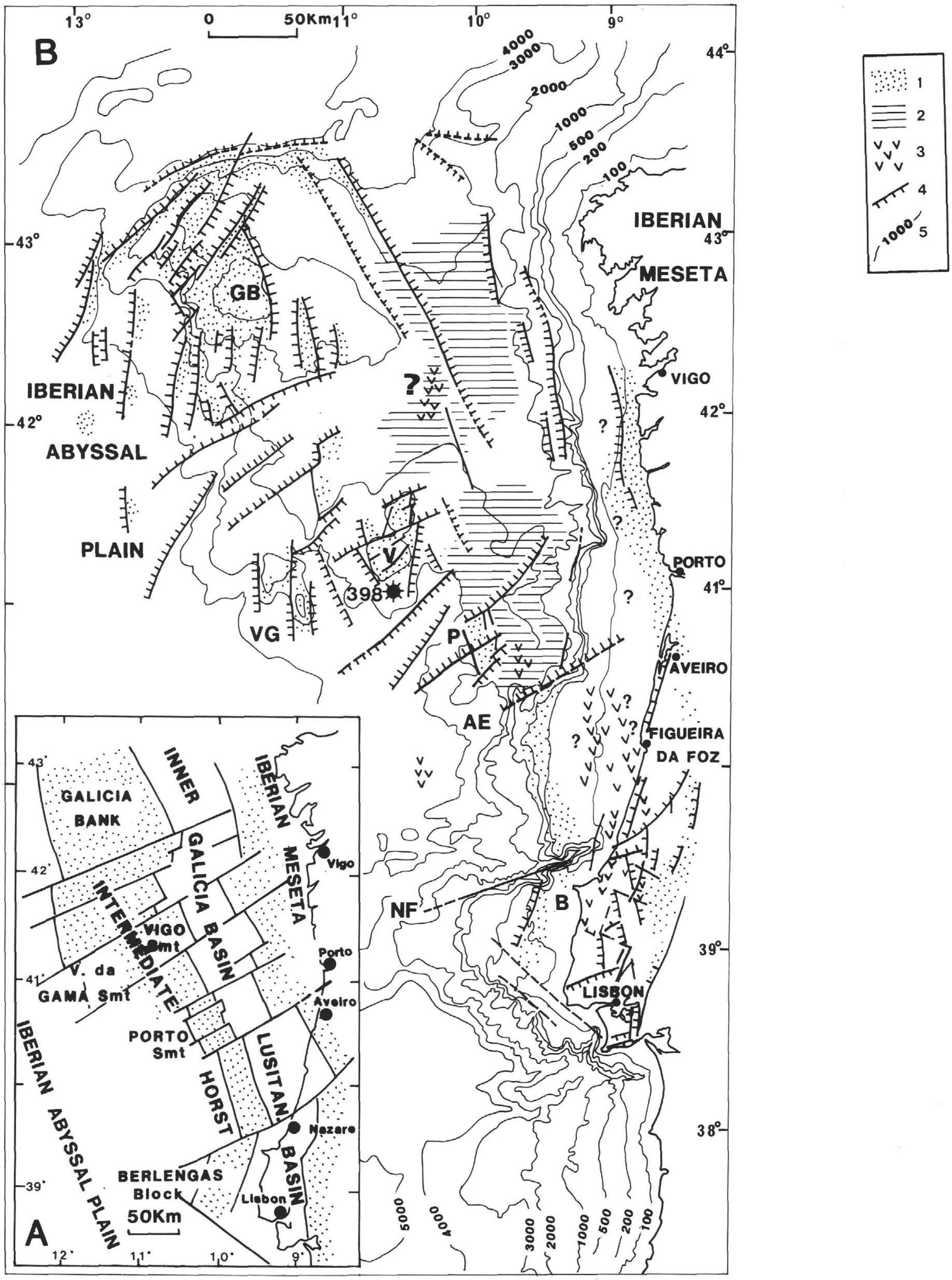


Figure 1. The western Iberian margin, modified from Mauffret et al., 1978; Réhault et al., 1979; Montadert et al., 1979; Groupe Galice, 1979; and Guery, 1984. **A.** Schematic representation of the different structural Mesozoic domains. From east to west: prolongation of the Iberian Meseta (dotted); the inner Galicia Basin and its southern prolongation, the Lusitanian Basin; the intermediate horst (dotted), segmented from Galicia Bank to Berlengas Block by transverse faults; and the deep margin and the abyssal plains. **B.** The western Iberian margin, including the Lusitanian Basin. 1. shallow basement; 2. areas within the Inner Galicia Basin with thick Triassic and Jurassic(?) deposits; 3. diapirs (Triassic evaporites); 4. fault; 5. isobath in meters. AE = Aveiro Escarpment; B = Berlengas Block; GB = Galicia Bank; NF = Nazaré fault; P = Porto Seamount; V = Vigo Seamount; VG = Vasco da Gama Seamount.

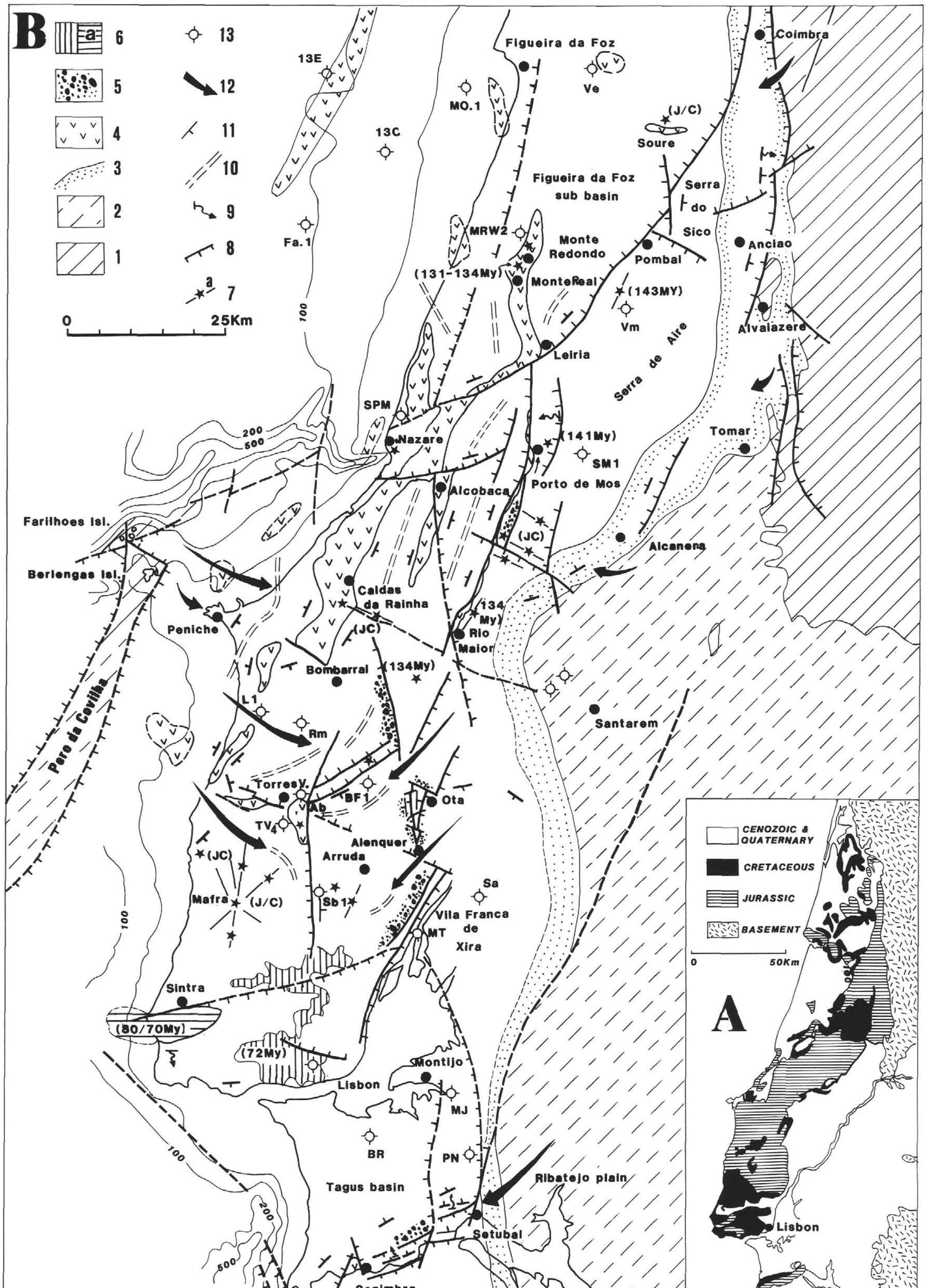


Figure 2. **A.** Generalized sketch map of the Lusitanian Basin (from geological map of Portugal, 1:1,000,000. Serviços geol. de Portugal). **B.** Mesozoic structural framework of the Lusitanian Basin. 1. basement; 2. basement with thin Jurassic cover including hiatus; 3. approximate boundary between clastic and evaporitic Triassic facies; 4. diapirs and salt ridges; 5. olistoliths and breccias along Upper Jurassic faults; 6. volcanics and plutonics (a) of Late Cretaceous age; 7. Upper Jurassic to Lower Cretaceous magmatic features (a = indication of direction of main dikes; My = radiometric age; J/C = stratigraphic dates (Late Jurassic to Early Cretaceous); 8. fault; 9. major synsedimentary collapses and slumps; 10. area of main subsidence; 11. basinal slope; 12. main sources of clastics; 13. borehole.

## Adjacent Margin

The morphological-structural organization of the western Iberian margin between the Galicia Bank and Lisbon can be divided into four main physiographic units (Boillot et al., 1975; Laughton et al., 1975; Vanney et al., 1979; Lallemand et al., 1985) (Fig. 1): the continental shelf and slope, the Inner Galicia Basin (named "Valle-Inclan" in Vanney et al., 1979), the Galicia Bank and the southernmost seamounts, and the deep margin adjacent to the Iberian and Tagus abyssal plains. The first three of these physiographic units are discussed as follows.

### *Continental Shelf*

The narrow continental shelf, approximately 45 km wide, is wider to the south (offshore Estremadura) than to the north (Galicia). This northward narrowing is not gradual but occurs abruptly where structural discontinuities cut through the shelf and slope (Nazaré canyon and off Aveiro and Porto to the north; Fig. 1). The Nazaré canyon is controlled by a major northeast-trending fault, the landward prolongation of which cuts through the Meseta basement. This fault played an important role within the Mesozoic tectonic and sedimentary evolution, prior to its subsequent remobilization by Cenozoic tectonics (Boillot et al., 1975). It probably acted as a transform fault during the Mesozoic rifting process (Boillot et al., 1974).

Another important discontinuity (the Aveiro escarpment) is further north, off Aveiro. The northeast-southwest morphostructure of the slope is floored by a narrow strip of Cretaceous rocks within the surrounding Eocene and Recent deposits (Boillot et al., 1978). The onshore extension of this lineament into the northern part of the Lusitanian Basin is masked by Recent deposits; it corresponds to an important fault trending northeast in the Iberian basement. As it will be discussed subsequently, the Aveiro escarpment is regarded as an important structural feature of the margin (Fig. 1).

To the south, off Lisbon, a northwest-trending fault system cuts across the continental shelf and slope and guides the general orientation of the continental slope overlooking the Tagus Abyssal Plain (Baldy et al., 1977; Mougenot et al., 1979).

### *Inner Galicia Basin*

The eastern border of the Inner Galicia Basin is fairly smooth, oriented north-south to north-northwest–south-southeast, and parallel to the Iberian continental slope. Its western border is more complex and consists of a discontinuous succession of submarine reliefs from Galicia Bank to Porto Seamount (Fig. 1).

Within these bounds, the Inner Galicia Basin widens to the north toward the Biscay Abyssal Plain. It narrows to the south and terminates against the northeast-trending Aveiro escarpment. Its southern equivalent onshore is the Lusitanian Basin.

### *Galicia Bank and Seamounts*

The Galicia Bank and Vasco da Gama, Vigo, and Porto seamounts are offset and separated by deeper areas. These highs display many outcrops of the acoustic basement. A Meseta-type basement was sampled at some places (Galicia Bank and Vasco da Gama Seamount; Mauffret et al., 1978). The bank and seamounts are generally considered to be remanent structures inherited from Mesozoic distensive tectonics that were more or less rejuvenated by Cenozoic compressional stress (Boillot et al., 1979).

South of Porto Seamount and the Aveiro escarpment is a ridge of shallow basement (unpubl. seismic data), tilted eastward and trending north to north-northwest, close to the edge of the continental shelf and slope (Fig. 1). The ridge may be considered as the southern continuation of the Galicia Bank in a shallower part of the margin. South of the Nazaré fault, the same basement high is offset to the west and runs along the Estremadura continental shelf with a north-northeast trend. The Berlengas-Farilhões archipelago and the Pero da Covilha submarine reliefs (Boillot et al., 1978) evidence the rise of the basement. They consist of granitic (Berlengas Islands) and metamorphic (Farilhões Island) rocks of the Hercynian basement.

The main structural features of the margin, as recognized by subsurface exploration, do not differ notably from those observed on land in the Lusitanian Basin. The extensional structures (tilted blocks, horsts, and grabens; Groupe Galice, 1979) are controlled by faults trending north-northeast to north-northwest, the same as onshore. Nevertheless, the north- to north-northwest-trending faults are better developed on the margin (Fig. 1). The structures are offset by several northeast- and east-northeast-trending faults that bound the bank and seamounts. Where the banks joins the continental shelf to the south, faults with these same trends crosscut the continental slope and shelf (Aveiro scarp, Nazaré fault).

As already stated in previous works (Boillot et al., 1974, 1979; Mauffret et al., 1978), the submeridian and northeast-trending fault are obviously inherited from the basement structures of the Iberian Meseta. There is no precise indication of the origin of the west-northwest trend.

During the Cenozoic, the Lusitanian Basin as well as the Iberian margin (Mauffret et al., 1978) were deformed by polyphased compressive stress (Lepvrier and Mougenot, 1984; Guery, 1984), resulting in a submeridianal shortening. As a result, the main Mesozoic faults were rejuvenated into strike-slip faults, along with some drag folds, commonly in association with the reactivation of salt structures (Zbyszewski, 1959). Between these strike-slip zones, large Mesozoic blocks (Jurassic platforms) remain essentially undeformed. In many cases, the Cenozoic tectonics have favored the exhumation of the Mesozoic structures.

# MESOZOIC EVOLUTION OF THE LUSITANIAN BASIN

## Triassic Evaporites: First Stage of Subsidence in the Lusitanian Basin

Within the Lusitanian Basin, the Triassic is poorly documented. On the basin's eastern border, the deposits consist entirely of shaly sand and sandstone (Palain, 1976, 1979, 1984) (Fig. 3). Within the basin, the Triassic outcrops, which consist mainly of clays and evaporites (sulfates and halite) overlying sandy marls and sandstones with conglomeratic lenses, occur only in salt structures (Zbyszewski and Faria, 1971) (Fig. 2). This formation has been drilled through over more than 2000 m (Fig. 3), but its base remains unknown. The top is usually composed of variegated gypsiferous pelites (Dagorda marls) overlain by gray dolomites (Cabeços limestones). According to Choffat (1882, 1903) the Cabeços limestones are Sinemurian in age, and a Rhetian to Hettangian age is assigned to the underlying gypsiferous pelites. However, the fauna from the Cabeços is not diagnostic and thus, does not permit distinction of the Hettangian from the Sinemurian (Palain, 1976). Moreover, because the Dagorda marls have yielded a rich microflora of Carnian age (Montenat and Guery, 1984), the underlying evaporites must be Triassic.

The Triassic sediments were not uniformly deposited across the Lusitanian Basin. According to Vanney and Mougenot (1981), the evaporitic Lusitanian Basin could correspond to a graben controlled by a single westward-tilted block, which may be an oversimplification. Guery (1984) and Guery et al. (1986) suggested that the basement was cut into several blocks, each about 10 km wide, that slope to the west and are bordered by north-northeast-trending faults (Peniche transverse). The clays and evaporites deposited in the deeper parts of the half-grabens would have been mobilized along the fault scarps during the Ju-

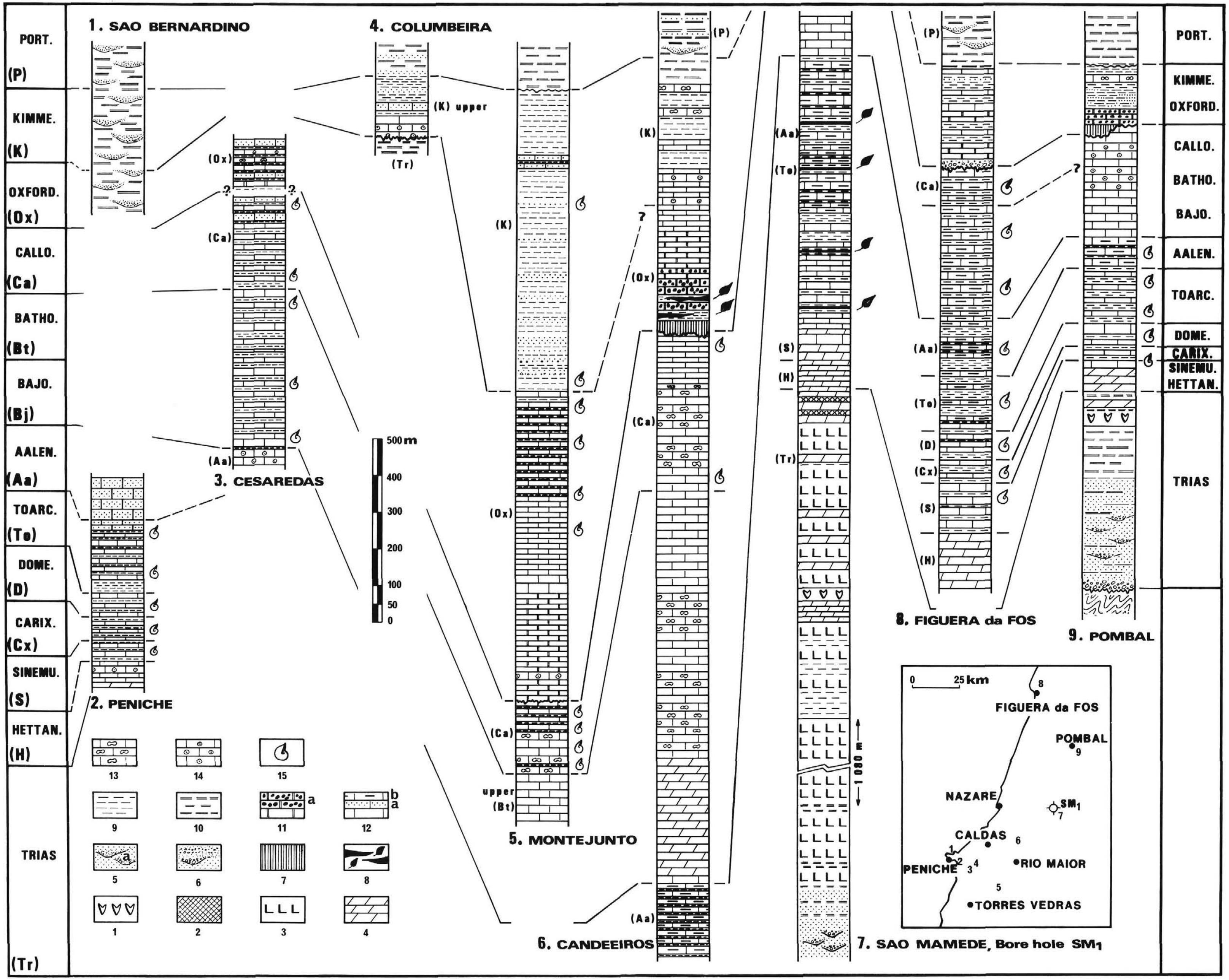


Figure 3. Jurassic deposits of the Lusitanian Basin. 1. gypsum; 2. anhydrite; 3. salt; 4. dolomite; 5. sand and sandstone (a = fluviatile channel); 6. conglomerate; 7. lateritic horizon; 8. lignite; 9. marls; 10. continental variegated marls; 11. lacustrine and brackish fetid limestones (a = with "black pebbles"); 12. limestone (a = sandy; b = marly); 13. oncolitic limestone; 14. oolitic limestone; 15. main fossiliferous horizons with ammonites.

rassic (i.e., halokinetic movements) (Montenat and Guery, 1984). The same faults may also have controlled the emission of Triassic mafic volcanics (dolerites), which are associated with evaporites in some instances (e.g., Caldas diapir). The increasing Triassic clastic input toward the present shoreline (south of Peniche; Fig. 2) is the first indication of the paleogeographic influences of the Berlengas Block. The morphology of the Berlengas Block had been previously delineated by north-northeast-trending faults to form the western shoulder of the basin (Guery, 1984).

Subsurface data (seismic and drilling) indicate that transverse and submeridian faults acted in concert during Triassic block faulting. South of a west-southwest–east-northeast tectonic line through Torres Vedras (Figs. 2, 4, and 5) the deposits are fairly thin and, in many places, quite free of evaporites (Figs. 5B and 5C). This is confirmed by the absence of salt extrusions in this southern area. On the contrary, the northwestern border of the northeast-trending Nazaré fault is characterized by the extensive removal of a thick evaporite accumulation by Jurassic halokinesis and later deformations (unpubl. seismic data).

To summarize, the deposition of a thick evaporitic formation indicates that subsidence had already started during the Triassic within the Lusitanian Basin and probably within its northern continuation offshore, in the Galicia Basin (Boillot et al., 1979) (Fig. 1). There is some evidence for the existence of a Triassic block-faulted basin that would have been mainly controlled by north-northeast-trending and transverse faults. Nevertheless, the most recent seismic interpretations have not provided a conclusive image of the pre-salt basement. In many cases, the base of the salt appears as a strong and even reflector, but the structure of the underlying levels is rarely recorded (Fig. 5).

## Early and Middle Jurassic: Platform Stage and Halokinetic Movements

### *Sedimentary Evolution*

During the Liassic, open-marine sedimentation extended throughout the Lusitanian Basin. Open-marine influences are recorded as early as Hettangian or lower Sinemurian (Peniche, for example); ammonites first appear in the upper Sinemurian (Fig. 3; Mouterde et al., 1979).

From the middle Lias, open-marine conditions prevailed across the basin (Mouterde, 1971; Mouterde et al., 1979). A general transgression occurred from the middle to late Lias (Fig. 3). The widespread development of marls interbedded with fine-grained carbonates indicates uniform conditions across the basin. Lateral facies and thickness changes gradually occurred over large areas. A cross section of the basin from the late Lias would appear almost horizontal, or with a slight dip to the east (Guery, 1984) (Fig. 5B). Maximum thickness of these sediments occurs in an elongate zone trending north-northeast, to the west of Coimbra (Mouterde et al., 1971, 1979). Generally, the Early Jurassic was a period of a slow subsidence. The start of the halokinesis was the only cause of disturbance within the sedimentary process (see the following discussion of "Halokinesis").

The regional dip of the Lusitanian Basin was accentuated during the late Liassic to early Middle Jurassic. In the western part of the basin (Peniche), the Toarcian sequence is regressive (Figs. 3 and 6). The ammonitic marls of early Toarcian age (Mouterde, 1955) are overlain by upper Toarcian and lower Aalenian coarse, mixed carbonate and detrital sediments (Hallam, 1971; Guery, 1984; Wright and Wilson, 1984). Such clastic input originated from a western source as a consequence of the uplift of the Berlengas Block. The regressive tendency may either be continuous (Peniche) or with some sedimentary breaks (hiatus at the Toarcian/Aalenian boundary in Serra del Rei) (Figs. 3 and 6). At that time, the eastern part of the basin underwent continuous subsidence (Guery, 1984) (Fig. 3).

This early eastward tilting, which continued up to the Late Jurassic, has been recorded throughout the basin. One example is to the north of the Nazaré fault, in the Figueira sub-basin along the Mondego transverse (east of Figueira da Foz; Figs. 2 and 3). The Bajocian ammonitic marly limestones thicken from the present-day coast (Cape Mondego) toward the east (Mouterde et al., 1979). A similar disposition occurs farther to the east, in the Serra de Sico (Figs. 2 and 7), where shallow-water carbonates of the same age thicken eastward, which indicates another tilted block of eastward dip. The repetition of such sedimentary arrangements indicates that the thickness changes, which are quite systematic on seismic sections, do not result from a single basinwide block but from a network of smaller blocks, most of which have a slight eastward tilt (Fig. 5B).

Local increase in the dip of the blocks has induced large syndepositional slumps and slides within the Middle Jurassic carbonate cover. These collapses have a significant eastward direction (Atheana, north of Anciao, and Serra de Alvaiazere; Figs. 2 and 7). Such large but localized deformations have been interpreted as the result of Tertiary compression (Rosset et al., 1975), but their synsedimentary character is more convincing.

The influence of northeast-trending faults on Early and Middle Jurassic sedimentation is difficult to determine. No significant thickness variation occurs across the Montejunto–Torres Vedras fault (Figs. 4 and 5) in pre-Oxfordian deposits. On the contrary, the Nazaré fault was active as early as the middle Lias and especially during the Toarcian, resulting in notably thicker sediments within the Figueira sub-basin, northwest of the fault (Mouterde et al., 1979). These differences in thickness are less marked within the Middle Jurassic. Block tilting was influential mainly during the Bajocian. During the Bathonian, more uniform platform carbonates with reefal and associated facies became extensive (Ruget-Perrot, 1961). Marly limestones with ammonites were then restricted to the Cape Mondego area (Mouterde et al., 1979).

### *Halokinesis*

The most spectacular variations of thickness and facies within the Lower to Middle Jurassic are due to halokinetic movements (Montenat and Guery, 1984; Guery, 1984, 1987b).

At least as early as the Toarcian, movement began on the north-northeast-trending salt ridge, at such locations as Caldas da Rainha, Rio Maior, and the more complex ridges of Torres Vedras (Figs. 2, 4, and 5). Early movement is confirmed by the reworking of Triassic material (red pelite fragments and Triassic authigenic quartz), synsedimentary slump phenomena on the flanks of the diapir, and evidence of emersion in the facies capping the structures.

Most of the extrusions follow the north-northeast-trend of the major faults (Caldas, Alcobaça, and Rio Maior, for a distance of some 10 km), although some occur along northeast- and west-northwest-trending faults (Nazaré and Torres Vedras faults, respectively; Fig. 2). Such structures are well documented at the Caldas da Rainha salt structure and the Alcobaça ridge by both surface and subsurface data (Guery et al., 1986) (Figs. 2 and 5A) to delineate the following sequence:

1. The Lower and Middle Jurassic deposits thin against the salt ridge, indicating the precocity of the halokinetic movements

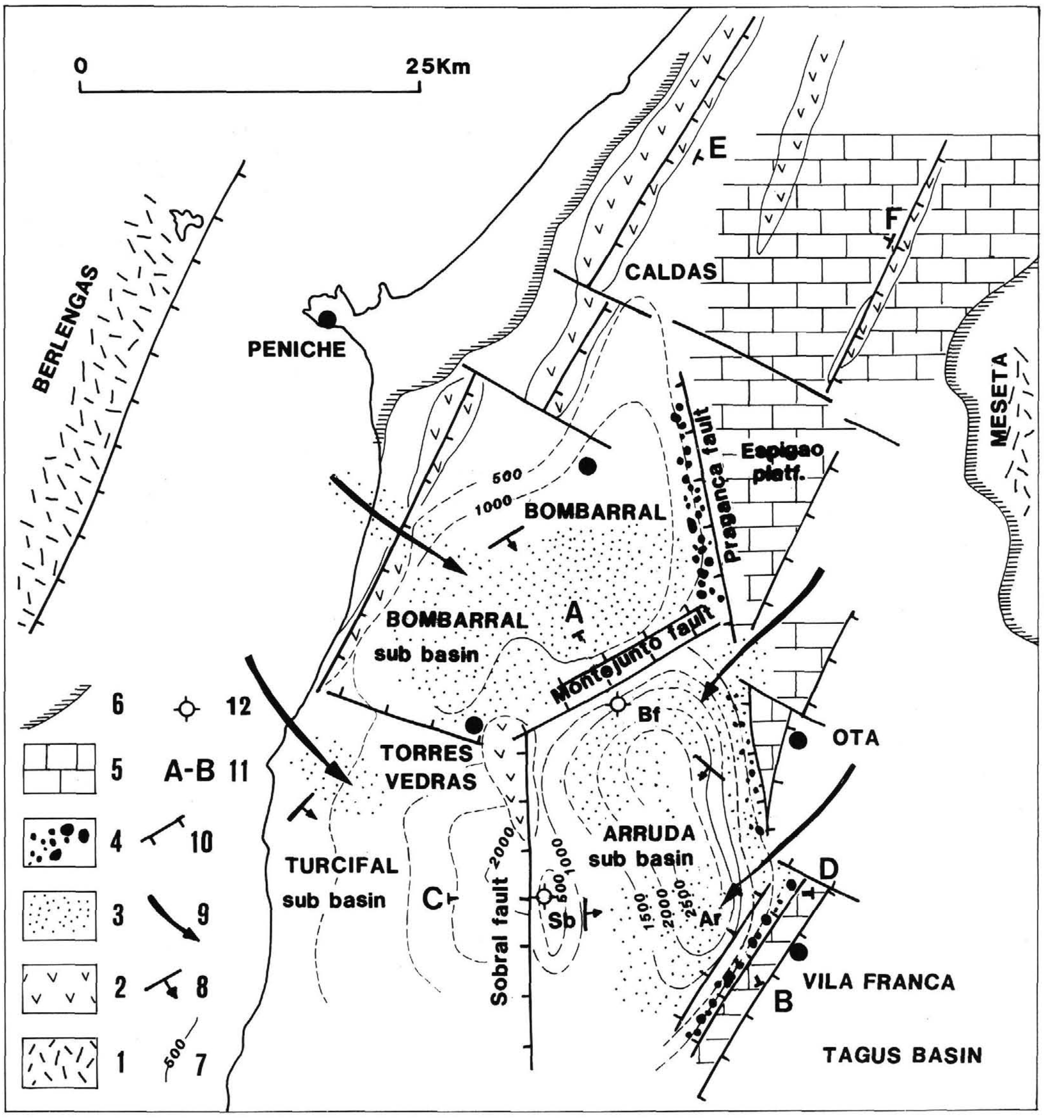


Figure 4. The Oxfordian-Kimmeridgian Estremadura trough (northern part, modified from Riché, 1963). 1. basement; 2. diapirs and salt ridges; 3. clastic submarine fan; 4. olistoliths and breccias; 5. platform carbonate deposits; 6. paleoshoreline; 7. isopachs of Kimmeridgian deposits; 8. basinal slope; 9. source of clastics; 10. fault; 11. location of seismic profiles (see Fig. 5); 12. borehole.

(Parant, 1963; Montenat and Guery, 1984), which were very active during the Middle Jurassic.

2. The transverse section of the salt ridges is asymmetrical, displaying a low slope to the west and a steeper one to the east.

3. West of the diapir, Middle Jurassic deposits indicate moderate subsidence. The successive layers pinch out progressively toward the structure culmination. On the eastern flank, sediments are thick, prograde to the east-southeast, and display synsedimentary, east-facing, normal growth faults. The subsidence rate was maintained by salt migration toward the top of the ridge. Under the rim synclines, the amount of salt material is very reduced, if not totally absent (Fig. 5A). However, the geometry of these salt ridges is quite different from the classical "turtle structure" (see Fig. 5A) and indicates a relatively slow migration of salt that stopped before the production of salt scars.

4. Depending on the location, outcrops of Bajocian or Bathonian thin, shallow-water deposits rest on the Triassic culmination. The Amoreira breccia (southwest of Caldas; Guery, 1984) is composed of limestone fragments that remain connected, brecciated *in situ* without any significant displacement. This brecciation, contemporaneous with deposition, is related to the vertical halokinetic motion.

Near the end of the Middle Jurassic, during the middle and late Callovian, the sedimentary evolution of the Peniche-Montejunto transverse reveals that the subsidence of the eastern part of the basin was quick and stepped (Fig. 6). On the contrary, the western part of the basin is strongly uplifted along with the Berlengas Block, which caused the rejuvenated reliefs to be eroded and to provide clastic materials (Fig. 6). These movements were accompanied by the reactivation of halokinesis, as indicated by the erosion of the salt ridge cover (e.g., eastern flank of Caldas; Guery, 1987b). These phenomena delineate the beginning of the tectonic event that prevailed during the Oxfordian-Kimmeridgian.

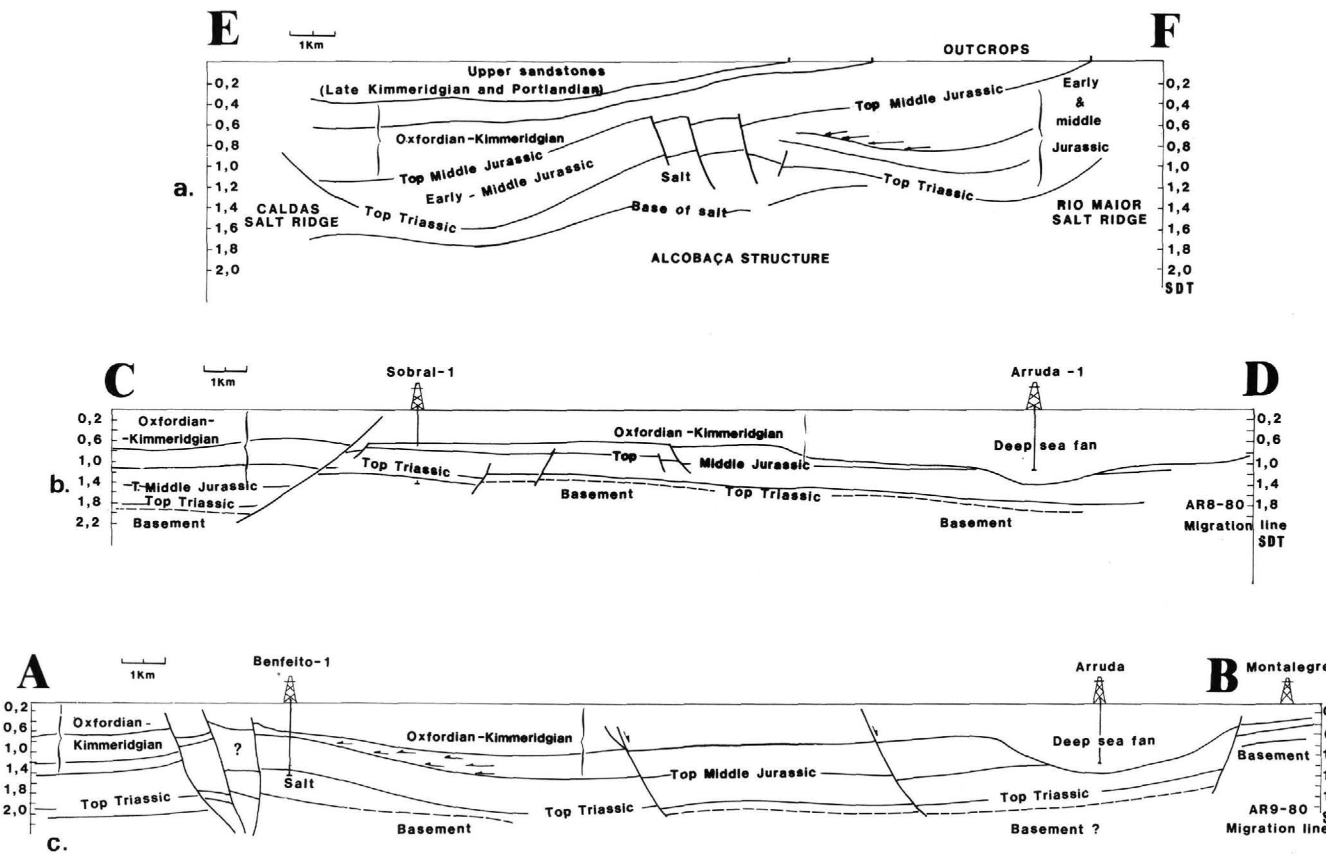


Figure 5. Interpretation of seismic profiles (for location see Fig. 4; arrows = indication of onlap). **A.** Alcobaça. Halokinetic movement contemporaneous with Early and Middle Jurassic sedimentation. **B.** Section of the Arruda dos Vinhos sub-basin. Note eastward tilting of the block between Sobral and Vila Franca submeridian faults. **C.** Rejuvenation of Torres Vedras–Montejunto fault (northeast trend; see Fig. 4) by Cenozoic strike-slip compressional deformation ("flower-structure"). This fault was not active during the Early and Middle Jurassic (equal thickness of deposits on both sides) but moved during the Oxfordian-Kimmeridgian (see Fig. 4).

## Oxfordian-Kimmeridgian Extension

### *General Setting*

During the Oxfordian and Kimmeridgian, the Lusitanian Basin underwent a new extensional episode, which led to significant changes in the paleogeography. Two major breaks, including extreme variations in sedimentary environments, clearly delineate the timing of this episode, which corresponds to the "Lusitanian cycle" defined by Choffat (1887, 1901): (1) the Callovian/Oxfordian boundary corresponds to an angular unconformity known throughout the basin and associated with a lack of uppermost Callovian/lower Oxfordian marine deposits (Mouterde et al., 1971) and (2) the end of this extensional episode is documented by a regional sedimentary hiatus and by an unconformity in the eastern part of the basin at the transition from Kimmeridgian to Portlandian sediments.

The Lower and Middle Jurassic deposits were affected by many faults, the most important of which are those trending north-northeast. However, new faults were initiated along a north-northwest, with a few along a north, trend (e.g., Pragança, Sobral, and Ota faults) (Guery et al., 1986). Northeast- and west-northwest-trending faults were also active (Figs. 4, 5, and 8).

Various examples of synsedimentary deformation have been observed in the field and on seismic sections (Riché, 1963). They clearly indicate the synsedimentary movement of the faults (Figs. 9 and 10). Paleoscarps of faults within the Dogger are sealed by Oxfordian-Kimmeridgian sediments, and gravity flows, olistoliths, and synsedimentary collapses occur along these faults. During the Lusitanian cycle, the vertical throws of some of the faults exceeded 2000 m (Fig. 4).

These fault movements created a complex structural pattern consisting of half-grabens tilted to the east, southeast, or rarely, to the north (Serra de Arrabida), as well as horst and graben structures of various size (Figs. 2 and 4). Definitive data concerning the horizontal component of the movement are still lacking.

### *Estremadura Trough*

The Estremadura trough (Figs. 3–6) displays a great thickness of Upper Jurassic deposits (Wilson, 1979; Guery, 1984, 1987a, 1987b), which provides the best example for demonstrating the Oxfordian-Kimmeridgian extension within the Lusitanian Basin. Field and subsurface data (seismic and drilling) enable a precise reconstruction of the trough's evolution.

The Estremadura trough is bounded to the west by the Berlengas Block. Its eastern boundary is mostly hidden under the Cenozoic formations of the Tagus Basin. The Estremadura trough widens progressively from north to south, from the vicinity of

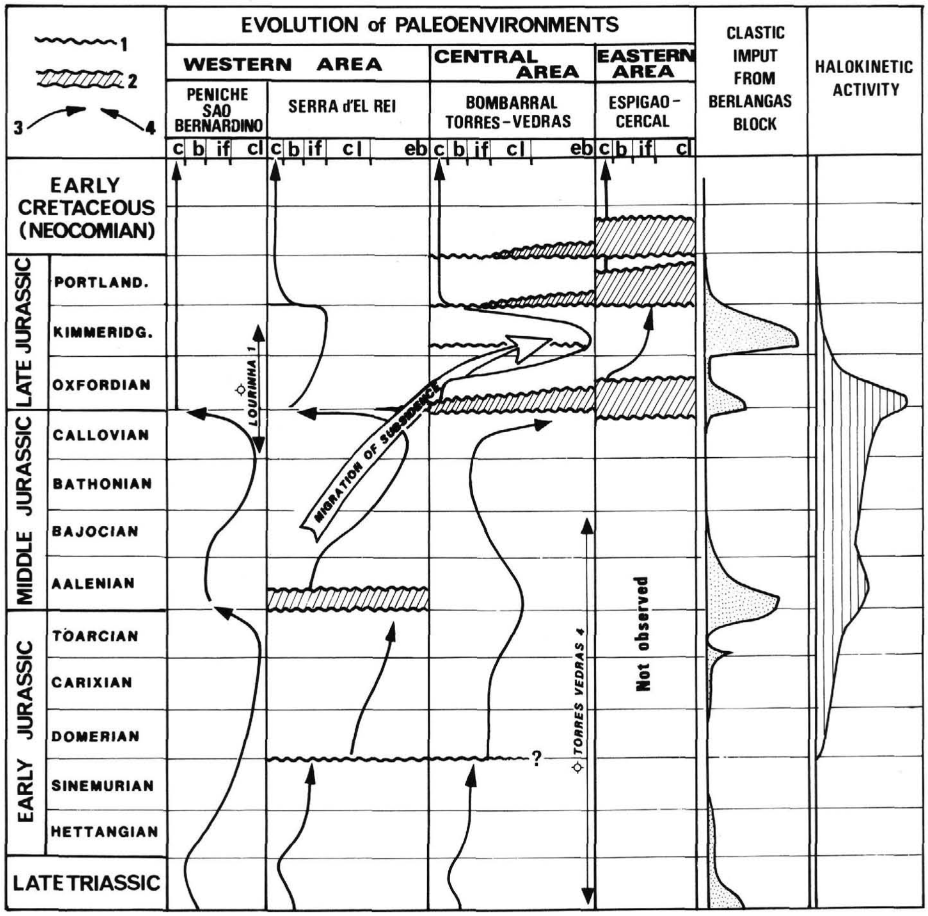


Figure 6. Evolution of Jurassic sedimentary sequences on a transverse from Peniche to Espigao platform (modified from Guery et al., 1986; for lithologic and biostratigraphic data see Mouterde et al., 1971, 1979; Guery, 1984; Fig. 3). Intervals shown of Lourinha 1 and Torres Vedras 4 wells (Figs. 2 and 4). 1. unconformity; 2. unconformity, erosional or stratigraphic hiatus; 3. positive evolution of the sequence (deepening); 4. negative evolution of the sequence (shallowing). Abbreviations for environments: c = continental; b = brackish; if = infralittoral; cil = circalittoral; eb = epibathyal.

Caldas da Rainha to the Lisbon area. The thickness of the Oxfordian-Kimmeridgian deposits increases in the same direction, ranging from 1500 m in the Bombarral area to about 3000 m to the south, close to Arruda-dos-Vinhos. North of Caldas, the trough is bounded by thin, shallow-water deposits.

Faults, active during Oxfordian-Kimmeridgian sedimentation, have partitioned the trough into three sub-basins (Fig. 4). The Bombarral sub-basin is to the north. Its eastern limit is the north-northwest-trending Pragança fault, which has paleoscarp morphology that is still visible. The southern limit of the Bombarral sub-basin consists of a complex network of faults (trending east-northeast between Montejunto and Torres Vedras and west-northwest to the west of Torres Vedras). To the south are the Arruda-dos-Vinhos and Turcifal sub-basins. They are separated by the north-trending Sobral fault.

These three sub-basins represent antithetic blocks, dipping to the east or southeast (Figs. 4, 5, and 8). In detail, the basin slopes are not uniform, especially in the Arruda sub-basin (Fig. 4). Its eastern boundary consists of narrow and elongated horsts, Ota (about north-south) and Vila Franca de Xira (with a north-northeast trend), both of which were active during the Oxfordian-Kimmeridgian (Guery, 1987b). The horsts are separated by a narrow, corridorlike depression that is elongate along west-northwest-trending faults. This corridor enables the transit of clastic material from the Iberian Meseta into the basin (Figs. 2 and 4). A similar corridor separates the Ota horst from the Montejunto-Espigao platform. Owing to the eastward or southeastward regional slope of the basement, the deposits reach their maximum thickness on the eastern part of the basin along the Pragança, Ota, and Vila Franca faults (Fig. 4).

The Bombarral sub-basin to the north has been thoroughly studied, and the timing of its tectonosedimentary evolution is well known (Guery, 1984, 1987b; Guery et al., 1986):

1. Following a depositional gap in the upper Callovian and lower Oxfordian deposits (Figs. 3 and 6), the first manifestation of the Pragança fault within the middle Oxfordian is indicated by a westward flexure along this lineament. Evidence includes common and large synsedimentary slides, as well as repeated and sudden episodes of subsidence recorded by the sediments.

2. The activity of the Pragança fault at the beginning of the late Oxfordian is recorded by a submarine scarp that increases in height to the south-southeast (Fig. 8), thus separating two sedimentary areas. To the west is the Estremadura trough, the basement of which is inclined to the southeast. The trough extends from the emerged Berlengas highs to its greatest depth (epibathyal) against the Pragança fault. The zones that subsided the most are along this fault between Alenquer and Vila Franca (Fig. 4). The eastern sedimentary area is the carbonate platform of Espigao-Cercal. It has a narrow reefal fringe on its western

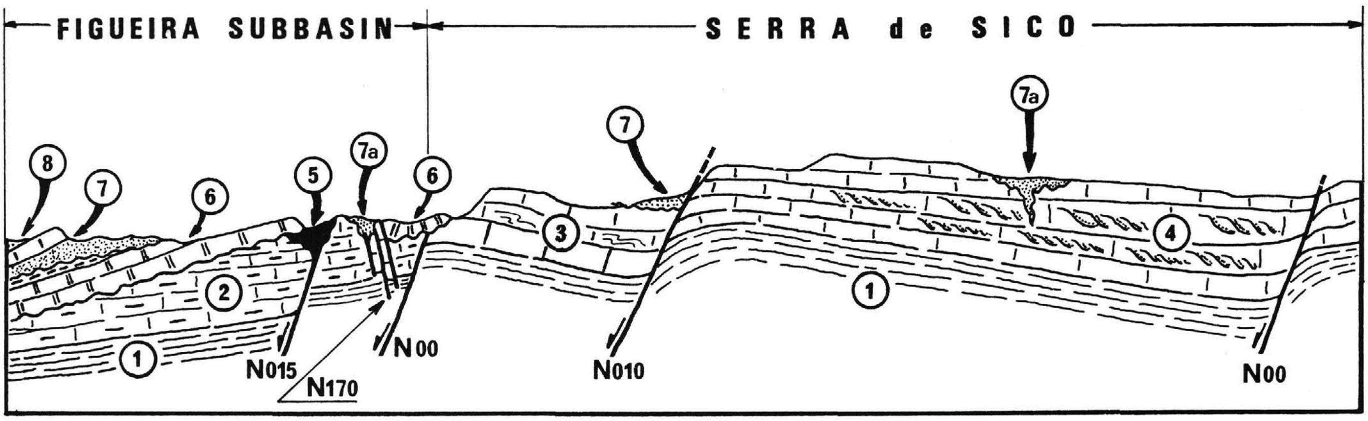


Figure 7. Jurassic tilted-block structure on a transect between Figuera da Foz sub-basin and Serra de Sico (see Fig. 2 for location; length of the section = about 12 km). 1. upper Liassic deposits; 2. Middle Jurassic marly limestone with ammonites; 3. Middle Jurassic limestones, with slumped beds indicating synsedimentary eastward tilting of the block; 4. Middle Jurassic platform carbonate, with tilting of the block evidenced by eastward thickening and progradation; 5. lateritic material filling post-Middle Jurassic karstic surface; 6. Upper Jurassic deposits; 7. Lower Cretaceous continental sandstones (a = filling karstic depressions); 8. Upper Cretaceous marine deposits.

edge along the fault and an inner platform zone (tidal flat) with a great thickness of sediments (over 500 m) that suggests continued subsidence.

3. Following rapid sinking during the late Oxfordian, bathymetric conditions stabilized during the early Kimmeridgian.

4. Gravity flows with two different sources can be recognized within the Oxfordian/Kimmeridgian transition and lower Kimmeridgian (Figs. 3 and 8). In the first phase (Oxfordian/Kimmeridgian transition), the outer border of the eastern platform (Espigao-Cercal) broke up along the Pragança fault. An olistostrom of platform carbonate blocks built up at the foot of the fault scarp. These materials display indications of emersion and karstification, which occurred prior to the disaggregation. Similarly, a succession of sand and mud flows or turbidites composed of reworked platform carbonates were deposited in alternation with epibathyal sediments (Abadia marls). Immediately following the faulting of the eastern border of the basin and deposition of these reworked carbonate materials, a thick sequence of coarse siliciclastics was fed into the basin from the crystalline highs of the Berlengas-Farilhões. The freshness of

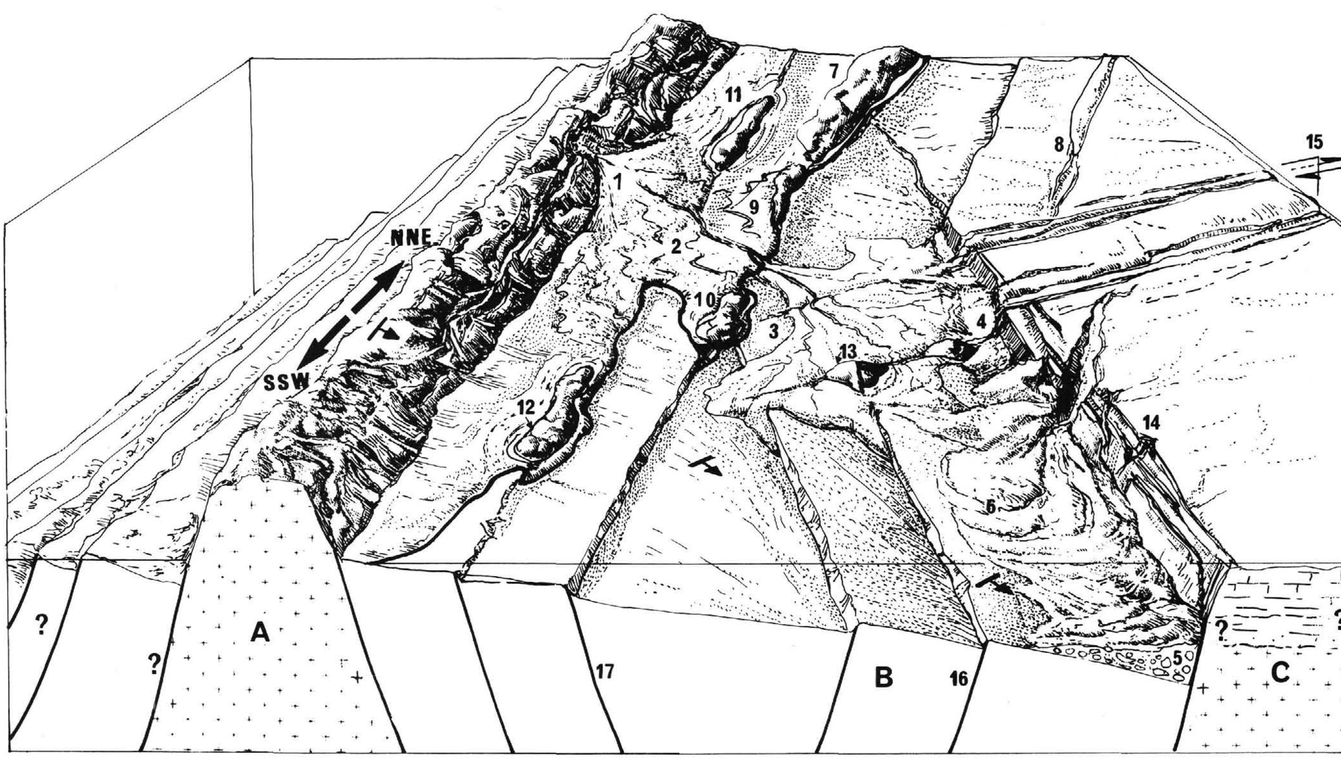


Figure 8. Diagrammatical representation of the northern part of the Estremadura trough during the early Kimmeridgian. A = Berlengas Block; B = Estremadura trough; C = eastern block: Espigao-Cercal and Ota platforms. Deposits: 1 = alluvial fan?; 2 = flood plain (São Bernardino); 3 = submarine fan (Bombarral sub-basin); 4 = carbonate olistostrom and breccia (Pragança); 5 = polygenic olistostrom and breccias (Vila Franca); 6 = submarine fan (Arruda sub-basin). Diapirs and salt ridges: 7 = Caldas da Rainha; 8 = Rio Maior; 9 = Bolhos-Santa Cruz; 10 = Vimeiro; 11-12 = offshore (Vanney et al., 1981); 13 = Torres Vedras. Faults: 14 = Pragança; 15 = east-northeast-trending faults; 16 = Sobral fault; 17 = north-northeast trending faults related to Jurassic halokinesis.

the minerals (feldspars, ferromagnesian minerals) indicates an intense erosion of the highs, which had been rejuvenated by vertical uplift and rapid sediment transit. To the west (São Bernardino, south of Peniche), these terrigenous series were deposited in a fluviatile environment (Figs. 3 and 8) of flood plains and meandering channels with fossil wood and dinosaur remains (Lapparent and Zbyszewski, 1957; Wilson, 1979; Werner, 1986). To the east, these clastics built up a marine detrital cone, trending northwest, the external (eastern) fringe of which overlies the carbonate olistostrom closed against the Pragança fault. This geometry demonstrates the general southeastward slope of the basin floor (Guery, 1984).

5. During the middle and late Kimmeridgian, the activity of the Pragança fault progressively decreased, leading into a quiet phase for the basin. The trough was rapidly filled by a regressive sequence of detrital and marly material.

The activity of salt extrusions during the Oxfordian and early Kimmeridgian ceased during the late Kimmeridgian. Halokinetic morphologies were buried by littoral carbonates or terrigenous deposits (Fig. 3). The eastern (Espigao) platform prograded westward onto the filled basin and buried the Pragança paleoscarp. The escarpment was later rejuvenated and exposed at the surface, as a result of Cenozoic tectonics.

On the western side of the Ota and Vila Franca horsts (Arruda sub-basin) the accumulated carbonate breccias and olistoliths confirm the existence of fault paleoscarps similar to those of Pragança. Large fans were also deposited in the basin environment during the early Kimmeridgian (Figs. 4 and 8). The siliciclastic material, which is more diversified than in the northern Bombarral sub-basin, originated from the basement of the Iberian Meseta.

Throughout the three sub-basins, sedimentation was typically littoral, or even lagoonal, during the late Kimmeridgian (Fig. 6). Maximum tectonic extension, with a high amplitude of vertical movement, was restricted to the late Oxfordian and early Kimmeridgian.

### *Oxfordian-Kimmeridgian Extension Outside of the Estremadura Trough*

Outside of the Estremadura trough, the Oxfordian-Kimmeridgian extension phase is also recognizable (Fig. 2 and 9). In the area between Rio Maior and Coimbra, numerous faults cutting through the Dogger platform carbonates are sealed by Upper Jurassic deposits (Fig. 10). The paleoscarps display mainly north-northeast trends and are generally westward facing. There are also several fault reliefs with a west-northwest trend (Figs. 2 and 9). Throughout this area faulting did not result in any significant subsidence; Oxfordian and Kimmeridgian sediments were deposited in a shallow-water environment (Mouterde et al., 1979; Wilson, 1975) (Fig. 3).

The Serra dos Candeeiros (north of Rio Maior) displays significant examples of faulted blocks sealed by Upper Jurassic deposits, with the faults trending north to N150° (Becquart et al., 1987) (Figs. 9 and 10A). Locally, the formation of fault scarps triggered olistolith slides. The faulted blocks were overlain by continental deposits (varying in thickness from a few meters to some tens of meters), with composition varying according to the paleomorphologies induced by previous faulting: lignites and shaly sands with dinosaur remains in the depressions and lateritic horizons filling karstic morphologies on the highs (Fig. 10B).

The evolution of the littoral zone to the north of the Nazaré fault remains unknown. Jurassic outcrops are scattered, and unpublished subsurface data show local thickening of Oxfordian-Kimmeridgian deposits that is related to halokinetic processes (e.g., the flanks of the north-trending salt ridge of Monte Real). In contrast, the Lower Cretaceous sandstones were more uniformly deposited over the area, thereby burying these structures (as observed at outcrops close to Monte Real).

## Portlandian and Cretaceous Paleogeographic Evolution

### *Portlandian Sedimentation*

The regressive evolution of the Kimmeridgian sedimentary sequence resulted in almost total emersion of the Lusitanian Basin (Fig. 6). Portlandian deposits are represented mainly by red pelites and continental sandstones. Littoral marine influences remain in the southwest part of the Estremadura Basin (Leinfelder, 1986) (Fig. 12).

The Portlandian continental deposits have a variable thickness, according to the inherited paleostructures. For example, they are well developed in some areas of the Estremadura trough (over 400 m at Bombarral) but are reduced or absent on the eastern platform of Espigao-Cercal, where they buried karstic morphologies. The contact with underlying Kimmeridgian deposits appears conformable within the trough and nonconformable on the highs (Espigao-Cercal). As a general rule, erosional processes prevailed in the northern part of the basin during this period (reworked Triassic material of the salt ridges accumulated as mud flows in local depressions). Evidence of tectonic events is limited to the southern part of the basin (Fig. 2). On the northern slope of the Arrabida Block (Setúbal), red Portlandian deposits are very thick (over 500 m) and contain a considerable amount of conglomerates made up of Jurassic and Hercynian basement pebbles. These clastics resulted from active erosion of the previously existent structures of the Mesozoic Arrabida blocks and basement reliefs that are now buried under the Tagus Basin to the east (Ribatejo plain; Fig. 2). These Portlandian deposits include large olistoliths and megabreccias resulting from the collapse of fault scarps along N70°-trending faults cutting through the Jurassic limestones and north-trending faults (Setúbal) bordering the eastern basement reliefs (Fig. 11).

### *Cretaceous Sedimentation*

During the Early Cretaceous the Lusitanian Basin was tilted to the southwest. Marine deposits are located in that southwestern area. Clastic sediments were provided mainly by uplift and erosion of the basement of the Iberian Meseta. However, the Berlengas Block remained an important source for clastics (Rey, 1972, 1979) and contributed to the infilling of the Estremadura trough.

From the Portlandian to the early Cenomanian, marine deposits related to different transgressive episodes were not deposited east of a line running from Torres Vedras through Lisbon to Sezimbra (Fig. 12). During the same time interval, other areas were covered by lagoonal or detrital continental sediments. A general transgression occurred during the late Cenomanian (Berthou, 1973; Berthou and Lauverjat, 1979). Since the Turonian, deposition was to the north of the Nazaré fault, in an increasingly confined area (Fig. 13).

In the Sintra area, deposition of the lower Portlandian ammonite limestones was followed by a regressive episode (Ellis, 1984). Calcareous marls of lagoonal, brackish, or littoral environments were characteristically deposited during the late Portlandian, Berriasian, and early Valanginian interval (Choffat, 1887, 1901; Ramalho, 1971, Ramalho and Rey, 1975; Rey, 1979). Bedding surfaces bearing dinosaur footprints are well exposed at Cape Espichel (Telles Antunes, 1976). A transgressive episode occurred during the late Valanginian (ammonite levels of the Calcaires Roux) and early Hauterivian (ammonite- and echinoid-rich marls). A carbonate-platform environment prevailed throughout the basin during the late Hauterivian (lower reefal limestones) and early Barremian (Chofatella and dasyclad lime-

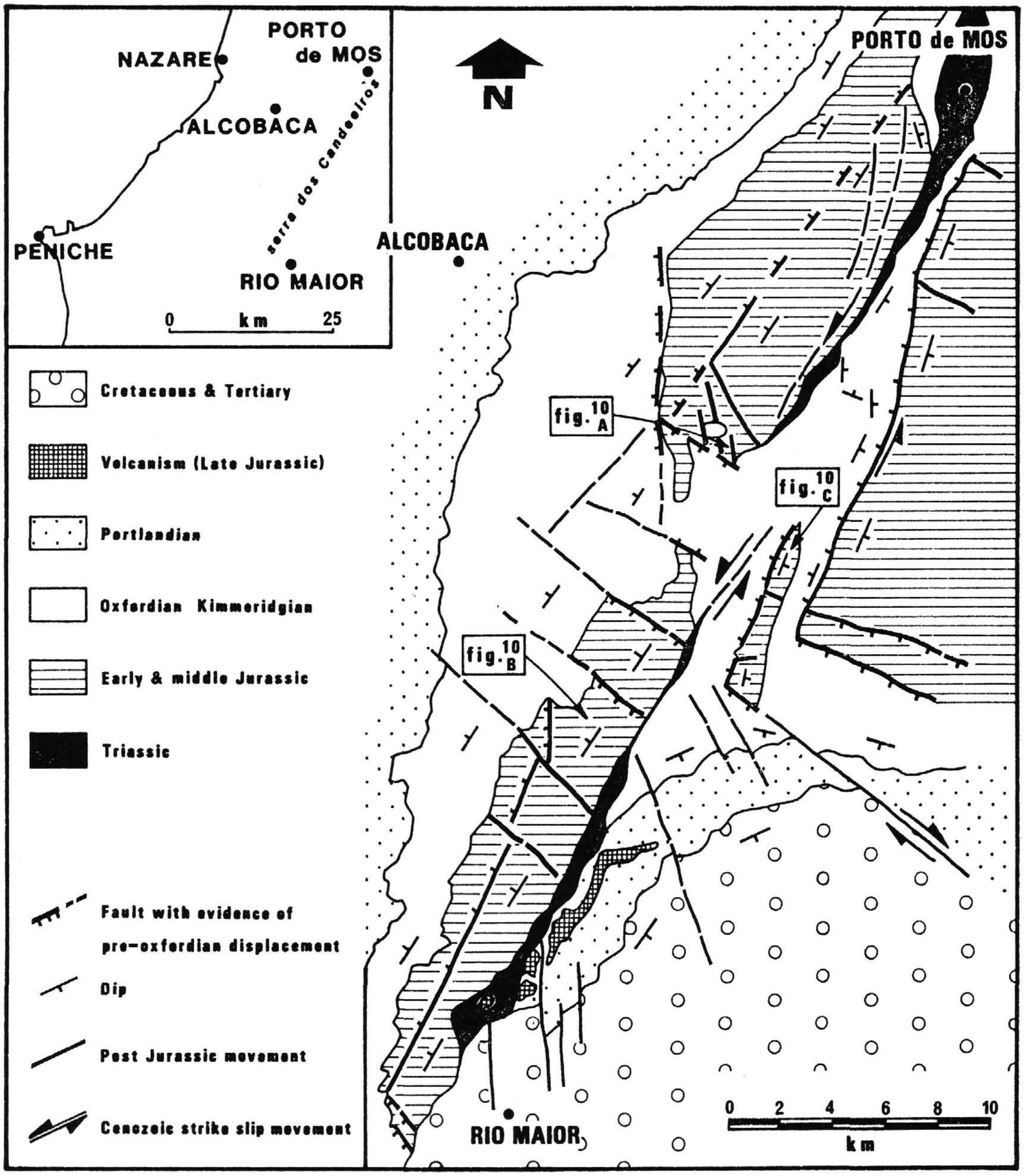


Figure 9. Structural map of the Serra dos Candeeiros area. Main faults display evidence of Jurassic movements and post-Mesozoic reactivations. Note the location of Upper Jurassic volcanics along the salt ridge. The present-day salt scar results from Cenozoic deformation within a sinistral shear zone.

stones) (Rey, 1979). A major sedimentary change caused by local emersion occurred at the top of the Barremian limestones and resulted in a sedimentary gap within the upper Barremian. A nonmarine detrital unit (lower Almargem sandstones) extends this regressive episode (Figs. 12–14). Carbonate-platform conditions were reestablished with the deposition of marly carbonates with echinoids and rudists. At the top of these carbonates, deposition of oyster marls indicates the renewal of regressive conditions. This interval, from the lower Almargem sandstones to the oyster marls, is of early Aptian age. A significant regression is indicated by the deposition of a fluviodeltaic sandy formation (upper Almargem sandstones), separated from underlying deposits by an erosional surface. A middle Albian age is assigned from dinocysts to the upper part of this detrital formation (Hasenboehler, 1981; Berthou et al., 1981; Berthou and Hasenboehler, 1982). In fact, the upper Almargem sandstones indicate that a large-scale regressive episode occurred from the late Aptian through the early to middle Albian (Berthou, 1984b).

The marine environment was progressively restored during the middle Albian as siliciclastics interbedded with Orbitolina limestones were deposited. Carbonate sediments (rudist limestone formation) were deposited during the late Albian (Berthou, 1984a).

Cenomanian deposits are separated from the underlying units by a significant discontinuity consisting of an erosional surface and, in some areas, an angular unconformity (southeast of Torres Vedras). Lower Cenomanian neritic marls and carbonates are confined to the Lisbon area. Middle Cenomanian carbonates were initially deposited across the Estremadura trough to the Nazaré fault and later, to the north of Figueira da Foz

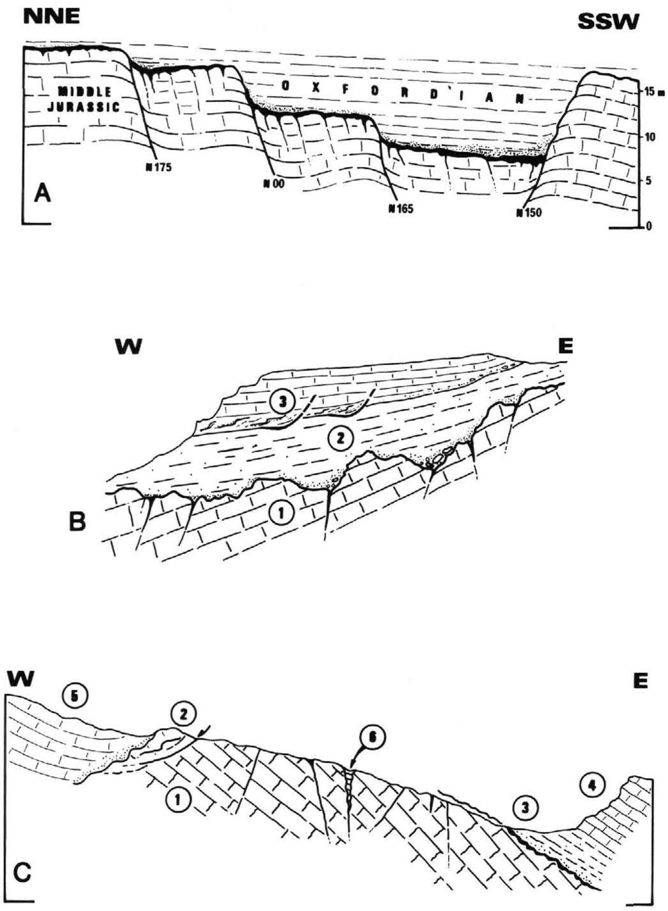


Figure 10. Examples of relations between Middle and Upper Jurassic deposits in Serra dos Candeeiros (location, see Fig. 9). **A.** Cabezo Gordo (length of the section = about 100 m). Faults affected Middle Jurassic platform carbonates before lithification was complete (note plastic deformation along faults). They are sealed by Oxfordian brackish limestone.The unconformity is underlain by karstic (black) and clastic (dotted) material. **B.** Moita da Poço (length of the section = about 80 m). 1. Middle Jurassic platform carbonate; 2. karstic erosional surface overlain by lateritic material (variegated clays, ferruginous crusts, etc.); 3. Upper Jurassic brackish and shallow marine carbonates with slumped beds in the lower part. **C.** Valverde (length of section = about 300 m). 1. Middle Jurassic carbonates; 2. Middle Jurassic synsedimentary collapse; 3. variegated marls overlying the unconformity; 4. Upper Jurassic brackish and shallow-marine carbonates; 5. same Upper Jurassic carbonates overlapping escarpment; 6. fracture filled by Upper Jurassic carbonate.

(Fig. 13). Middle Cenomanian sedimentation terminated with regressive deposits, including gypsiferous beds and stromatolitic horizons. A new transgression occurred during the late Cenomanian. It resulted in the maximum marine extension during the Cretaceous for the Lusitanian Basin (Fig. 13). A regional unconformity separates upper Cenomanian rocks from the underlying units, including deposits of middle Cenomanian age. Carbonates with echinoids and rudists are prevalent (Lisbon, Arruda, and Leira) throughout the basin; ammonite limestones were confined to the lower Mondego valley (Berthou, 1973; Berthou and Lauverjat, 1979).

Turonian deposition was mainly north of the Nazaré fault, within the coastal area of Beira Province. Further south at this time, the Estremadura region and its continental shelf were emergent (Fig. 13). Lower Turonian deposits consist of detrital carbonate with ammonites. The middle and upper Turonian are represented by a continental sequence (upper coarse sandstones; Fereira Soares et al., 1982). The areal extent of Senonian and Maestrichtian sediments is even less extensive. They consist of lagoonal sandy clays, including two marine beds with ammonites of Coniacian and Campanian age. The upper part of the sandy clays is considered to be the Campanian/Maestrichtian boundary (Telles Antunes, 1979; Ferreira Soares et al., 1982; Lauverjat, 1982).

On the continental shelf and slope north of the Nazaré fault, the Turonian is represented by a pelagic limestone facies with *Globotruncana* and *Pithonella* (Boillot et al., 1975). The early Senonian is represented by limestone deposits, some of which are detrital, with planktonic microfossils. The latter deposition (Maestrichtian) was coarser and included neritic fauna, indicating a regressive evolution similar to that observed onshore (Boillot et al., 1975). This evolution could have resulted from the accumulated effects of the regression at the end of the Cretaceous and from the uplift of the margin in response to the beginning of Pyrenean tectonics (Boillot et al., 1979; Mougenot et al., 1984).

### *Comparison with Cretaceous Sections from Holes Drilled on the Margin*

The Cretaceous formations recovered in boreholes on the margin (Deep Sea Drilling Project (DSDP) Hole 398D, Leg 47B on the southern flank of Vigo Seamount—Sibuet, Ryan et al., 1979; ODP Sites 638, 639, and 641, Leg 103 on the western flank of Galicia margin—Boillot et al., this volume; Boillot, Winterer, et al., 1987) differ from those recognized in the Lusitanian Basin. Nevertheless, despite the facies contrast, the timing of events allows for comparison (Sigal, 1979; Berthou et al., 1982; Müller et al., 1983, 1984) (Fig. 14).

On the margin (ODP Site 638), event E0 (early/late Barremian boundary) corresponds to a change of facies with the deposition of black shale (Müller et al., 1983). In the Lusitanian Basin this event is related to a discontinuity at the top of the lower Barremian and to the lack of upper Barremian sediments. Event E1, mainly late Aptian in age, is represented at DSDP Hole 398D by black shale. At the same time, the Lusitanian Basin recorded the most important Cretaceous regressive episode (Fig. 14). Event E2 is Cenomanian in age. Offshore deposits of that age are characterized by large amounts of organic matter and by a significant decrease of the sedimentation rate. These deposits probably include a sedimentary hiatus. Onshore, the Cenomanian is well developed; however, an important discontinuity that includes a sedimentary hiatus is observed at the transition from middle to upper Cenomanian. It may be equivalent to Event E2. This event, as well as the two preceding ones, point out a correlation between the regressions recorded the Lusitanian Basin and the development of an anoxic environment in the deeper part of the margin.

## Mesozoic Magmatic Occurrences

Mafic volcanic intrusions (dolerites) are associated with the Triassic evaporites (Caldas da Rainha), but their age is not clearly defined and they may be confused with younger intrusions. Northwest of the Lusitanian Basin, the Meseta basement was intruded during the early Triassic (230 Ma; Portugal Ferreira and Macedo, 1979) by a swarm of lamprophyre dikes, orientated mainly north-northeast and west-northwest. Faults with similar trends were probably active as early as the Triassic within the basin.

Jurassic magmatics are common but scattered and of little volumetric significance. They are linked to the major faults and usually associated with the salt structures that developed along these fractures (Figs. 2 and 9): (1) north-northeast-trending lineaments (Rio Maior Batalha and Caldas da Rainha trends), (2)

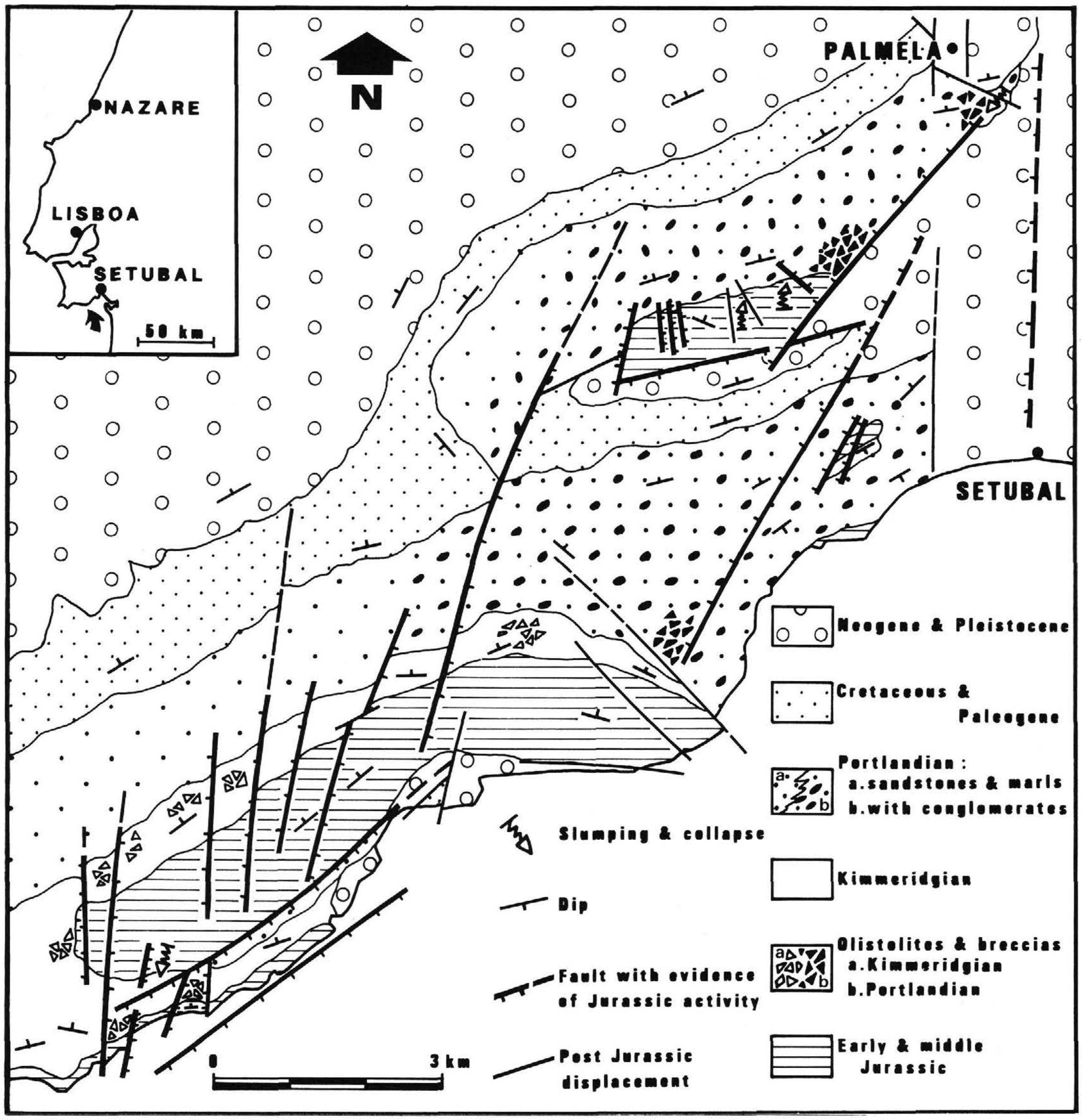


Figure 11. Structural map of the Serra de Arrabida area. Main fault displays evidence of Jurassic movements. Note location of Portlandian conglomerates, including basement pebbles, in the eastern area. Cenozoic tectonics resulted in the reactivation of the Jurassic faulting pattern: strike-slip faults, sinistral north-northeast- and northeast-trending faults, dextral northwest-trending faults, and east-northeast- and east-trending reverse faults. Reverse faults are not shown on map.

north- to north-northwest-trending lineaments (Monte Real), and (3) salt domes of Soure and other areas. The magmatic bodies are primarily dikes, sills, and pseudodomes injected parallel to salt ridges or through transverse fractures. Volcanic flows are scarce. A small number of intrusions are found away from the diapirs (e.g., Vermoil north-northeast-trending dikes, south of Pombal, and those trending west-northwest, east of Alcanena; Fig. 2).

Petrographic composition of these magmatic rocks is diverse (Aires Barros, 1979; Portugal Ferreira and Macedo, 1983). The igneous rocks of the eastern area (e.g., Rio Maior–Porto de Mos) are mostly olivine dolerites, issued from a deep alkaline magma. In the western area (e.g., Caldas, Monte Real, and Soure), compositions are more variable, including gabbros, diorites, syenites, and aphanitic equivalents. These rock types result from more complex magmatic differentiations.

Reliable radiometric data (e.g., Monte Real, Vermoil, Rio Maior lineament; Portugal Ferreira and Macedo, 1983) indicate ages ranging from 145 to 134 Ma (i.e., Late Jurassic to Early Cretaceous) (Fig. 2). Thus, this igneous episode occurred just after the major Oxfordian-Kimmeridgian extension in the Lusitanian Basin and is contemporaneous with the main episode of rifting that occurred in the deep margin.

The second magmatic episode (100 to 70 Ma; Portugal Ferreira and Macedo, 1979) that occurred in the southern part of the Lusitanian Basin (Sintra gabbro and granitoids and Lisbon basalt flows) indicates that the magmatic activity migrated south (Fig. 2).

## RELATION OF THE LUSITANIAN BASIN WITH THE ADJACENT MARGIN

### Main Morphostructural Units

As previously stated, different physiographic units that correspond to different Mesozoic paleogeographic domains have been identified between the emergent Iberian Meseta and the

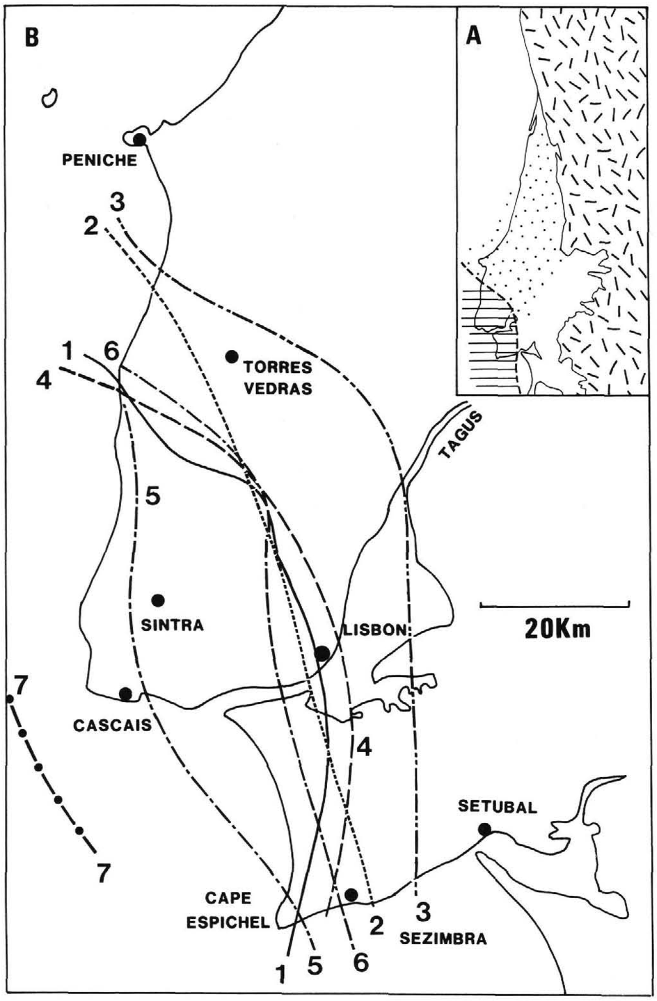


Figure 12. Paleogeographic map of Early Cretaceous marine deposition. **A.** Location of marine (ruled) and continental (dotted) deposits. **B.** 1. Portlandian–early Berriasian(?); 2. late Valanginian; 3. late Hauterivian; 4. early Barremian; 5. early Aptian (sandstones); 6. early Aptian (upper reefal limestones); 7. late Aptian to middle Albian.

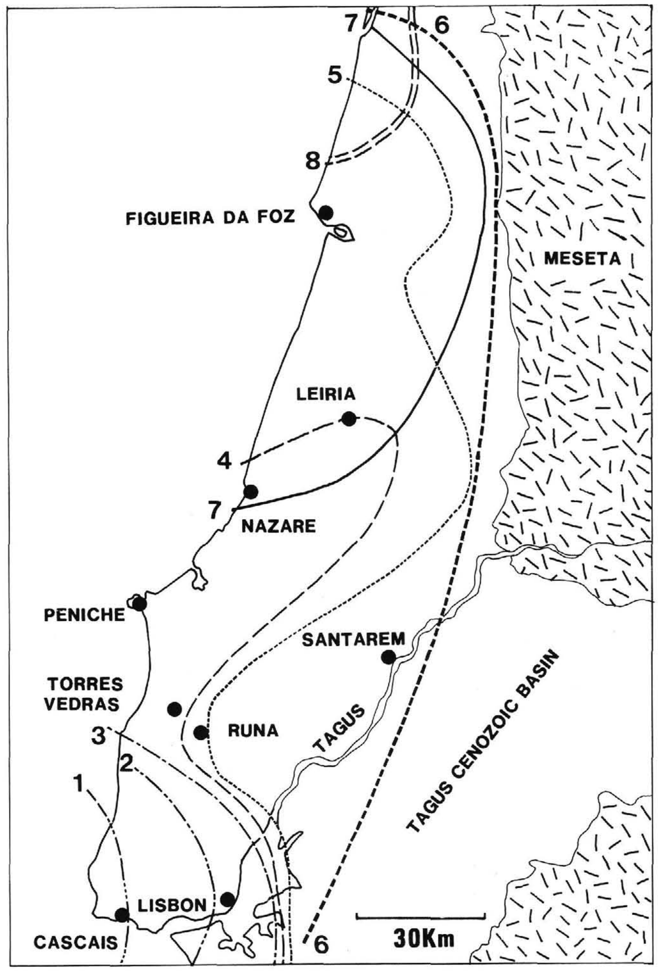


Figure 13. Paleogeographic map of Late Cretaceous marine deposition. 1. end of middle Albian; 2. end of late Albian; 3. end of early Cenomanian; 4. middle Cenomanian; 5. end of middle Cenomanian; 6. late Cenomanian; 7. end of early Turonian; 8. Coniacian to Maestrichtian.

Iberian Abyssal Plain (Fig. 1A): (1) the deep margin, not described in this paper (see Boillot, Winterer, et al., 1987); (2) a succession of Mesozoic highs, termed "intermediate horst" in this paper; and (3) the Inner Galicia Basin and its southern extension, the onshore Lusitanian Basin.

From north to south, northeast-trending faults, of which the most significant are the Nazaré and Aveiro faults, separate this framework into segments (Fig. 1A).

## Comparison of the Mesozoic Tectonic and Sedimentary Events

### *Early Rifting Phase*

A rifting episode of Triassic age, suggested by plate kinematics data (Olivet et al., 1984), is related to the deposition of a thick sequence of evaporites within the Lusitanian Basin. Subsidence was probably controlled by normal faults, the most influential of which are oriented north-northeast. The Berlengas Block (a part of the intermediate horst) was controlled by north-northeast-trending faults and formed, as early as the Triassic, the western shoulder of the Lusitanian Basin.

The offshore extension of the Lusitanian Basin evaporites is inferred from the interpretation of diapiric structures to have been induced by Triassic salt movement. Included are structures on the shelf, offshore Cape Mondego (Boillot et al., 1975), and in the southern part of the inner Galicia Basin, east of Porto Seamount (Montadert et al., 1974, 1979) (Fig. 1B).

No direct evidence exists concerning the extension of Lower and Middle Jurassic deposits into the Inner Galicia Basin. However, seismic profiles reveal the presence of a faulted trough within the Inner Galicia Basin (Montadert et al., 1974, 1979; Mauffret et al., 1978; Réhault and Mauffret, 1979; Groupe Galice, 1979) (Fig. 1B). In comparison to the adjacent areas, this trough contains an exceptionally thick sedimentary sequence of a few kilometers. It is supposed that the deepest part of that sedimentary infill (pre-Albian unit 4 of seismic stratigraphy; Montadert et al., 1974) contains Triassic deposits, as suggested by salt plugs, as well as Lower to Middle Jurassic deposits. The average width of the trough (< 50 km) is of the same order as that of the onshore Lusitanian Basin (Fig. 1). Present-day knowledge does not permit a more detailed statement concerning these (hypothetical) first stages of development of the inner Galicia Basin.

Nevertheless, paleobiogeographic data (Mouterde et al., 1979) support the existence of a narrow marine strip (Inner Galicia and Lusitanian basins), between the Iberian Meseta and the emerged reliefs of the intermediate horst. The influence of open-

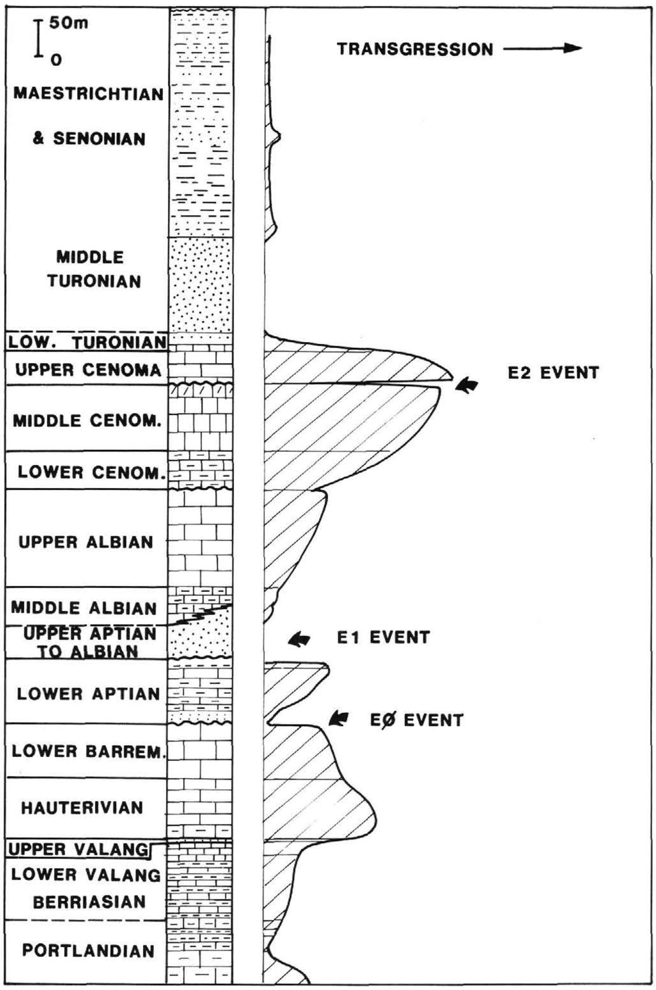


Figure 14. General schematic section of Cretaceous outcrops, showing indication of transgressive and regressive tendencies. Correlation with sedimentary events recognized in deep-margin recovery from DSDP Hole 398D (see text).

marine conditions first reached the Lusitanian Basin from the northwest during the late Sinemurian, and the first ammonites appear to indicate sub-boreal origin. Mesogean fauna appears only at the end of the middle Lias. The presence within different horizons of fauna restricted to the Portuguese Lias testifies to the relative confinement of the basin at that time. Within the upper Lias and Middle Jurassic, the presence of Cephalopod fauna indicates an interference of sub-boreal and Mesogean influences. The basin plays the part of a corridor for faunal exchange between these two biogeographic provinces. The Callovian fauna of the Estremadura trough indicates that at that time the basin was still open to sub-boreal influences, whereas Mesogean populations (Phylloceratids) that are common in southern Portugal (Algarve; Rocha, 1976) are absent from the Lusitanian Basin. The beginning of the second rifting episode reversed this tendency during the Oxfordian; the basin then was open wide to Mesogean influences.

### *Second Rifting Stage*

The timing of events related to this second rifting episode is quite different in the Lusitanian Basin and on the margin.

1. In the Lusitanian Basin an important episode of normal faulting expressed by movement along submeridian and transverse faults occurred after the Middle Jurassic. In reference to the Estremadura trough, north-northwest- to north-trending faults display the largest vertical throws (over 3000 m). The period of maximum faulting was of short duration (less than 10 m.y. from late Oxfordian to early Kimmeridgian). By the late Kimmeridgian, the downfaulted zones were filled and the diapiric structures were buried. Finally, by Portlandian and during Early Cretaceous time, most of the inland basin was emergent. Continental deposits buried the former structures and thus appear as post-rift deposits.

2. Dredge sampling of the deep margin on and around Galicia Bank and Vasco da Gama, Vigo, and Porto seamounts has not recovered any Mesozoic samples older than Late Jurassic (Mauffret et al., 1978; Mougenot et al., 1985). The age of the volcano-sedimentary basement underlying these Upper Jurassic deposits is not yet apparent. It may be Paleozoic or younger (Boillot et al., this volume). The oldest dated Mesozoic sediments seem to be Kimmeridgian neritic limestones (comparable to platform carbonates surrounding the Kimmeridgian Estremadura trough). They are overlain by open-marine limestones with calpionellids (Dupeuble et al., 1976, 1987; Boillot, Winterer, et al., 1987).

Seismic stratigraphy, calibrated with drilling results from DSDP Hole 398D on Vigo Seamount (Sibuet, Ryan, et al., 1979; Sibuet and Ryan, 1979) and ODP Sites 638, 639, and 641 on the Galicia margin (see Mauffret and Montadert, this volume; Boillot, Winterer, et al., 1987), establishes the following timing for regional rifting events: (1) after the deposition of Kimmeridgian platform carbonates ("pre-rift" deposits), sedimentation of Tithonian-Berriasian calpionellid beds indicates the initiation of subsidence; (2) syn-rift deposits (seismic units 4 and 5A) filling the extensional structures (tilted blocks and grabens) are of Early Cretaceous age (from 134 to 114 Ma); and (3) post-rift deposition began during the latest Aptian-Albian.

The apparent difference in the record of Mesozoic rifting events, onshore and on the margin, suggests the following remarks (Fig. 15):

1. The extensional tectonics of Oxfordian-Kimmeridgian age probably occurred both in the Lusitanian Basin and the Inner Galicia Basin, formation of which was initiated during the Triassic. Up to the Oxfordian-Kimmeridgian, the Inner Galicia Basin was bordered to the west by reliefs of the intermediate horst.

2. From the Tithonian, the part of the intermediate horst including the Galicia Bank and southernmost seamounts subsided. At ODP Site 639, Tithonian carbonates, with a basal conglomerate, are directly transgressive over the Galicia Bank basement (see Boillot, Winterer, et al., 1987). The usual recovery of Tithonian and Berriasian calpionellid limestones by dredging on the different seamounts indicates generalized subsidence of these reliefs and thus, of the whole margin (including the basement of the present-day Iberian Abyssal Plain). During the same time interval, the Lusitanian Basin and its northward extension up to the Aveiro scarp were emerged, as well as the segments of the intermediate horst to the south of Aveiro escarpment (e.g., the Berlengas Block). They continued to provide the Lusitanian Basin with detrital material during the Early Cretaceous (Rey, 1972).

3. Transverse northeast-trending faults (Nazaré fault and Aveiro scarp) are the major *en relais* boundaries separating two different domains. To the northwest along the Galicia margin, extensional tectonics continued during the Early Cretaceous, at which time they generated block tilting and active subsidence. To the southeast, the relatively inactive Lusitanian Basin became a starved basin and an aborted segment of the Iberian margin.

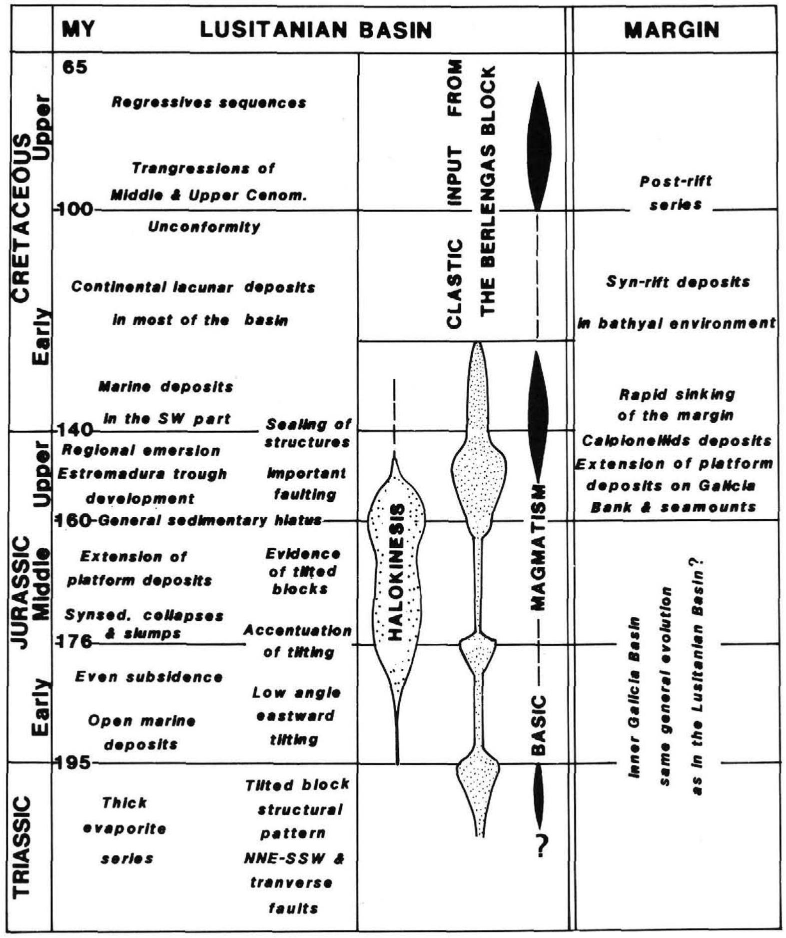


Figure 15. Comparative evolution of the Lusitanian Basin and of the adjacent margin during the Mesozoic.

## CONCLUSIONS

Using data recovered both onshore and offshore, it is possible to sketch the Mesozoic organization of the western Iberian margin and to describe the main stages of its evolution.

From east to west, four more or less parallel domains are recognized:

1. The western border of the Iberian Meseta, which remained emergent during the Mesozoic, constituted an important source of detrital material. The major structural trends of the Mesozoic margin (north-northeast–south-southwest, north-northwest–south-southwest, and northeast-southwest faults) are inherited from the Meseta basement structures.
2. An elongate, submeridian, relatively narrow basin includes the Inner Galicia Basin on the margin and the onshore Lusitanian Basin.
3. To the west, the inner Galicia Basin was bordered by reliefs including different blocks that are more or less deeply emerged today, from the northern Galicia Bank south to the Berlengas Block. These reliefs constitute the intermediate horst.
4. The Iberian and Tagus abyssal plains, not discussed here, extend to the west of the intermediate horst. Subsidence of the Iberian Abyssal Plain was probably initiated during the extensional episode that affected the Galicia margin during the Early Cretaceous.

The basins between the border of the Meseta and the intermediate horst probably experienced the same tectonic and sedimentary evolution from the Triassic up to the Kimmeridgian. The succession of events recognized in the Lusitanian Basin can thus be tentatively extended to the northern Galicia Basin: (1) an early stage of rifting, resulting in the deposition of thick Triassic salt deposits; (2) continuation of moderate extensional tectonics during the Early and Middle Jurassic, as indicated by block tilting and salt extrusions; and (3) a second stage of rifting, Oxfordian-Kimmeridgian in age, evidenced by intense block faulting.

A major change in the geodynamics of these two domains occurred at the end of the Jurassic. In the Lusitanian Basin, faulting stopped and most of the area emerged. On the contrary, the northern area of the margin significantly subsided, in relation to reactivation of the rifting process during the Early Cretaceous. The boundary between these domains of different comportment corresponds to *en relais* northeast-trending transverse faults (Aveiro escarpment, Nazaré fault), which probably acted as transform directions.

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