a reconnaissance study of upper jurassic sediments of the lusitanian basin

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RESUMO

Palavras-chave: Jurássico superior — Fácies carbonatadas — Fácies terrígenas clásticas — Controlo estrutural da sedimentação — Fase de «rifting» da separação dos continentes

A evolução do Jurássico superior da bacia lusitaniana está relacionada com a fase de «rift» que precedeu a separação entre a Ibéria e o Grand Banks.

A sedimentação foi estruturalmente condicionada quer por falhas do soco hercínico de direcção NNE-SSW, quer por movimentos contemporâneos de diapiros salíferos.

No início do Oxfordiano superior o fundo da bacia encontrava-se aplanado a poucos metros abaixo do nível do mar o que explica que as fácies de água doce com algas e as fácies marinhas marginais de Cabaços e camadas de Vale Verde repousem em formações desde o Triásico até o Caloviano.

A sedimentação carbonatada prosseguiu no fim do Oxfordiano superior com lagoas de salinidade variável a Norte (camadas de *Pholadomya protei*), separadas das lagoas pouco profundas de meio marinho aberto, a Sul (camadas de Montejunto), pela ilha-barreira diapírica de Caldas da Rainha.

O início do «rifting» está registado no Kimeridgiano pelo súbito acarreio de clastos terrígenos (desenvolvidos em meio fluvial e submarino-deltaico) e por deposição em ritmo acelerado (superior a 10 cm/$/10^3$ anos), em associação com falhas contemporâneas ao longo da margem SE da sub-bacia de Arruda. A cadeia de estruturas diapíricas de Caldas-Santa Cruz continuou a influenciar a distribuição dos sedimentos carbonatados e clásticos.

No Portlandiano observa-se modelo de fácies mais simples, com clastos fluviais interpenetrando-se para Sul com fácies carbonatadas pouco profundas e de baixa energia.

RÉSUMÉ

Mots-clés: Jurassique supérieur — Faciès carbonatés — Faciès détritiques terrigènes — Controle structural de la sedimentation — Phase de «rifting» de séparation des continents

L'évolution du Jurassique supérieur du bassin lusitanien est en rapport avec la phase de «rift» qui a précédé la séparation entre l'Ibérie et le Grand Banks.

La sédimentation a été structuralement controlée soit par des failles du socle hercynien, d'orientation NNE-SSW, soit par des mouvements contemporains des diapirs salifères.

Au début de l'Oxfordien supérieur le fond du bassin serait plat, sous quelques mètres d'eau seulement, ce qui expliquerait que les faciès d'eau douce à algues et les faciès marginaux (calcaires de Cabaços et couches de Vale Verde) reposent directement sur des formations d'âge Trias à Callovien.

La sédimentation carbonatée s'est poursuivie à la fin de l'Oxfordien supérieur dans des lagunes à salinité variable au Nord (couches à *Ph. protei*) et, dans des lagunes peu profondes, en liaison avec la mer ouverte au Sud (couches de Montejunto): ces deux domaines seraient separés par l'île-barrière diapirique de Caldas da Rainha.

Le début du «rifting» est marqué au Kiméridgien par l'apport subite de clastiques terrigènes (deposés en milieu fluviatile et sous-marin-deltaïque); leur dépôt rapide (supérieur à 10 cm/10^3 années), est lié au jeu de failles contemporaines, le long de la marge SE du sous-bassin d'Arruda. La ligne de structures diapiriques de Caldas-Santa Cruz continue à régir la distribution des sédiments carbonatés et clastiques.

Au Portlandien on observe un modèle de faciès plus simple à clastiques fluviatiles qui s'imbriquent, vers le Sud, avec des faciès carbonatés peu profonds et de basse energie.

ABSTRACT

Key-words: Upper Jurassic — Carbonate facies — Terrigenous clastic facies — Structural control of sedimentation — Rifting phase of continental separation

The Upper Jurassic evolution of the Lusitanian Basin is shown to be linked to the rifting phase which preceded the separation of Iberia and the Grand Banks.

Structural controls on sedimentation include both NNE-SSW trending faults in the Hercynian basement, and contemporaneous movement of salt diapirs.

At the beginning of Upper Oxfordian times, the entire basin had been levelled to within a few metres of sea level, so that the freshwater algal marsh and marginal marine facies of the Cabaços and Vale Verde Beds rest on Triassic to Callovian strata.

In the latter part of the Upper Oxfordian, carbonate sedimentation continued, with fluctuating salinity lagoons in the north (*Pholodomya protei* Beds) separated from shallow open marine carbonates in the south (Montejunto Beds) by the Caldas da Rainha diapir-barrier island complex.

The commencement of rifting is recorded in the Kimmeridgian by the sudden influx of terrigenous clastics (developed in both fluviatile and deltaic/submarine fan environments) and accelerated depositional rates in excess of 10 cm/10^3 yrs in association with contemporaneous faulting along the SE margin of the Arruda sub-basin. The Caldas-Santa Cruz chain of diapiric structures continued to influence the distribution of carbonate and clastic sediments.

In the Portlandian, a simpler facies pattern occurs, with fluviatile clastics interfingering to the south with shallow low energy carbonates.

I. INTRODUCTION

The stratigraphic terminology of the Portuguese Upper Jurassic is complex and sometimes confusing, largely because existing literature contains a mixture of lithostratigraphic and biostratigraphic terms. This has resulted from the wide variety of facies types present in the Lusitanian Basin, and perhaps also from the wide variety nationalities of geologists who have studied the area. The early work of PAUL CHOFFAT (1901) still dominates the Portuguese literature concerning the Mesozoic, but this has been modified and adapted by geologists working for the Companhia dos Petróleos de Portugal during the late 1950s and 1960s. Unfortunately, most of the oil company results are not published, but are available for consultation; the reports that have been published (MEMPEL, 1955; OERTEL, 1956; SEIFERT, 1963) add a germanic ingredient to the terminology, whereas later work by members of the Serviços Geológicos de Portugal and that by French workers (eg. RUGET-PERROT, 1961; MOUTERDE et al., 1972) have in general used Choffat's original terminology.

The problems of studying the Upper Jurassic of the Lusitanian Basin are summarised well by H. SEIFERT (1963, p. 291, translation):

> «In the Malm the Lusitanian Basin was tectonically active so that its palaeogeography changed continually. The resultant strong facies variations made it very difficult to correlate beds in different parts of the basin. Only in the centre of the basin is it possible to construct a biostratigraphy for the Malm and then only in the lower part of the formation. In general, the lower part of the Portuguese Malm is more marine than the upper part. It is formed of limestones and shales, whereas the Upper Malm is formed of coarse clastic sediments. The boundary between these two formations is diachronous.»

This variable distribution of facies made it impossible for Paul Choffat to adopt the usual European stage names. Instead, he introduced a new stage — the *Lusitanian* — for the lower calcareous part of the Upper Jurassic, and *Neojurassic* for the clastic upper part (see left side of Table 1). Choffat's original stratigraphic units were defined at Torres Vedras where the Upper Jurassic is almost continuously marine. The extension of the stratigraphic units of the type area to other regions was based on their fauna, and presumably on their approximate position in the stratigraphic sequence. This procedure seems to have been carried through to the present day, for the Serviços Geológicos de Portugal 1:50 000 maps and explanatory notes use Choffat's original terminology, with the result that it is difficult to be certain whether lithostratigraphic or biostratigraphic units are shown, especially when essentially non-marine strata have been mapped. The establishment of an adequate lithostratigraphic division is further complicated by the fact that as a result of the development of salt diapirs during sedimentation, many Upper Jurassic rock units show rapid variations in thickness and lithology, thus making it difficult to trace them over wide areas.

This paper is an interim report concerning work in progress. It is based largely on the results of fieldwork on coastal exposures, supplemented by personal observations of the comparatively poor inland exposures and re-interpretation of published work and reports on open file at the Serviços Geológicos de Portugal at Castanheira.

II. STRATIGRAPHY — SYNTHESIS OF PUBLISHED WORK

Introduction

Table 1 is a summary of the age and geographic distribution of the main units in the Lusitanian Upper Jurassic, based on published accounts. The French, rather than the English definition of the Kimmeridgian stage is used in this paper, following all previous workers concerned with the Portuguese Upper Jurassic. Beyond the fully marine areas of the Lusitanian Basin (only the successions in the two columns to the far left), the correlations indicated on Table 1 should be regarded as *extremely* tentative,

ENGLISH STAGES	FRENCH STAGES	Choffat's (1901) divisions	1 SINTRA Choffat's (1901) units dated after Ramalho (1971)	2 TORRES VEDRAS & MONTEJUNTO Choffat's (1901) units dated after Ramalho (1971) with additional information from Mouterde *et al.* (1973)*, Ruget-Perrot (1961), Zbyszewski & Ferreira (1966), Zbyszewski & Almeida (1955)	3 VIMEIRO & CESAREDA Ruget-Perrot (1961), with additional data from França & Zbyszewski (1960, 1961), Zbyszewski & Almeida (1960).	4 ALCOBAÇA & SERRA DOS CANDEEIROS Ruget-Perrot (1961) & França & Zbyszewski (1963)	5 FÁTIMA Ruget-Perrot (1961)	6 LEIRA Vermoil borehole dated after Teixeira & Zbyszewski (1968)	7. CABO MONDEGO Ruget-Perrot (1961)
PORTLANDIAN	PORTLANDIAN	Neojurassic	Freixialian and Upper Pterocerian (Nodular Limestones of Ramalhão) 326m	Freixialian 200m	Upper sandstones with plant and dinosaur fossils ?600m+	Upper sandstones with plant and dinosaur fossils 800m	?Upper sandstones	Portlandian & Pterocerian*	
KIMMERIDGIAN	PORTLANDIAN	Neojurassic	Coral Limestones (oncolitic Limestones of Ramalhão) 10–60m	Pterocerian 300m Upper Sandstones* ?100m					
KIMMERIDGIAN	KIMMERIDGIAN	Neojurassic	Shaley-marly limestones 440–480m	*Lima pseudo-alterni-costa* Beds† / Amaral Coral Limestones†	Abadia Beds ?500m	Alcobaça Beds ?100m	? ?	Vale de Lagares complex (including lignite beds at the base) 160m+	? ? Red sandstones 400m+
KIMMERIDGIAN	KIMMERIDGIAN	Lusitanian	Ramalhão Shales 395m	Abadia Beds 800m / Abadia Formation* Cabrito formation*			? ?		? ?
OXFORDIAN	UPPER OXFORDIAN	Lusitanian	? ? ? ? S. Pedro Limestones 90m+ ? ? ? ?	Tojeira formation* Montejunto Beds 350m Cabaços Beds 300–500m	3 Oolitic and compact limestones 100m 2 Littoral marine beds 600m 1 Lagoonal beds 65m	*Pholadomya protei* Beds* } 300–400m Vale Verde Beds*	3 Alternation of brackish & marine lsts 85m+ 2 Marine series (many lamellibranchs) 200m 1 Brackish Series 200m	Limestones with lamellibranchs 346m Limestones (bituminous, with breccias') 130m	*Pholadomya protei* Beds 60m Cement Limestones 50m Carbonaceous complex 40m
OXFORDIAN	LOWER OXFORDIAN		Late Cretaceous granite intrusion						
OLDER STRATA				Callovian	Trias – Callovian	Callovian	Callovian	Callovian	Callovian

†taken as facies equivalents

*total thickness of 1000m+ west of Serra dos Candeeiros

*dated as Kimmeridgian on 1 :50 000 map
'dated as Lower Oxfordian by Teixeira & Zbyszewski (1968)

Table 1 — Summary of the published stratigraphic terminology of the Upper Jurassic of the Lusitanian Basin

for palynological methods of correlation have yet to be applied to the non-marine strata. Furthermore, the stratigraphic names used should be regarded as informal terms, pending the revision of the lithostratigraphic nomenclature of the region to conform to widely recognised stratigraphic codes. Figure 1 is a map showing the positions of localities mentioned in the text.

Upper Oxfordian: Cabaços Beds and equivalents

At the base of the Oxfordian in the Lusitanian Basin, the occurrence of a freshwater fauna (*Planorbis, Nerita, Cerithium, Paludina, Cyrena* and Charophytes; SEIFERT's (1963) faunal assemblage *a*) appears to be ubiquitous (SEIFERT, 1963, pp. 299-300). At Torres Vedras the basal 20 metres of the Cabaços Beds are developed in this facies (RUGET-PERROT, 1961), with thin bedded bituminous limestones («plaquettes»); these are overlain by 300 metres of thick bedded, fine grained marly limestones dated by C. RUGET-PERROT (1961, table 5, p. 172) as the *Gregoryceras transversarium* Zone in age. In the Montejunto area, C. Ruget-Perrot recorded the Cabaços Beds resting on the *Peltoceras athleta* Zone of the Callovian, thus proving the absence of the Lower Oxfordian. M. RAMALHO (1971, p. 29) supported this conclusion, and suggested, on the basis of borehole evidence, that south of the Tagus Estuary the basal unit of the Upper Jurassic is rather variable, ranging from brackish water to shallow marine limestones up to 130 metres thick. This basal group rests on limestones of Callovian age, but to the south in the Serra da Arrábida, H. SEIFERT (1963, p. 297) described the Montejunto Beds (which M. Ramalho dated as basal Upper Oxfordian rather than the Lower Oxfordian age suggested by H. Seifert) resting on an erosion surface which oversteps eastwards from Callovian onto Lower Lias. Above this erosion surface, which in places has a strong relief, occurs a basal conglomerate with locally derived Middle and Lower Jurassic limestone pebbles up to 30 centimetres across; this is the famed ornamental Arrábida marble. In the east of the Arrábida region, H. SEIFERT reported the occurrence of a brown pisolitic iron ore above the basal conglomerate, and described a lateral change from carbonates in the west to terrigenous clastics in the east (1963, fig. 5).

The initial brackish water episode of the Upper Oxfordian can be traced to the northern part of the Lusitanian Basin, and in places, such as the Serra dos Candeeiros, it rests unconformably on an eroded, possibly karstic surface, even developing a canyon in Middle Jurassic limestones (RUGET-PERROT, 1963, p. 133). In places the development of iron and bauxitic ores is reported (ZBYSZEWSKI and MOITINHO DE ALMEIDA, 1960, pp. 27-28, FRANÇA and ZBYSZEWSKI, 1963, p. 33). According to H. Seifert (*in* RUGET-PERROT, 1961, p. 133) the marine and brackish Lusitanian may reach 300 to 400 metres thickness in this area.

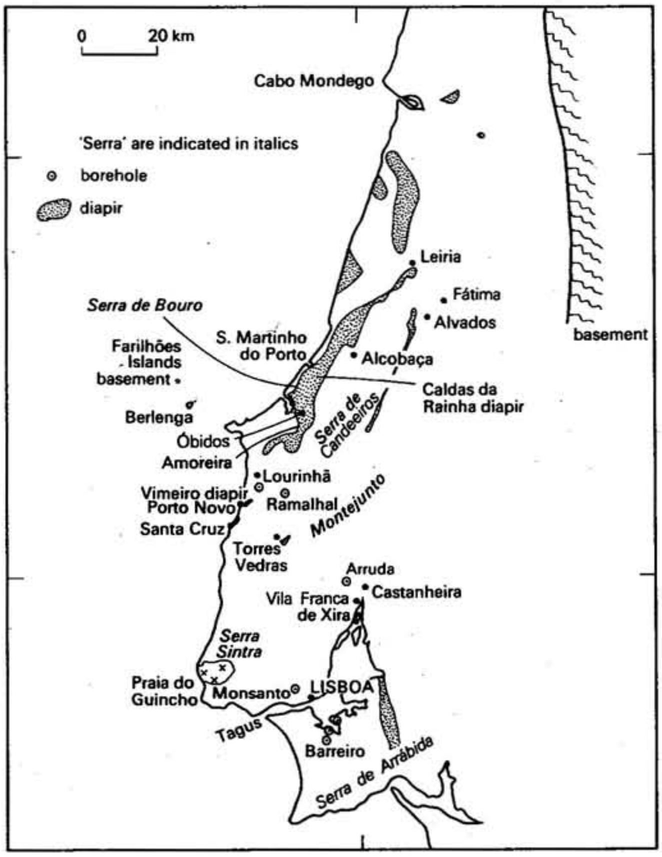


Fig. 1 — Locality map showing places mentioned in the text

The brackish water sediments occurring at the base of the Upper Jurassic also occur to the west of the Serra dos Candeeiros, being described at the edge of the Cesareda Plateau by C. RUGET-PERROT (1961, pp. 102-103). A map of this area by G. OERTEL (1956, fig. 5) shows the basal brackish unit at this locality to be extremely variable laterally, ranging from red conglomerates to sandstones, through shales to limestones. In the whole of this northern area the brackish development is referred to as the Vale Verde Beds (see column 4 of table 1). The Leiria sequence was dated by C. TEIXEIRA and G. ZBYSZEWSKI (1968) as Lower Oxfordian, but its lithology is similar to facies that elsewhere are dated as Upper Oxfordian (ie. Vale Verde Beds).

The brackish strata at the base of the Upper Jurassic occur nearly everywhere in the Lusitanian Basin. In only two areas in the north of the basin, namely Alvados (RUGET-PERROT, 1961, p. 130) some 20 kilometres east of Alcobaça, and at Cabo Mondego is the brackish development underlain by marine strata which may be Upper Oxfordian in age, or could represent continuous sedimentation from the Callovian. Unfortunately in the centre of the Lusitanian Basin (Sintra, and the Monsanto borehole) the basal part of the Upper Oxfordian is not encountered, and so in this region the relationship of the Lusitanian to older beds cannot be determined.

The base of the Portuguese Upper Jurassic is marked by an extremely important discordance, which increases in magnitude in the Arrábida region from west to east, and is present over the whole of the Serra dos Candeeiros, and in all other sections associated with salt diapirs. Indeed, it appears that major salt movements in the Lusitanian Basin were initiated during Lower Oxfordian times.

Upper Oxfordian: Montejunto Beds and equivalents

The Montejunto Beds and their probable equivalents mark a period of generally marine conditions throughout the Lusitanian Basin, with the major exceptions of influxes of terrigenous sediments in the eastern part of the Serra da Arrábida and to the north of Lisbon.

In the Sintra area (table 1, column 1), the S. Pedro Limestones are contact metamorphosed by the late Cretaceous Sintra granite, so their original lithology is largely destroyed by metamorphism. However, the succession in Monsanto borehole gives an indication of the lithology of the Montejunto Beds equivalents in the centre of the Lusitanian Basin (RAMALHO, 1971, pp. 95-96). Here, the upper part of the Upper Oxfordian is dominated by calcirudites with bioherms (Ramalho's «Récifal à organismes encroutants»), being similar in the Barreiro boreholes (except in Well No. 1, where a brackish episode with ostracods and *Charas* intervenes). A similar shallow water facies occurs in the western part of Arrábida, but the marine character is lost to the

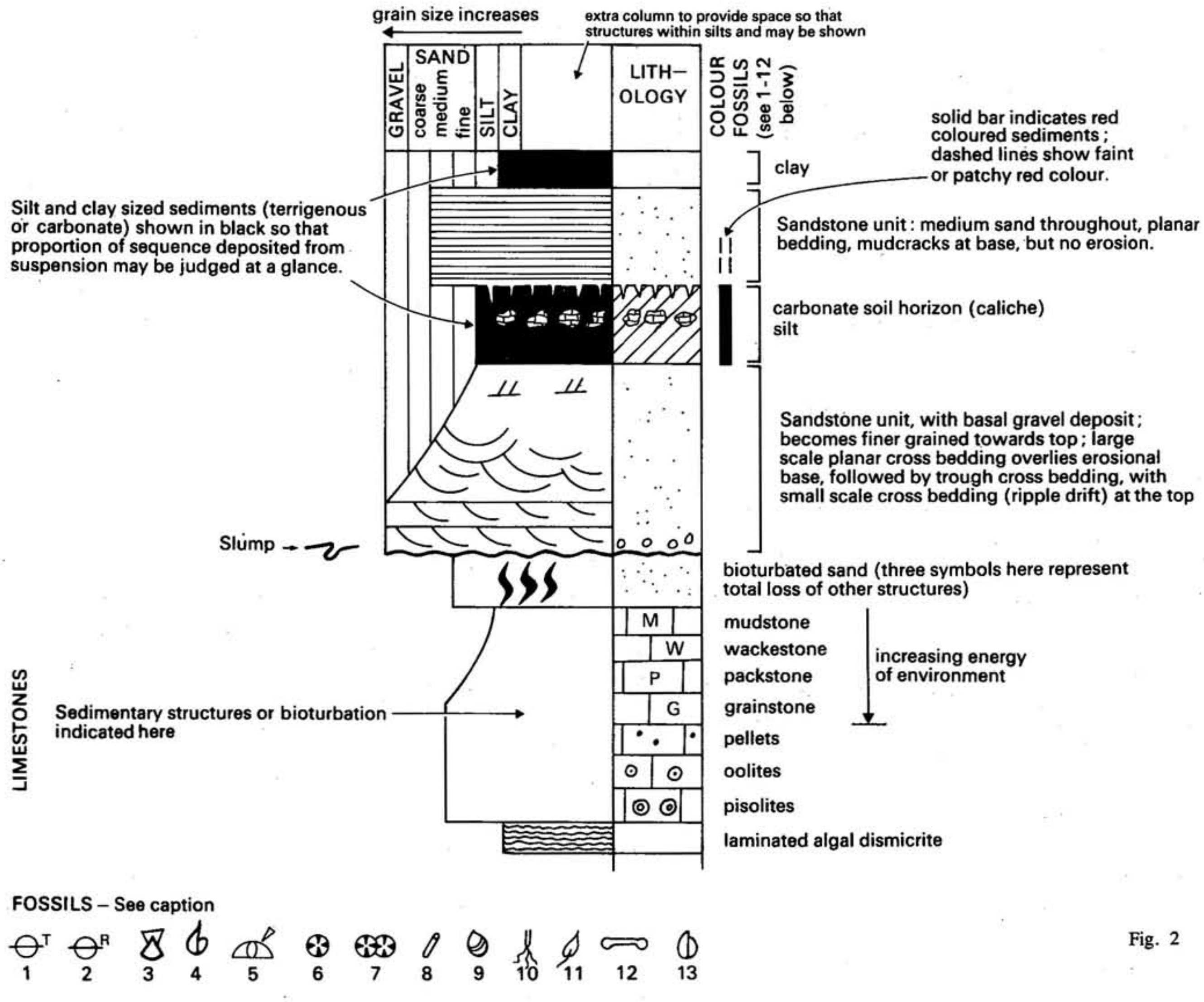


Fig. 2

Fig. 2 — Explanation of lithological logs used in figures 3, 4 and 7. The system used is based on the Shell Standard Legend (Royal Dutch/Shell Group 1976), with the left hand column used to show grain size variation rather than bulk sand content. The textural terms used for limestones (mudstones, wackestone etc.) are those defined by R. DUNHAM (1962). Most of the symbols used in the Figures are explained here. Those that are not shown in this key Figure do not form an important basis discussion in the text, and so those interested in a comprehensive key are referred to the Shell Standard Legend.

1 Trace fossils — *Thalassinoides*
2 Trace fossils — *Rhizocorallium*
3 Lamellibranchs
4 Ammonites
5 Echinoids
6 Solitary corals
7 Colonial corals
8 Serpulids
9 Gastropods
10 Plant-roots
11 Plants — leaves, stems
12 Vertebrate remains
13 Brachiopods

east (RAMALHO, 1971, p. 136) being replaced by terrigenous clastic sediments (SEIFERT, 1963, figs. 2 and 5). In the Torres Vedras and Montejunto areas (the type area, table 1, column 2) the Montejunto Beds are 350 metres thick, with an open marine fauna of bivalves and ammonites, although oolitic horizons are present (RUGET-PERROT, 1961). R. MOUTERDE et al. (1973) recognised a separate «formation» at the top of the Montejunto Beds, consisting of 80-100 m of alternating shales and limestones, the latter sometimes containing *in situ* coral colonies. They named this the Tojeira formation.

Further north, in the region of the Cesareda plateau, the lateral equivalents of the Montejunto Beds exhibit a much shallower water aspect, and so the area marks a transition to the *Pholadomya protei* Beds development in the far north (see table 1, columns 3 and 4), consisting of some 600 metres of shallow water carbonates («Les couches marines littorales» of RUGET-PERROT, 1961, p. 103), containing H. Seifert's faunal assemblage *d* (Corals, stromatoporoids, *Trichites*, algae) and some ammonites. To the north, the lateral equivalents of the Montejunto Beds are, as previously stated, termed the *Pholadomya protei* Beds, the occurrence of which is recorded in the literature from São Martinho do Porto and Alcobaça northwards to Cabo Mondego (see table 1, column 7) containing H. Seifert's faunal assemblage *c* (*Ostrea*, *Mytilus*, *Avicula*, *Isognomon*, *Ceromya*, *Pholadomya*, *Pecten*, *Nerinea*, Terebratulids, foraminifera).

The succession exposed in the Fátima region (table 1, column 5) described by C. RUGET-PERROT (1961, pp. 120-121) shows some 200 m of *Pholadomya protei* Beds (termed «Couches marines à nombreux lamellibranches» by Ruget-Perrot) overlain by four alternations of marine and brackish water limestones, [apparently an alternation of H. SEIFERT's (1963) faunas *a* and *b* (*Cyrena*, *Astarte*, *Corbula*), and *c*], possessing a total thickness of some 70 m. C. Ruget-Perrot gave no indication as to whether she considers these alternations to be equivalents of the Montejunto Beds, or younger.

In the Leiria region (table 1, column 6), the lateral equivalents of the Montejunto Beds also consist of shallow marine and freshwater brackish water limestones (TEIXEIRA and ZBYSZEWSKI, 1968, pp. 61-64).

Kimmeridgian: Abadia Beds and equivalents

In the Torres Vedras region, the calcareous silts, shales and sandstones comprising the Abadia Beds reach a thickness of 800 m (table 1, column 2). R. MOUTERDE et al. (1973) divided this sequence into a lower sandstone unit (the Cabrito formation) which they estimated to be 400 m thick in the Torres Vedras area, and an upper shaley sequence (some 60 m thick) for which they retain the term Abadia marl formation. The Cabrito formation thins to the east, being absent on the south east flank of the Montejunto massif, which R. MOUTERDE et al. (1973) interpret as indicating a westerly, rather than easterly source for the influx of clastic sediments that mark the beginning of the Kimmeridgian. G. MEMPEL (1955) described the Abadia strata as consisting largely of fine grained calcareous micaceous sandstones and siltstones, with abundant plant fragments, ripple marks, cross bedding and slumping. Clay ironstone nodules occur in the upper part of the sequence. Like R. MOUTERDE et al. (1973), Mempel recognised a threefold division of strata above the Oxfordian carbonates, with a thick sandstone sequence separating two argillaceous units.

The top of the Abadia strata is generally marked by a calcareous facies, which may either be rich in bivalves (the *Lima pseudoalternicosta* Beds) or corals and algae (the Amaral Coral Limestones, the Monte Redondo and Ota Limestones). H. SEIFERT (1963) considered these two types of facies to be local shallow water developments at the top of the Abadia Beds, but M. RAMALHO (1971, table 1, p. 29) following P. CHOFFAT (1901) identifies the *Lima pseudoalternicosta* Beds as a unit overlying the Abadia strata.

In the Sintra region, M. RAMALHO (1971), correlated the Ramalhão Shales with the Abadia Beds of the Torres Vedras region. Eastwards, in the Monsanto borehole, he (RAMALHO, 1971, p. 96) recorded 900 m of Abadia Beds, and compared them to the facies development at Sintra, whereas in the Barreiro boreholes he showed the unit to be thinner (around 400 m), containing shales, terrigenous sandstones and conglomerates similar to the type section near Torres Vedras. M. Ramalho correlated the younger «Shaley-marly limestones» of the Sintra area with the *Lima pseudoalternicosta* Beds of the Torres Vedras area. He reported the occurrence of reefal limestones at the top of these «Shaley-marly limestones».

M. RAMALHO (1971, p. 110) interpreted the influx of terrigenous clastics in the Barreiro boreholes as indicating the emergence of Palaeozoic basement to the east. Earlier workers suggested a similar derivation for some of the coarse clastics within the Abadia Beds, for north of Lisbon, at Vila Franca de Xira, C. FREIRE DE ANDRADE (1934) and G. ZBYSZEWSKI (1965) described a series of conglomerates with intercalations of reef limestone, and the latter author reported these to be up to 1500 m thick. A similar association of conglomerates and reef limestones occurs in the exposures around the Montejunto anticline; these were described by G. MEMPEL (1955) and G. ZBYSZEWSKI and O. FERREIRA (1966). G. Mempel (1) described in some detail the grain size and petrology of pebbles found in the conglomerates of the lower-most Abadia Beds, and suggested an easterly source for them. He accounted for the association of reef limestones and conglomerates in the Montejunto area by postulating that the carbonates accumulated on a structural high in the basin, and that

(1) G. Mempel dated the Abadia Beds as Upper Oxfordian but, as already discussed, the Abadia Beds are now generally accepted to be Kimmeridgian in age.

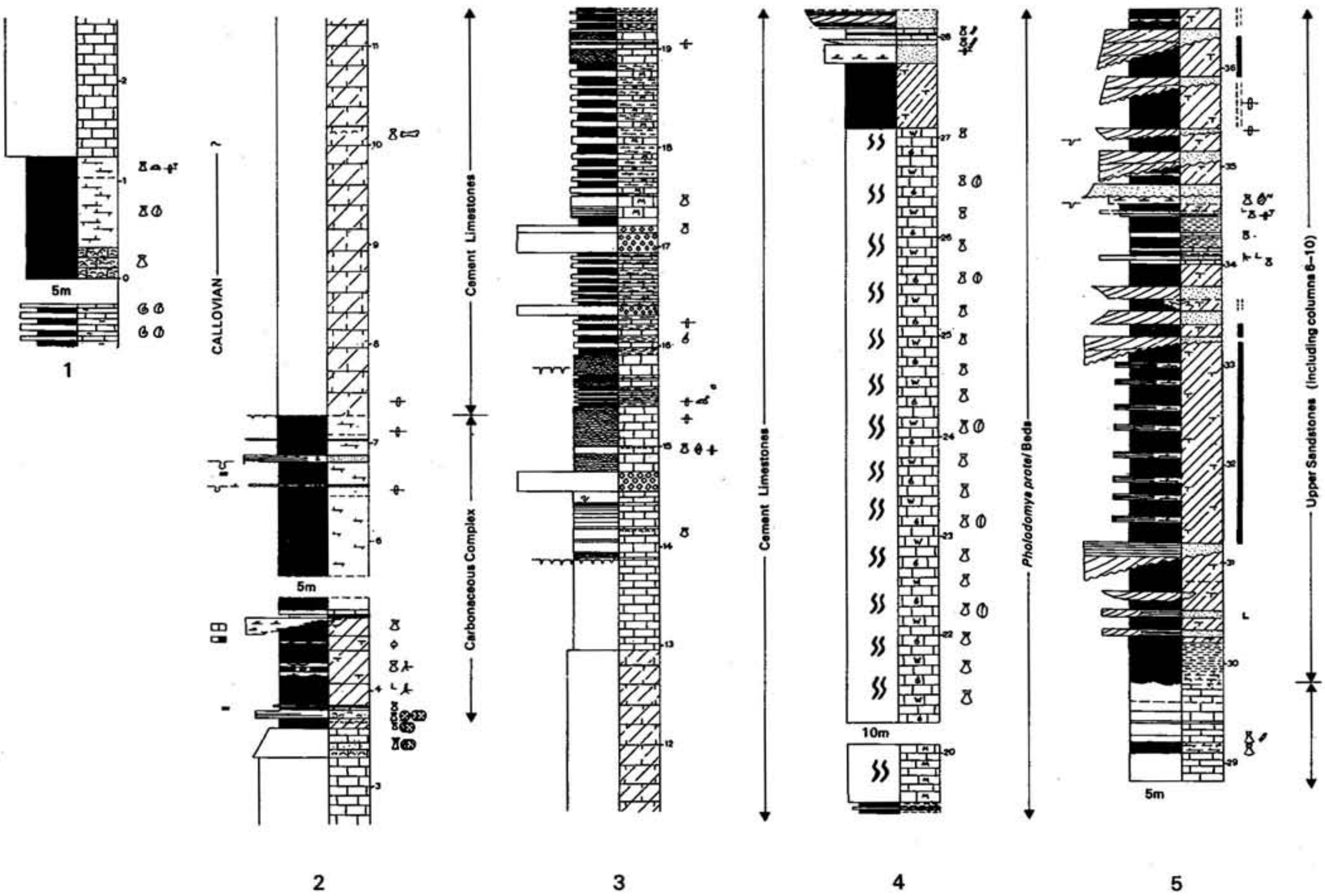


Fig. 3 — Lithological log of the Upper Jurassic sequence exposed along the coast southeast of Cabo Mondego. The names of the rock units are those used by C. RUGET-PERROT (1963). The numbers on the right side of the columns refer to the height in the succession, in tens of metres, above the Callovian. Unexposed portions of the sequence are not drawn to scale, but their extent is indicated (eg. base of column 5 — gap of 5 m)

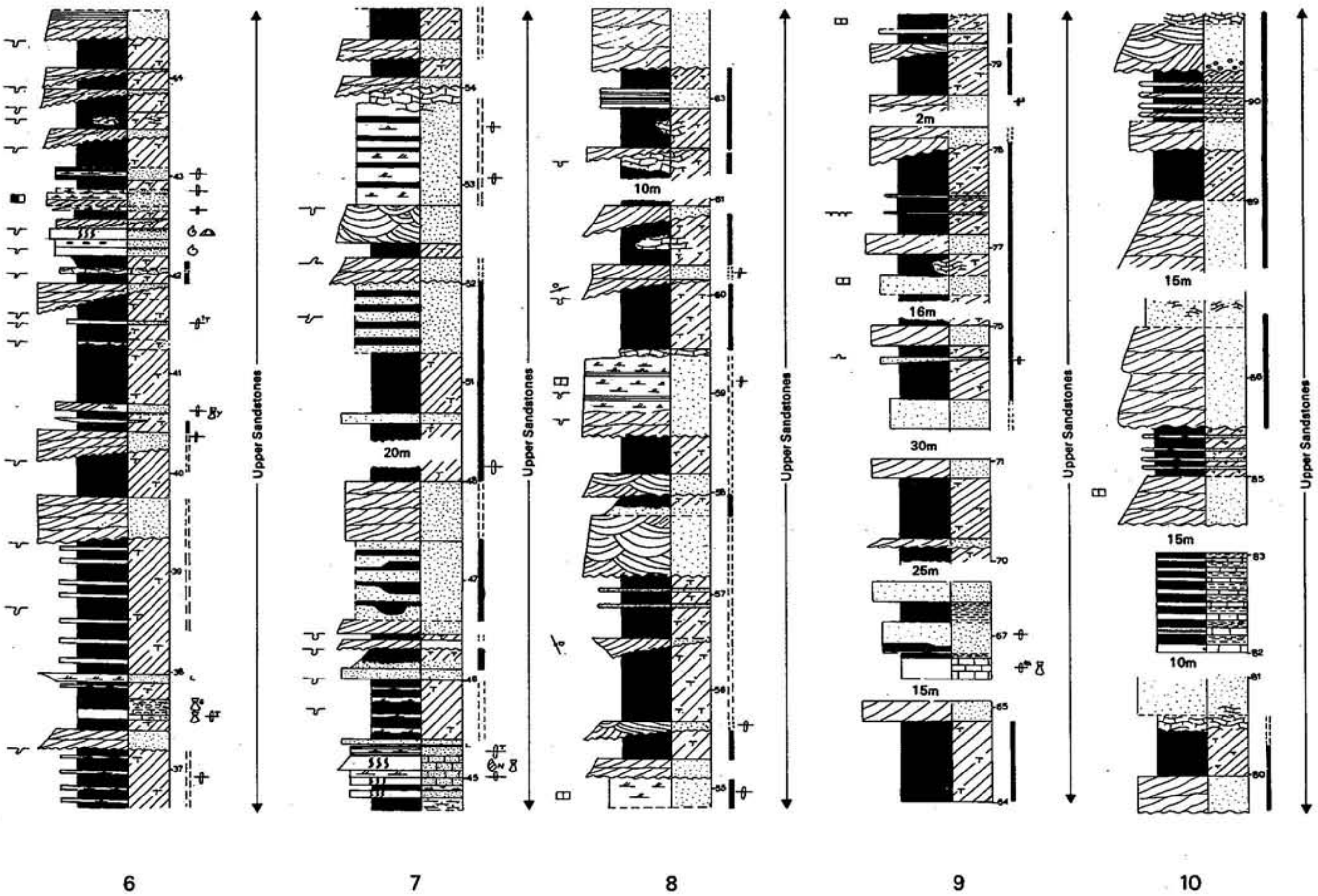
this feature also acted as a barrier to the westward spread of the coarse clastic sediments, thus explaining the rapid westward grain size decrease he described.

G. MEMPEL (1955) also studied the petrology of pebbles found in the presumed lateral equivalent of the Abadia Beds on the coast at Santa Cruz, west of Torres Vedras. Like R. MOUTERDE et al. (1973), he cited a westerly source for these sediments, on the grounds that fine grained sediments occupy the centre of the Lusitanian Basin, thus precluding the same source as for the Montejunto conglomerates, and because of the great similarity between the pebbles and the Hercynian metamorphics and granite of the Farilhões and Berlenga islands to the north west (see figure 1). G. Mempel considered that the conglomerates (and reef limestones where they occur) mark the eastern and western flanks of the Lusitanian Basin. He showed a facies map for the lowest Abadia Beds (MEMPEL, 1955, fig. 5, p. 122) indicating the general north-south trend of the Lusitanian Basin, with shelf-limestone facies occurring at its northern end. This latter conclusion was based on his own work in the Montejunto area, and on that of G. OERTEL (1956) in the Serra de El-Rei — Cesareda region.

G. OERTEL'S (1956) description of the discordance at the base of his «Kimmeridgian» (equivalent to Abadia Beds) around the Vimeiro diapir raises the question as to whether the conglomerates of the Montejunto area really do have reef limestones as their lateral equivalents, or whether there is a discordance between them. In many parts of the Lusitanian Basin, the Abadia Beds and their lateral equivalents often rest discordantly on older beds in the vicinity of diapirs. This is the case for the Matacães diapir near Torres Vedras, where the Abadia Beds rest on Infra-Lias (ZBYSZEWSKI, 1965, p. 53), and also around much of the flanks of the Caldas da Rainha diapir (OERTEL, 1956, fig. 5) where the Abadia Beds rest on basal Lusitanian strata (considered in this account to be basal Upper Oxfordian, and not Lower Oxfordian as suggested by Oertel). As can be seen from table 1, this discordance is widespread in the northern part of the basin, and like the discordance underlying the basal Upper Oxfordian is associated with salt movements.

North of the Cesareda plateau, the equivalents of the Abadia Beds are the Alcobaça Beds, described as a series of calcareous sandstones, fossiliferous limestones, oolites and pisolites by J. FRANÇA and G. ZBYSZEWSKI (1963). They are much thinner than the Abadia Beds to the south, perhaps reaching two or three hundred metres thickness at most. They have a fauna similar to that of the *Lima pseudoalternicosta* Beds.

In the Leiria region, the presumed lateral equivalent of the Abadia Beds is considered to be the lower part of the



Vale de Lagares Complex (table 1, column 6), which contains a series of limestones and lignites which until fairly recently were exploited commercially (TEIXEIRA and ZBYSZEWSKI, 1968; HAHN and HELMDACH, 1971). According to F. Helmdach, these limestones contain abundant *Charas*, and so are reminiscent of the brackish limestones at the base of the Upper Jurassic.

Portlandian

P. Choffat divided the Upper Jurassic above the «Lusitanian» into Pterocerian and Freixialian. M. RAMALHO (1971, table 1, p. 29) suggested that these two stages are approximately equivalent to the Portlandian (*sensu gallico*). It is only in the Sintra region that the uppermost Jurassic is wholly marine, and a passage into the Cretaceous occurs in a marine carbonate facies, and even here, the System boundary is marked by a brackish «Purbeck» facies (e.g. see RAMALHO, 1971, pp. 57-58). In the Arrábida region (RAMALHO, 1971; SEIFERT, 1963), the Portlandian shows an alternation of sandstones and limestones indicating conditions fluctuating from marine to continental. Elsewhere in the basin the Portlandian appears to be dominated by coarse sandstones and shales, with occasional marine bivalve horizons, whose content is reputedly distinct from that found in older strata (see SEIFERT, 1963, p. 294). It should be emphasised that this part of the sequence is almost devoid of reliable zonal indices.

In the northern part of the basin, beds of *presumed* Portlandian age are referred to as «Grés Superiores com Vegetais e Dinossáurios», and in several areas rest discordantly on older strata (see table 1) usually around the flanks of diapirs.

III. UPPER OXFORDIAN ENVIRONMENTS

Introduction

This section is based on the author's detailed study of Oxfordian carbonate successions exposed south of Cabo Mondego and at S. Martinho do Porto, and supported by a reconnaissance field study of other localities.

Cabo Mondego and S. Martinho do Porto

Figure 3 is a lithological log of the Oxfordian succession exposed south of Cabo Mondego. It shows that there is no major break between the Callovian and the overlying succession; indeed, it is difficult to be sure where the Callovian-Oxfordian boundary is situated, or whether Lower Oxfordian is present in this section. Above the ammonite-rich marls and limestones of the Callovian, there occurs, after a gap (covered by beach material), a 12 m sequence of silts with abundant *Exogyra* and terebratulids. Above these the section may be divided into six principle parts; from the base up:

i) *12-36 m* (numbers on right side of lithological columns on fig. 3 refer to height in tens

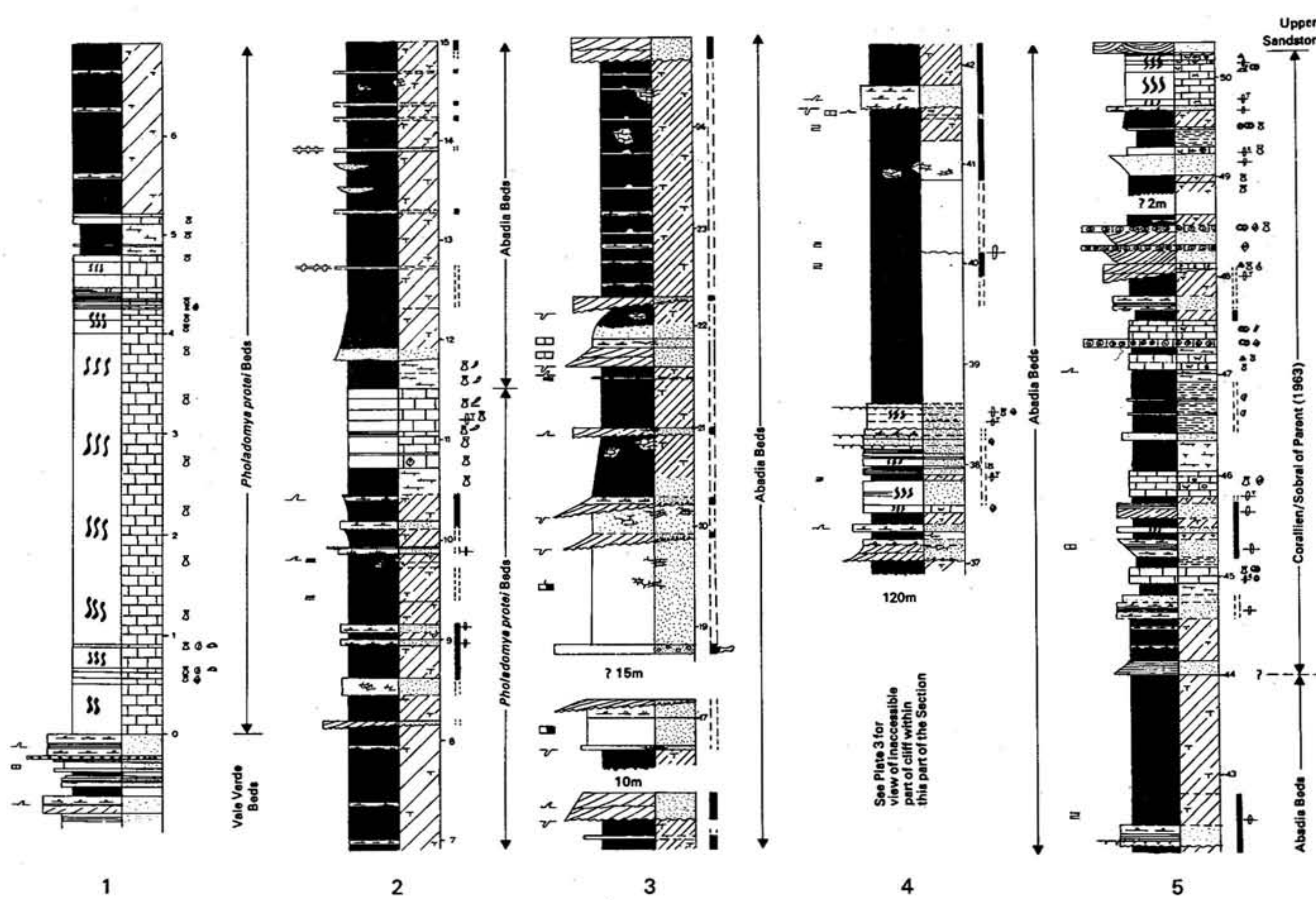


Fig. 4 — Lithological log of the Upper Jurassic sequence developed on the north west flank of the Caldas da Rainha diapir and exposed on the cliffs from S. Martinho do Porto and north westwards along the sea cliffs to Mangas. The names of the rock units are based on the accounts of C. RUGET PERROT (1963) and B. PARANT (1963). The figures on the right of the columns refer to the height in the succession, in tens of metres, above the Vale Verde Beds. Unexposed portions of the sequence are not shown to scale, but their extent is indicated (eg. base of column 4, 120 m gap not recorded — in this case because it is an inaccessible cliff section)

of metres above Callovian): a marine cream coloured limestone (12-33 m) with well developed *Thalassinoides* burrows on its bottom surface. Most of the limestone unit is inaccessible save during a combination of low tide and calm sea conditions. It consists of packstones and grainstones containing a mixture of intraclasts of probable algal origin and skeletal sand usually dominated by echinoid debris. This unit is overlain by 3 m of coarser grained less well cemented carbonate containing pisoliths and corals.

ii) *36-38 m*: This thin unit marks the first influx of terrigenous clastic material, commencing with olive silts, and followed by medium grained sands. The beds are extremely fossiliferous, containing abundant *Exogyra*, *Isognomon* and a variety of corals (*Isastrea*, *Thamnasteria*, *Cyathopora*, *Montlivaultia*, *Rhabdophyllia*) none of which are in their growth position (see plate 1A).

iii) *38-49 m*: In marked contrast to the underlying beds, this unit has a freshwater aspect. It consists of light grey siltstones, rich in wood fragments, and containing small scale cross bedding, sand lenses and flaser bedding. Near the top of this unit, a sandstone lense occurs (see plate 1B) and is overlain by a thin lignite seam, followed by a limestone containing *Unio*, *Corbula*, *Paludina* and *Planorbis*. In addition to the rootlet beds in the silstones, some horizons contain abundant well preserved plant remains. Dinosaur footprints have been reported from this unit (LAPPARENT and ZBYSZEWSKI, 1957).

iv) *53-129 m*: The basal 25 m of this part of the section consists of slightly calcareous silts with a few thin bands of evently laminated or rippledrift--cross bedded coarse sandstones, which are often considerably load-casted. The remainder is a rather featureless succession of massively bedded calcareous silts, largely unfossiliferous.

v) *129-196 m*: This part of the sequence consists of three lithologies:

a) bioturbated dark grey sparse biomicrite (see plate 2A), sometimes pelletoidal and containing millimetre sized high spired gastropods and *Gervillia*;

b) Laminated dismicrites (plate 1D), containing layers of micrite and ostracod debris (plate 2C), occasionally calcite pseudomorphs after gypsum (plate 2B), and abundant *Chara* remains (plate 2D, E);

c) Laterally persistent breccia horizons (plate 1E), containing large blocks of the other lithologies present in the sequence.

This sequence has been described briefly by R. WILSON (1975a) and compared to modern marginal marine-freshwater algal marsh deposits of Andros Island, Bahamas.

vi) *196-277 m; 288-300 m*: These intervals are characterised by «bivalve biomicrites»; they are grey, sparse biomicrites in bedded units up to 1 m thick, pelletoidal in places, with thin marl partings. These limestones are intensively bioturbated (plate 1F), and contain an abundant, but comparatively restricted fauna of bivalves (*Pholadomya, Ostrea pulligera, Arcomytilus, Gervillia, Perna, Trichites*, terebratulids and small high spired gastropods).

The succession exposed in the cliffs around S. Martinho do Porto is shown in figure 4. Here, there are only a few metres of sediment below the «bivalve biomicrites». These are coarse sandstones, with one breccia layer similar to those at Cabo Mondego. The limestone blocks in the breccia show algal textures similar to the Cabo Mondego sequence. A few metres below the section illustrated, there is a fault contact with the Triassic Dagorda formation. The «bivalve biomicrite» sequence is interrupted by about 60 m of reddish silts and thin sandstones.

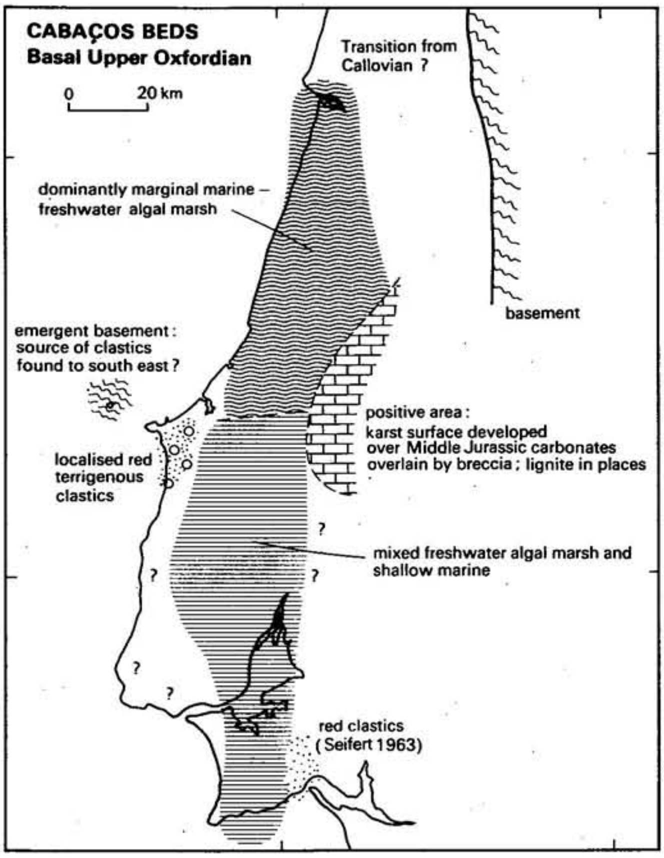


Fig. 5 — Palaeogeographic sketch map for the basal part of the Upper Oxfordian

Environmental interpretation

As already mentioned, R. WILSON (1975a) interpreted part of the Cabo Mondego sequence (129-196 m on figure 3) as an ancient analogue of marginal marine and freshwater algal marsh sediments accumulating today on Andros Island, and described by GINSBERG and HARDIE (1975). The Oxfordian succession illustrated in figure 3 shows a transition from the open marine conditions of the Callovian to the continental fluviatile clastic sediments of the Kimmeridgian. These transition beds contain freshwater and restricted marine faunas, suggesting that they were deposited in a marginal marine environment. H. SEIFERT (1963) recognised four distinct faunal assemblages in the Upper Jurassic of the Serra da Arrábida region to the south of Lisboa, and these assemblages strongly resemble some of those distinguished today in the lagoons and associated environments of the Texas bays. Table 2 suggests the kind of environments in which H. SEIFERT's (1963) assemblages may have lived. The red terrigenous clastic interval in the S. Martinho do Porto section, and the freshwater silts and sands in the Cabo Mondego sequence (fig. 3, 38-49 m) adds weight to the comparison with the Texas bay environments, for these sediments are similar to those formed in deltaic and marsh and lake environments in this region today (see DONALDSON et al., 1970; KANES, 1970). A summary of the environmental interpretation of the sequences is given in table 3.

The Oxfordian in other areas

The lowest part of the Cabo Mondego sequence beneath the algal marsh sediments (ie. below 129 m on fig. 3) has not been found elsewhere during this reconnaissance study, and neither can it be recognised in any of the published accounts of lithological sucessions. Even on the coast at Pedrógão some 25 km south of Cabo Mondego, the algal marsh facies rests on Callovian. But the marginal marine — freshwater facies with its characteristic content of *Chara* appears at the base of the Upper Jurassic throughout the Lusitanian Basin, appearing as the Vale Verde Beds in the north, and the Cabaços Beds ([2]) in the south. The sequences do not exceed 160 m thickness at Cesareda and Montejunto, suggesting that the thickness given by many authors (summarised in table 1, column 2) is excessive and includes part of the overlying Montejunto Beds. Several authors have described the latter formation as bituminous, presumably because of its characteristic oily smell when freshly broken. This facies may indeed have been a potential hydrocarbon source, not because it accumulated in a euxinic facies, but because of its original high content of algal material.

([2]) Referred to as the «Lusitanian B» in some oil company reports.

Within the Cabaços Beds there is evidence for agitated marine conditions as well as the algal facies. In the Cesareda and Montejunto sections packstones and a few grainstones composed of intraclasts (possibly derived from fragmented algal mats), pisoliths and pellets occur. In the Barreiro boreholes, M. RAMALHO (1971) records the presence of *Chara*, ostracods, algae, large forams, and mollusc and echoinoid debris. Terrigenous red clastics were recorded by G. OERTEL (1956) at the base of the Oxfordian to the south west of the Serra de El-Rei, and demonstrated that they die out to the north east. Similar sediments, some 200 m thick, were encountered in the Lourinhã borehole. The location of these clastics in an otherwise predominantly carbonate succession is analogous to the influx of clastics during the Toarcian in this region described by A. HALLAM (1971).

The bivalve biomicrites comprising the *Pholodomya protei* Beds do not extend to the south and south east of the Caldas da Rainha diapir, and neither does the red clastic interval within them. This suggests that the diapir was already in existence during the Upper Oxfordian, forming a barrier or shoal that influenced the development and distribution of sediments.

On the flanks of the Serra dos Candeeiros, the Upper Oxfordian is quite thin (< 100 m), being termed the Serro Ventoso formation in an unpublished report by B. PARANT (1963). Further south, in the Serra de El-Rei and Montejunto regions, the succession is thicker; J. GOMES (1962) measured some 250 m at Montejunto, and G. FERREIRA (1962) just under 1000 m at Cesarada. All these southerly successions contain higher energy carbonates (packstones and grainstones) including oolite horizons, and they contain a more diverse fauna including bivalves, corals and some ammonites. In the Montejunto section, higher proportions of micrite indicate lower energy conditions. In the Montejunto sequence, the top part of the sequence is developed in a shaly lower energy facies which contains some corals; this was termed the Tojeira formation by R. MOUTERDE et al. (1973). The descriptions of the sequences in the Monsanto and Barreiro boreholes by M. RAMALHO (1971) indicate that similar deposits to those of Cesareda and Montejunto accumulated in this part of the basin.

Palaeogeography

Cabaços Beds: Figure 5 shows that during this interval, there was little contrast in environments across the Basin. Apart from the area of red terrigenous clastics of presumed fluvial origin in the area south west of Peniche, and possibly in the east of the Arrábida region, the area of the Lusitanian Basin must largely have been at sea level — or just a few metres below in the south where there are shallow marine carbonates. The Serra dos Candeeiros area developed a karstified surface, presumably during the Lower Oxfordian, and according to published accounts (eg RUGER PERROT, 1963) this is overlain by lignites in places.

Montejunto Beds: Figure 6 shows that the Caldas da Rainha diapir exerted a considerable influence on sediment type and distribution, separating shallow open marine carbonates from lagoonal bivalve biomicrites, and ponded back terrigenous sediments on its north west flank.

IV. KIMMERIDGIAN AND PORTLANDIAN ENVIRONMENTS

Introduction

In contrast to the Oxfordian, the Kimmeridgian of the Lusitanian Basin is dominated by clastic sediments, which to the north of Torres Vedras and Montejunto are almost entirely non-marine. The only exception to this pattern is the level of the *Lima pseudoalternicosta* Beds, which represents a period when marine conditions returned for a brief interval.

	SEIFERT'S (1964) FAUNAL GROUPS	INTERPRETATION AFTER PARKER (1959), TEXAS BAYS	FACIES ASSOCIATIONS IN PORTUGAL
A	*Planorbis, Paludina Cyprina, Chara.*	Freshwater (not present in Texas Bays)	Limestones and sandstones in Kimmeridgian red terrigenous clastic sequences.
B	*Cyrena, Astarte, Corbula*	River influenced	Limestones associated with lignites; Terrigenous red clastic sequences
C	*Ostrea, Mytilus, Avicula, Isognomon*	Enclosed bays	Lumachelles in clastic sequences (see facies IV on Table 3)
+	*Ceromya, Pecten, Pholadomya, Nerinea, Terebratulids*	Open bays	'Bivalve biomicrites' – Cabo Mondego; 'Bivalve biomicrites' – S. Martinho do Porto
D	*Corals, Stromatoporoids, Trichites,* algae.	Inlets, and inlet influence	Base of sequence at Cabo Mondego (Fig 3, 36-38m); Top Kimmeridgian of S. Martinho do Porto (Fig 4, 450-500m)

Table 2 — A re-interpretation of H. SEIFERT'S (1963) Upper Jurassic faunal assemblages

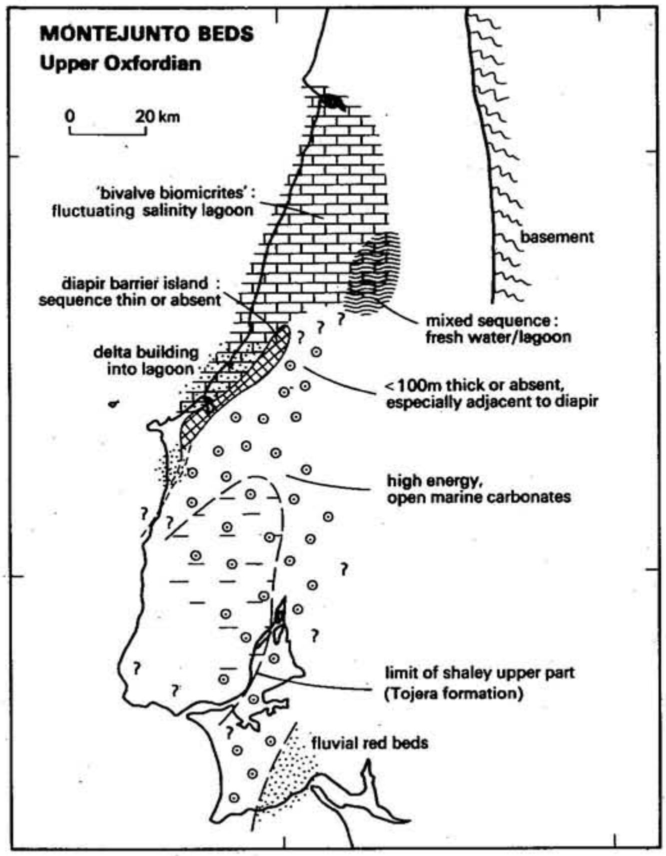


Fig. 6 — Palaeogeographic sketch map for the higher part of the Upper Oxfordian

The interpretations presented in this section are based on studies of coastal sections and evidence afforded from existing reports and publications concerning the development of clastics inland. Further original work concerning the inland outcrops and wells, supported by palynological data to aid correlation might completely change the conclusions presented. However, without any reliable means of correlation, environmental interpretations such as those presented here are the only means of providing a framework around which future investigations can be planned (see note added in proof.).

Cabo Mondego

Figure 3 shows that the Oxfordian carbonate sequence is followed by about 600 m of terrigenous clastics. Many of the sandstone units are characterised by fining upward sequences, in which coarse and medium grained cross bedded sandstones are replaced by red fine sands and silts, the latter sometimes culminating in the development of caliche horizons (fossil carbonate soils). A number of marine shale, marl and sandstone horizons occur in the succession (see fig. 3 at around 342 m, 375 m, 422 m, 450 m, 665 m). Sediments immediately above and below these marine intervals lack the red colouration of the finer sediments which characterises the rest of the sequence, suggesting that higher water table levels associated with marine advances immediately after deposition prevented the oxidation of any ferromagnesian minerals in the sediments.

The assemblage of features, particularly the fining upwards units and fossil soil horizons suggests a fluvial environment, with deposition occurring from relatively low sinuosity meandering streams (see COLLINSON, 1978, for review of the features of fluvial sediments). Changes in sea level, or periodic waning in the volume of sediment input led to marine incursions, during which fluvial sands were reworked and often bioturbated, possibly within an interdistributary bay environment between fluvial/deltaic channels.

S. Martinho do Porto and the Caldas da Rainha Diapir

Figure 4 shows that the 250 metres of terrigenous clastics following the Oxfordian bivalve biomicrites are dominated by fine sandstones and siltstones, containing only a small proportion of coarser channel sandstones. Thus the floodplain environment is dominant here, and the streams showed a high sinuosity meander pattern (see plate 3A).

At the top of the section (376-386 m, 447 m to top on fig. 4), marine conditions are indicated by abundant bioturbation and the occurrence of bivalve Nerineiid and coral faunas, and pisolitic horizons (see plate 3 B). Traced laterally, only the marine horizons appear to be persistent, with the sandstones generally wedging out. About 10 km to the south west of S. Martinho do Porto (in the sea cliffs at the edge of the Serra do Bouro), a 20 m thick massively bedded limestone horizon is developed at this level. It is largely micritic, and contains mudcrack horizons and traces of algal laminations. To the south of Óbidos, near the village of Amoreira, this unit rests unconformably on Bathonian limestones (see RUGET PERROT, 1963, fig. 24 for illustration). This unconformity has been recognised all around the Caldas da Rainha diapir by B. PARANT (1963), and around the Serra de El-Rei and Vimeiro diapirs by G. OERTEL (1956). This sub Kimmeridgian unconformity is yet more evidence suggesting that the diapirs were active during Upper Jurassic sedimentation. B. PARANT (1963) showed that the «Upper Sandstones» (of presumed Portlandian age) also have an unconformable base, which may cut out all other Upper Jurassic strata and come to rest on Triassic Dagorda series in some localities. Parant also demonstrated that the red terrigenous clastics of the Abadia formation that characterise the north east side of the diapir are replaced to the south east by the dominantly oolitic, pisolitic and skeletal sand rich limestones of the Alcobaça Beds. This provides more evidence in favour of the existence of the Caldas da Rainha diapir as a string of islands between which wind driven or tidal currents flowed leading to the deposition of high energy carbonates.

FACIES	Proportion of coarse & medium sand to fine sand & silt (% indicates amount of coarser sediment in the sequence)	Exotic conglomerates and gravels	Caliche conglomerates and gravels	*In situ* caliche horizons (Types A and B as described by Steel, 1974)
(i)	40–50%	Polymictic: granite, phyllite, quartz, orthoclase feldspar	Absent	Present, A & B but not as abundant as in facies (ii) & (vii)
(ii)	20–30%	Absent	Present, abundant in places	Types A & B well developed
(iii)	10% in S (S of Santa Cruz) 20–40% to N (facies similar to (ii) with addition of shell beds)	Absent	Present at base of sandstone	Present, mainly A
(iv)	Only one coarse clastic unit in > 300m of silts	Present: pebbles & cobbles of granite, phyllite, quartz	Absent	Absent
(v)	> 50%	Present (gravels only): orthoclase feldspar & quartz	Absent	Few, A
(vi)	40–50% W of Lourinha 30–40% S of Santa Cruz	Scattered clasts: only quartz & metaquartzites	Present	Present, mainly A, but some B.
(vii)	> 75%	Common: only quartz & metaquartzites	Common, but usually developed exclusively from exotic conglomerates	Very few

Table 3 — Summary of the features of the seven terrigenous clastic facies exposed in the cliffs in the vicinity of Lourinhã, Porto Novo and Santa Cruz (see also Fig. 7)

Coastal sections between Praia da Lourinhã and Santa Cruz

Along this 15 km of coast, most of which is flanked by cliffs up to 75 m high, seven distinct facies are discernable in the Kimmeridgian and Portlandian clastic sequence. As shown on fig. 8, it is possible to observe two relatively continuous sections, spanning several kilometres of cliff, and separated by approximately 7 km in a north south direction. The only facies that can be traced between the two areas is iii), which may be traced eastwards, toward the basin centre, into the *Lima pseudoalternicosta* Beds which mark the top of the Kimmeridgian. The fact that the Santa Cruz diapir lies between the two sections, and that apart from the marine facies iii) there are few similarities between them points once more to the possibility of a diapir forming a barrier of some kind that exerted a control on sendimentation.

Figure 8 and table 3 together summarise the main features of the facies types except that iii) an iv) are not illustrated by summary logs in the figure, so additional comments on them are given below:

iii) The base and top this interval is marked by shell bands, respectively termed key beds C and E by B. TRZESNIOWSKI and H. SEIFERT (1958). Bed C contains abundant *Isognomon rugosa* (see plate 3C), and lesser numbers of *Cyprina*, *Mytilus* and *Ostrea*. Bed E is dominated by «*Trigonia*» *lusitanica* still preserved in aragonite, plus *Corbula*, *Isognomon rugosa*, *Cyprina*, *Mytilus*, *Cerithium* and *Cidaris*. Both these beds were mapped over distances of 20 km by B. Trzesniowski and H. Seifert. Other shell horizons occur in the predominantly silty sequence south of Santa Cruz. But to the north of Porto Novo only key beds C and E remain, and the sequence is comparable to facies ii) with channel sandstones and caliche horizons. The southward decrease in sand content of the sequence, and the more marine character of the sediments in this direction suggest a fluvio-deltaic complex building out onto a shallow shelf. Key bed C may represent a delta abandonment facies, with other shell beds being wave winnowed lag deposits.

iv) The bulk of this facies consists of grey green fine sandstones, siltstones and mudstones, the coarser fractions usually being bioturbated. However, the most interesting feature is the 40 m tan coloured sandstone sequence, at the base of which occurs the polymictic conglomerate (plate 3D) described by G. MEMPEL (1953). This sandstone unit channels down into the siltstones with a relief of at least 10 cm, and large flute casts (up to 1 m long, 15 cm

Fossil wood and debris	Marine horizons	Red colour present in :	Intepretation
Absent	Absent	overbank and abandoned channel deposits	FLUVIAL. low sinuosity meander belt/braided stream
Abundant, including logs and *in situ* roots	Absent	overbank deposits only	FLUVIAL – high sinuosity meander belt
Present	Common, but fewer to N	some silts	DELTAIC – distributary channel and inter-channel bays or abandonement facies in north ; distributary bays and pro-delta in south
Abundant	Silt; . probably entirely marine	none	SUBMARINE FAN – sandstone unit deposited in distal channel
Common near base	One horizon only, ~ 10m from base	only in silts and fine sands	DELTAIC – delta plain with large fluvial channels
More common at base, and in south	Only south of Santa Cruz	overbank deposits	FLUVIAL – in north, low sinuosity meander belt/ braided streams FLUVIO-DELTAIC - in south ; moderate sinuosity river channels & interdistributary bays
fine grained sands & silts	Absent	Only in finer grade sediments	FLUVIAL – braided river system, possibly distal end of alluvial fan

wide and 10 cm deep) are developed on its bottom surface; they indicate currents flowing from the north west. The isolated stack of this sandstone that stands proud of the beach at Santa Cruz shows faintly planar partings that are inclined (if the steep tectonic dip is removed) towards the east in sandstone with scattered pebbles. The inclined partings were probably formed by lateral accretion in this direction. Above this are flat bedded sandstones with abundant lignite fragments and showing crude grading with «floating» pebbles which are also well exposed in the main cliff (plate 3E). The sequence becomes finer upwards and changes to decimetre bedded medium sandstones, again with lignite, and small scale cross bedding and some slump horizons. This lithology grades up into laminated silts with orange weathering ironstone nodules similar to those of the Abadia formation inland at Torres Vedras. The features of the sandstone part of this facies are suggestive of deposition in a channel in the proximal part of a submarine fan (but in a distal part of the channel).

The possibility that diapiric movements may account for the considerable differences between the two clastic sequences shown in fig. 7 has already been mentioned. Although no time correlation is possible between the sequences, it does appear that in early Kimmeridgian times the Santa Cruz area was sommewhat lower than that around Porto Novo, for the former sequence shows progressive basin fill towards sea level (starting with submarine fan deposits) whereas the latter shows deposits formed progressively nearer base level (as indicated by the interpreted increasing sinuosity of the stream sediments). This suggests that fault movement occurred along the line of diapirs. Detailed analysis of the clastic sequence in the Lourinhã and Ramalhal boreholes might confirm or refute this hypothesis.

Reef limestones

The term «reef» is used rather loosely in the Lusitanian Basin, and seems to include any carbonate formation in which appreciable quantities of corals are found. In the uppermost Kimmeridgian, banks of limestone, such as the Monte Redondo Limestone and the Ota Limestone developed around the margins of the Lusitanian Basin. The latter formation, which is situated on the north eastern side of the Arruda Basin (see fig. 8), is up to 100 m thick, thinning out to a few metres in a lateral distance of about 1 km (CHAMEAU, 1962). However, a reconnaissance visit by the author failed to locate any reef debris material, and so the formation is probably not a reef in the true sense, but perhaps a build up of carbonate sediments on a change in depositional slope (the slope break of BALL, 1967). It is probable that all the «reefs» marked on P. RICHÉ's (1963) facies map are carbonate banks and bioherms developed on a slope-break.

However, the Upper Kimmeridgian of the Lusitanian Basin does contain a true reef complex, although previous accounts do not describe it. The coastal sequence of the Sintra region (Praia do Guincho) described by M. RAMALHO (1971) contains a number of features that

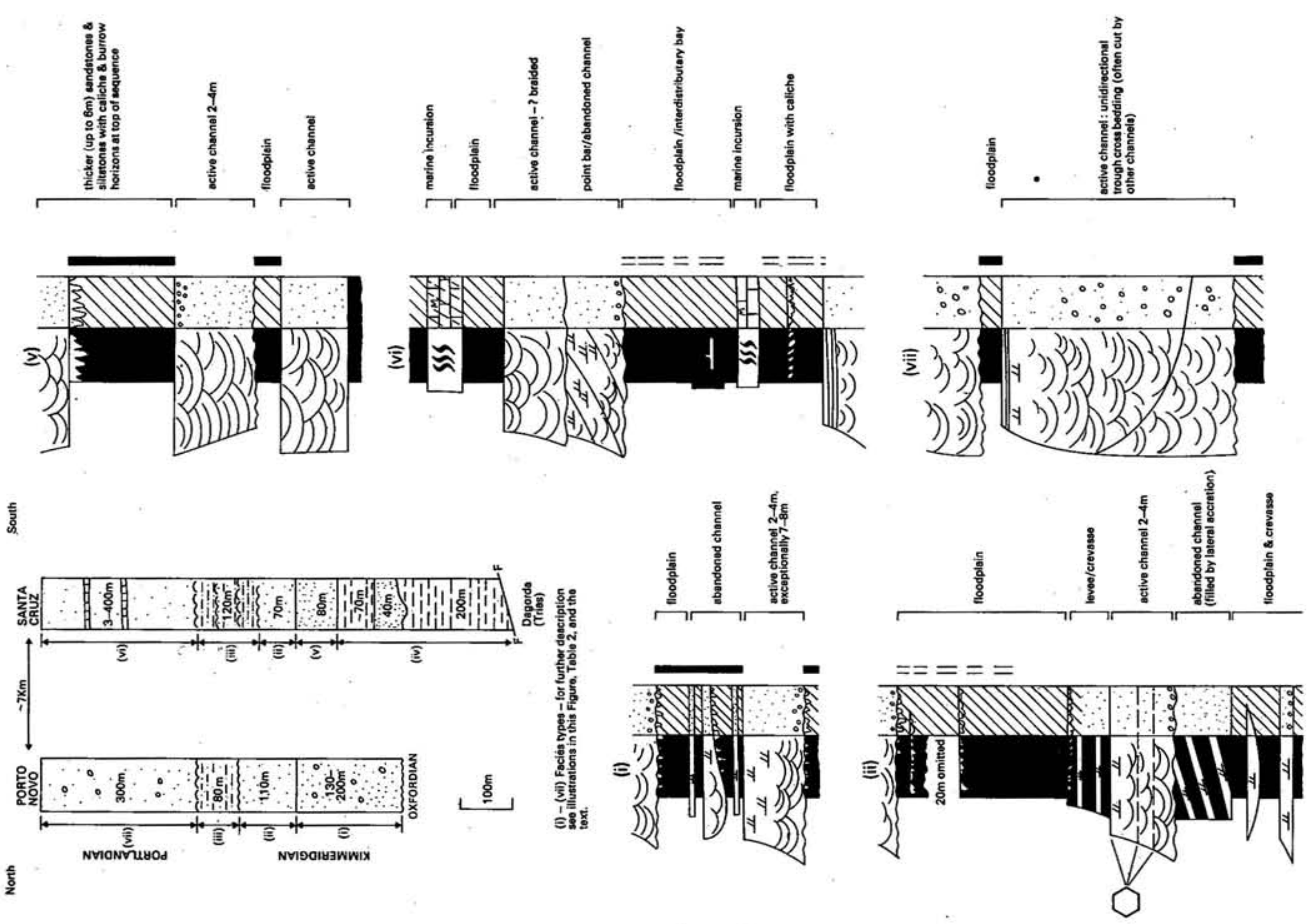


Fig. 7 — Facies variation in the Kimmeridgian-Portland terrigenous clastic sequences in the vicinity of the Santa Cruz-Vimeiro diapirs (the «axis» of the diapiric structure passes between the two columns shown in the top left diagram).
The columns in the top left of this figure show the approximate thicknesses of the different facies types; they are based on personal field observations, supplemented by data from B. TRZESNIOWSKI and H. SEIFERT (1958) and B. PARANT (1963).
The five lithological logs are diagrammatic summaries of all but two of the facies. Full descriptions of all seven facies are given in Table 3 and the text.

identify it as a reef facies complex totalling around one kilometre in thickness. The description given in table 4 is a reinterpretation, based on personal examination in the field, and on M. RAMALHO's (1971) published section. The complete reef complex is only developed at this locality. To the east only the back reef facies is developed.

Torres Vedras and Arruda areas

The eastward thinning of the clastic Cabrito formation described by R. MOUTERDE et al. (1973) has already been described. As yet, no detailed study of this formation has been made, but graded beds containing only Unit A of the Bouma turbidite sequence, together with flute and groove casts have been observed by the author in loose blocks of the Cabrito formation to the south of the Montejunto Massif, after being alerted to their presence by F. Gradstein (personal communication, 1978).

Further to the east, the Kimmeridgian clastic sequence is developed in yet another facies. On the eastern border of the basin at Vila Franca de Xira and Castanheira, arkosic conglomerates and gravels are developed. They were first described by C. ANDRADE (1934), and logs of their upper part were made by J. CHAMEAU (1962). They consist of large angular pink feldspar clasts mixed with more rounded granules of Mesozoic (presumed Lower and Middle Jurassic) limestones. J. Chameau noted that the topmost parts of the arkosic sediments to contain coral colonies, and observations by the author at Vila Franca indicate that some of these colonies, which are several metres across, are inverted, perhaps having «tumbled» into their present position. J. CHAMEAU (1962) showed the arkosic sediments interfingering with more normal Abadia facies to the west. The Arruda borehole penetrated 2.5 km of Kimmeridgian sediments, and much of this thickness comprises coarse arkosic sediments (see fig. 8). C. ANDRADE (1934) suggested that these sediments were associated with contemporary faulting. The isopachyte pattern and postulated extent of this facies (taken from RICHÉ, 1963) suggest deposition in an alluvial fan or submarine fan environment backed by a fault scarp.

Lower Kimmeridgian palaeogeography

The isopachyte pattern shown on fig. 8 (from RICHÉ, 1963) reveals two distinct Kimmeridgian sub-basins (Bombarral and Arruda) separated by the Torres Vedras-Montejunto high. In the Arruda Basin, the sequence of arkose sediments accumulated to the incredible total of 2.5 km. Given the presence of the Torres Vedras high, and the fact that the Cabrito formation contains no limestone clasts in its graded units, it seems unlikely that the Cabrito sands were derived from the fan-sediments of Vila Franca and Castanheira. R. MOUTERDE et al. (1973) suggested a westerly derivation on the grounds

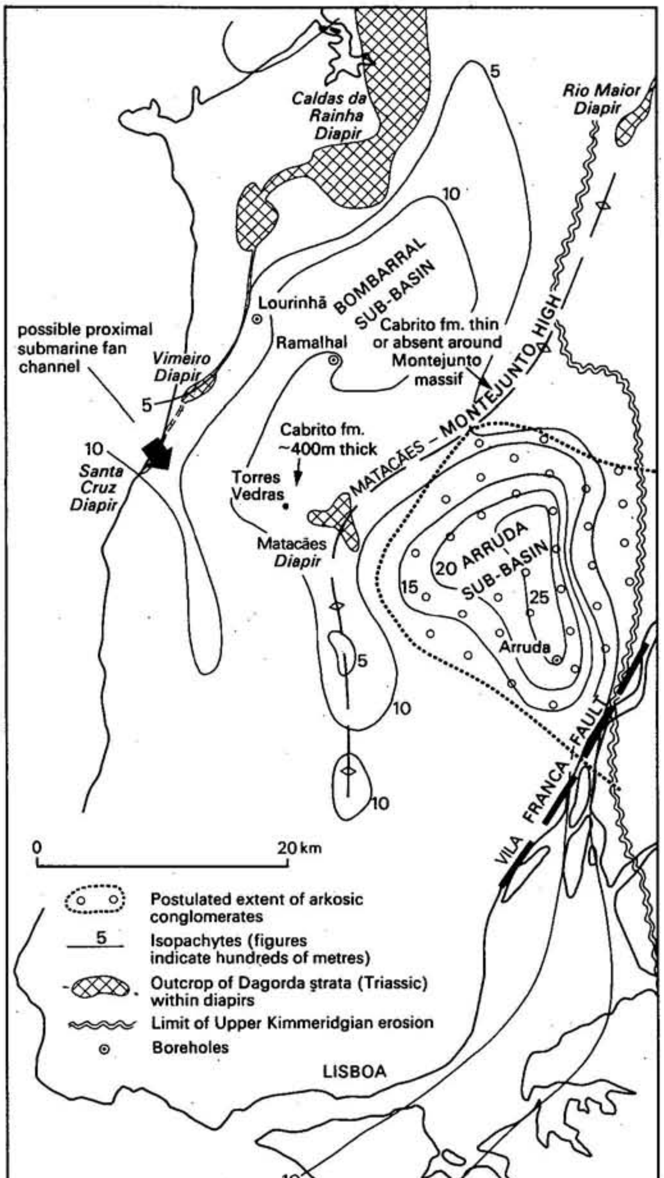


Fig. 8 — Isopachyte map for the Kimmeridgian of the southern part of the Lusitanian Basin, based on P. RICHÉ (1963), with additional information concerning the Cabrito formation from R. MOUTERDE et al. (1973)

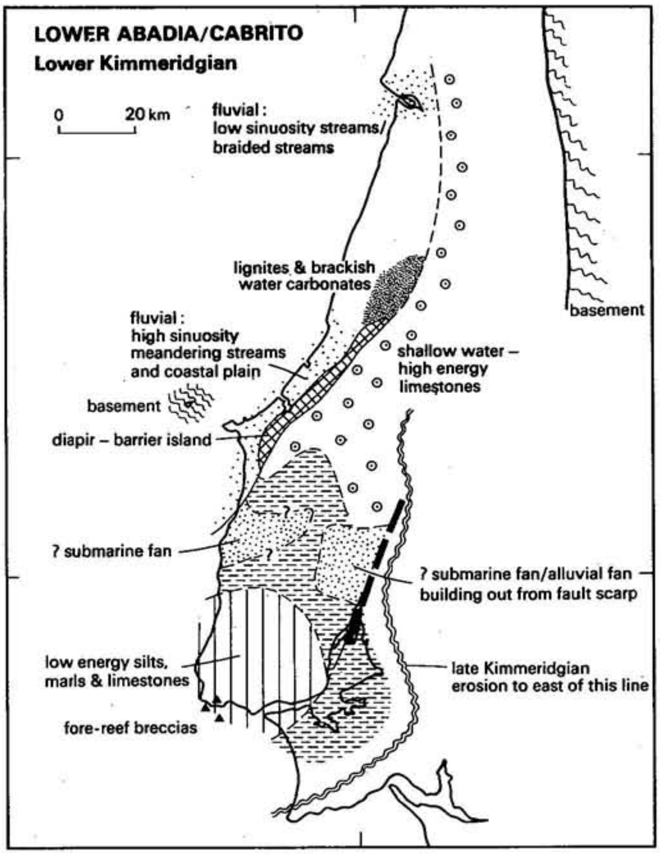


Fig. 9 — Palaeogeographic sketch map for the lower part of the Kimmeridgian, based partly on personal observations, and partly on data from P. RICHÉ (1963)

that the Cabrito formation thins to the east. Such a westerly source could be the proximal submarine fan (and perhaps others like it) postulated earlier in this paper at Santa Cruz.

Figure 9 is a palaeographic sketch map for the Lower Kimmeridgian based largely on the earlier discussion in this paper. Once more, the influence of the Caldas da Rainha diapir-barrier is clearly demonstrated. The development of the reef complex in the south of the Basin may be indicative that it fringed a deep ocean — presumably the newly formed southern North Atlantic. A similar facies, of comparable age, forms the Abenaki carbonate of the Scotian Shelf off eastern Canada (ELIUK, 1978).

Upper Kimmeridgian palaeogeography

Figure 10 is a palaeogeographic sketch for the Upper Kimmeridgian. The slope break discussed earlier is marked by a number of carbonate banks, and the Caldas da Rainha diapir continues as an emergent feature.

Portlandian palaeogeography

No palaeogeographic sketch map is presented for this interval, as the basin north of Santa Cruz and Torres Vedras is dominated by fluvial sediments. Southwards, marine horizons, in the form of nodular bioturbated biomicrites replace the clastics. In the Sintra region, back reef carbonates are developed. During this period, there is no indication that the central region is a relatively more rapidly subsiding depocentre as is the case in the Kimmeridgian.

V. EVOLUTION OF THE LUSITANIAN BASIN

Introduction

The purpose of this section is to summarise the main events in the development of the Lusitanian Basin, to discuss the structural controls of facies distribution and thickness, and to relate the Basin's evolution to events leading to the opening of the Atlantic Ocean.

During the Upper Jurassic, the Lusitanian Basin developed a unique range of facies types and distributions, and subsided at relatively rapid rate (in places in excess of 10 cm per 1000 years), so it seems that this period marks a turning point in its development. Lower and Middle Jurassic palaeographic patterns are quite simple, with, in the Lias, sediments thickening to the north, and shallowest sediments to the south of the Basin (WILSON, 1975b fig. 2B, C). In the latter part of the Middle Jurassic, the pattern changes somewhat, with one depocentre between Cabo Mondego and Peniche, and another to the south, in the Torres Vedras/Montejunto area (RUGET-PERROT, 1961, p. 185).

Main events in the Upper Jurassic

1. *Lower Oxfordian*. To date, no sediments of this age have been proved in the Lusitanian Basin. Thus it is probable that during this interval the area was subjected to general uplift, plus localised elevation over diapiric structures. After this movement, erosion and/or subsidence levelled the area, so that it was approximately at sea level, as demonstrated by the ubiquitous algal marsh facies, and algal marsh-marginal marine facies at the base of the Upper Oxfordian (see fig. 5). Exposed areas of Middle Jurassic (Serra dos Candeeiros) developed a karst topography during this interval.

RAMALHO'S BED NUMBERS, NAME & THICKNESS			AGE	BRIEF DESCRIPTION	SUGGESTED ENVIRONMENT
29	Nodular Limestones	~65m	PORTLANDIAN A	Nodular sparse skeletal wackestones, with occasional oolitic/pelletoidal horizons	BACK REEF LAGOON
25-28	Oncolitic Limestones	~75m	MIDDLE KIMMERIDGIAN – PORTLANDIAN	Coral and algal boundstones,	PATCH REEF
23, 24	Shaley-marly limestones	~115m		Decimetre bedded skeletal wackestones	INTER-REEF, LOW ENERGY
20-22		~150m		Limestones, breccias, with corals; marly intercalations	BACK REEF TALUS
19		~40m		Massive algal boundstone with dispersed corals: algal material contains Birds-eye structures; unit shows possible quaqua – quaversal dip pattern	MAIN REEF MASS
2-18		~180m		Alternation of limestone breccias (containing algal textures and corals) and shaley-marly horizons	PROXIMAL FORE-REEF TALUS
1	Ramalhão Shales	> 10m, total thickness probably ~400m	LOWER – MIDDLE KIMMERIDGIAN	Shales with limestone breccias between 10-50cm thick, with thicker 'slide' units containing blocks up to 3-4m across	DISTAL FORE-REEF TALUS

Table 4 — Preliminary re-interpretation of M. RAMALHO'S (1971) Kimmeridgian-Portlandian section at the northern end of Praia do Guincho, west of Cascais

2. *Upper Oxfordian* (fig. 5 and 6). Deposition was dominated by carbonates, with freshwater and restricted marine facies (Vale Verde Beds and *Pholodomya protei* Beds respectively) confined to the northern part of the Basin, and separated from the freshwater/marginal marine and open marine facies (Cabaços and Montejunto Beds respectively) by a diapir high (shoal or islands — see fig. 5 and 6).

3. *Early Kimmeridgian* (fig. 9). Over most of the basin, the base of the Kimmeridgian is marked by an influx of terrigenous clastic sediments which in many areas, especially around salt diapirs, rest unconformably on Oxfordian or older strata. Subsidence rates increased markedly, and local tectonic structures exerted a strong influence on facies distribution (diapirs at Santa Cruz and Caldas da Rainha, fault at Vila Franca de Xira). The increased subsidence rates were complemented by rapid uplift of source-lands composed of Hercynian basement (as evidenced by the petrography of the sands), thus indicating regional block faulting, with the horst areas supplying sediments to basins developing over graben structures. To the west of Lisbon, the development of a reef complex is recorded by the presence of graded coralgal breccias and sands in the Ramalhão Shales.

4. *Late Kimmeridgian* (fig. 10). This stage is marked by a transgressive phase in which shallow marine (carbonate banks such as the Ota Limestone) and marginal marine (*Lima pseudoalternicosta* Beds) replaced terrigenous clastics. The Caldas da Rainha diapir continued to exert a trong influence over facies type and geometry. In the area to the west of Lisbon, a true reef facies is exposed, overlying fore-reef talus facies. Over 1 km of Kimmeridgian sediments had accumulated over the southern part of the Lusitanian Basin (south of Peniche), and in the Arruda sub-basin, in excess of 2 km accumulated (see fig. 8).

5. *Portlandian*. In the northern part of the Basin (north of Torres Vedras) coarse fluviatile clastics returned, but interfingered southwards with shallow marine carbonates.

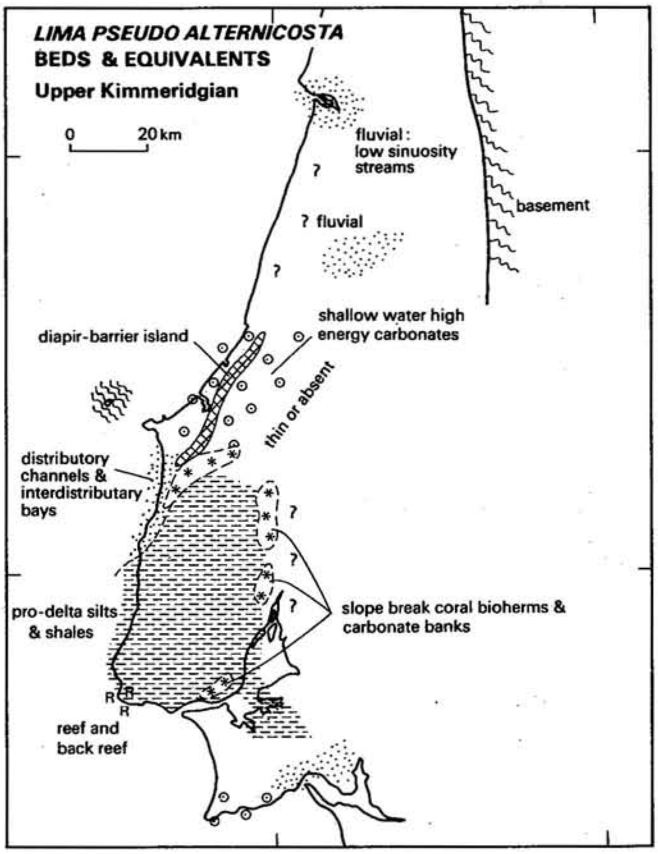


Fig. 10 — Palaeogeographic sketch map for the upper part of the Kimmeridgian (*Lima pseudoalternicosta* Beds and equivalents) based partly on personal observations, and partly on data from P. RICHÉ (1963)

Structural controls on sedimentation during the Uper Jurassic

H. SEIFERT (in both his 1963 publication and in various reports and correspondence now available for inspection at the Serviços Geológicos de Portugal) suggested that during the Upper Jurassic the central, more rapidly subsiding part of the Lusitanian Basin was separated from flanking shelf areas by a «hinge-line» or flexure. Although the results of this study suggest that this is a rather oversimplified picture, there is some support for it in the palaeogeographic sketch maps presented (eg. Seifert's flexure coincides with the limit of the Tojeira formation (fig. 6) and the locations of the coral bioherms and carbonate banks (fig. 10). However, as shown in fig. 8, the central part of the Lusitanian Basin, at least during the late Kimmeridgian, consists of two sub-basins (Arruda, Bombarral). The geometry of these two sub-basins was probably controlled by both contemporaneous diapiric movements (Santa Cruz and Caldas da Rainha diapirs, and the Maceira-Montejunto high) and fault movements (east side of the Arruda sub-basin: the Vila Franca de Xira fault). The generalised NNE-SSW trend of the Santa Cruz-Caldas diapir, the Maceira-Montejunto high, and the Vila Franca fault is comparable to one set of faults in the Hercynian basement to the north (see RIBEIRO et al., 1972). The important NE-SW trending Nazaré fault (see MOUGENOT et al., this volume) appears to have had no influence on Upper Jurassic basin configuration.

The relatively small lateral dimensions of the Arruda sub-basin (about 20 km) and very thick fill of Kimmeridgian sediments, coupled with the rapid facies change from breccias and conglomerates in the south east to finer grained «normal» Abadia facies in the north west is characteristic of basins controlled by wrench tectonics (WILCOX et al., 1973; CROWELL, 1974).

Basin evolution and Atlantic Opening

D. FALVEY (1974) and I. DEIGHTON et al. (1976) have suggested a model for the development of sedimentary basins marginal to oceans widening due to sea floor spreading. They recognise the following stages:

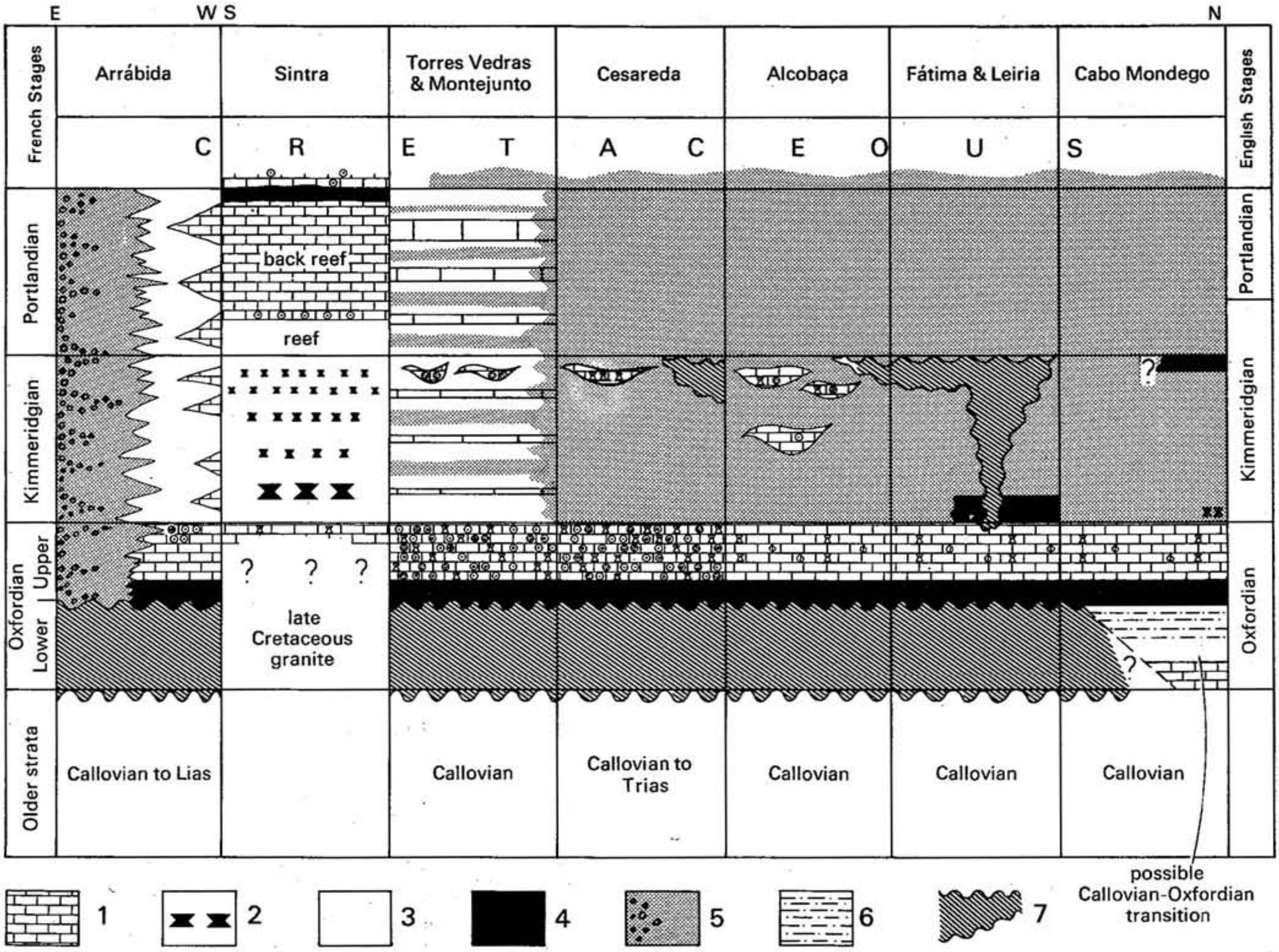


Fig. 11 — Summary chart of the distribution of the main facies types in the Upper Jurassic of the Lusitanian Basin, based on this account.

Key 1 Limestones (for explanation of symbols added to this pattern, see Fig. 2); 2 Fore-reef talus breccias; 3 marine silts, shales and marls; 4 freshwater algal marsh and/or marginal marine facies; 5 terrigenous clastic sandstones and conglomerates; 6 non-marine siltstones (Cabo Mondego only); 7 hiatus (associated with diapiric movements in the Kimmeridgian).

1. Pre-rift intracratonic basin;
2. Initial rift stage sediments, filling both a graben which is the site of future ocean opening, and rifts near the future continental margins;
3. Progradation of sediments, following continental separation, to form a seaward thickening wedge on both continental margins.

Unconformities may separate sediments accumulated during each stage, and are likely to be most marked at the beginning of stage 2 (rift fill sediments).

In terms of this model, the pre-rift intracratonic basin stage spans the Lias and Middle Jurassic (following a probable Triassic phase of rifting which did not lead to ocean opening west of Iberia), with changes in basin form in the Callovian (see WILSON, 1975b) and the pre Upper Oxfordian unconformity being a prelude to the larger movements of the rifting stage that followed. There can be little doubt that the Kimmeridgian of the Lusitanian Basin represents the rift stage in the model outlined above, for it shows accelerated subsidence rates and an abrupt influx of coarse clastic sediments derived from uplifted horsts.

The post break-up progradation phase cannot be identified in the southern part of the Lusitanian Basin, either in the Portlandian, or overlying Lower Cretaceous (judging by the evidence presented by REY, 1972). Thus, though it is probable that the main rifting phase preceding the opening of the Atlantic between Portugal and the Grand Banks occurred in the Kimmeridgian, the evidence afforded by the facies geometry of the southern half of the Lusitanian Basin provides no clues concerning the timing of the commencement of actual continental separation and ocean opening. Research is continuing in an attempt to add more precision to the interpretation of the evolution of the Lusitanian Basin in terms of events in Atlantic opening.

Acknowledgements

The author gratefully acknowledges financial support from the Natural Environment Research Council and the Open University Research Committee. The author thanks Dr. M. M. Ramalho and Dr. J. H. Monteiro for their help in making available various facilities and information at the Serviços Geológicos de Portugal, and John Taylor for preparing the diagrams.

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NOTE ADDED IN PROOF

Recent micropalaeontological and palynological work commissioned by Sceptre Resources Ltd on the sequences exposed in the coastal sections around Santa Cruz suggest a basal Cretaceous (Berriasian) age rather than Kimmeridgian. This result has been confirmed by my colleague John Exton (personal communication). These new dates suggest that a major revision of the late Upper Jurassic and basal Lower Cretaceous may be necessary for at least part of the Lusitanian Basin (as shown in table 1 and figure 11). Similarly palaeogeographic reconstructions presented in this paper (figures 8, 9 and 10) will also need major revision. This new information also suggests that the timing of the major clastic influx may have to be revised upwards from basal Kimmeridgian to basal Lower Cretaceous.

DOCUMENTAÇÃO FOTOGRÁFICA

PLATE 1

Field photographs of the Oxfordian Carbonate sequence south of Cabo Mondego.
Figure quoted in metres refer to the height in the sequence shown in figure 3.

A 39 metres. The hammer rests on a limestone lens packed with *Exogyra*. The surrounding lithology consists of olive coloured massive silty mudstone above the hammer handle occurs a lumachelle with abundant corals and thick shelled bivalves (*Isognomon*). *Inlet facies.*

B 46 metres. The hammer rests on a coarse grained sandstone that overlies, with an erosive contact, silts containing rootlets. The sandstone grades up into evenly laminated and sand lensed silts, and the whole sequence shown grades laterally into thicker coarse grained sandstones surmounted by a lignite seam. *? Back-barrier marsh or river influenced marginal bay facies.*

C 152 metres. Laminated fenestral micrites, with crenulations similar to those in modern sediments described by G. DAVIES (1970). Lighter layers are extremely porous and crumbly in texture, whereas darker layers contain fine laminations (see Plate 2, B and C). Tape is 4.5 cm across. *Algal marsh facies.*

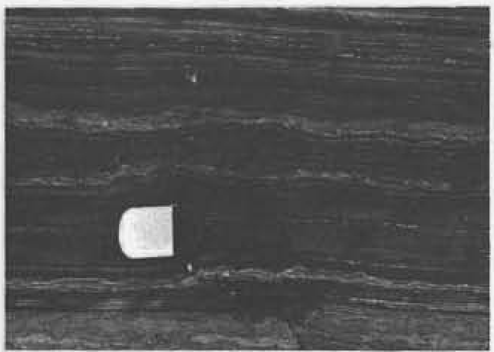
D 158 metres. Massive, slightly laminated cream limestone overlying, and filling dessication craks that penetrate 20 cm down into the underlying dark laminated limestones. *Algal marsh facies.*

E 146 metres. Breccia containing limestone blocks up to one metre across. The lithologies of these blocks match those in the surrounding sequence. Lack of any significant amounts of pseudomorphs after evaporite minerals argues against the breccias being produced by evaporite mineral solution, and so a basal channel deposit is suggested, derived by the collapse of a channel wall. *Algal marsh facies.*

F 260 metres approx. Typical lower bedding surface within the bioturbated biomicrites of the *Pholadomya protei* Beds. In the upper part of the photograph, complete articulated *Gervillia* tests may be seen; in the lower part burrow fills (*Thalassinoides* type) are visible. *Open bay facies.*

A

B



C

D

E

F

PLATE 2

Photomicrographs of the Oxfordian algal marsh sequence South of Cabo Mondego.

A Bioturbated micrite, with empty mould of small Cerithid gastropod in lower part, and flattened burrow in upper part. 158 metres.

B Laminated micrite containing calcite pseudomorphs after gypsum. 139 metres.

C Detail of millimetre lamination, showing ostracod rich layers alternating with micrite layers. 148 metres.

D Two *Chara* oogonians, inbetween which is a partially open articulated ostracod test half filled with micrite. The micrite matrix contains scattered ostracod tests. 152 metres.

E A sediment largely consisting of *Chara* stems, between which micrite occurs. The clusters of oval holes (white) are sections through the nodes of the *Chara* stems. 143 metres.

PLATE 2

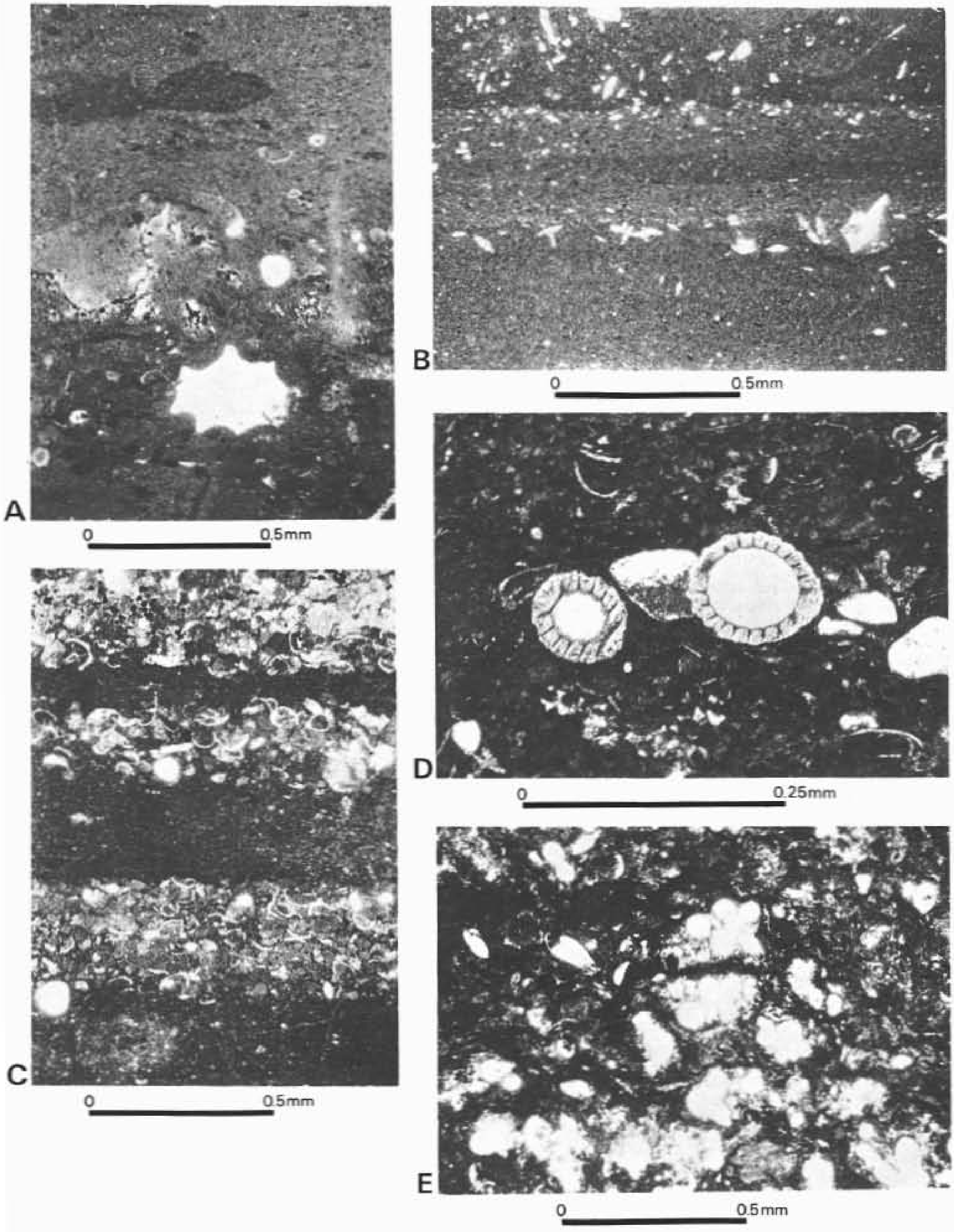


PLATE 3

Features of Kimmeridgian sediments of the Lusitanian Basin

A Cliff section in Abadia beds to the north west of S. Martinho do Porto (for approximate position in succession, see Column 4 of Figure 4). The sequence consists of alternating red medium to coarse sandstones and fine sandstones/silts, capped by relatively soft green silts without any sandstone bands. A prominent sandstone unit one third of the distance up the cliff shows good large scale cross bedding traversing its entire thickness; this was produced by lateral accretion of a point bar deposit of a low sinuosity river channel. The sequence above and below was formed as a flood plain deposit.

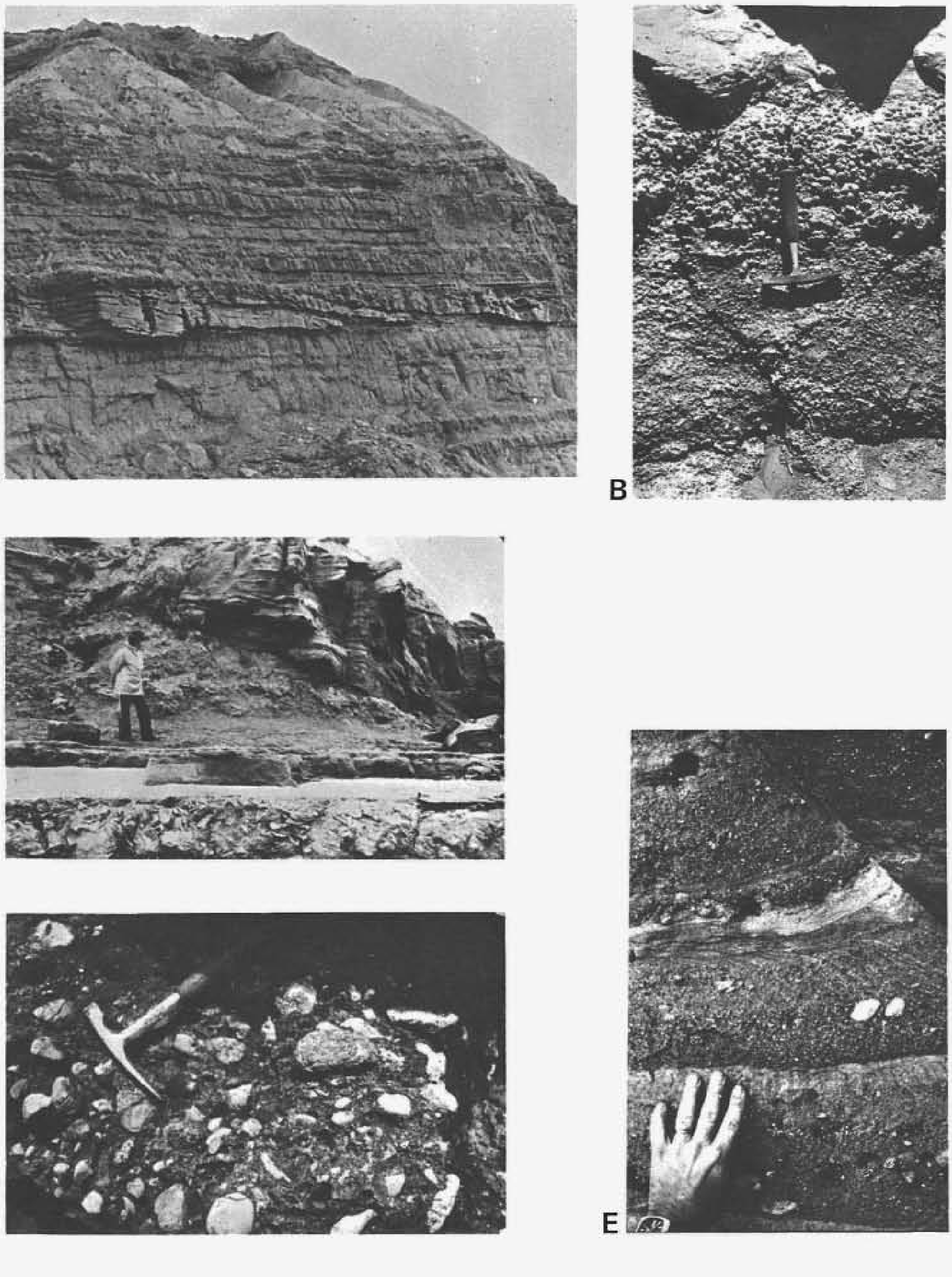
B Coarsening up sequence of pisolites exposed near the top of sequence shown in Figure 4 (at 485 m). Such pisolitic horizons are characteristic of carbonate sediments formed around the Caldas da Rainha diapir — barrier island during the late Kimmeridgian.

C The *Isognomon* shell bed at the bottom of the photograph is Key Bed C (TRZESNIOWSKI and SEIFERT, 1958) situated at the base of facies *iii*) shown in Figure 7. Above it occur silts with fossil carbonate soil horizon (caliche), which is truncated on the right of the photograph by a channel sandstone. At this locality (on the coast midway between Lourinhã and Porto Novo) facies *iii*) contains sandstones (such as that illustrated) similar to those that occur in facies *ii*).

D Polymictic conglomerate of facies *iv*) (see Fig. 7) exposed on the beach at Santa Cruz. The pebbles and cobbles consist of granites, phyllites, quartzite and vein quartz.

E Characteristic graded (fining up) sandstones of facies *iv*) (see Fig. 7), containing pebbles «floating» in the sand matrix. This texture is characteristic of grain flow deposits; exposed in the sea cliffs at Santa Cruz.

PLATE 3



A B C D E