English version of:

*Profil **6**: 1-207; 174 Abb.; Stuttgart 1994*

Karbonatplattformen und Korallenriffe innerhalb siliziklastischer Sedimentationsbereiche (Oberjura, Lusitanisches Becken, Portugal)

Carbonate Platforms and Coral Reefs within a Siliciclastic Setting (Upper Jurassic, Lusitanian Basin, Portugal)

REINHOLD R. LEINFELDER, STUTTGART*

The original monograph cited above is written in german language, but includes chapter summaries and figure/table captions in english language. This document provides these english parts of the monograph.

ABSTRACT

During the Late Jurassic, the Lusitanian Basin of Portugal experienced an intensive rifting phase which caused pronounced bathymetric and, hence, facies differentiation. Particularly during the Kimmeridgian and Tithonian, siliciclastics were fed into the basin, resulting in a mixed carbonate-siliciclastic basin fill. Carbonate platforms and isolated coraliferous reefs of different dimensions and composition frequently developed within this setting.

A shallow-water carbonate platform exhibiting distinct facies zonation is represented by the narrow Ota Platform (Kimmeridgian). The buildup exhibits an aggradational architecture and is rimmed by a high-energy, high-diversity coral reef. In contrast to most other Upper Jurassic high-energy reefs, the Ota coral reef contains abundant microbial and algal crusts. This was due to the achievment of equilibrium conditions between production and export of debris, which can be explained by the existence of a tectonically caused, steep by-pass margin. Sedimentation in interior platform settings is mostly characterised by stacked, autocyclic, small-scale shallowing-up sequences. The narrow Ota buildup developed over a basement horst and was protected from surrounding siliciclastics by its elevated position and a strong longshore current.

The Castanheira slope-type fan delta (Kimmeridgian) also formed at the strike-slip margin of a continental pull-apart subbasin. The fan sediments are dominated by coarse arcosic conglomerates. Coral-microbial reefs grew on deactivated fan areas during two phases of relative sea-level rise. Collapse events in the course of sea level falls led to resedimentation of allochthonous limestones in more distal fan areas.

During transgressive phases coral biostromes and ooid bars developed on top of a fine-grained siliciclastic slope system which formed coevally with parts of the Ota Platform and

* Adresse des Verfassers:
Prof. Dr. Reinhold R. Leinfelder, Institut für Geologie und Paläontologie der Universität, Herdweg 51, D-70174 Stuttgart, Germany; Fax **49/121-1341

the Castanheira Fan (Kimmeridgian Amaral-Abadia ramp system). The Alrota patch reefs (Tithonian), the Caldas-Bolhos carbonate unit (Kimmeridgian) and other structures also developed within siliciclastic settings. Diversity of coral faunas decreased where elevated sedimentation rates occurred. Functional parameters such as number of septae, calical type and general growth form of corals, as well as incrustation rates enable to estimate the rate of sedimentation.

Comparison with carbonate buildups developing distant from siliciclastic influence (Montejunto Platform, Oxfordian; Sintra Ramp, Kimmeridgian to Tithonian) shows that carbonate production and faunal diversity within siliciclastic settings need not be inhibited, as long as efficient siliciclastic fences and traps are active (e.g. rising salt diapirs, structural highs, subsidence traps, longshore currents, oolite filters). Relative sea-level rise additionally facilitates the growth of reefs and carbonate platforms. However, it is not a general necessity for carbonate production within siliciclastic settings. Well adapted corals may produce carbonate structures even directly within a terrigeneous environment.

The Upper Jurassic mixed carbonate-siliciclastic sediments of the Lusitanian Basin are characterised by rapid facies transitions. Third-order sea-level changes only modified the principal depositional systems rather than entirely changing them. These principal systems (particularly siliciclastic prograding slope, siliciclastic fan, carbonate platforms) were determined by pre- and synsedimentary rift tectonics and persisted over several third-order sea-level cycles. Oil plays were common within the Jurassic of the basin, although former fossil fuels were largely destroyed by later inversions and subsequent microbial decay.

The analysis of the architecture of Upper Jurassic deposits in the Lusitanian Basin shows the complexity of such ocean marginal basins, most of which today represent poorly accessible offshore basins. The interpretation of factors leading to the development of carbonate platforms and coral reefs within a dominantly siliciclastic realm is a powerful tool for reconstructing basin development and for assessing hydrocarbon potential.

Please note: This study also includes figure labelling, figure captions and ca. 8 pages of chapter summaries (see table of contents) in english language.

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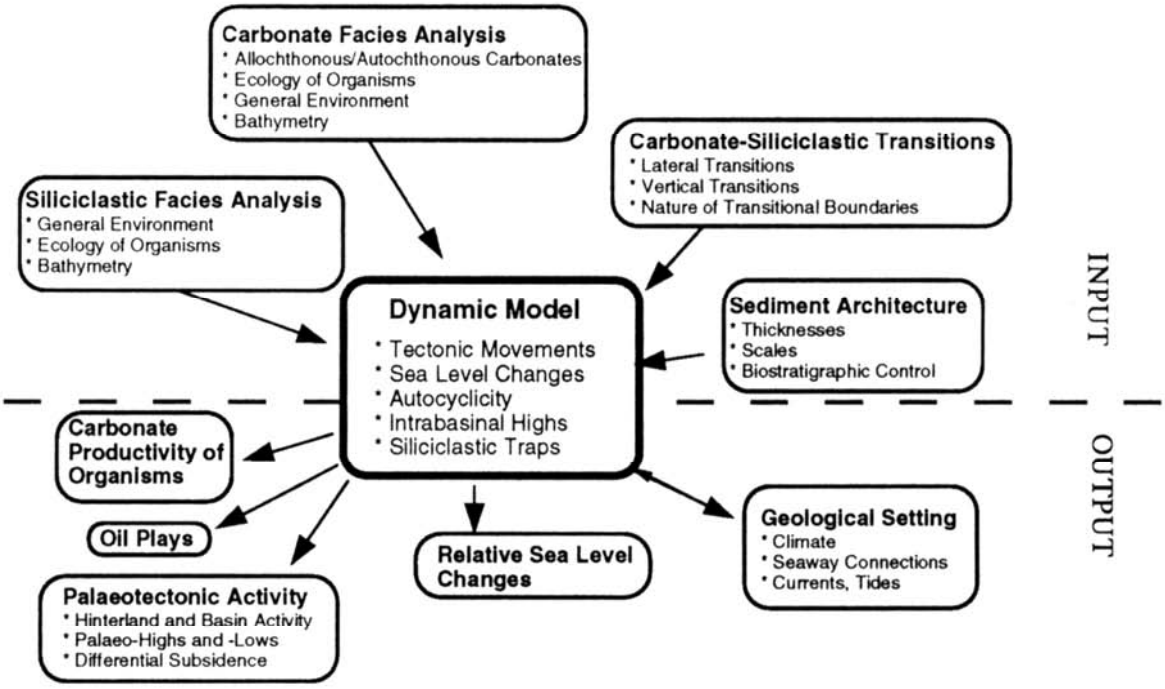
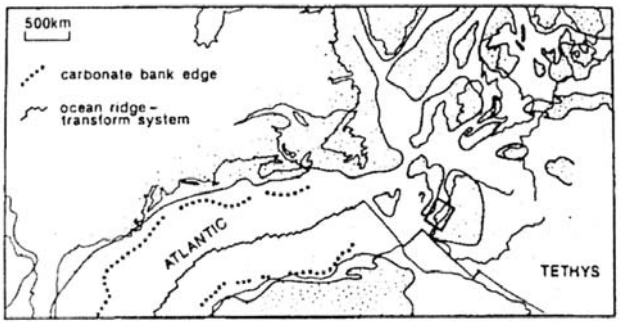


Fig. 1: The great potential of mixed carbonate-siliciclastic successions as a sensitive recorder of palaeostructuration and palaeo-environmental change.



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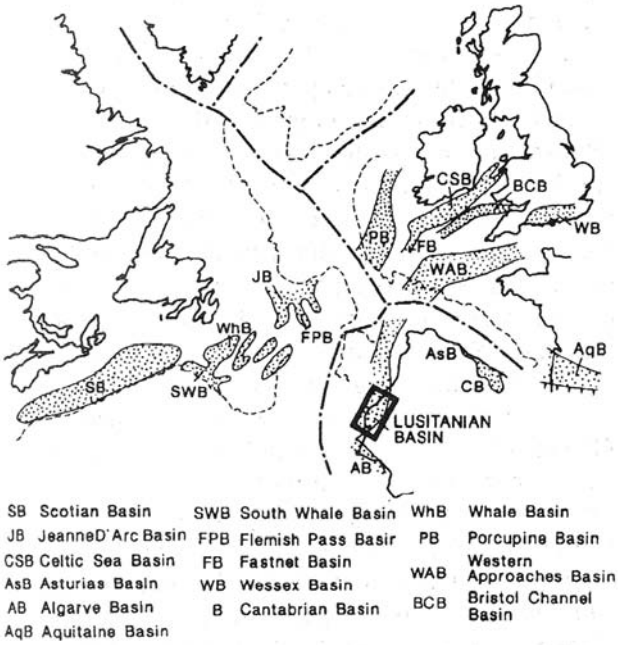

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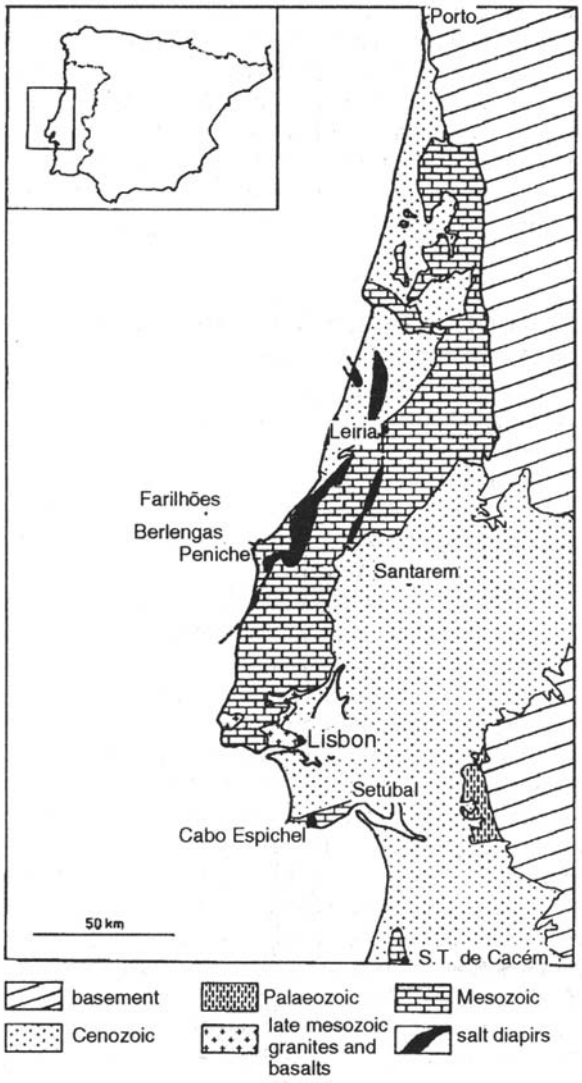

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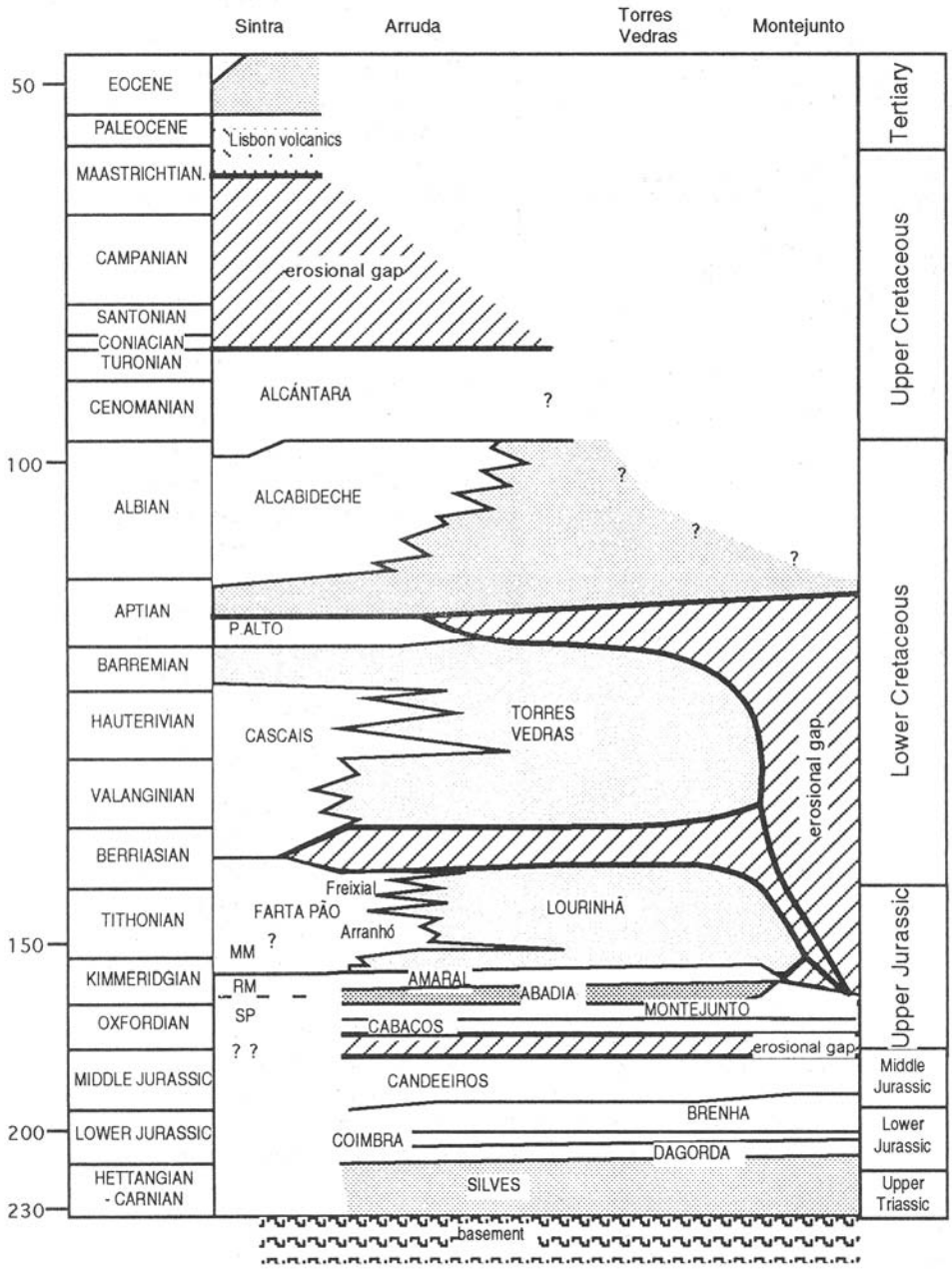

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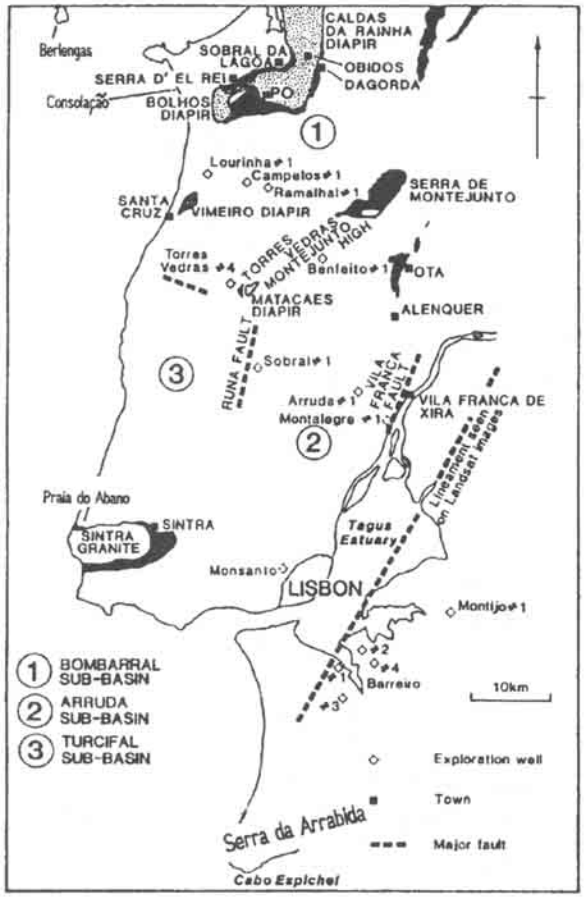

Fig. 5: Map of the central part of the Lusitanian Basin showing principal structural elements and sites (after WILSON et al. 1989, ELLIS et al. 1990). Black: outcrops of Upper Oxfordian and Kimmeridgian carbonate platforms. Dotted: Dagorda Formation. See Figs. 6, 117, 151 for location of additional smaller buildups and reefs.

1.4 Chapter summary: Introduction

Since the last century the Upper Jurassic of the Lusitanian Basin, situated in west-central Portugal, is studied for its rich fauna and its great diversity of sediment types. Coral reefs and carbonate platforms deserve a special interest, since they are perfect, mostly well exposed examples for the analysis of the sedimentary and faunistic pattern of small to large-scaled buildups and platforms. Interestingly, most of them grew in a setting dominated by siliciclastics. Hence, the study of these structures should contribute to the knowledge of (1) the sedimentology, ecology and controlling factors of Upper Jurassic coral-dominated reefs, (2) the structure, architecture, and origin of medium-sized Phanerozoic carbonate platforms, and (3) factors and control mechanisms allowing for penecontemporaneous siliciclastic and carbonate sedimentation.

The Lusitanian Basin is a Mesozoic Atlantic ocean marginal basin which, unlike most other Atlantic marginal basins, is exposed onshore. This is due to later inversion tectonics in the course of Alpine-Mediterranean compression. The character of the basin fill may, therefore, serve as a model for similar, yet less accessible offshore basins. The sedimentary and structural development of the Lusitanian Basin can be described by four tectono-sedimentary megasequences, each of which is terminated by major subaerial erosional unconformities. Megasequence 1 spans Upper Triassic to Callovian sediments. It comprises sediments of the initial rift phase (red beds, volcanics, evaporites) and the subsequent sagging phase (ramp-type carbonates, basinal marl-limestone successions). Megasequence 2 encompasses Oxfordian to Berriasian sediments and characterises a second, strike-slip dominated, rift phase of the basin, including the development of subbasins, and the more passive infill of the newly created basin morphology. Sediments are highly differentiated and include siliciclastic and carbonate deep-water to very shallow, marginal marine to lacustrine sediments, as well as an enormous amount of terrestrial red beds. Both source and reservoir rocks are frequent within this sequence. Megasequences 3 and 4 comprise sediments from the Valanginian to the Turonian, and show again a more simple facies patterns, with red beds to the North passing into shallow marine sediments towards south. The rest of the basin is filled up by sediments of Late Cretaceous to Miocene age, most of which were eroded after inversion, which largely occurred during the Miocene. A more complete record of basin development (in english language) is given by LEINFELDER & WILSON (1989) and WILSON et al. (1989).

The reefs and carbonate buildups analysed in this study grew during, or directly after, the rift peak of megasequence 2, which explains the highly differentiated morphology of the basin and the penecontemporaneous occurrence of carbonate and siliciclastic sedimentation.

2 THE OTA-PLATTFORM – A MODERN REEF COMPLEX IN THE UPPER JURASSIC

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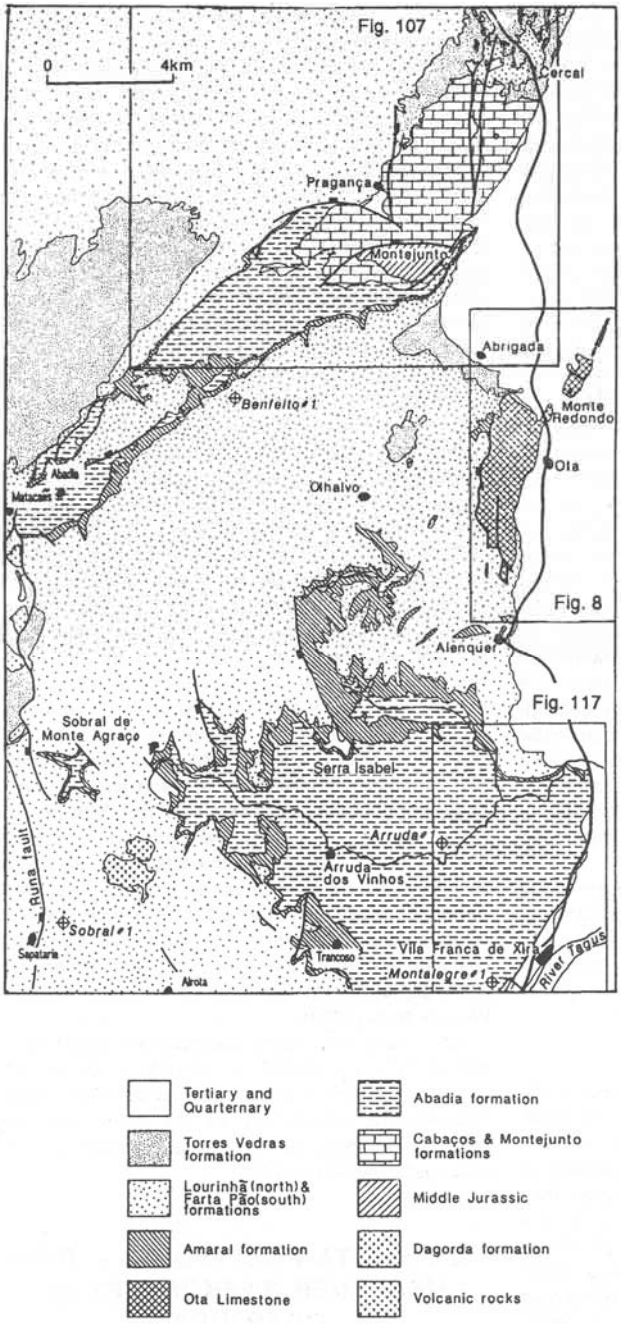
FIGURES



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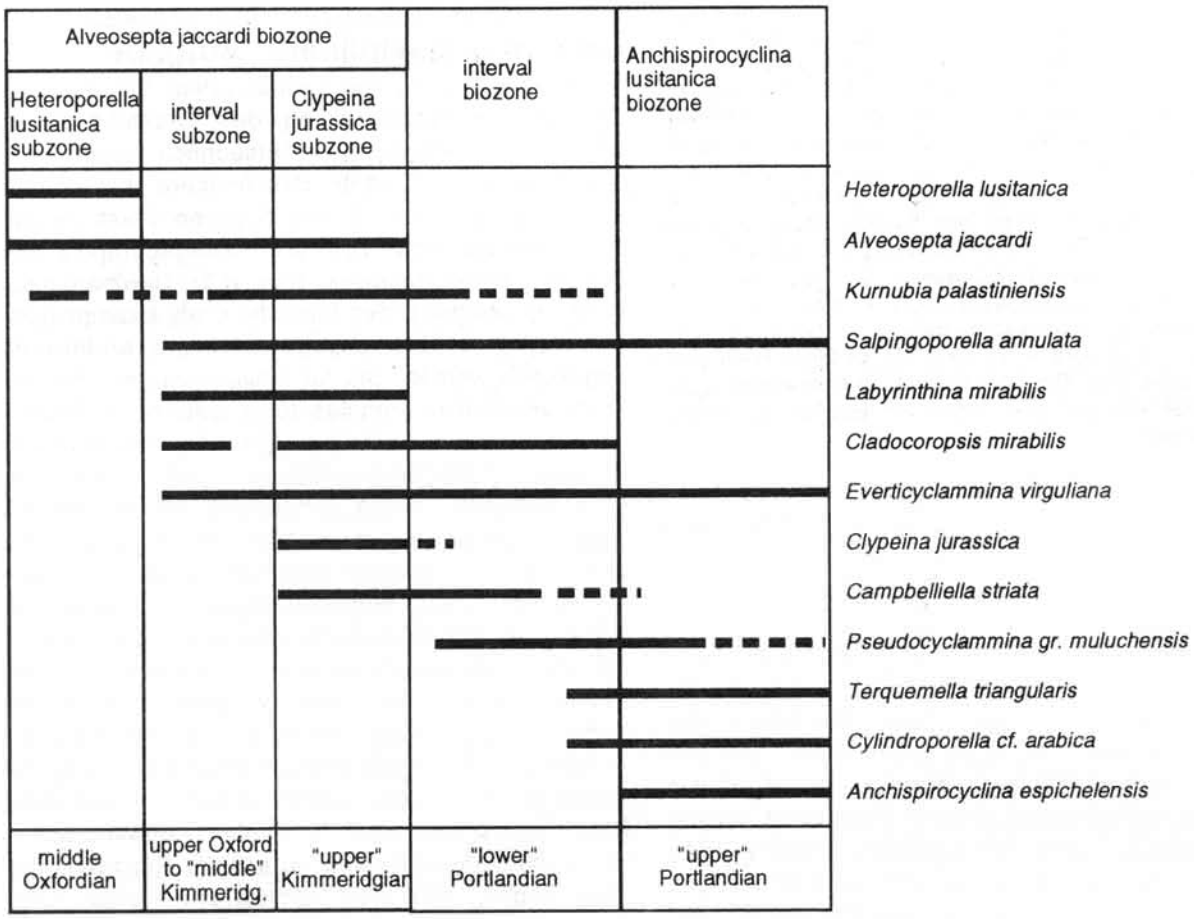

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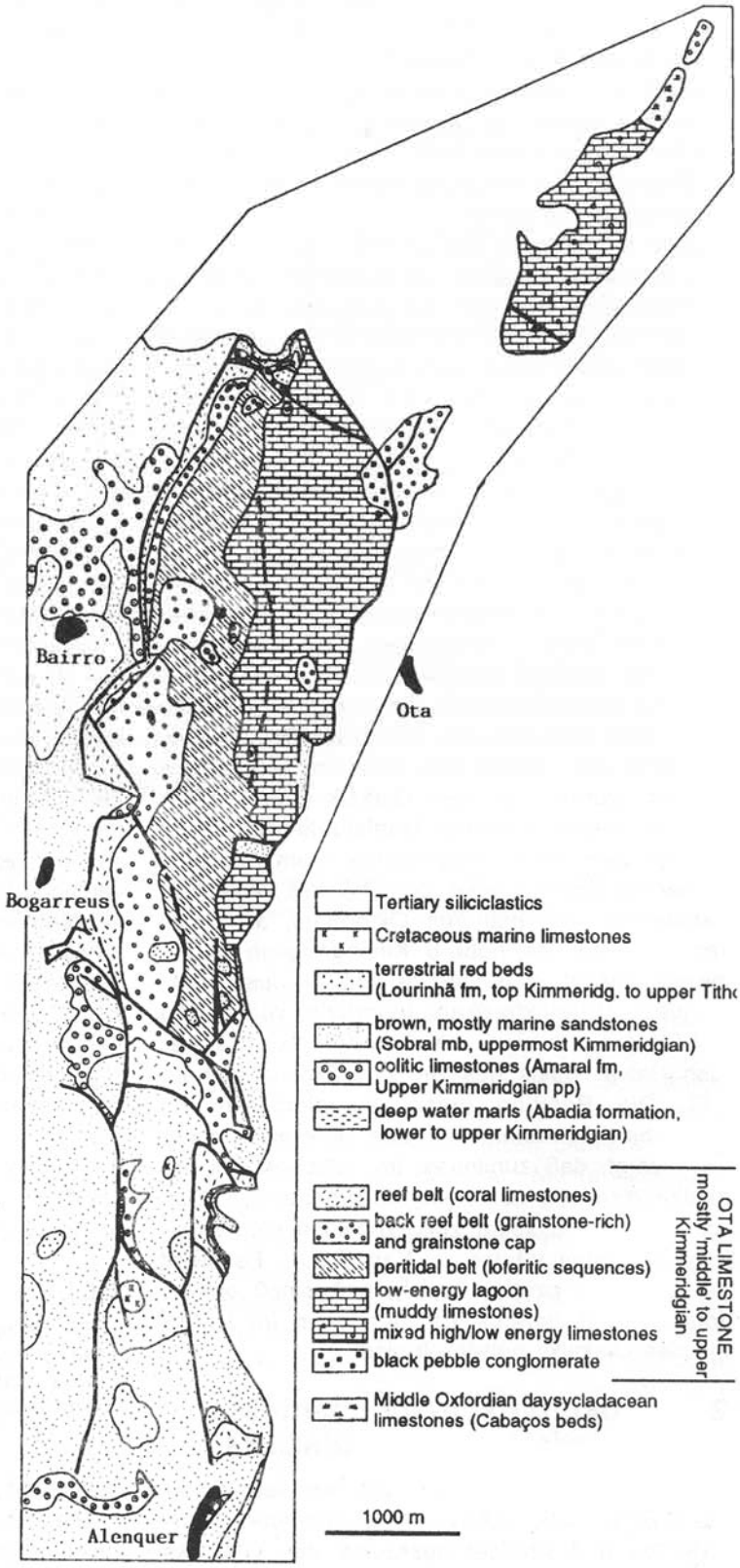

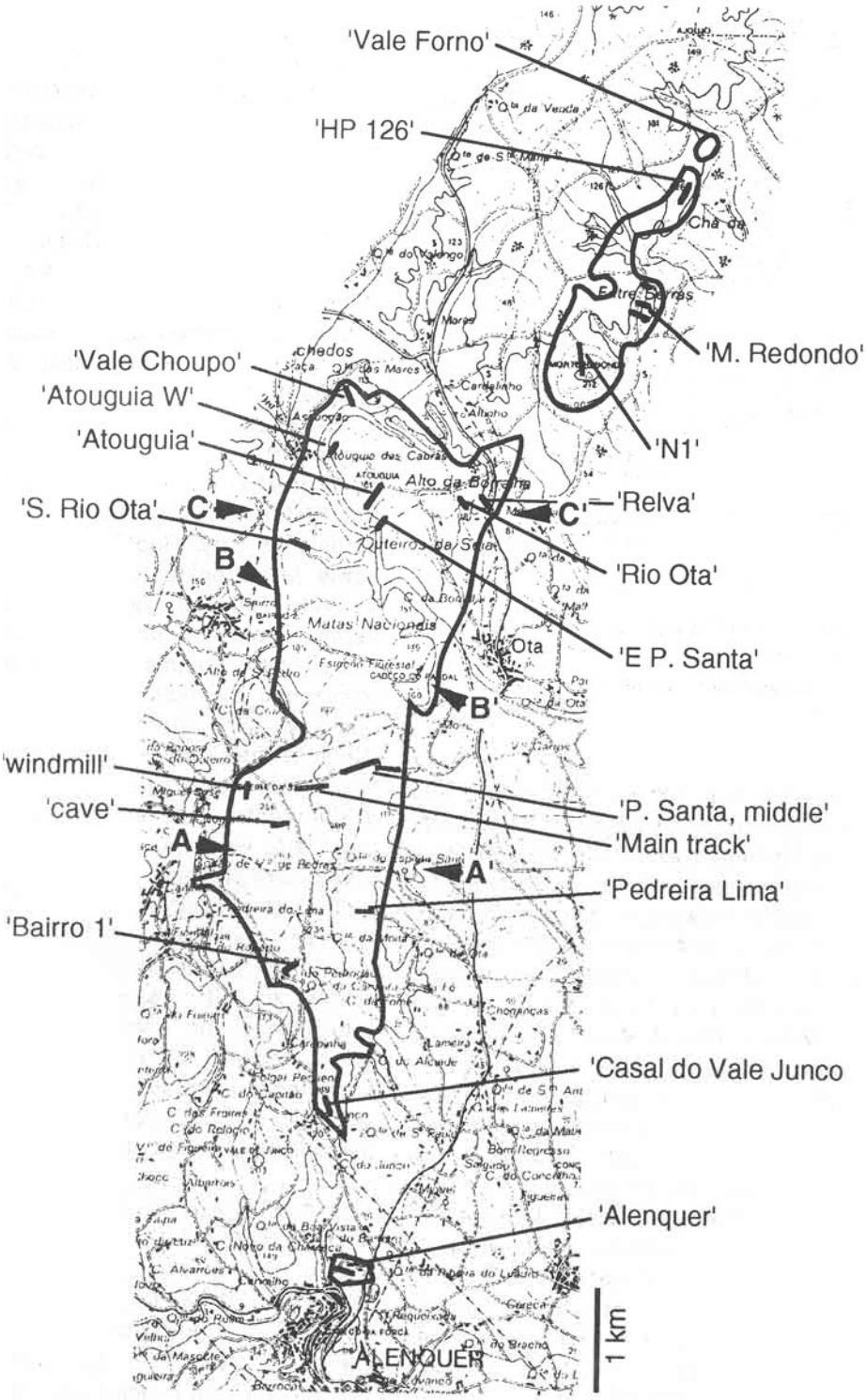
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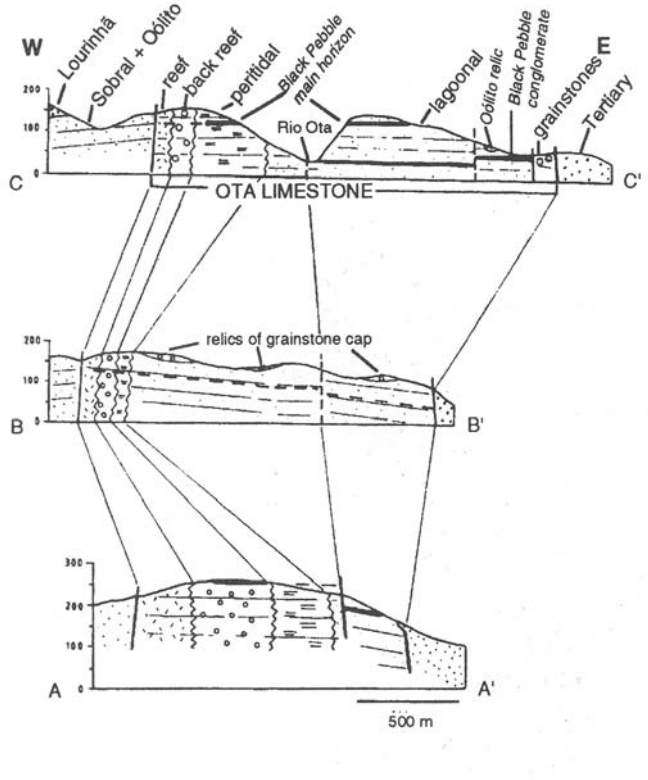

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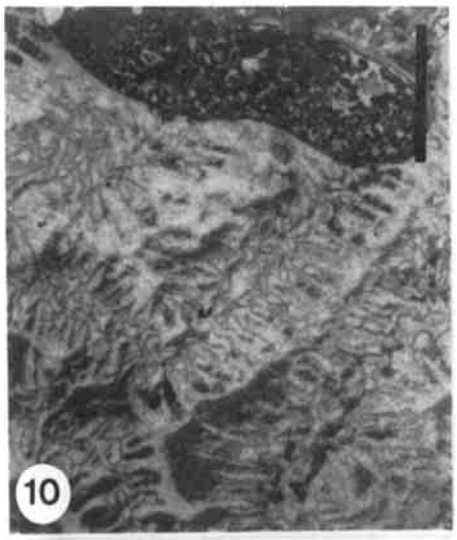
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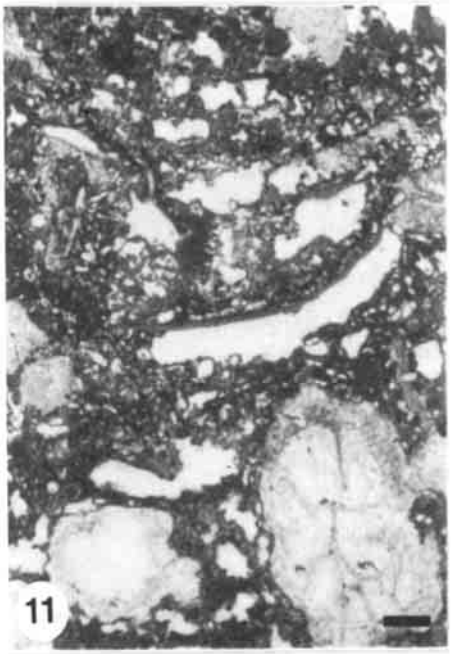
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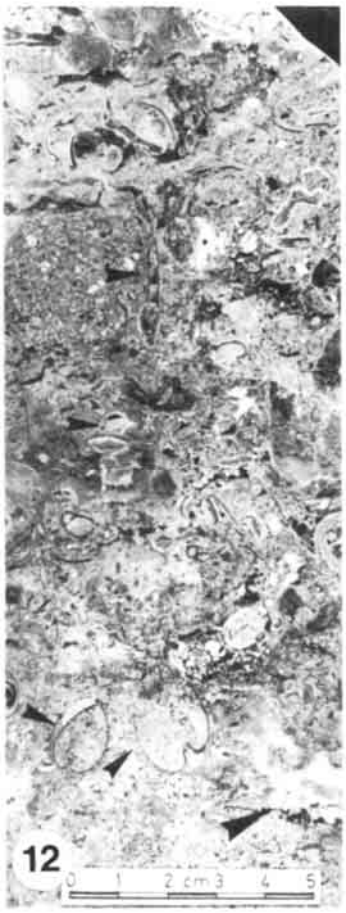
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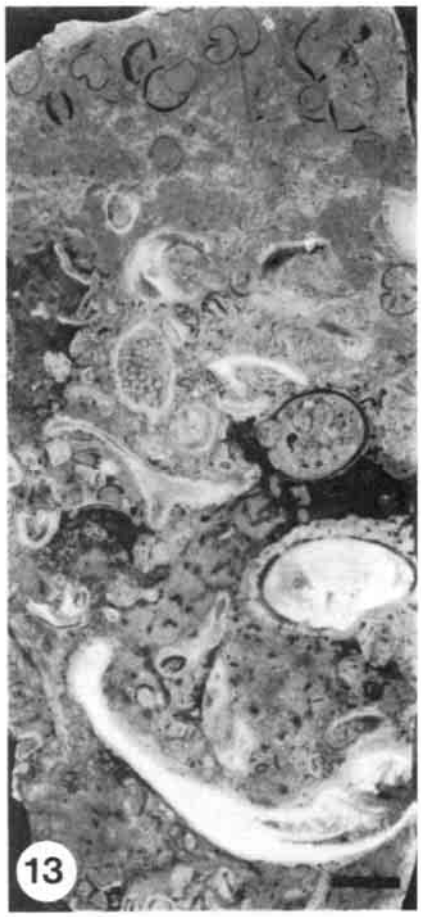
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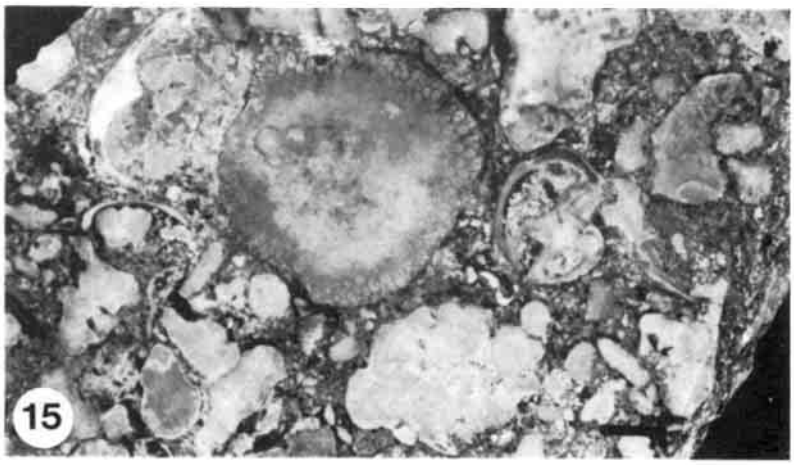
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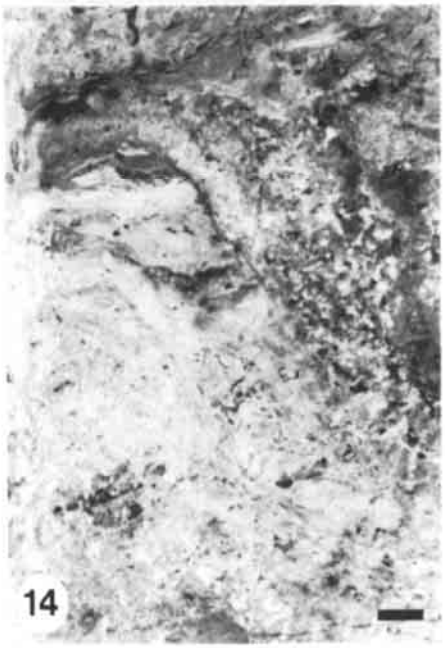
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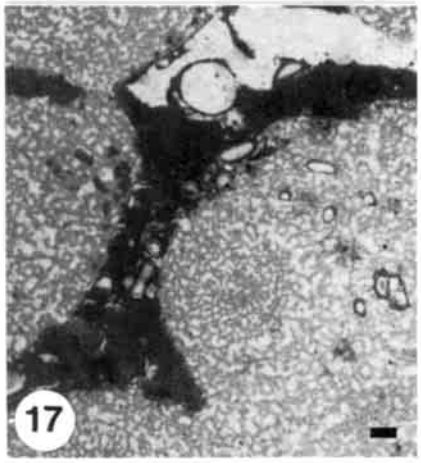
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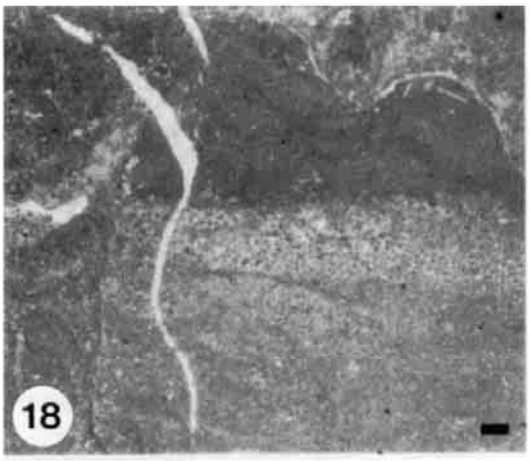
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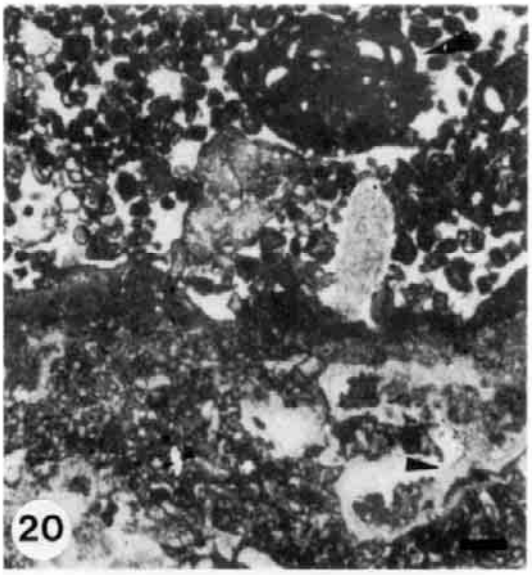
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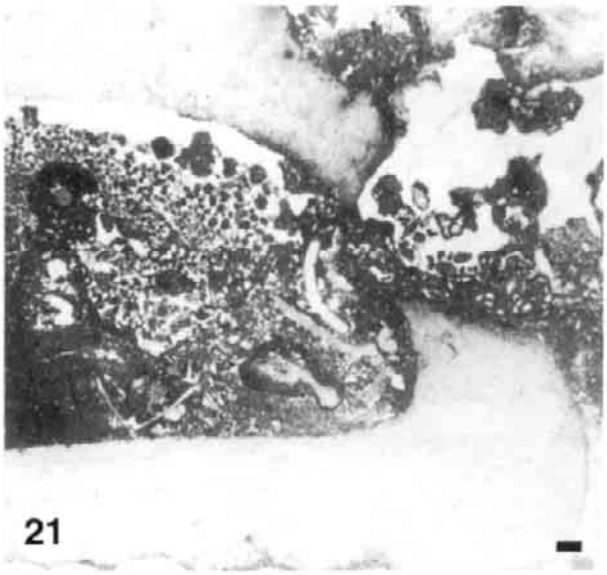
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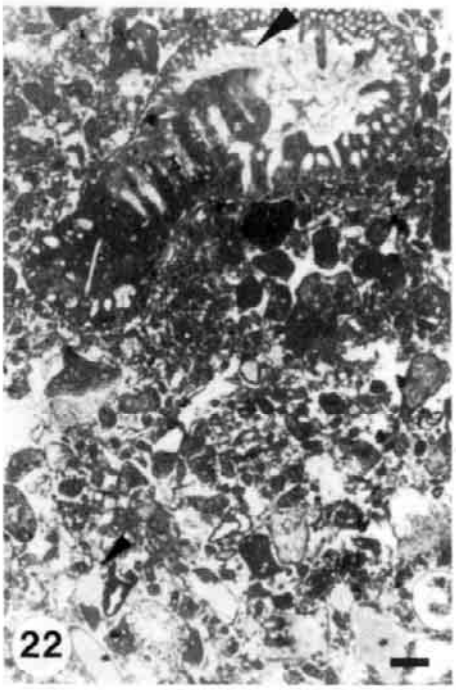
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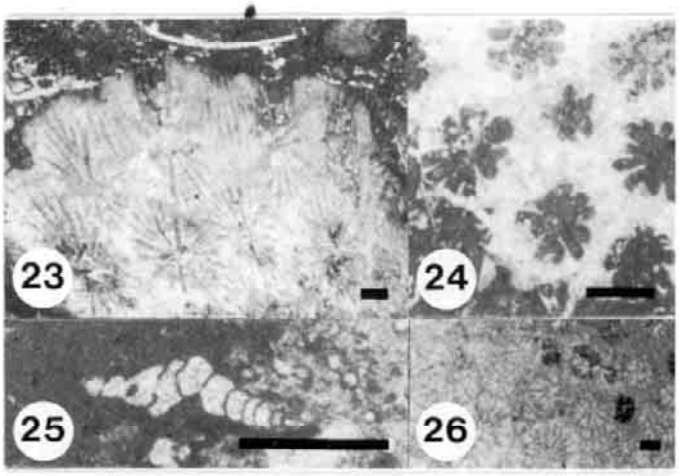
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Figs. 18-27: Organisms and sediments from the Ota Reef (2). length of bar 1 mm, otherwise indicated)

Fig. 18: Microbial, partly peloidal crusts, with domal upwards growth in top part.

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Fig. 26: The coral *Stylina* cf. *decipiens*

Fig. 27: Very poorly preserved ammonite within bindstone. Arrow indicates septal folding.

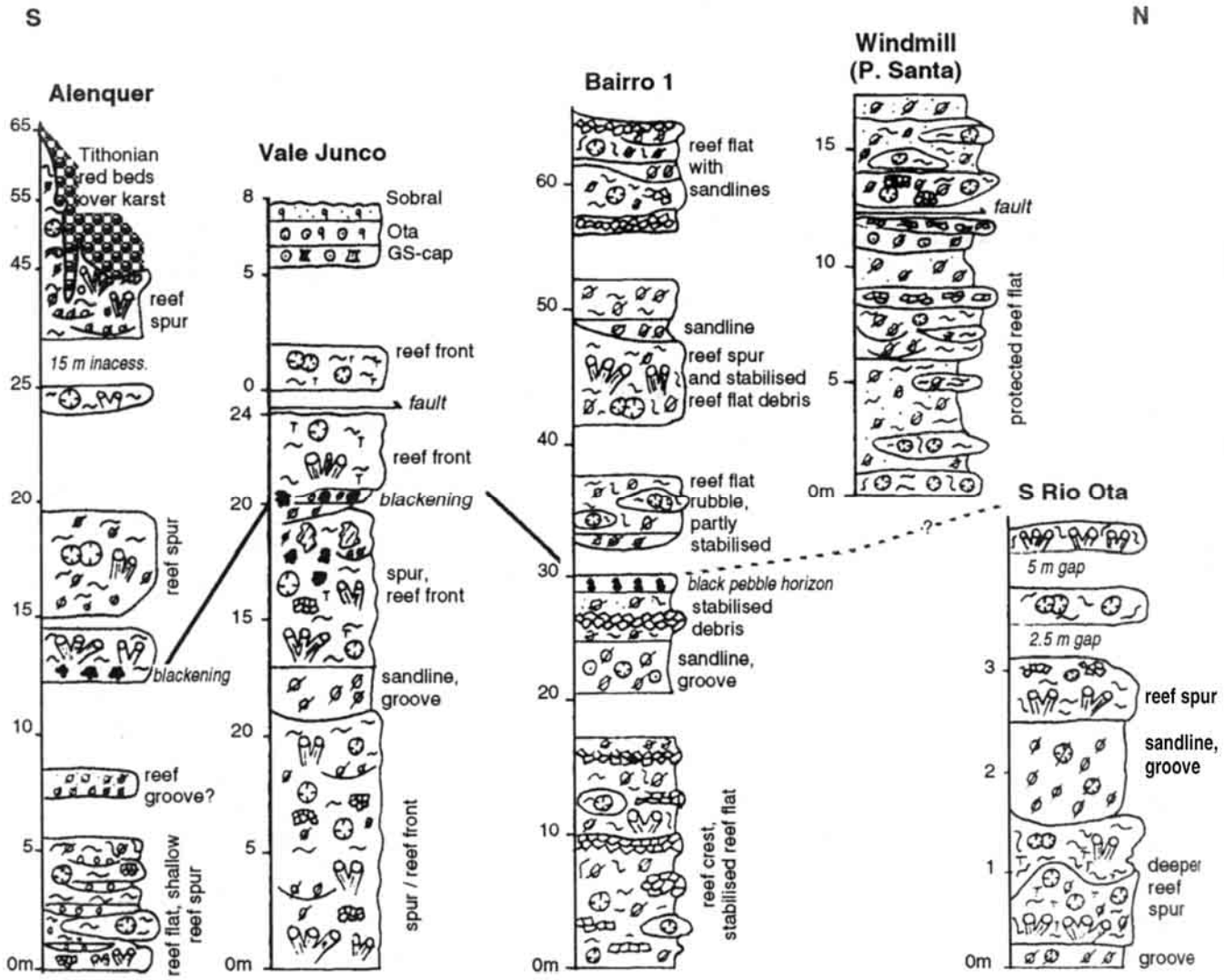

Fig. 28: Simplified lithological profiles from the marginal reef belt of the Ota-Platform. For location see Fig. 8 (for detailed logs see LEINFELDER 1992).

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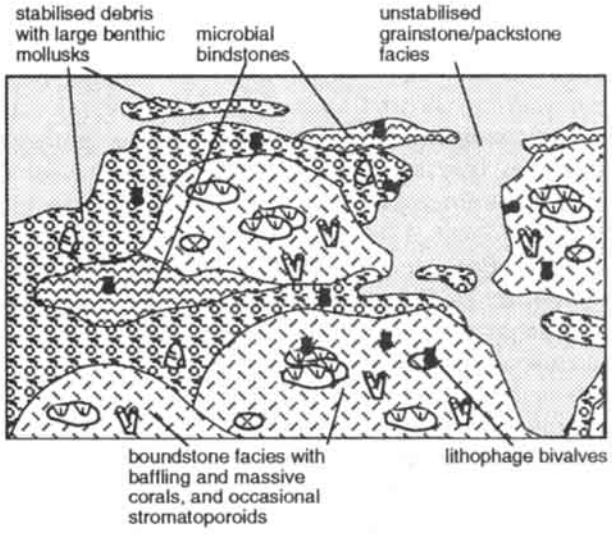

Fig. 29: Summary sketch diagram illustrating the inter-fingering of facies types in the southern part of the reef zone. A scale bar is not given, as the variations shown may occur across widths ranging from one to ten metres (from LEINFELDER 1992, modified).

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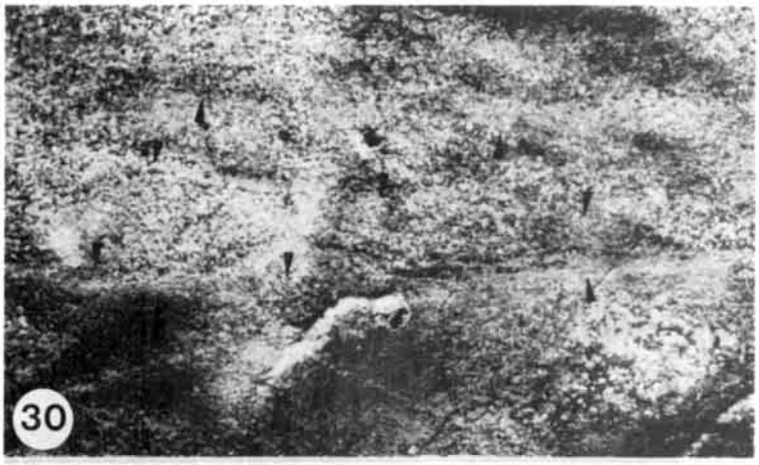
Fig. 36: Algal clast - peloid grainstone, with small keystone vugs. Length of bar is 1 mm.

Fig. 37: Well sorted peloid grainstone. Length of bar is 1 mm.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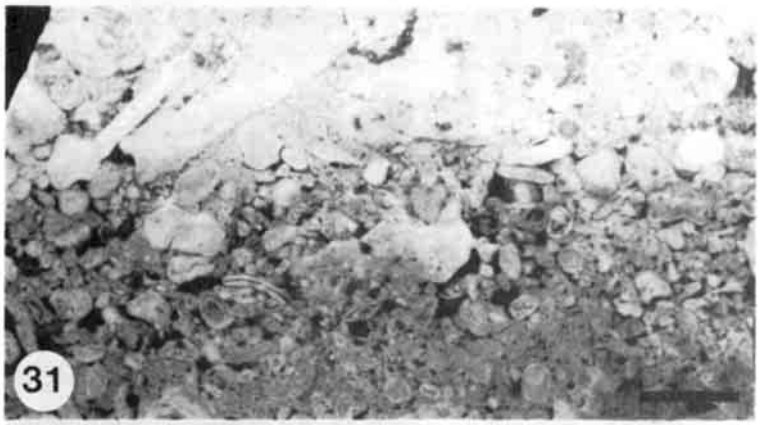
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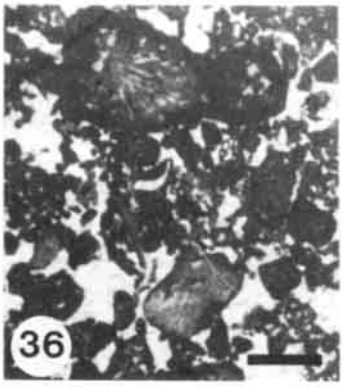
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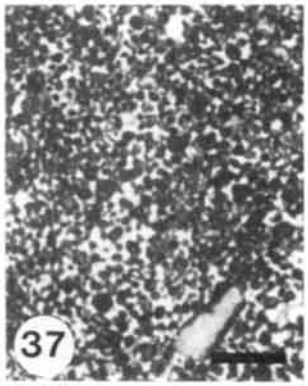
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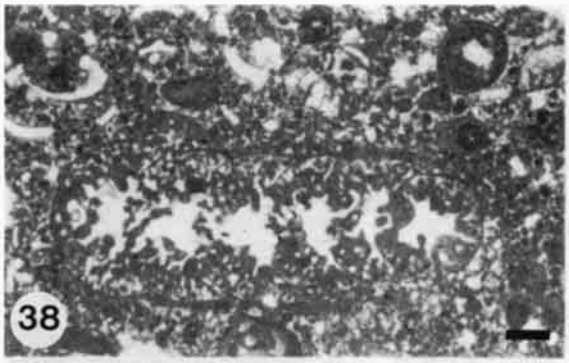
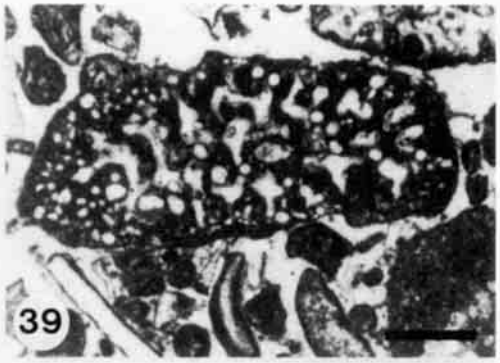
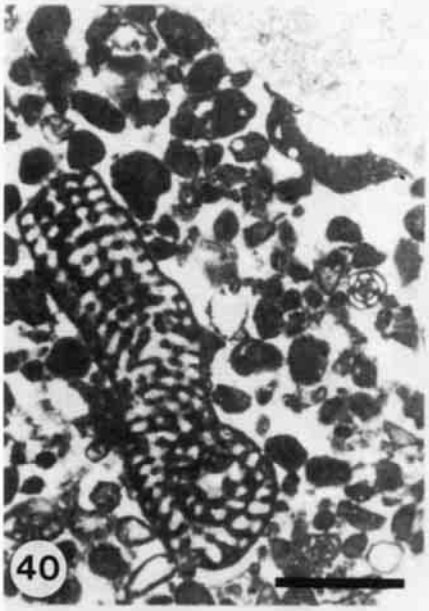
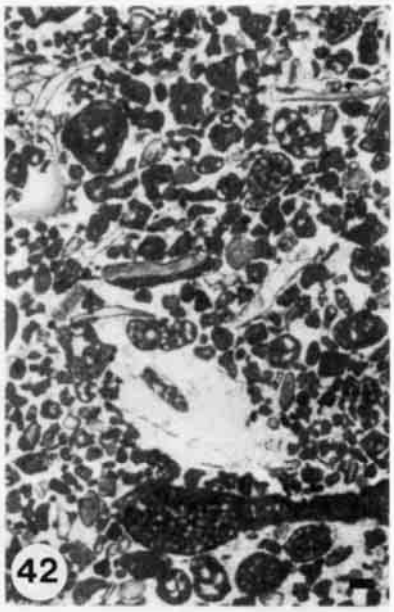
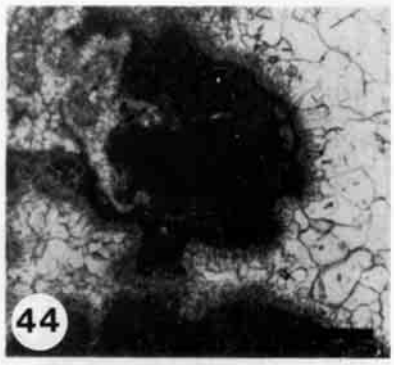
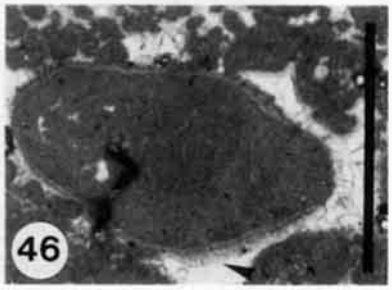












Figs. 38-46: Micro-organisms from the Ota reef and back reef belt. Cements from the back reef belt (44-46) (Balkenlänge 1 mm. Schliffe und Folienabzüge)

Fig 38: the foraminifera *Otaina magna*.

Fig. 39: Algal or foraminifera-like microproblematicum. Wall structure is similar to some *Lithocodium* crust from the Ota reef.

Fig. 40: The foraminifer *Labyrinthina mirabilis* within peloid bioclast grainstone from reef groove facies. Right: *Quinqueloculina*-type miliolid; upper right: echinoderm clast with *Placopsilina*.

Fig. 41: The foraminifer *Trocholina elongata*.

Fig. 42: *Labyrinthina* intraclast grainstone from the back reef zone.

Fig. 43: The dasyclad *Petrascula bursiformis* with cortoid rim, from the back reef zone.

Fig. 44: Relics of submarine fibrous cement, overgrown by meteoric phreatic dog-tooth cement. Blocky spar as last generation.

Fig. 45: Vadose dripstone cement in oncoid bioclast intraclast grainstone.

Fig. 46: Intraclast, overgrown by thin (submarine?) fibrous cement, followed by fibrous dripstone cement (arrow). Vadose beach rock cementation.

for additional plate-figures of organisms and sediments from the Ota Reef see LEINFELDER 1992).

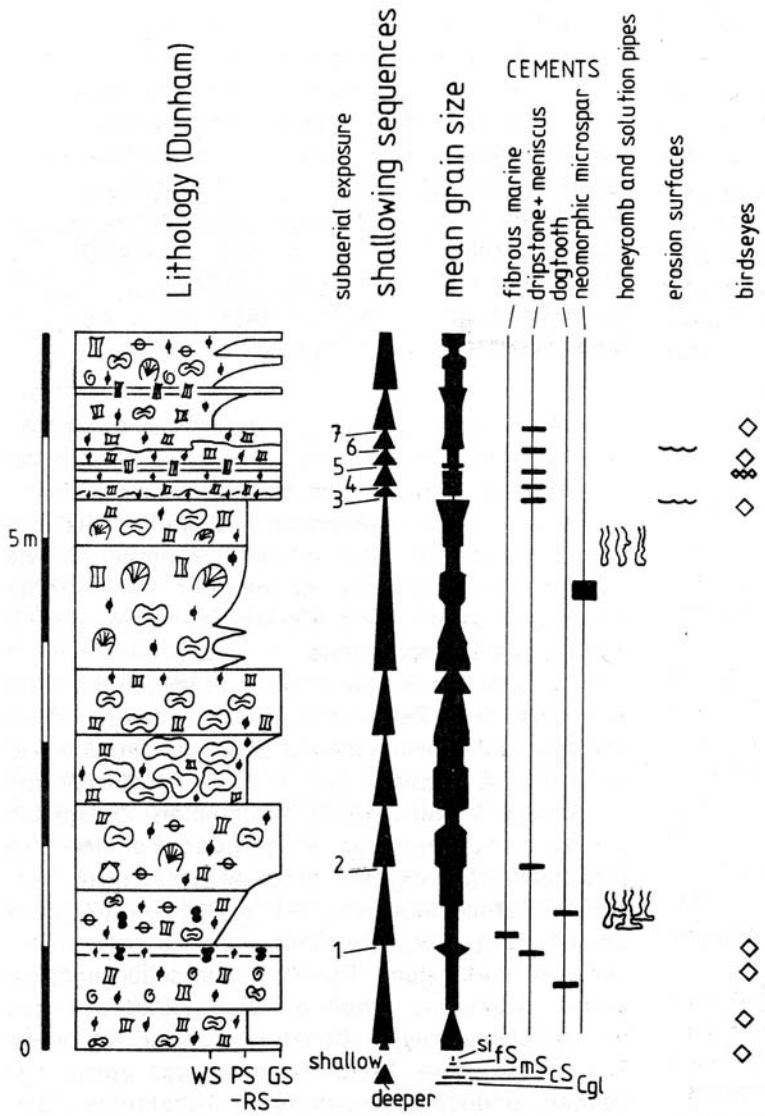


Fig. 47: Ota Limestone, profile 'cave' (back reef belt), exhibiting 14 autocyclic shallowing upwards sequences, 7 of which are terminated by subaerial horizons. The autocyclic sequences correspond to the progradation-cementation-(erosion)-model. (see text and fig. 97). For legend s. Fig. 174 (Appendix), location see Fig. 8 (also for following profiles of the Ota Limestone).

Figs. 48-53: Sediments from the back reeff (48, 49) and peritidal belt of the Ota-Platform (thin-sections, acetate peels (49, 52), of bar1 mm).

Fig. 48: Peloid grainstone with large keystone vugs. Upper left: *Lithocodium* clast. Lower left: coral.

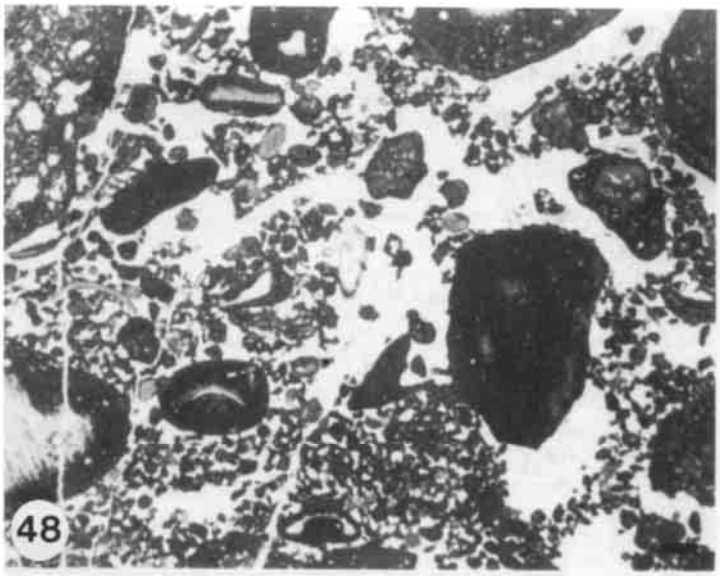
Fig. 49: Phreatic dog-tooth cement (arrow) of lump-clast grainstone (beach rock)

Fig. 50: LF-B-II type loferite. Sediment is a peloid grainstone, exhibiting gradings.

Fig. 51: 'Rim-clast'-birdseye wackestone. 'Rim-clasts' represent cortoids or diagenetically altered, marginally micro-sparitized grains. Burrows preserved as pseudobirdseyes, with vadose silt.

Fig. 52: Pelmicritic LF-B-II type loferite with microbial clasts and well developed dripstone cements.

Fig. 53: Cortex detail from giant oncoid. Note *Lithocodium/Bacinella*-like structure.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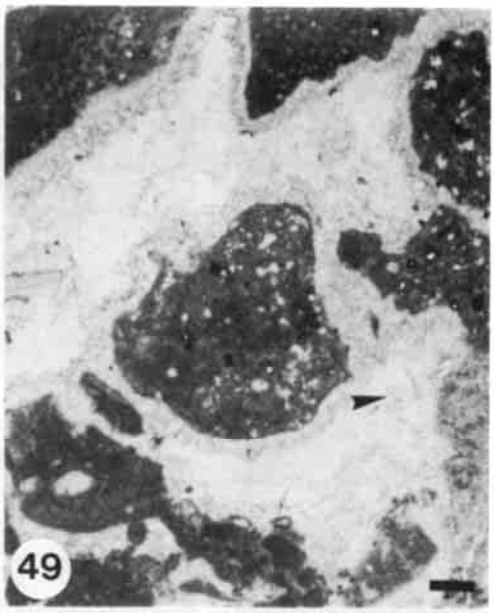
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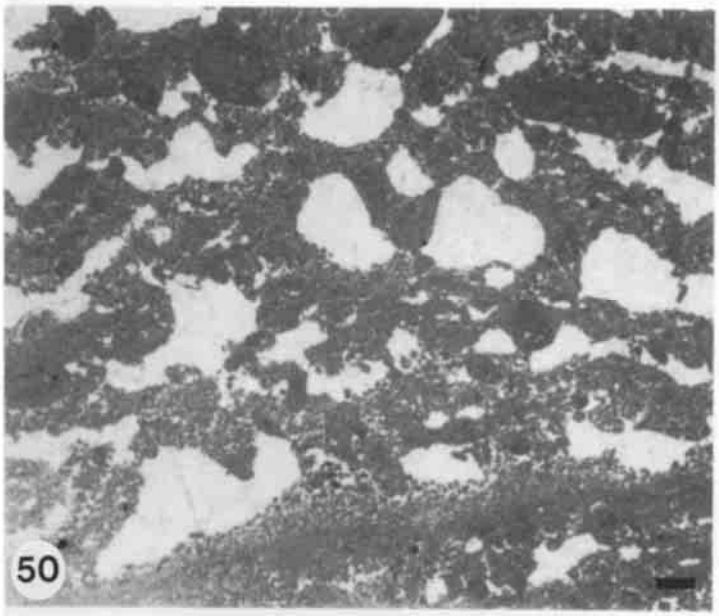
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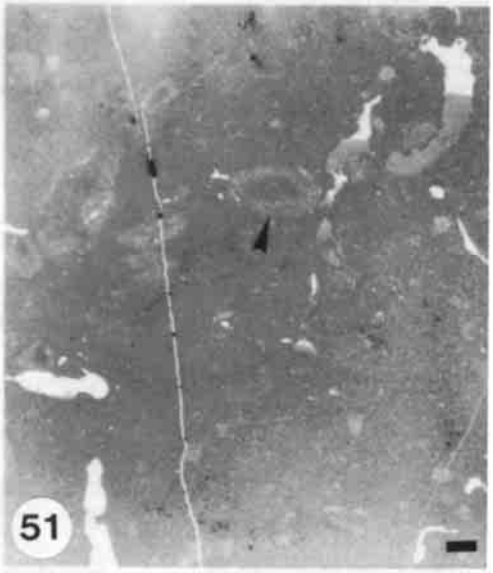
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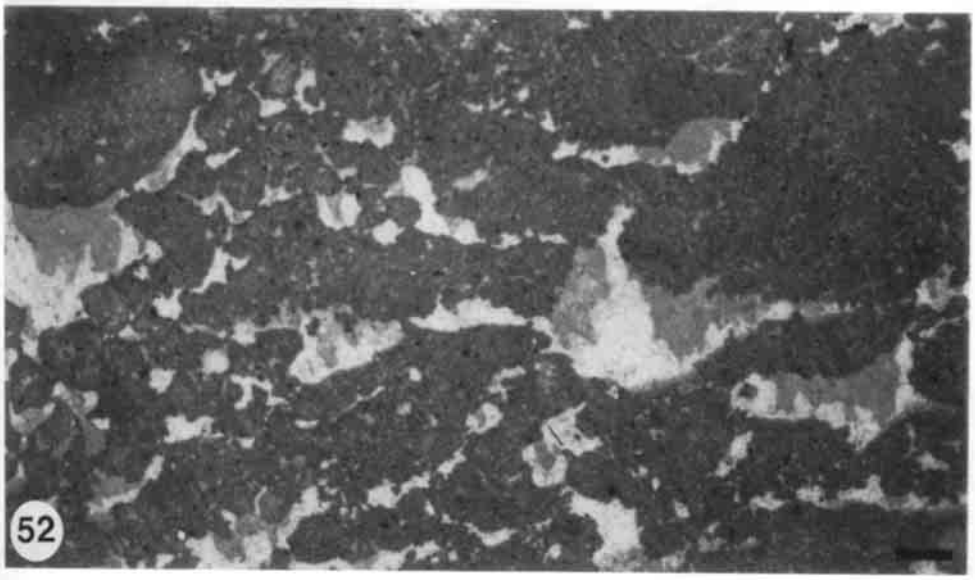
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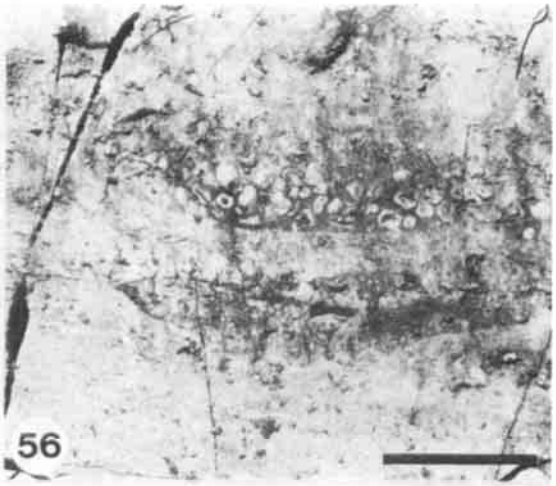
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Figs. 54-61: Sediments from the peritidal belt of the Ota-Platform

Fig. 54: Four stacked shallowing-up type-I tidal sequences. Arrows: loferites. Length of pen cap is 4 cm.

Fig. 55: Shallowing-up type II tidal sequence. Lower part micritic sediments with packstone patches, higher part grainstones, partly laminated. Arrow indicates position of indistinct loferite layer. Length of bar is 10 cm.

Fig. 56: Narrow tidal runnels within loferites, filled with oncoid grainstone. Length of bar is 10 cm.

Fig. 57: Small, tepee-like detachment structure within loferite, with vadose cements. Length of bar is 1 cm.

Fig. 58: Giant oncoids, at base of a type-I tidal sequence. Note domal growth in upper part of left oncoid. Length of bar is 5 cm.

Fig. 59: Burrowed birdseye wackestone from type I sequence. Arrows: cracks due to synaeresis. Length of bar is 5 mm.

Fig. 60: LF-A loferite with slope morphogy at top, possibly representing cemented natural levee. Length of bar is 5 cm.

Fig. 61: Irregular prism-cracks on the bottom of a channel structure. Diameter of lense cap is 5 cm.

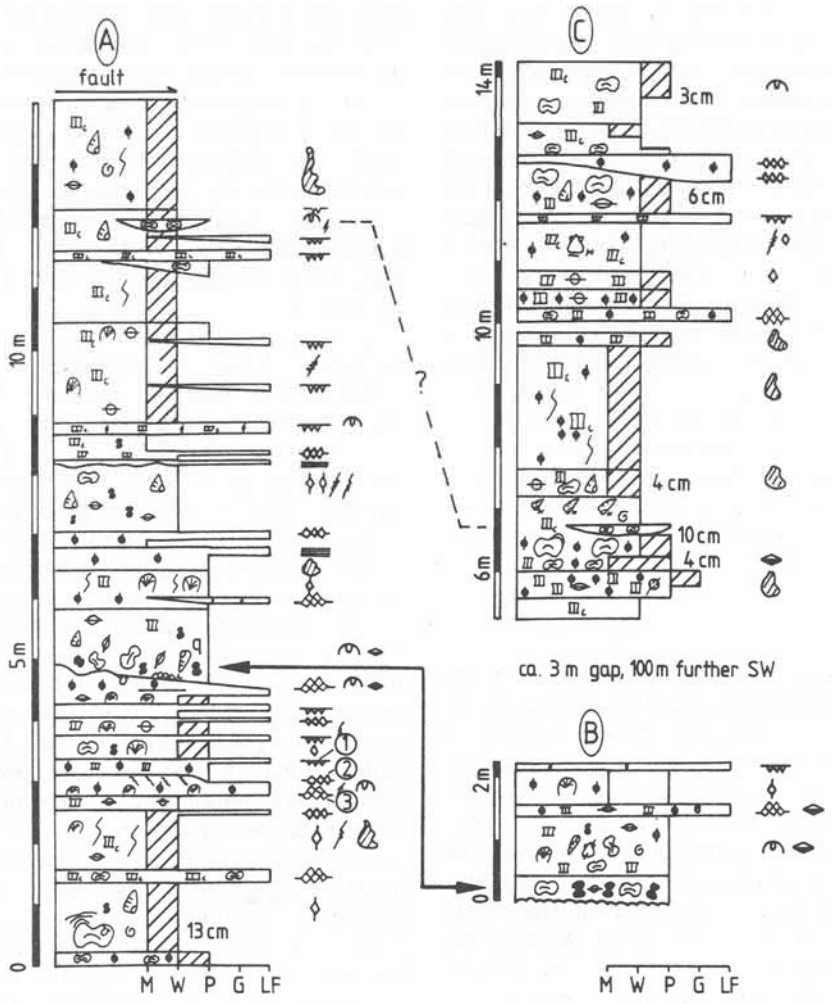


Fig. 62: Ota Limestone, profile 'main track' (southern part of peritidal belt). Centimetre indications refer to maximum size of large oncoids. Succession partly shows shallowing up sequences according to the tidal channel migration model (see text).

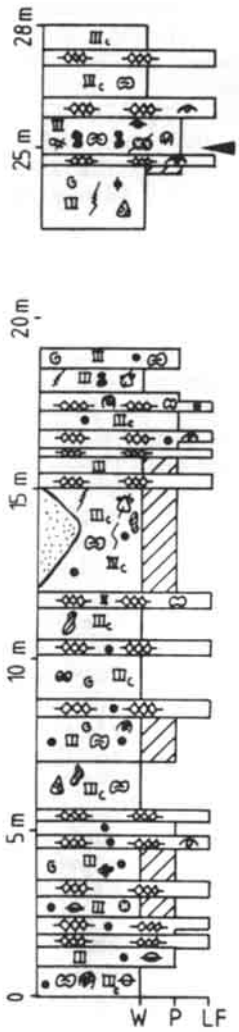


Fig. 63: Ota Limestone, summary profile 'Pedreiras de Santa (midddle)' from southern part of peritidal belt.

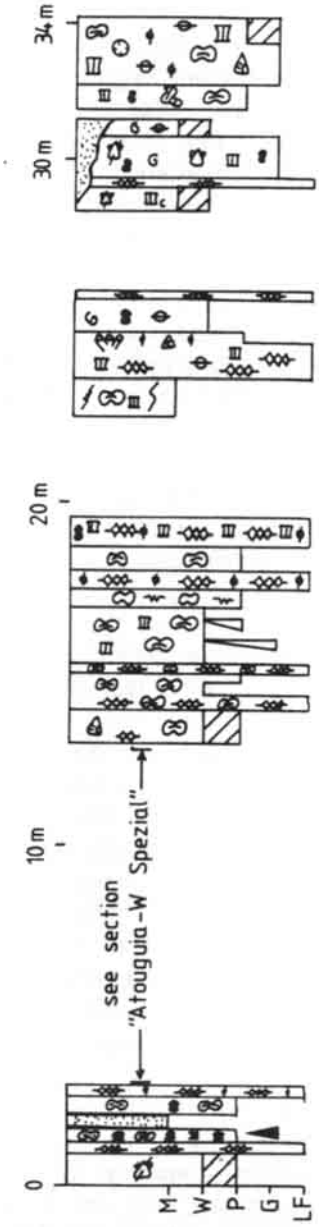


Fig. 64: Ota Limestone, profile 'Atouguia- West' (northern part of peritidal belt). Missing part of profile is shown in detail in Fig. 65.

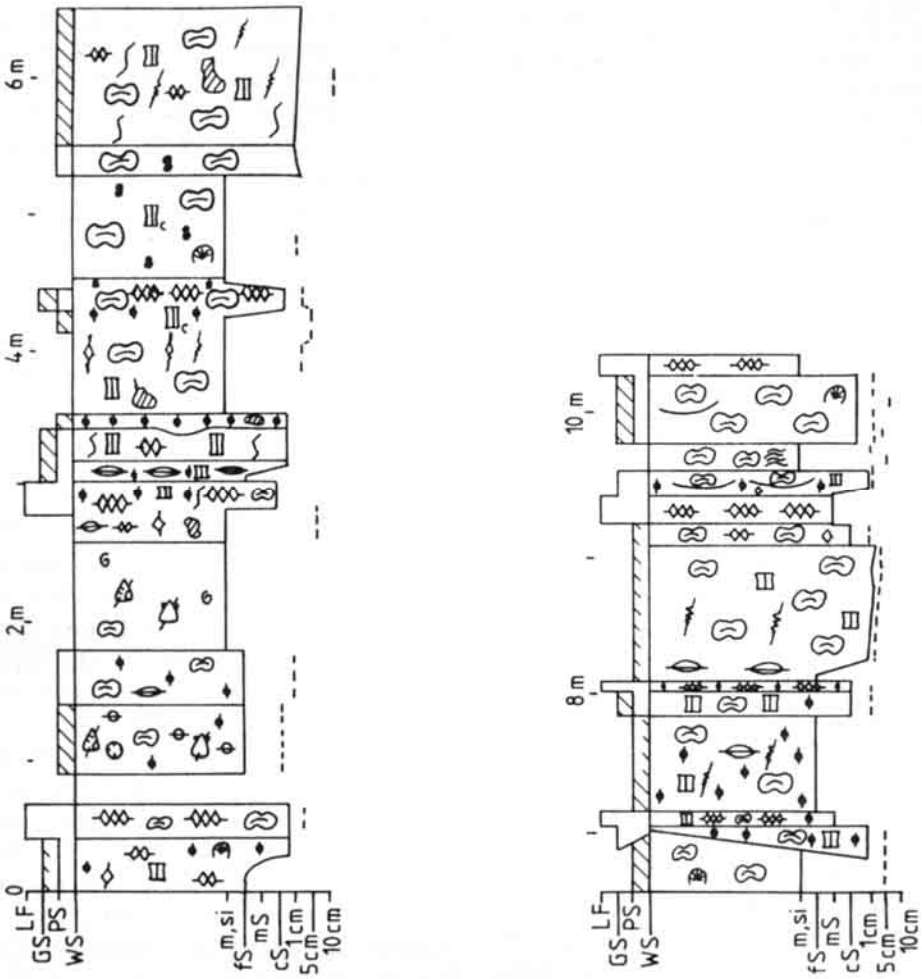


Fig. 65: Ota Limestone, profile 'Atouguia-West Special', with shallowing up-sequences according to the progradation wedge model (see text). m, si etc. is grain size (for closed fabrics), broken line is maximum grain size for poorly sorted sediments.

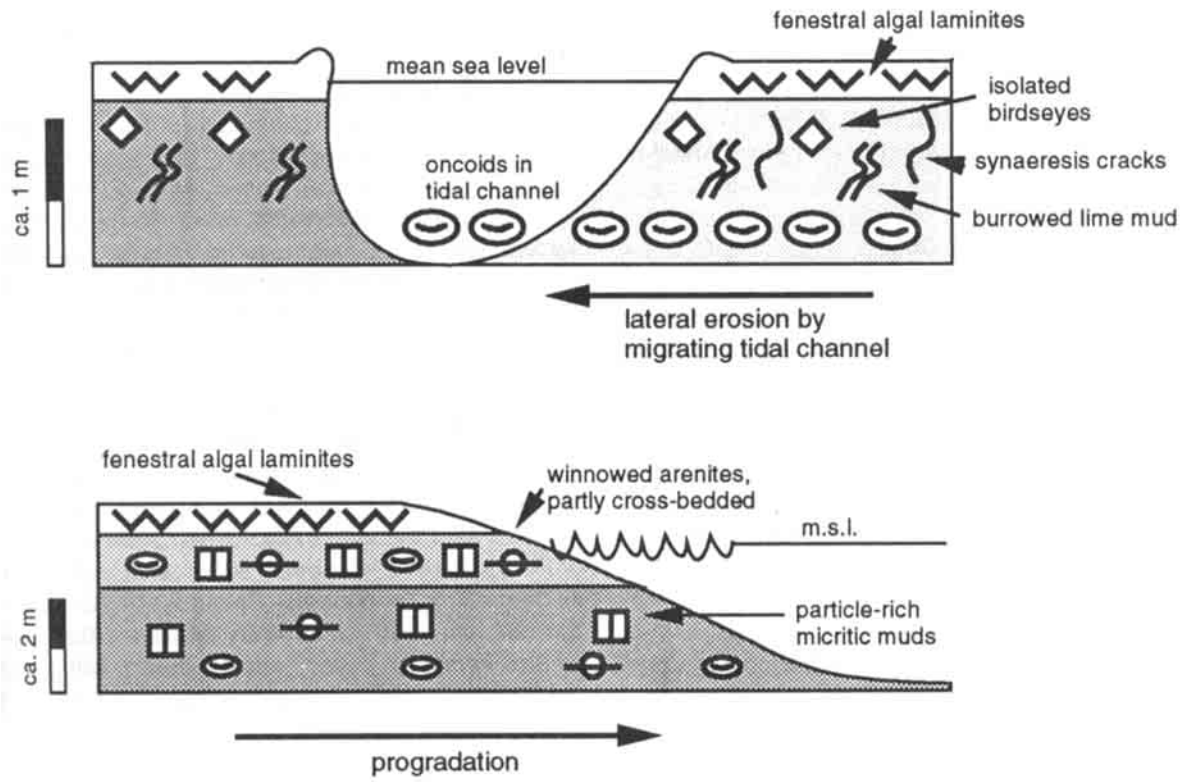


Fig. 66: Autocyclic models for the Ota peritidal belt. Top: tidal channel migration model (modified from SHINN et al. 1969) explains bipartite type-I muddy sequences; bottom: peritidal progradation wedge model explains tripartite type-II sequences exhibiting a grainstone interval (see text).

Fig. 67: 'Rim-clast' and microspar-clast wackestone. Top: early solution pipe with vadose silt and micritic clasts. Arrow: circumgranular leaching.

Fig. 68: Oncoid microbial-clast wacke/packstone, exhibiting circumgranular cracking and microsparitisation typical of initial calichefaction.

Fig. 69: *Otaina* wackestone. Arrow: 'rim-clast'-structure. Length of bar is 5 cm.

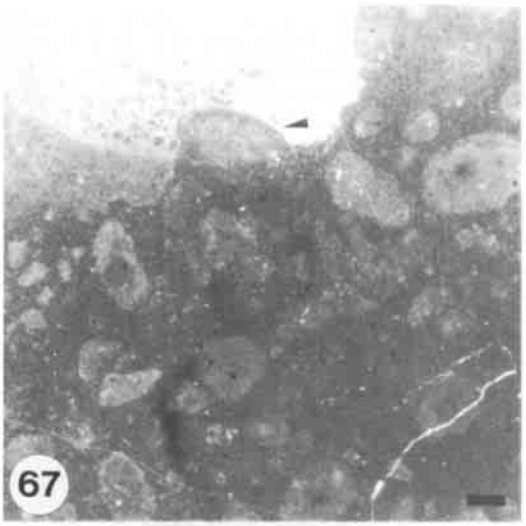
Fig. 70: Gastropod wackestone. Vadose Silt in biomould. Arrow: peloidal sediment within shell. Length of bar is 5 mm.

Fig. 71: Mud cracks and calichefaction in semi-lithified sediment at the top of a mud ridge sequence. Length of bar is 5 mm.

Fig. 72: *Campbelliella striata* dasycladacean wackestone with frequent microsparitisation of particles (arrow).

Fig. 73: The dasycladacean alga *Clypeina jurassica*.

Fig. 74: Loferitic microbial mat with primary morphology (right), possibly representing natural levee or mirroring original morphology of mud ridge. Diameter of coin is 2.5 cm.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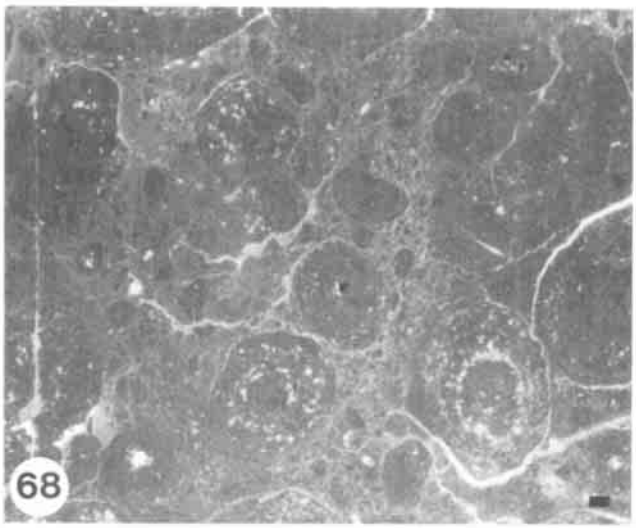
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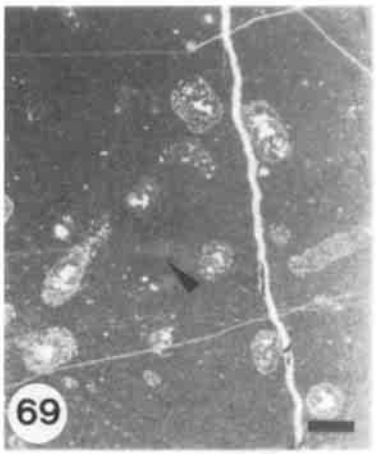
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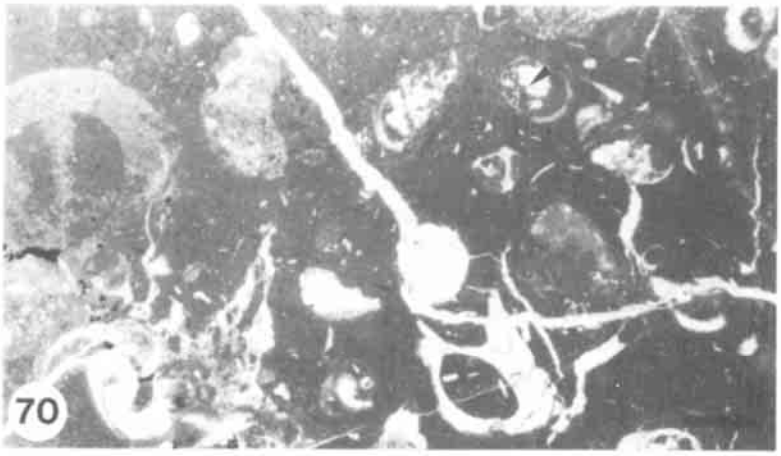
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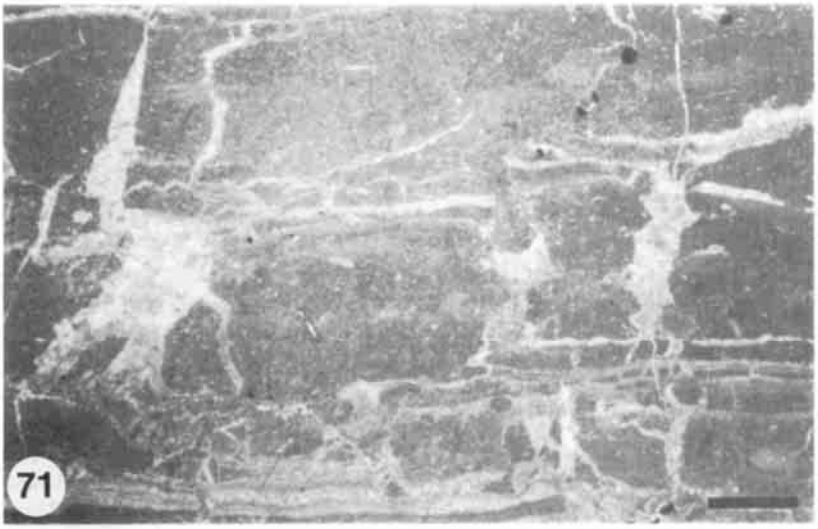
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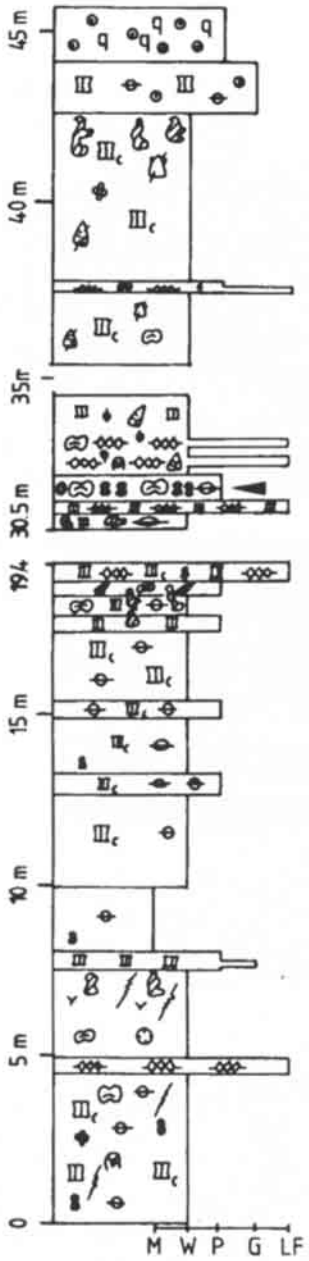

Fig. 75: Ota Limestone, profile 'Pedreiras 'Lima (southern part of lagoonal belt).

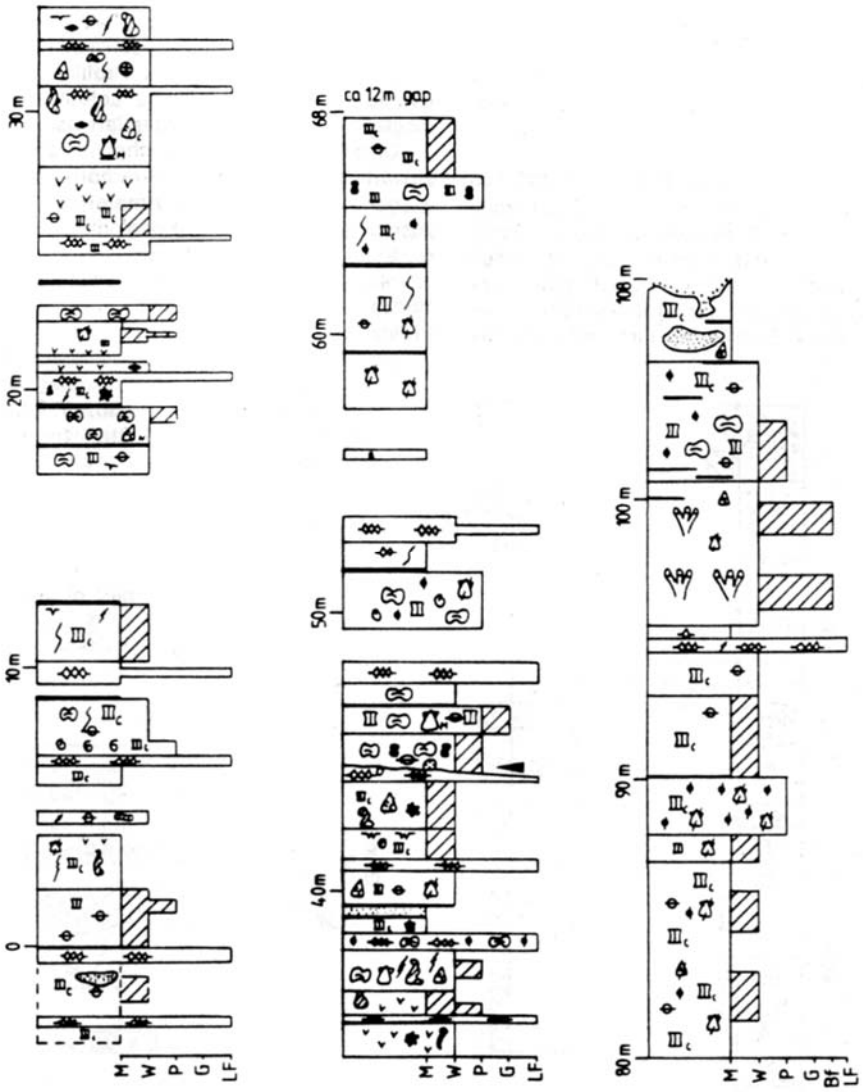

Fig. 76: Ota Limestone, wire line profile 'E Pedreiras de Santa' (middle part of peritidal and lagoonal belts). Note that reef is offset laterally and spans the transition from the peritidal belt to the lagoonal belt (above m 45). Thick lines indicate larger fissures.

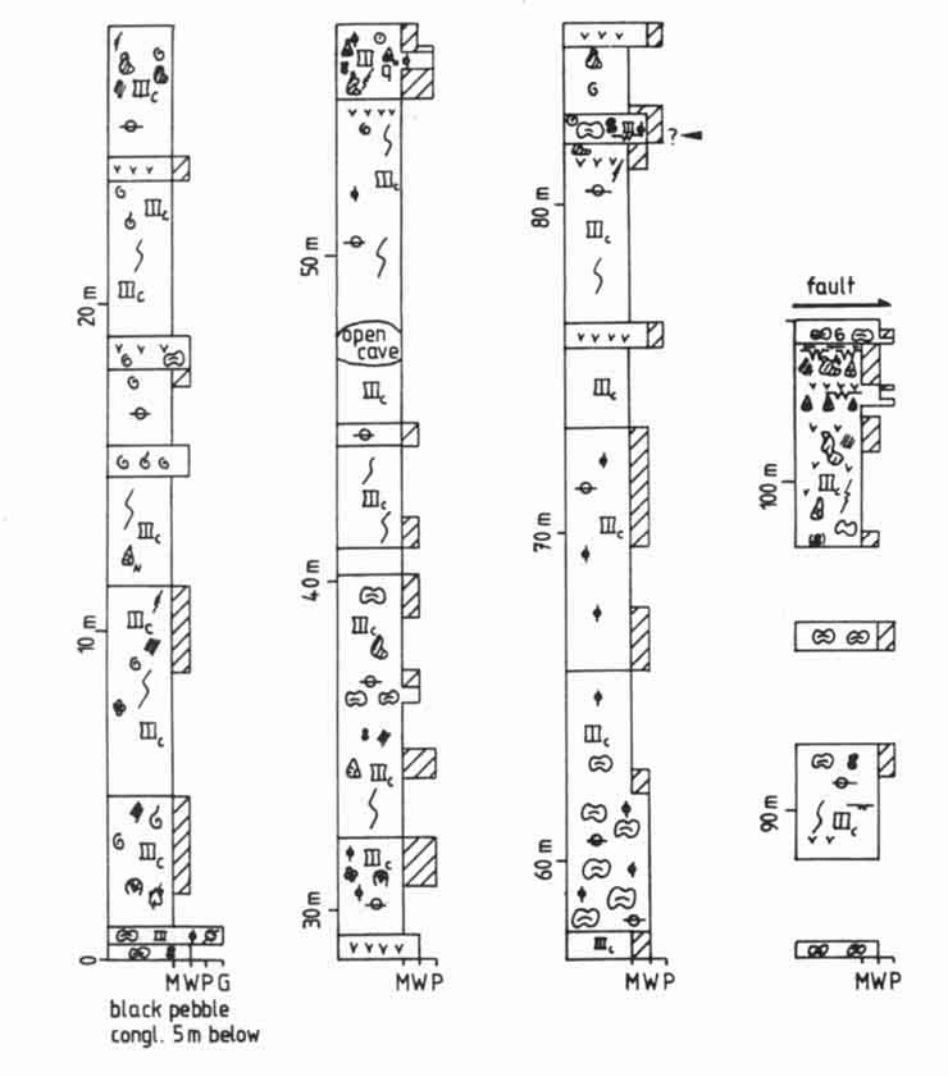

Fig. 77: Ota Limestone, profile 'Rio Ota' (northern part of lagoonal belt).

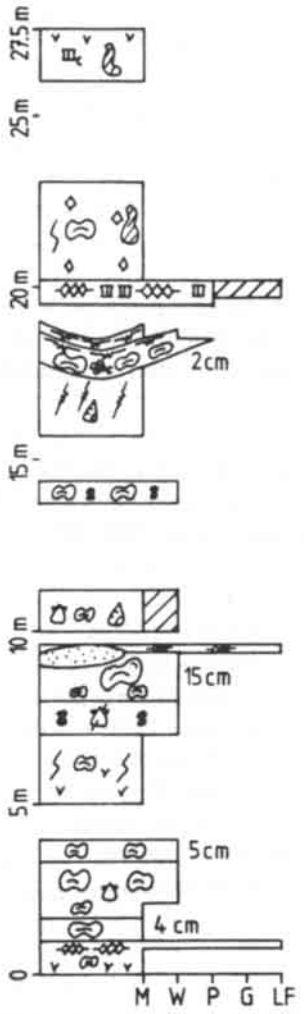

Fig. 78: Ota Limestone, profile at geodesic mark 'Atouguia' (northern part of lagoonal belt). Centimetre indications refer to maximum oncoid sizes (if > 2 cm).

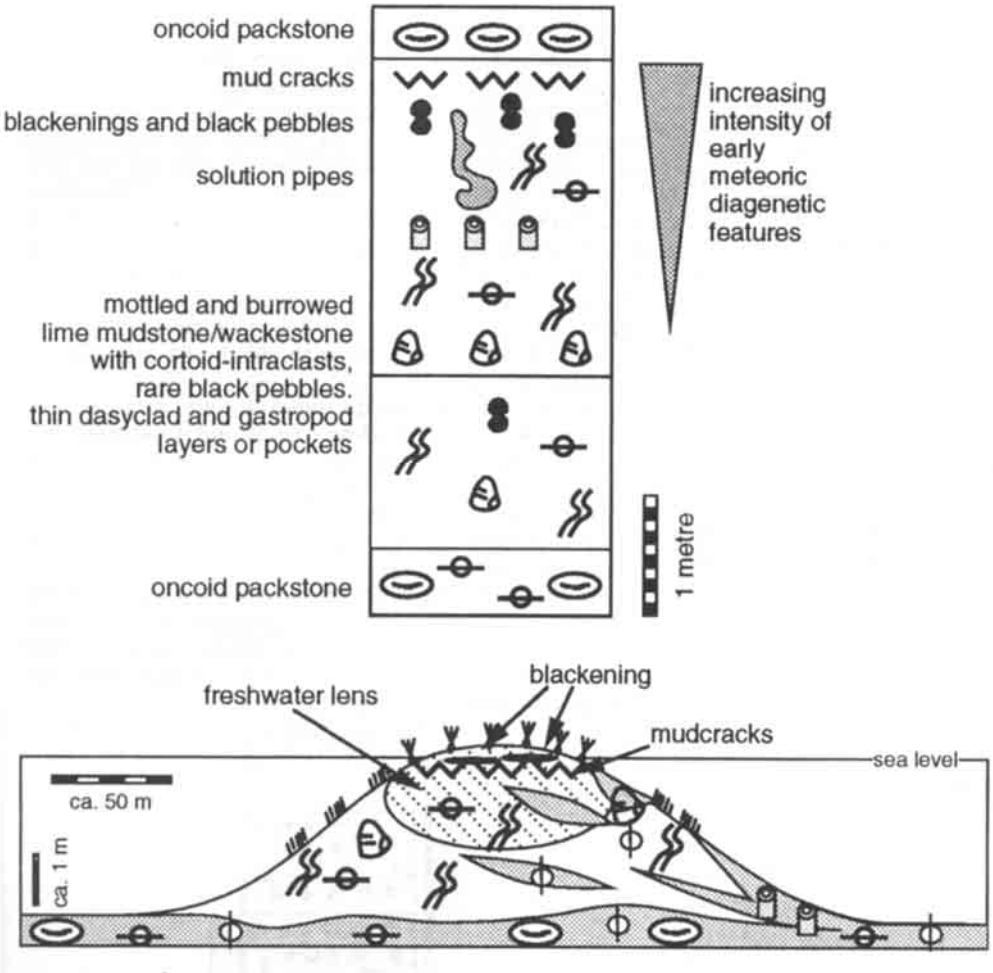

Fig. 79: The mud ridge model for the lagoonal zone of the Ota Limestone, based on modern mud ridge - mud mound formation in the Florida Bay. The model explains the occurrence of isolated, autocyclic shallowing-up sequences within the lagoonal belt (see text).

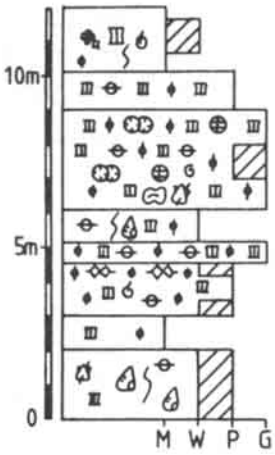

Fig. 80: Profile Entre Serras from the northeastern part of the distribution of the Ota Limestone. The schematic log represents a data compilation from different outcrops.

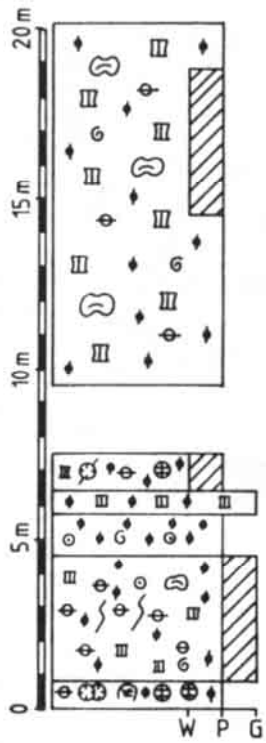

Fig. 81: Profile 'Vale Forno' at northernmost outcrop of the Ota Limestone. Upper part of log has a schematic character due to poor accessibility.

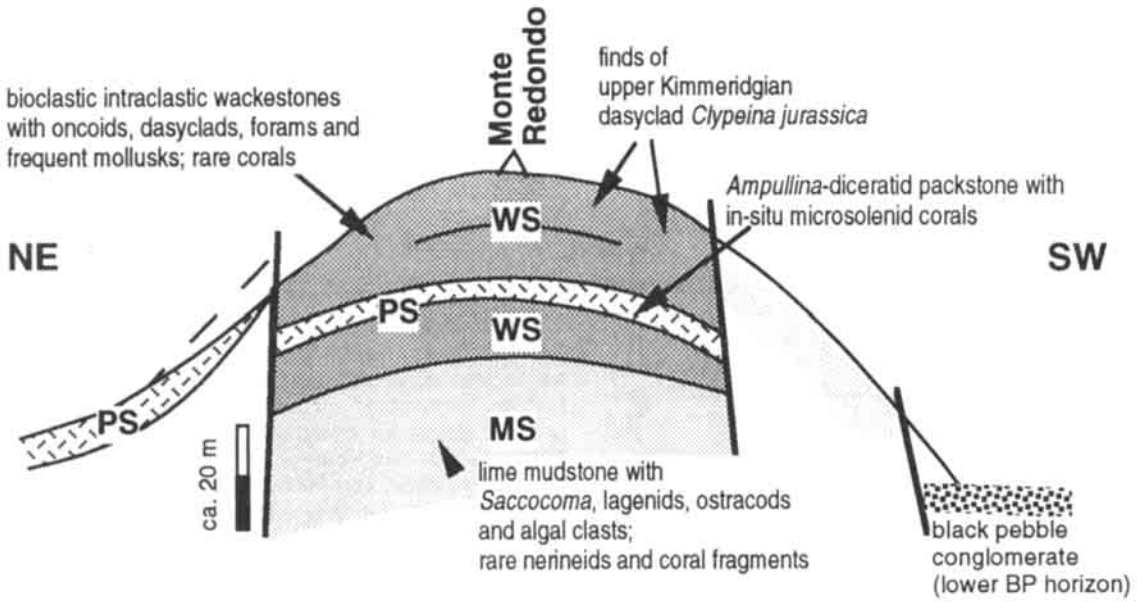

Fig. 82: Sketch of the structural and facies development of the 'Monte Redondo' hill (northern Ota region).

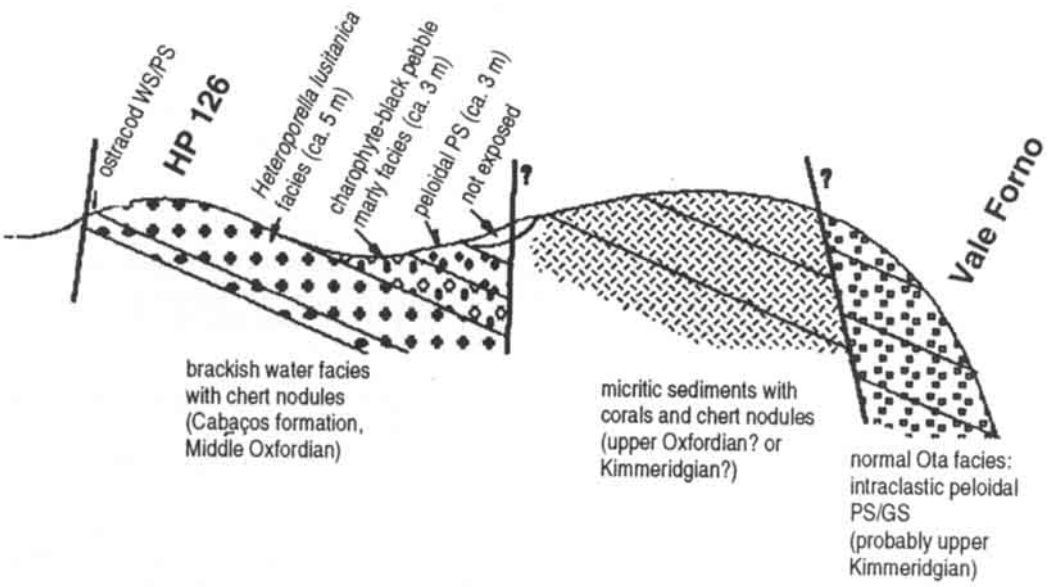

Fig. 83: Sketch of the probable structural setting and facies development in the region around Altitude 126, to the south of the Vale Forno. The middle part could possibly also represent the Upper Oxfordian Montejunto beds.

Figs. 84-91: Lithostratigraphic correlation horizons from the Ota Limestone.

Fig. 84: Angular unconformity below the 'black pebble main horizon'. Arrow: relic of (?wind-) rippled recrystallised peloid grainstone. Length of bar is 5 cm.

Fig. 85: Detail from 1: borings of lithophage bivalve, beneath unconformity. Peloid ripples are partly removed by erosion and overgrown by *Lithocodium* (not visible at this scale). LF-A loferite with laminae of peloid pack/grainstone below unconformity. Length of bar is 1 cm.

Fig. 86: Vadose cements within black pebbles are very common (from 'black pebble conglomerate horizon'). Length of bar is 1 mm.

Fig. 87: Early solution within coral limestone. Cavities and biomoulds (arrow) are filled with blackened sediment. This blackened level occurs in the south of the Ota-Platform and towards north can be correlated in the fields with the 'black pebble main horizon'.

Fig. 88: Hardground below 'black pebble main horizon' (from profile 'E Pedreiras Santa'). Note boring bivalves (arrows) and sediment-filled cavity. Length of bar is 1 cm.

Fig. 89: Oncoid facies is the most common type within the 'black pebble main horizon'. Note partial matrix blackening (at upper margin). Vicinity of profile 'main track'. Length of bar is 5 cm.

Fig. 90: Karst microtopography covered by caliche crusts, overlain by black pebble main horizon. Note rhizobrecciation (vicinity of profile 'main track'). Length of bar is 1 cm.

Fig. 91: Detail of debris flow from the 'black pebble conglomerate horizon' (profile 'Relva'). Arrow: large subangular detrital quartz interpreted as 'driftwood pebble'. Length of bar is 1 cm.


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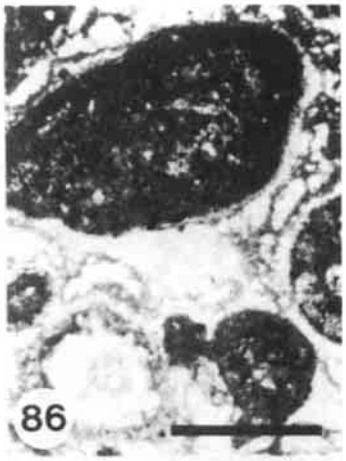
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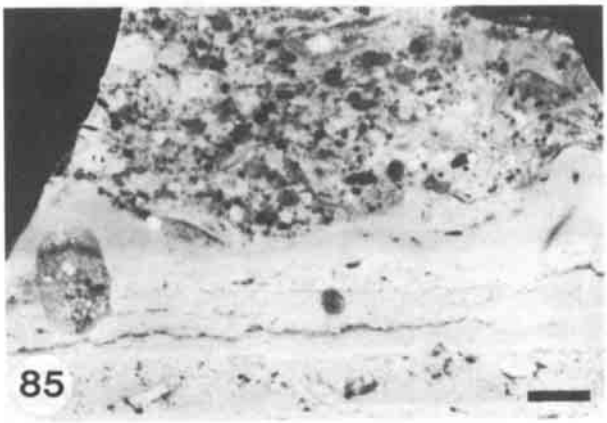
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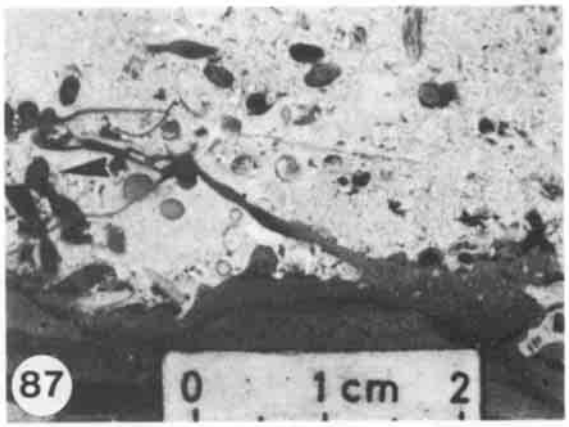
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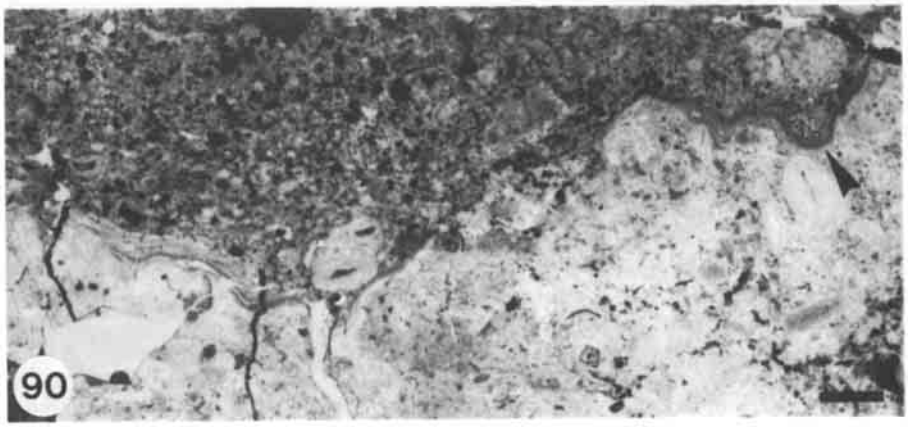
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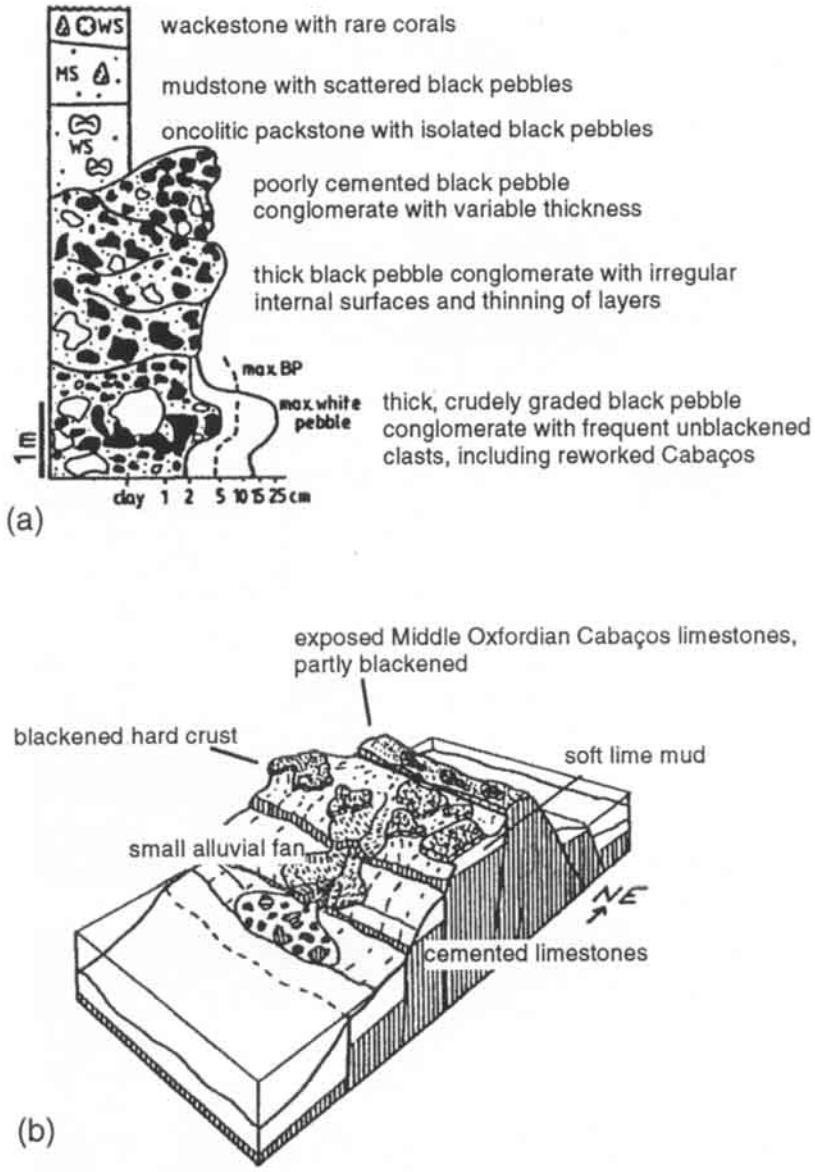

Fig. 92: The black pebble conglomerate (lower black pebble horizon) of the Ota Limestone. (a) profile 'Relva', (b) depositional model for the black pebble conglomerates (see text). (modified from LEINFELDER 1987b)

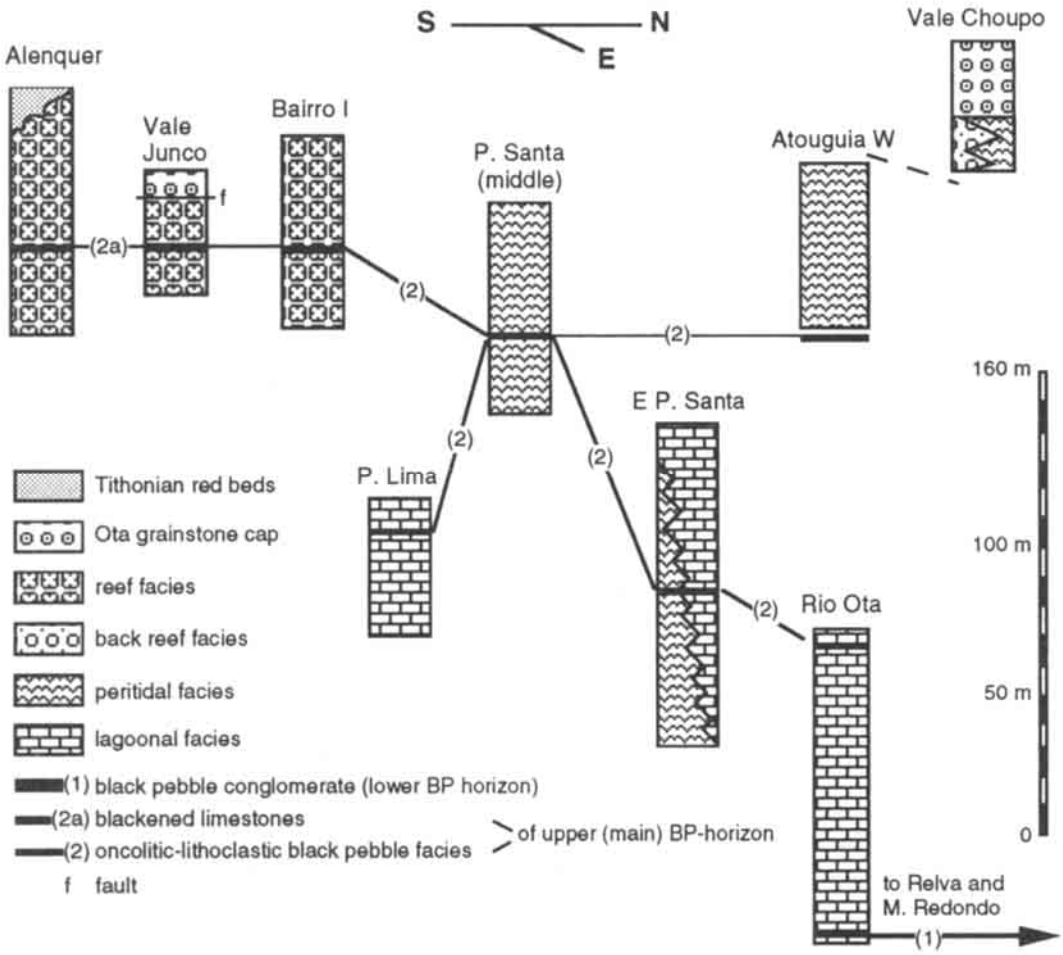

Fig. 93: Lithostratigraphic correlation of the principal Ota profiles by means of an upper and lower black pebble horizon ('main horizon' and 'conglomerate horizon', resp.). The exposed part of the Ota Limestone exhibits a thickness of ca. 160 metres. See Fig. 8 for location of profiles

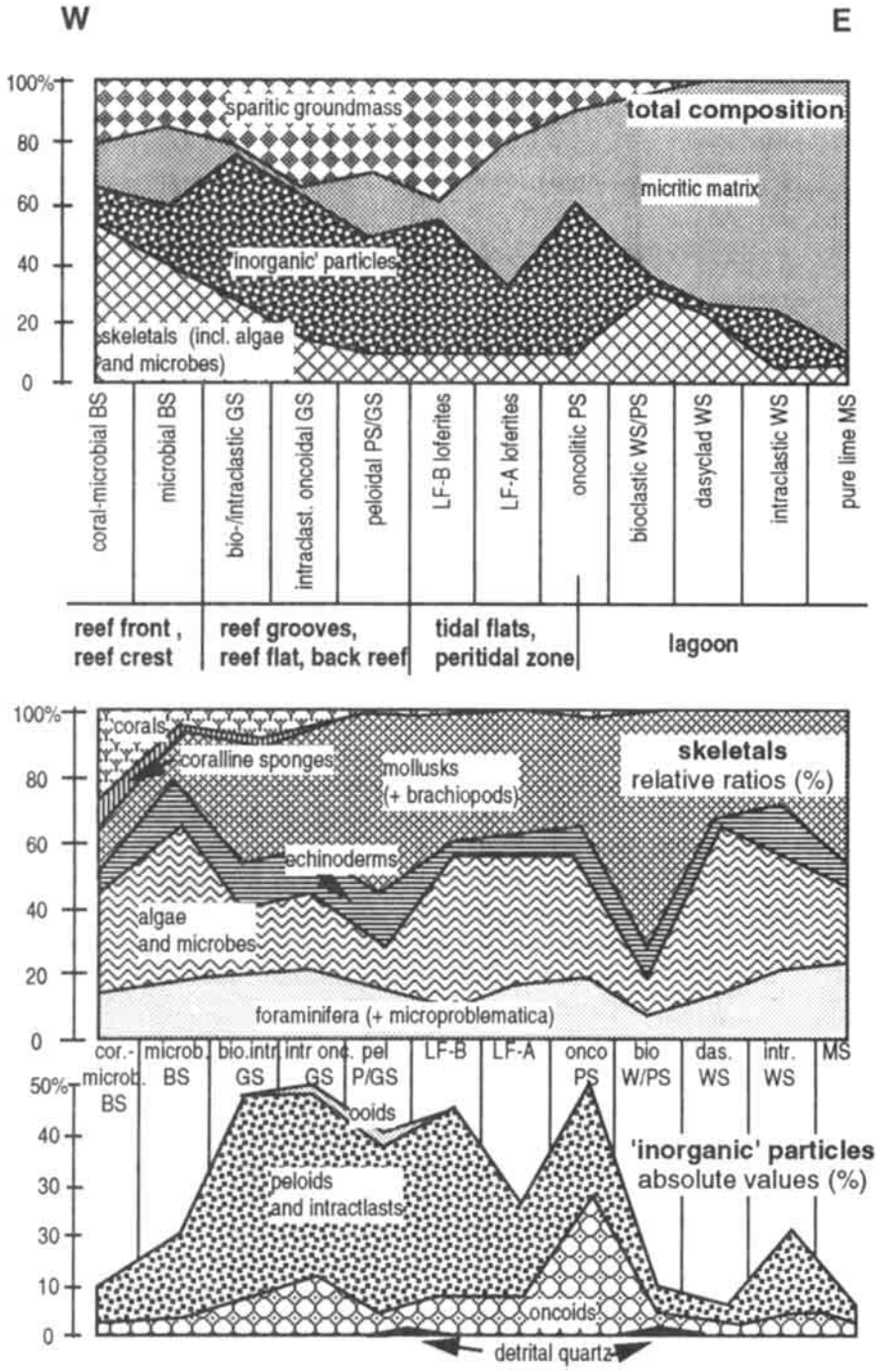

Fig. 94: Composition of sediments and particles in the facies belts of the Ota-Platform. Note scarcity of detrital quartz grains and ooids.

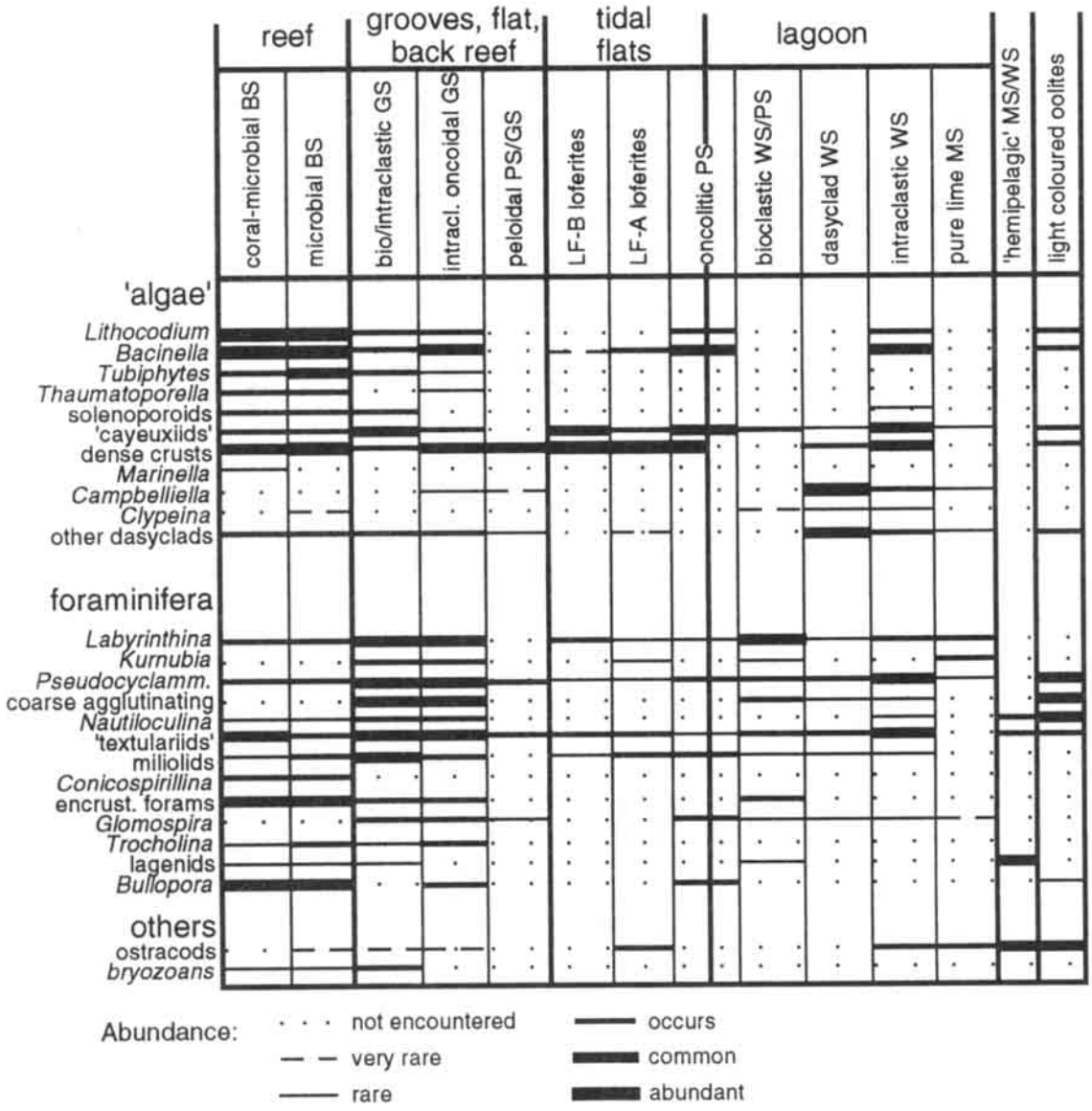

Fig. 95: Distribution of selected microorganisms within the facies belts of the Ota Limestone (right column refers to grainstone cap of the Ota Limestone). From LEINFELDER (1992), with additional data.

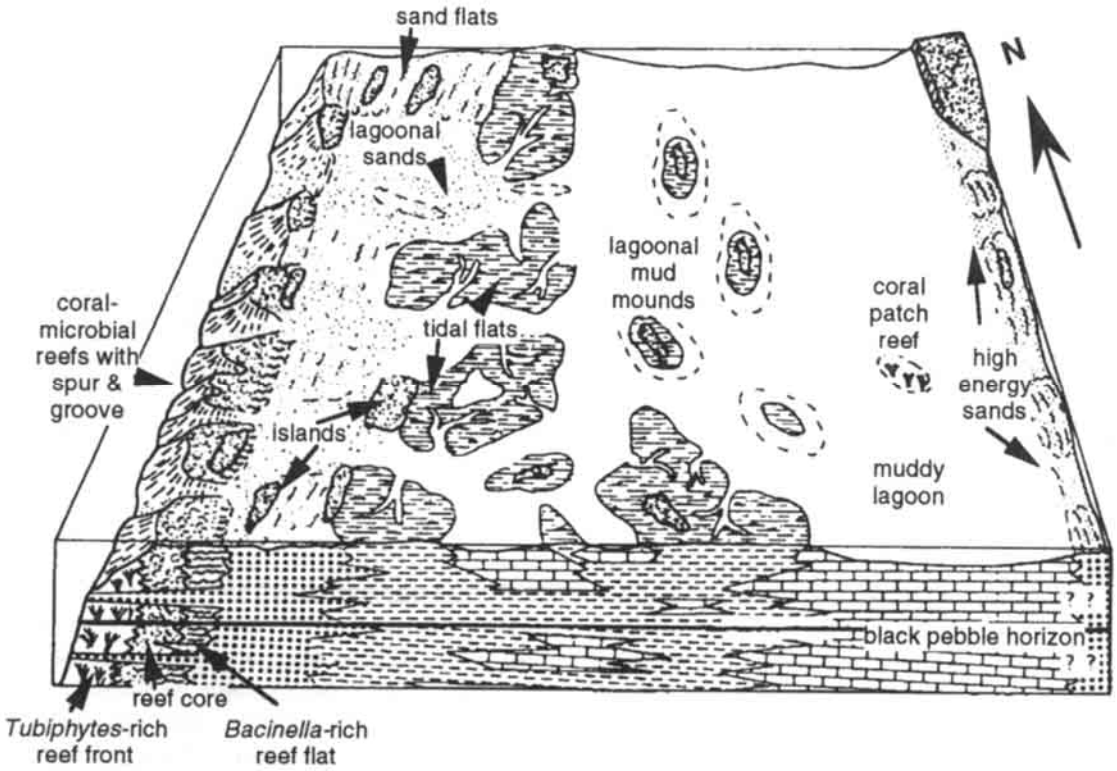

Fig. 96: The depositional model for the exposed part of the Ota Limestone. The aggradational shallow-water platform is rimmed by a high-energy coral-microbial-debris reef and exhibits well developed facies belts. In the inner platform autocyclic shifts of sediments led to small-scale shallowing up successions. (cf. Fig. 97). Sediment relics indicate that a grainstone shoal complex and local, ephemeral islands rimmed the inner platform margin. (see text for more details).

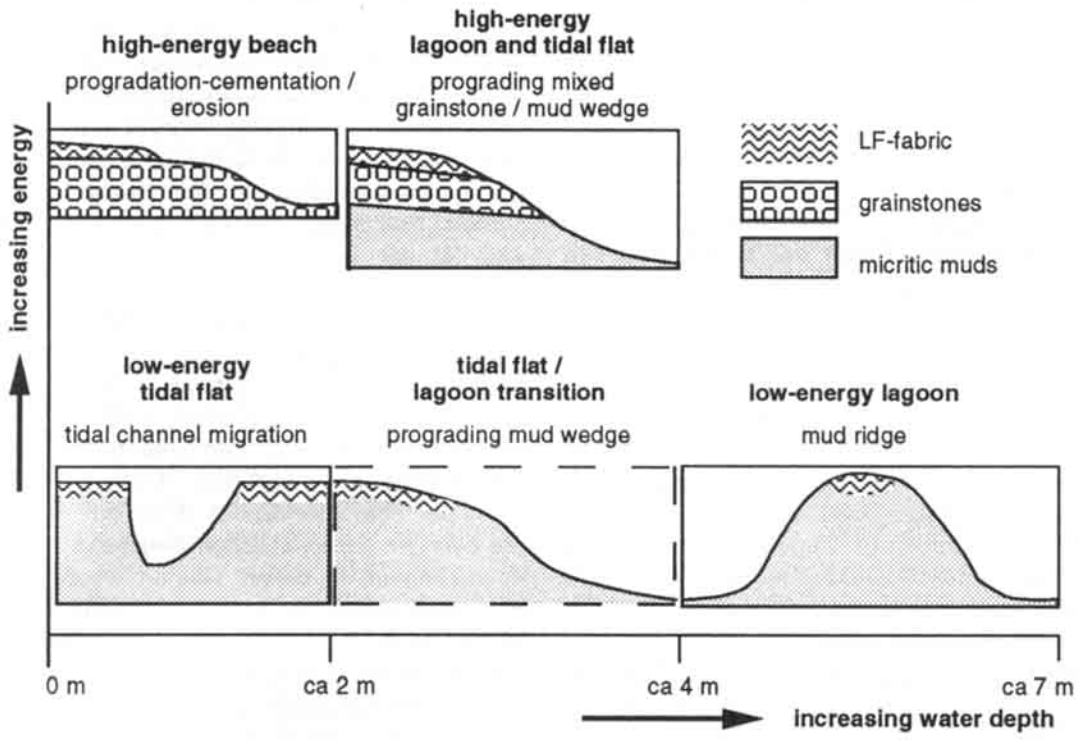

Fig. 97: The autocyclic shallowing-up models from the interior parts of the Ota Platform, and their relation to water energy and maximum water depth (cf. Figs. 66, 79). Frame with broken line shows an additional theoretic model which cannot be substanciated by field data due to insufficient facies criteria.

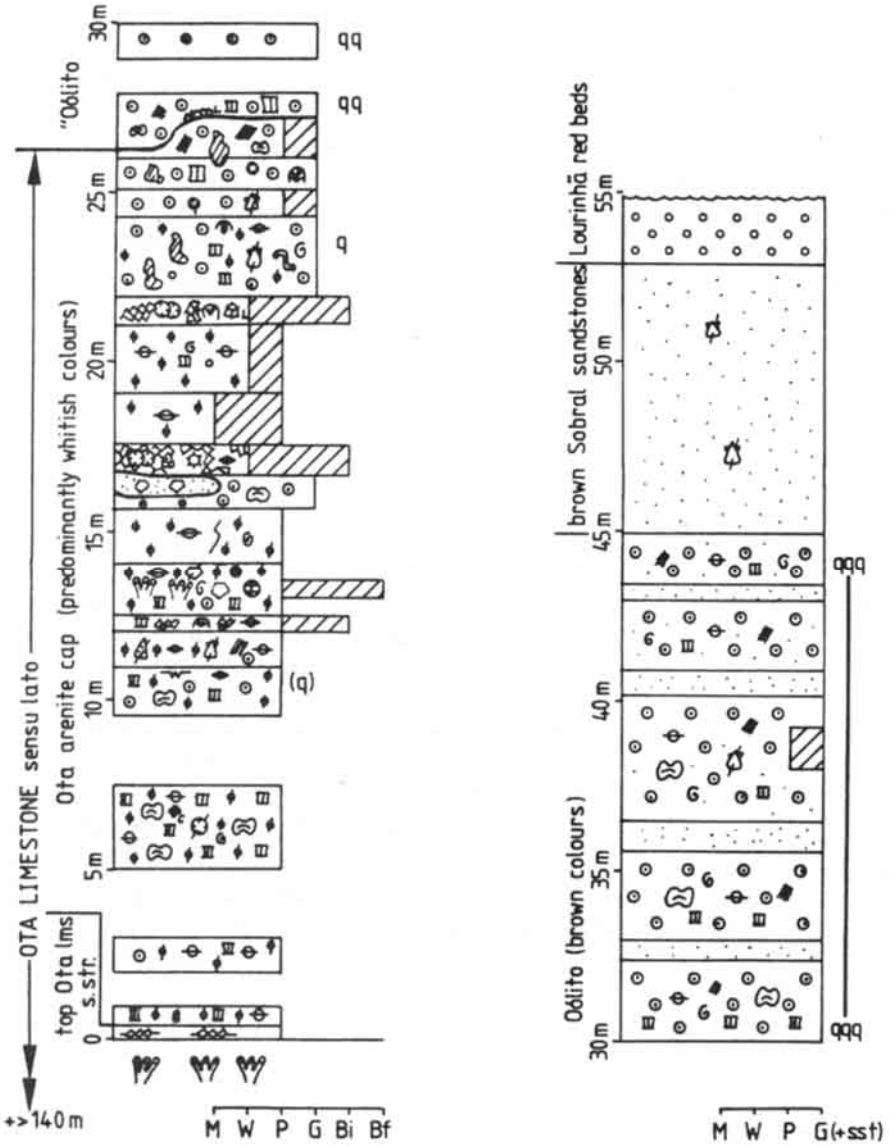

Fig. 98: Profile 'Vale Choupo' (northern part of Ota region). Profile shows successions paraconformably capping the Ota Platform.

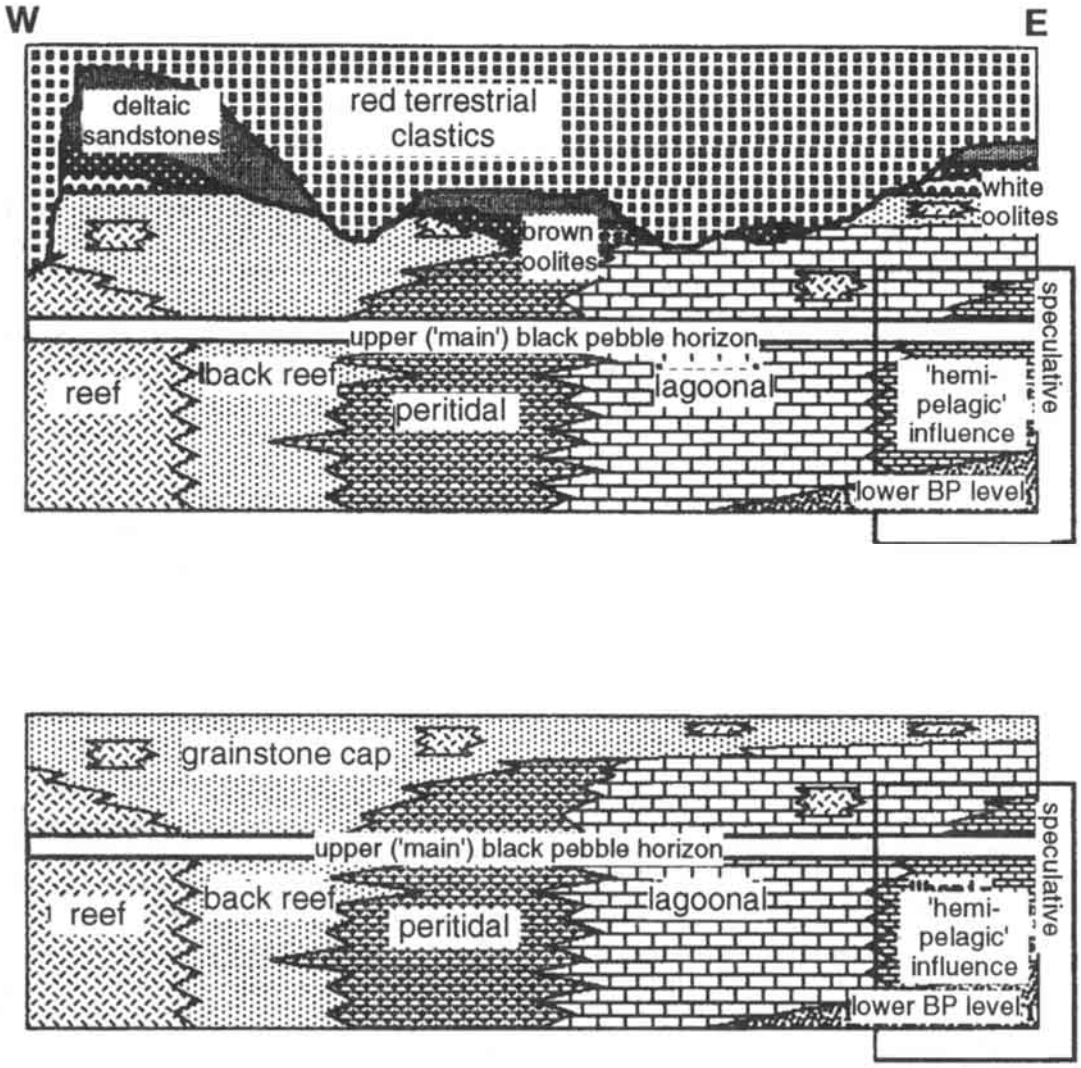

Fig. 99: Bottom: Sketch of platform architecture at the end of the development of the Ota Limestone (sensu latu, i.e. including the cap of white grainstones). Top: postdepositional units capping the Ota Limestone. Several karst phases led to the removal of major parts of the sediment caps. Red clastics are also mainly removed (not shown; cf. Figa. 8, 105, and text)

Figs. 100-104: Palaeokarst features from the Ota Limestone.

Fig. 100: Alenquer quarry: The Ota Limestone is unconformably overlain by Tithonian red beds along a pronounced palaeokarst surface. Karstification also penetrated fissures (arrow). Fissure formation was posterior to the formation of the Ota-Platform, but prior to sedimentation of Tithonian clastics.

Fig.. 101: Karstic collapse breccia, showing clasts of various fill types. Clast to the left represents host rock. Other fill material are brown oolites, light grainstones and chips of residual brown limestone. Black are iron crusts. Pedogenic processes caused a mottled, intensive violet colouration. Length of bar is 1 cm.

Fig. 102: Part of a flowstone spelaeothem crust. Note internal sediments interrupting crystal growth. Growth of palisade crystals of this size is only possible under absence of Mg-Ions. Scale is in centimetres.

Fig. 103: Palaeocave within coral-algal baffle/bindstone (upper left). Arrow: slightly clayey residual limestone, overgrown by spelaeothem crust. Right: cave iron ore. Palaeopedogenesis caused violet colouration around cave. Hammer length is 28 cm.

Fig. 104: Polyphase karstic fill. Light are intraclastic grainstones (first infill generation) brown are oolites and *Favreina* pellets. Note bauxite lining on top of calcite crust. Left: host rock. Length of bar is 1 cm.

Additional, intraformational palaeokarst features of the Ota Platform are figured in LEINFELDER 1992: Pl. 7


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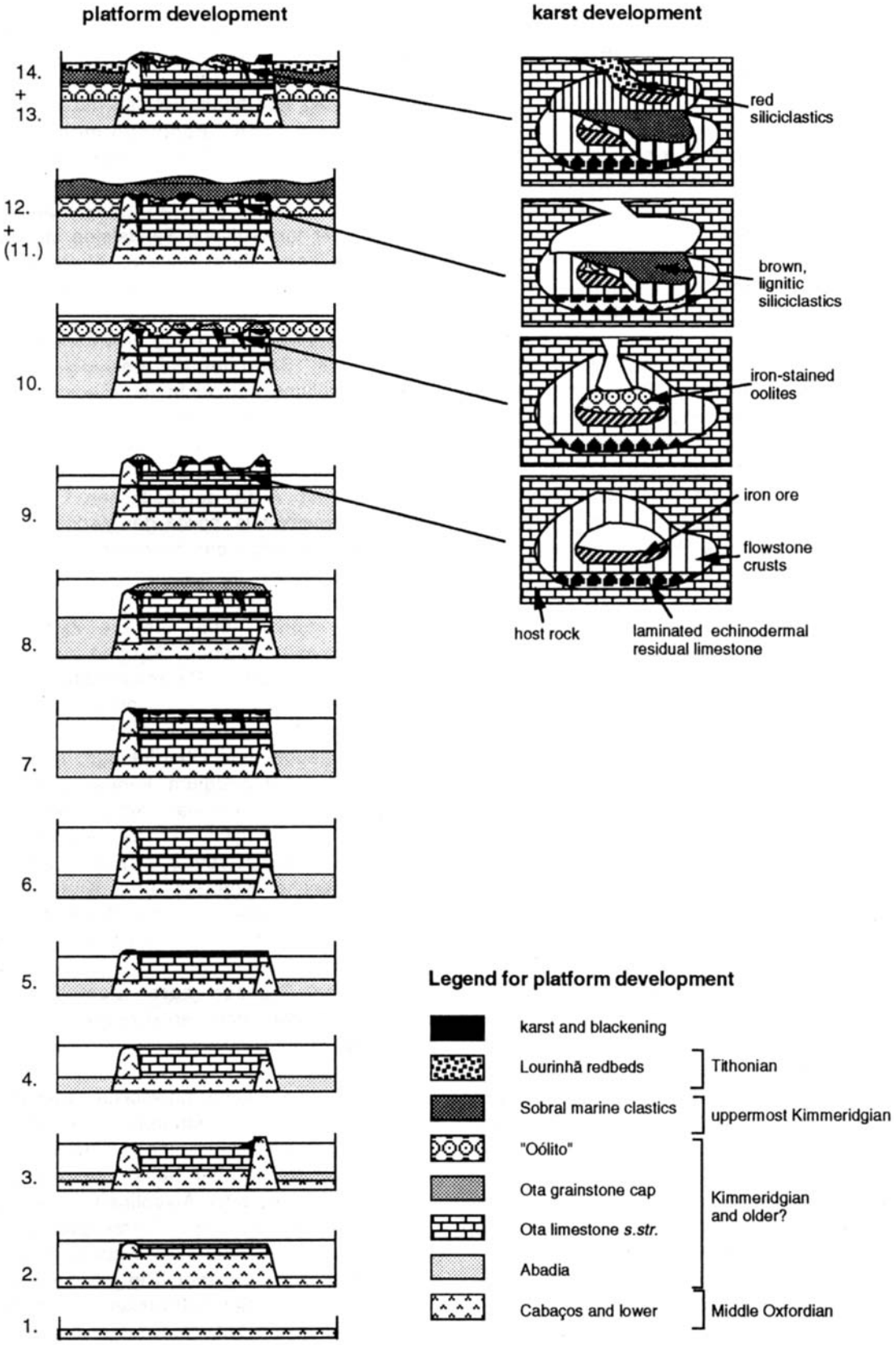


Fig. 105: Buildup and karstification phases of the Ota region. For further explanation see text.

2.4 Chapter summary: The Ota-Platform - a modern type reef complex from the Upper Jurassic

About 160 metres of the Ota Limestone, of late early to late Kimmeridgian age, are exposed in a narrow horst structure at the eastern margin of the Arruda Subbasin, which represents the easternmost Late Jurassic subbasin of the Lusitanian Basin. Due to subhorizontal bedding together with deep exposures by natural valleys and quarries, the perfect facies zonation and aggradational structure of the platform is well visible. Two major black pebble horizons, the upper of which crosses the entire platform, enable good lithostratigraphic correlation of sedimentary profiles.

The coral reef belt, at the western margin of the buildup, contains a high-diversity coral fauna as well as abundant microbial and algal crusts. Grainstones and sparitic rudstones, attributable to reef spurs, the general high amount of reef debris, and the character of back reef sediments are diagnostic of the high-energy character of the reef belt. Internal platform belts are composed of small-scale shallowing-up sequences. Their lateral incorrelatability suggests autocyclic formation. The back reef belt exhibits grainstone cycles with cyclic vadose cementation and partial erosion, comparable with the autocyclic progradation-cementation-erosion model of STRASSER & DAVAUD (1986). The peritidal belt, adjacent to the east, shows non-persistent subtidal to inter-/supratidal cycles, including micritic sediments, partly with huge microbial oncoids, peloidal-intraclastic-oncoid grainstones, and laminoid, micritic to sparitic fenestral limestones. Formation of some of these cycles is compatible with the tidal channel migration model of SHINN et al. (1969), resulting in bifold muddy sequences. Others support a threefold peritidal progradation wedge model containing a grainstone interval in the middle part. Further east, the lagoonal belt is dominated by lime mud containing micritic intraclasts and oncoids. These sediments display intercalations or patches of dasycladacean and foraminifera-rich deposits, oncolites and small coral bafflestone patch reefs. Isolated shallowing-up cycles occur, which are composed of a basal oncolitic lag overlain by mottled mud/wackestones, and capped by laterally non-persistent mud cracks. Additionally, the intensity of early diagenetic meteoric features increases towards the top of these sequences. They are interpreted to represent mud ridge autocycles comparable to those of modern Florida Bay.

Saccocomids, ophiuroids, and lagenid foraminifera show a partial deepening of the lagoonal belt towards the north (Monte Redondo), but these sediments may represent an earlier stage of platform development. Towards the northeast of the Ota horst, relics of a grainstone belt are preserved, probably representing the eastern margin of the platform. Further north, in the Vale Forno area, middle Oxfordian sediments (Cabaços formation) crop out in a narrow chip, a situation which similarly must have had existed already during the mid Kimmeridgian, as reworked clasts of these sediments were incorporated in a small alluvial black pebble fan at the eastern margin of the platform .

Both during, as well as posterior to, their formation, the platform underwent frequent sub-aerial exposure and partial karstification, caused by tectonic uplift and sea level falls (see Chap. 6.4). This is obvious by intraformational black pebble horizons, early karst features, and relics of younger sediments superimposing karstic unconformities. 14 phases of platform formation and decay can be recognised by these features.

The Ota Platform developed over a basement horst as can be seen in seismic sections. The aggradational architecture of the structure persisted over its entire history which spans several third-order sea-level cycles. High productivity kept the entire platform very close to sea-level but progradation nevertheless had not occurred. This must be explained by the existence of a steep, tectonically induced by-pass margin preventing reef progradation. Moreover, the by-pass zone facilitated winnowing of the reef and gravitational export of reef debris, which resulted in a reduced net accumulation of debris within the reef zone. This gave rise to the enormous development of microbial crusts, vulnerable to elevated sedimentation rates, in a high-energy, shallow-water setting. These microbial crusts anticipated the stabilising role of coralline red algae in Cenozoic and modern high-energy reefs and hence caused a 'modern-type' character of the coral-'algal'-debris Ota Reef unknown from most other Upper Jurassic reefs.

Deposition of the pure Ota limestones was coeval with the fine siliciclastic Abadia formation and the coarse Castanheira arkosic deposits directly to the west and south. (see Chap. 6.4).

Several studies in english language include aspects of the Ota Platform. Age discussion and a general overview of the facies development is given by LEINFELDER et al. (1988), Ota black pebbles are described by LEINFELDER (1987b), the reef zone is characterised by LEINFELDER (1992) and parts of the microbial crusts analysed by LEINFELDER et al. (1993b) are from the Ota Reef. The structural setting of the Ota Platform is discussed in LEINFELDER & WILSON (1989).

3 OTHER CORAL REEFS AND CARBONATE PLATFORMS IN THE EASTERN PART OF THE LUSITANIAN BASIN

For Chapter summary click here

Figures

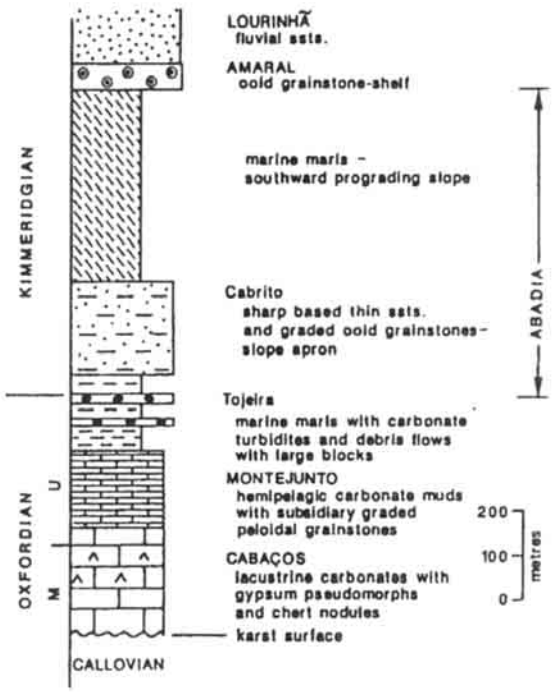


Fig. 106: Summary section of the Upper Jurassic succession to the south of the Montejunto (from LEINFELDER & WILSON 1989, slightly modified).

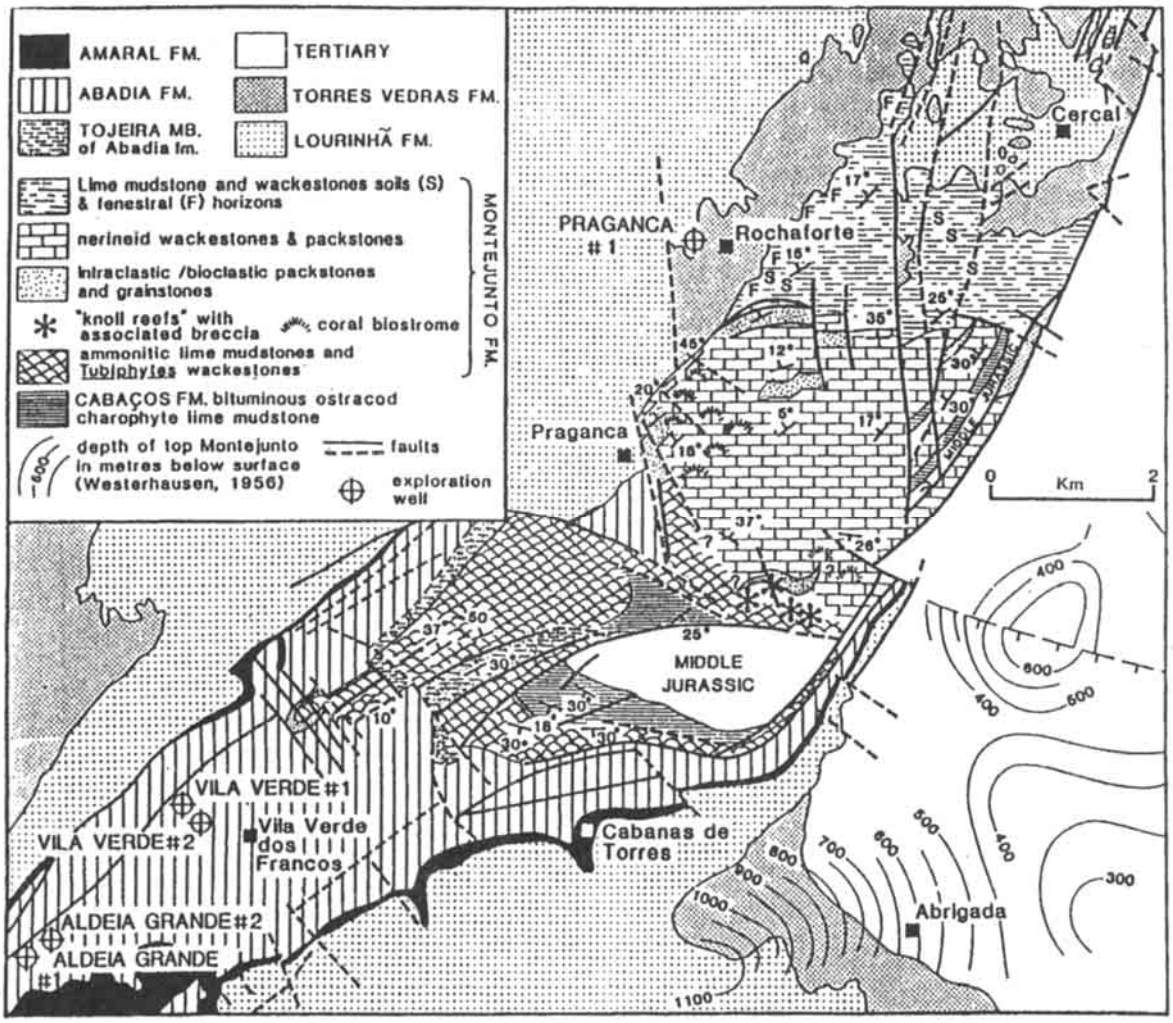


Fig. 107: Facies map of the Montejunto region (modified from ELLIS et al. 1990)

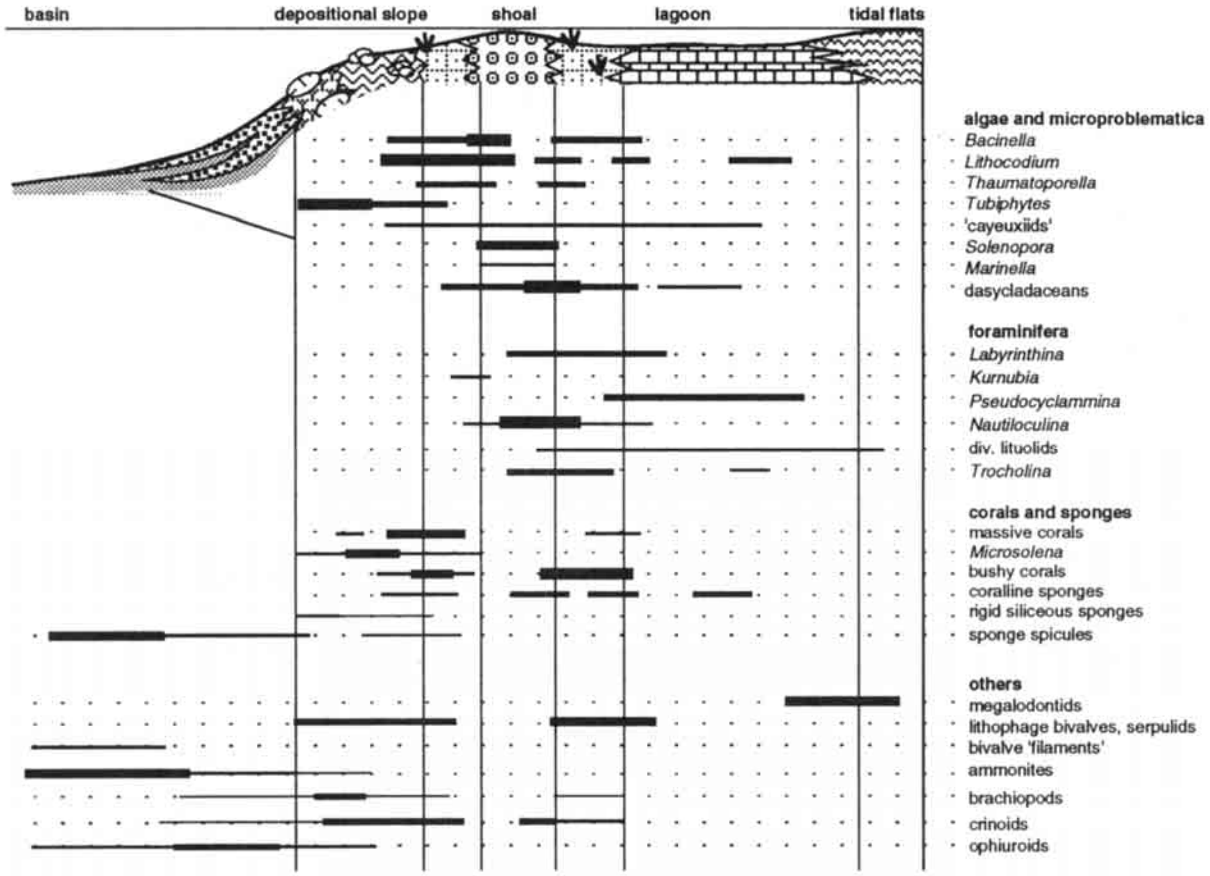


Fig. 108: Distribution of selected organisms from the Montejunto-Platform (after SCHERER 1991, modified). Section across platform is simplified (cf. Fig. 116).

Figs. 109-114: Facies examples and black pebbles from the Montejunto-Platform (Black Pebble facies is from Rochaforte quarry).

Fig. 109: Intraclast bioclast grainstone from platform margin shoal. Arrow: coarse agglutinating lituolid foraminifer, above *Labyrinthina mirabilis.* Length of bar is 1 mm.

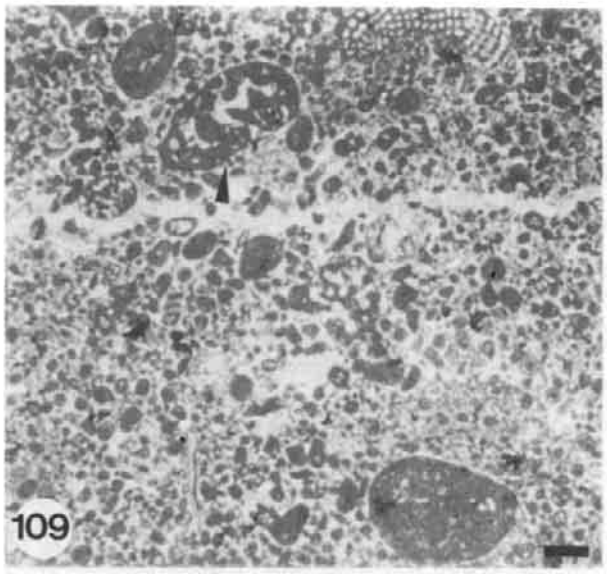
Fig. 110: Resedimented, allochthonous intraclast echinodermal grainstone within basinal limestones of Montejunto beds. Length of bar is 1 mm.

Fig. 111: In-situ preservation of horizon which was secondarily blackened by organic matter and subsequently leached. Length of hammer is 28 cm.

Fig. 112: Large black pebble measuring 22 cm. Pebble had strong bituminous smell.

Fig. 113: Pedogenic black pebble horizon, overlain by thin calcrete crust, marginal marine limestone with small black pebbles, and thick calcrete crust. Note erosional relief below upper calcrete. Visible part of yard stick is 14 cm.

Fig. 114: Pedogenic black pebble - calcrete breccia with blackened matrix. Brecciation was possibly created by uprooting during storm. Length of yard stick is 22 cm.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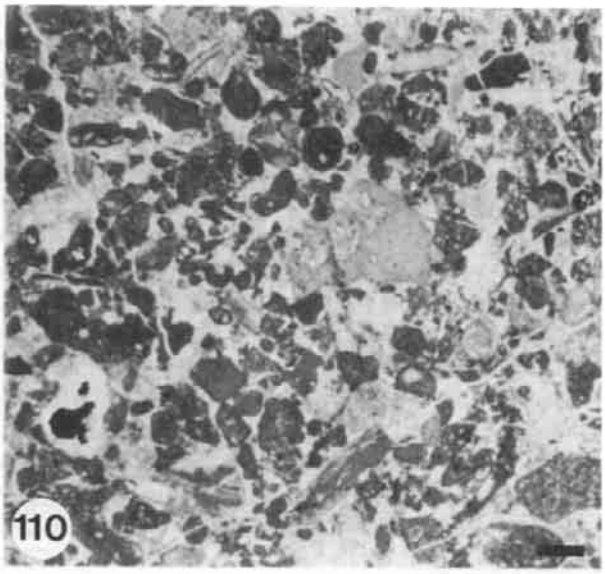
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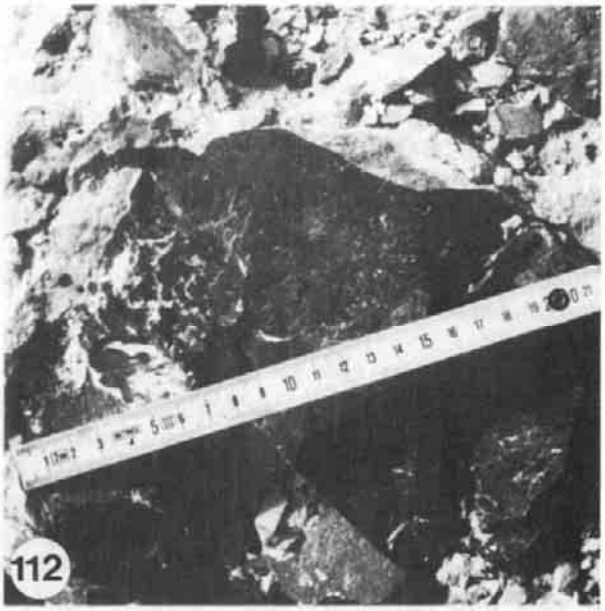
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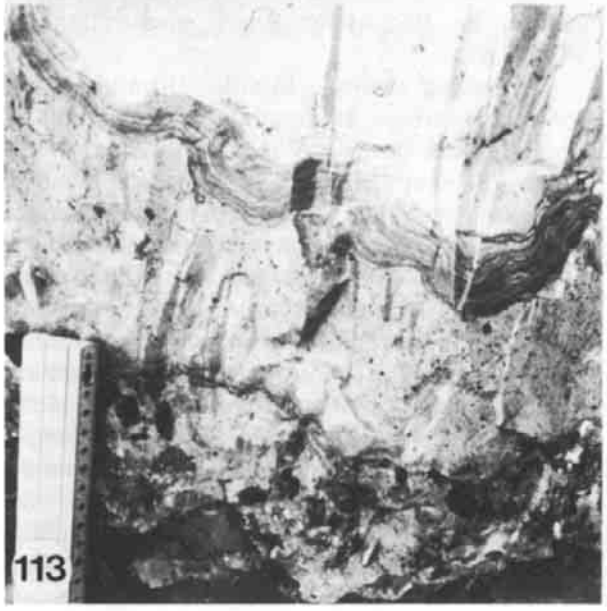
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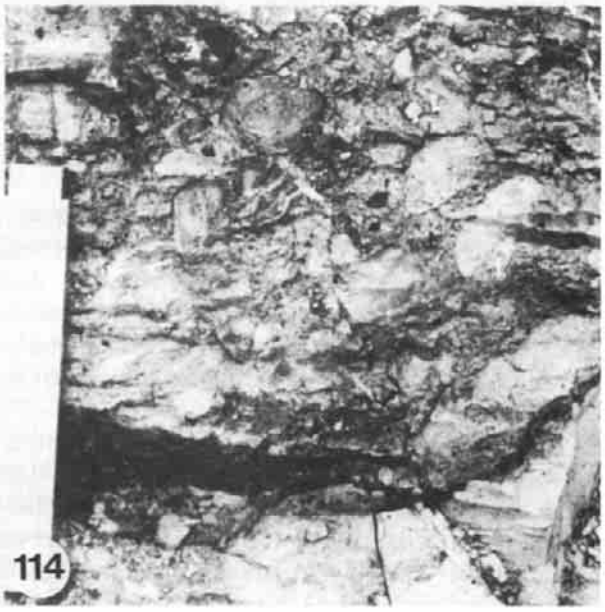
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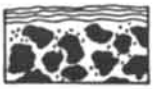
a  blackened horizon with rhizobrecciated top (autochthonous black pebbles). Overlain by laminated calcrete;

b  complete rhizobrecciation and minor transport results in parautochthonous black pebbles within partly blackened soil matrix. Commonly overlain by laminated calcrete;

c  reworking of b-type causes second generation black-pebble breccia, with additional calcrete clasts. Soil matrix partly blackened. Horizon may be overlain by laminated calcrete.

Fig. 115: Origin of three types of black-pebble horizons, as seen in the Rochaforte quarry, Montejunto Limestone.

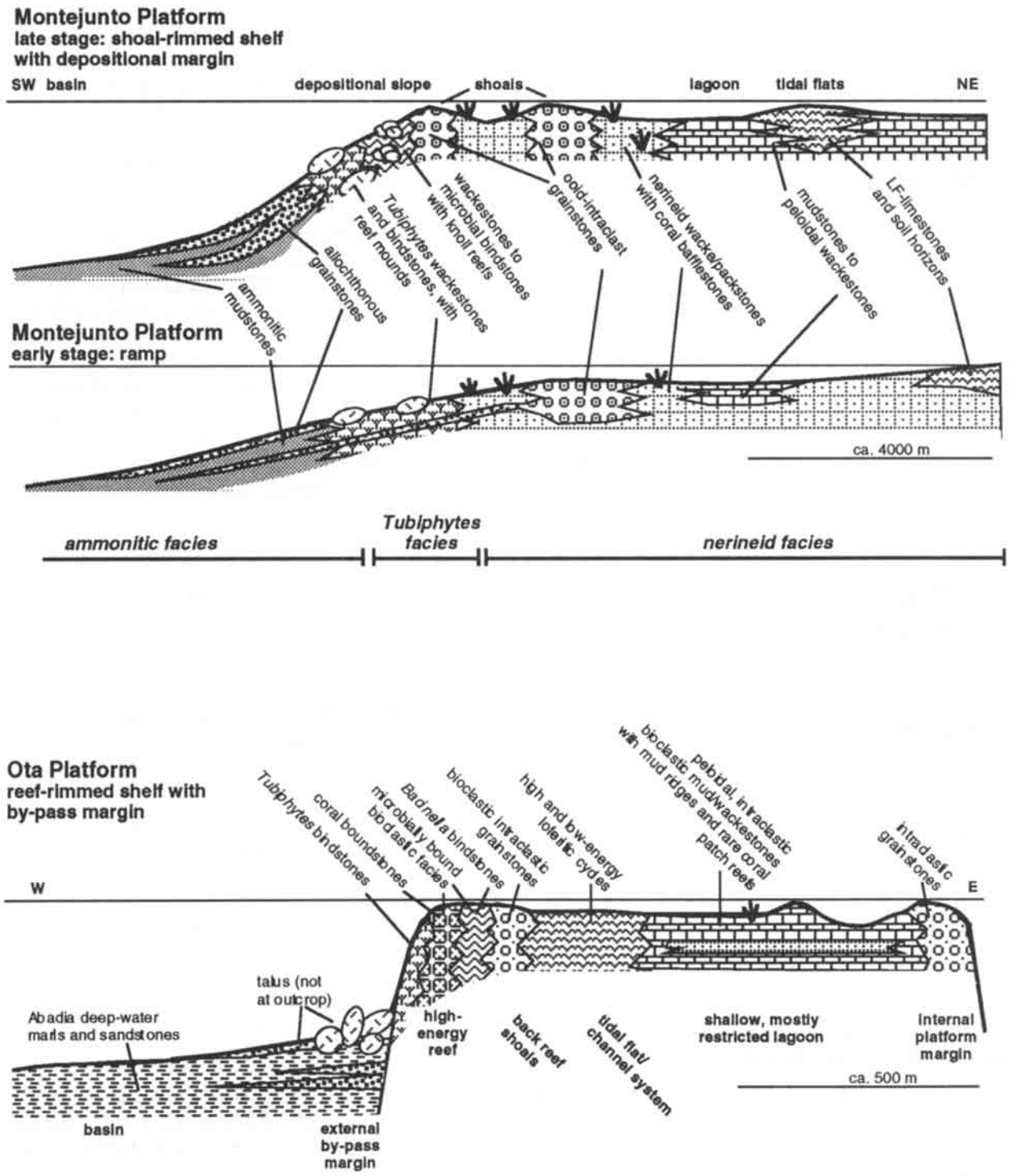


Fig. 116: Idealised time-slice sections across the Montejunto-Platform and comparison with the Ota-Platform. The Montejunto-Platform mostly exhibited a medially steepened ramp geometry, but probably transformed into a shoal-rimmed shelf at the end of its development. The existence of a depositional slope allowed slight progradation of the slope, which contrasts the Ota example (Montejunto partly from ELLIS et al. 1990 and SCHERER 1991).

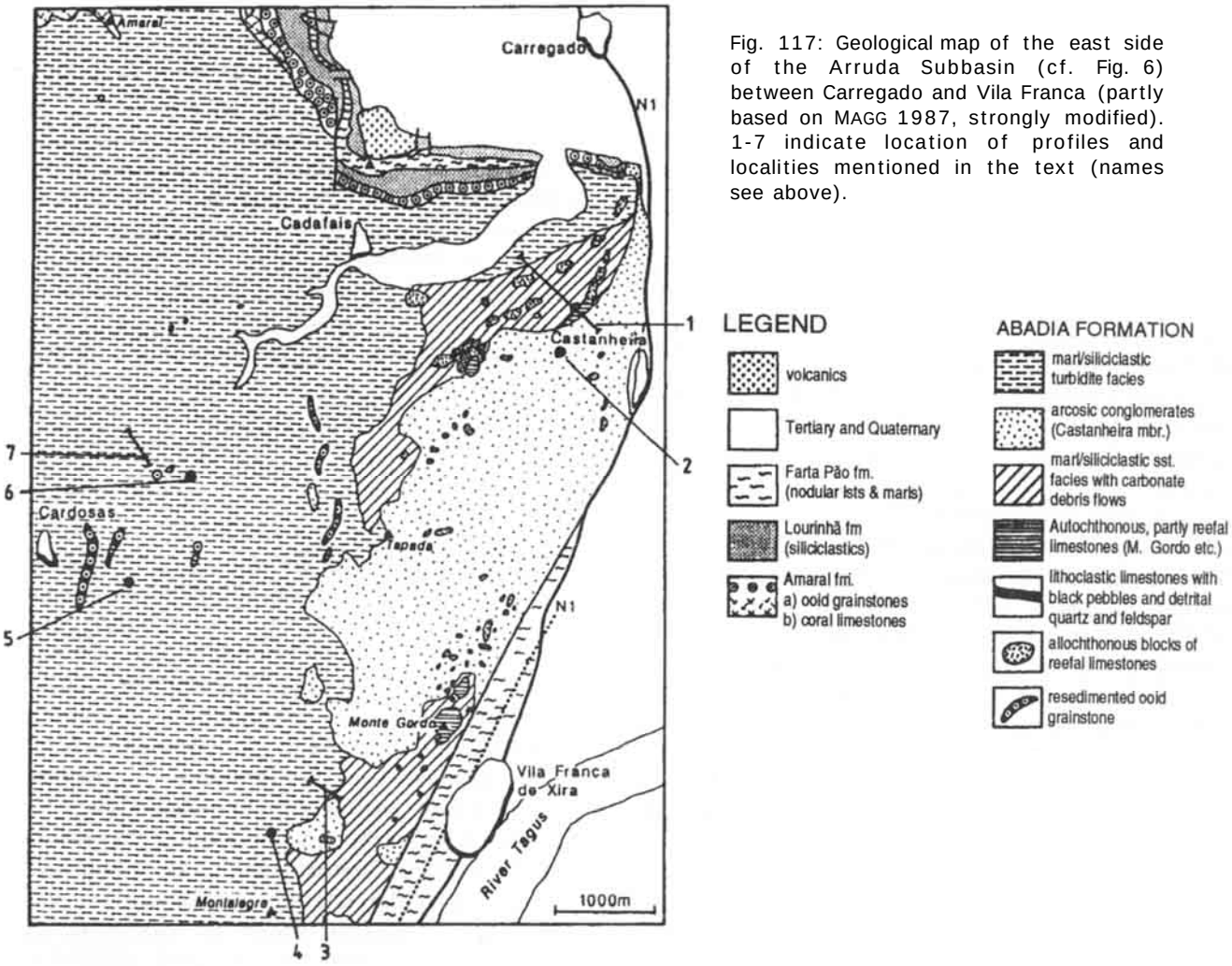


Fig. 117: Geological map of the east side of the Arruda Subbasin (cf. Fig. 6) between Carregado and Vila Franca (partly based on MAGG 1987, strongly modified). 1-7 indicate location of profiles and localities mentioned in the text (names see above).

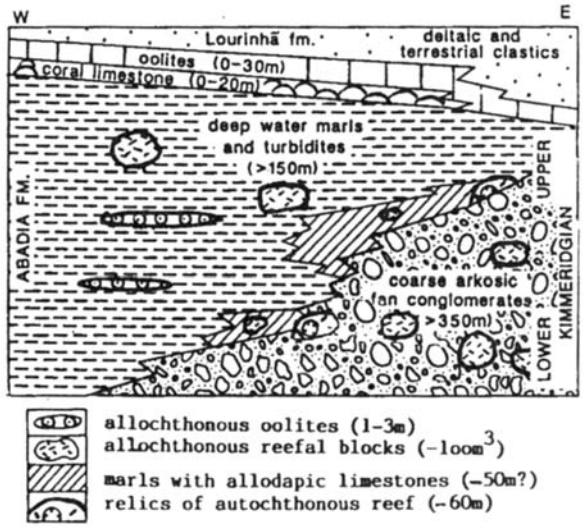


Fig. 118: Sketch of facies relationship within the Abadia and Amaral formations along the eastern margin of the Arruda Subbbasin (Castanheira region).

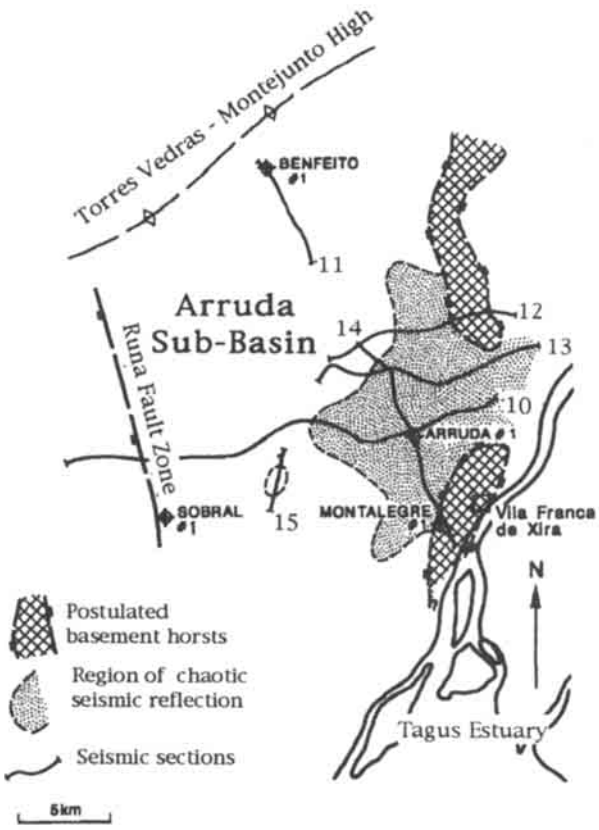


Fig. 119: Seismic map of the Arruda Subbasin (from LEINFELDER & WILSON 1989). The Ota-Platform is situated above the northern basement horst. The distribution of the proximal conglomeratic facies of the Castanheira fan is approximately outlined by the area with a chaotic reflection pattern. 10-15 refer to figures of seismic lines given in LEINFELDER & WILSON (1989).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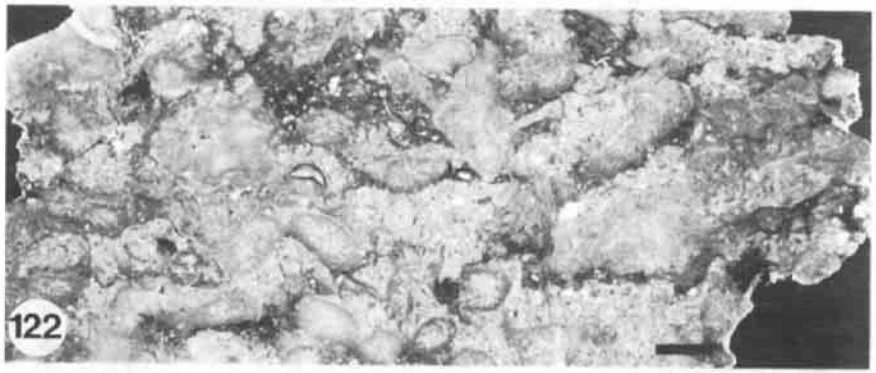
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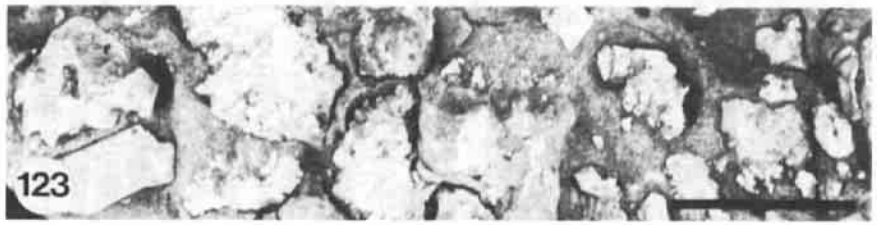
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Figs. 120-124: Castanheira fan delta (1): Facies examples. Top of all figures is to the left margin of page.

Fig. 120: View from Castanheira hilltop towards south. Beholder stands on reef relic. Hills covered by forest are formed by the conglomerates of the proximal fan facies. Center right: exposed conglomerates in the Quinta da Portela quarry. Hilltop in background at left margin is Monte Gordo reef limestone.

Fig. 121: Proximal fan: arcosic conglomerates with amalgamated, clay-floored channels. Hammer length is 28 cm.

Fig. 122: Coral bioclast debris flow. Light particles are detrital feldspar clasts. Length of bar is 1 cm.

Fig. 123: Lower bedding plane of marine sandstone with reworked reefal limestone clasts. Monte Gordo hilltop (isolated bed boulders). Length of bar is 5 cm.

Fig. 124: Disorganised arcosic conglomerate with transported clay boulders (arrows). Left boulder is 8 m long and in upright position. Length of bar is about 2 m. Close-up shows basement pebbles, mostly phyllites. Length of bar is 10 cm.

Figs. 125-130: Castanheira fan delta (2): Facies examples and organisms.

Fig. 125: Incompletely preserved ammonite (*Ardescia pseudolictor*) from the distal fan area. Diameter of coin is 2 cm.

Fig. 126: Allochthonous limestone blocks SW Quinta da Portela. Block in foreground is about 2 m high.

Fig. 127: Lithoclastic limestone with black pebbles, detrital feldspar (white) and quartz grains. Lithoclasts show mainly bindstone facies. Arrow: coral. Intergranular pores partly filled with vadose silt and internal sediments. Foundation of Monte Gordo reef. Length of bar is 1 cm.

Fig. 128: Thin-sectin from Fig. 137 under cross-polarised light. Dark particles are lithoclasts, white is quartz. Top: feldspar clasts. Thin cement crust around lithoclast (small arrow). Large arrow: vadose silt and internal sediment. Length of bar is 1 mm.

Fig. 129: Boundstone facies of the Monte Gordo reef. Bottom: bioeroded *Microsolena* coral, above bushy coral. Sediment is rich in microbial/algal crusts (including abundant *Tubiphytes*). Arrow: crinoid ossicle.

Fig. 130: Karstified microbial bindstone boulder. Boulder was collected in distal fan area. Arcosic material is preserved in karstic pockets due to by-passing through proximal fan area. Scale is 5 cm long.


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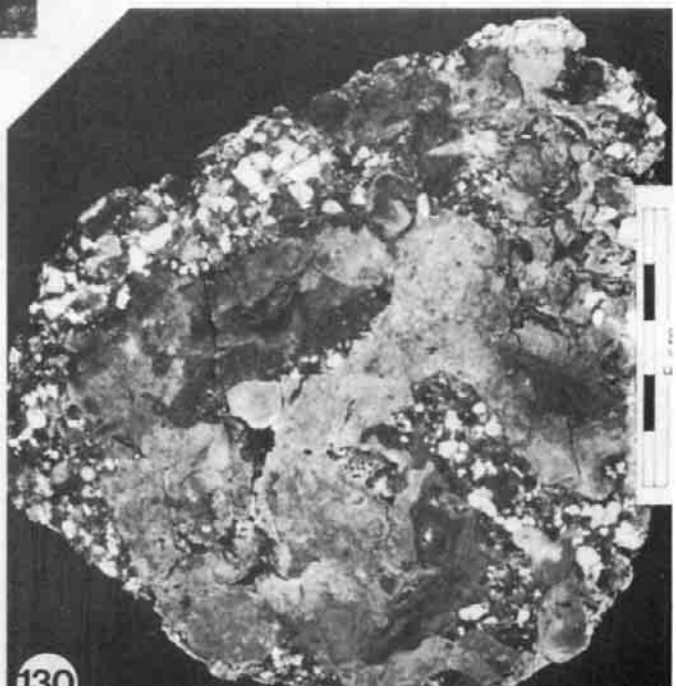
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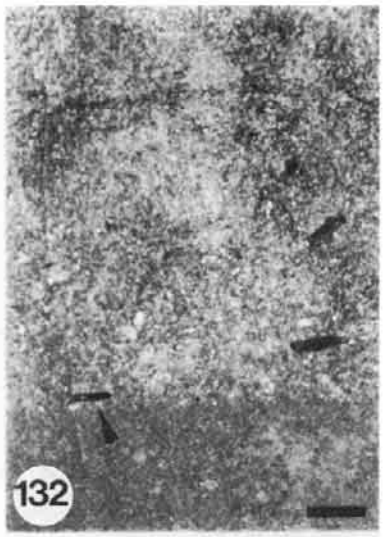
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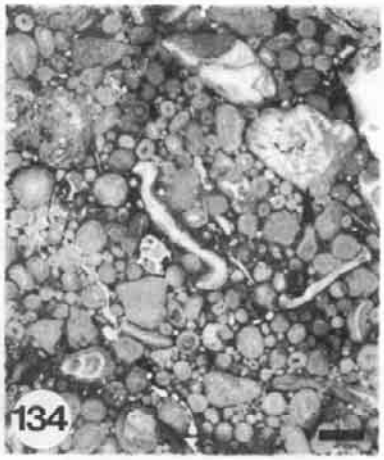
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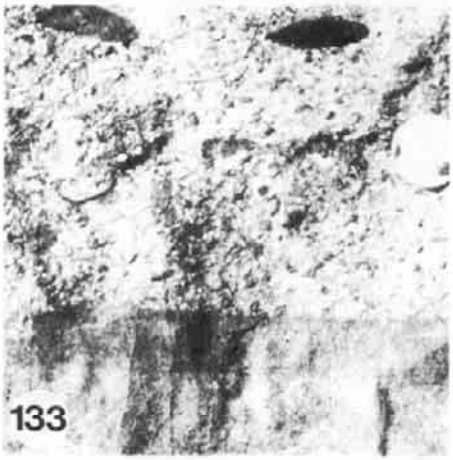
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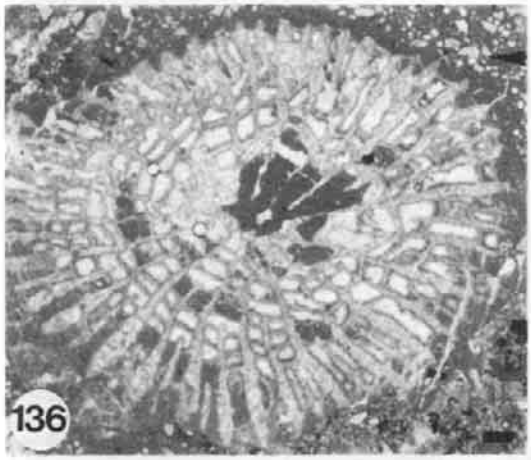
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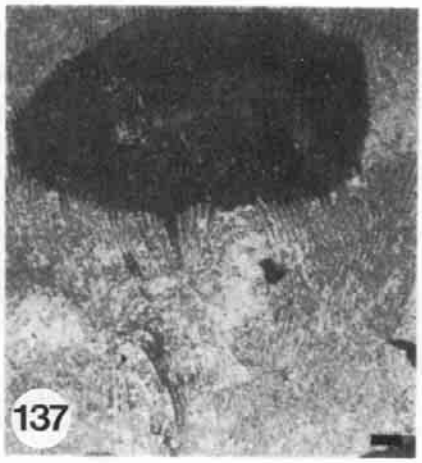
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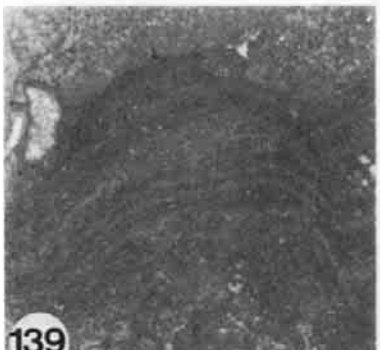
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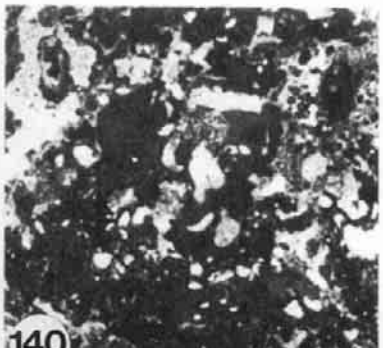
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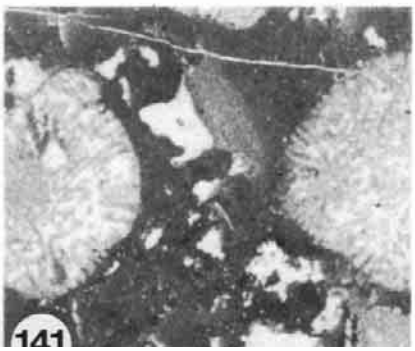
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Figs. 131-141 Castanheira fan delta (3): Facies examples and organisms (scale of bar 1 mm, otherwise indicated).

Fig. 131: *Microsolena* reefal facies with small palaeokarst cave. Corals are bored (allochthonous boulder near Castanheira hilltop). Scale of bar is 5 cm.

Abb. 133: Detail aus Abb. 132: Obere Einheit ist reich an Bivalven (v.a. Austern). Dunkle (original braune und rote) Komponenten stellen aufgearbeitete Konkretionen dar. Durchmesser der Münze 2.5 cm.

Figs. 132-134: Resedimented turbiditic oolite near Não Há. 132, 133: stacked fining-up sets. Note dark (i.e. red) components representing reworked siderite concretions and belemnite (arrow in 132). Frequent oyster clasts and chaotic position of particles in 133 and 134. Arrow in 134 indicates coral. Interparticle material (134) is a bituminous, clayey microsparite. Length of bars 2 cm (132) and 5 mm (134); diameter of coin in (133) is 2.5 cm.

Fig. 135: Coral bafflestone from top part of Monte Gordo Limestone. Corals are overgrown by stromatoporoids.

Fig. 136: *Thecosmilia* fragment from quartz-rich debris flow. Arrow: detrital quartz.

Fig. 137: bored *Microsolena* coral from top part of Monte Gordo Limestone

Fig. 138: Relic of hexactinellid (lychniskid) siliceous sponge, representing a resedimented particle of a debris flow.

Fig. 139: Dense and peloidal, finely laminated microbial crusts (top part of Monte Gordo Limestone).

Fig. 140: *Tubiphytes* bind/framestone. *Tubiphytes* formed a relatively resistent framework, which later became partially winnowed.

Fig. 141: Toppled phaceloid coral bush, possibly of *Dermosmilia*. Micritic microbial crusts encrust the coral branches. Internal sediments partly fills microcavities. Top of figure is to the left.

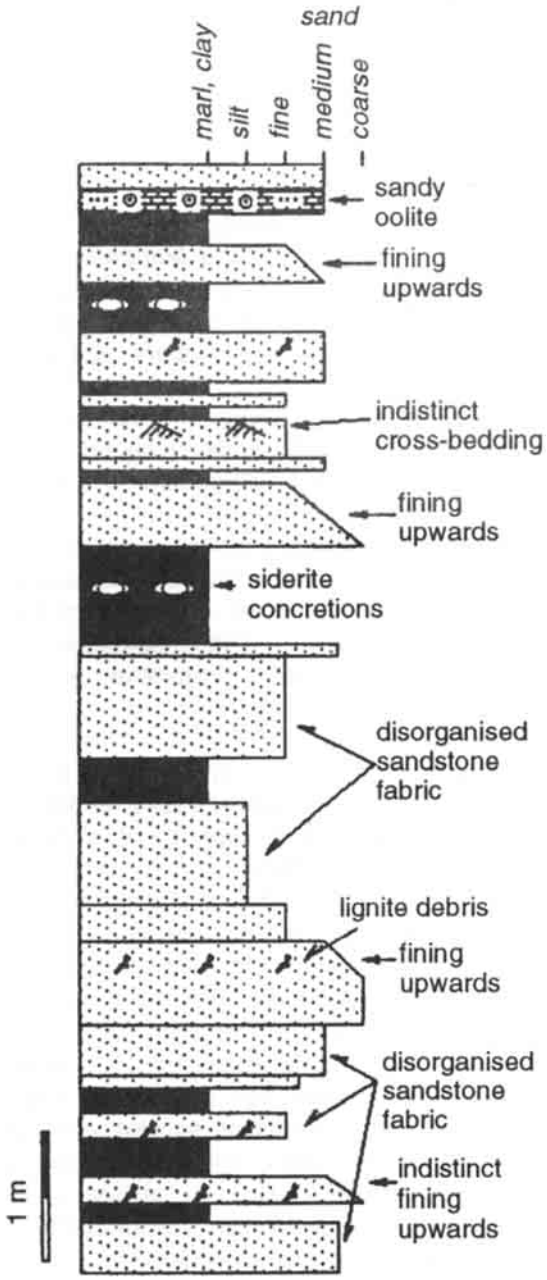

Fig. 142: Profile 'Cardosas' from the medial part of the Castanheira fan. See Fig. 117 for location.

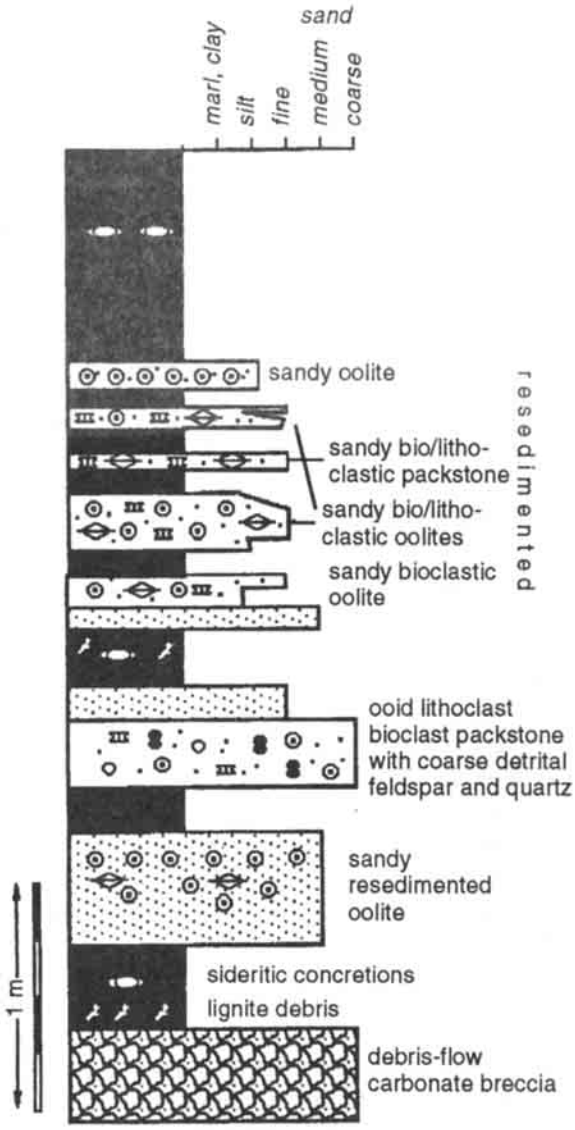

Fig. 143: Profile 'A dos Bispos', from the transition zone between medial facies to carbonate-rich facies within the the Castanheira fan.

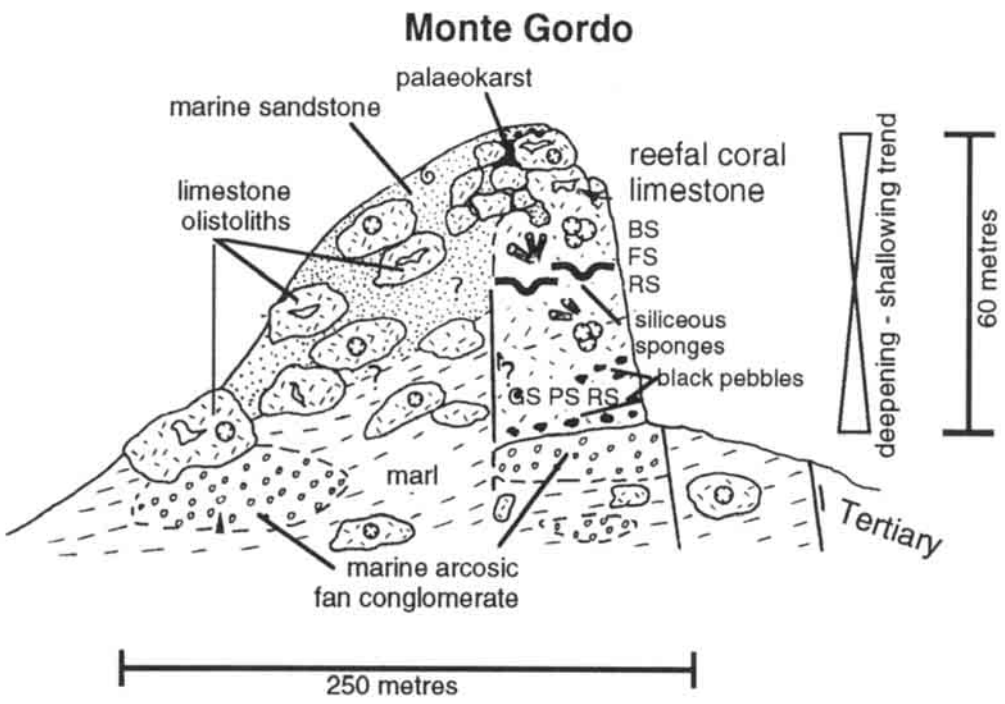

Fig. 144: Geological structure and facies succession of the Monte Gordo reefal limestone (Vila Franca). Allochthonous blocks are not to scale

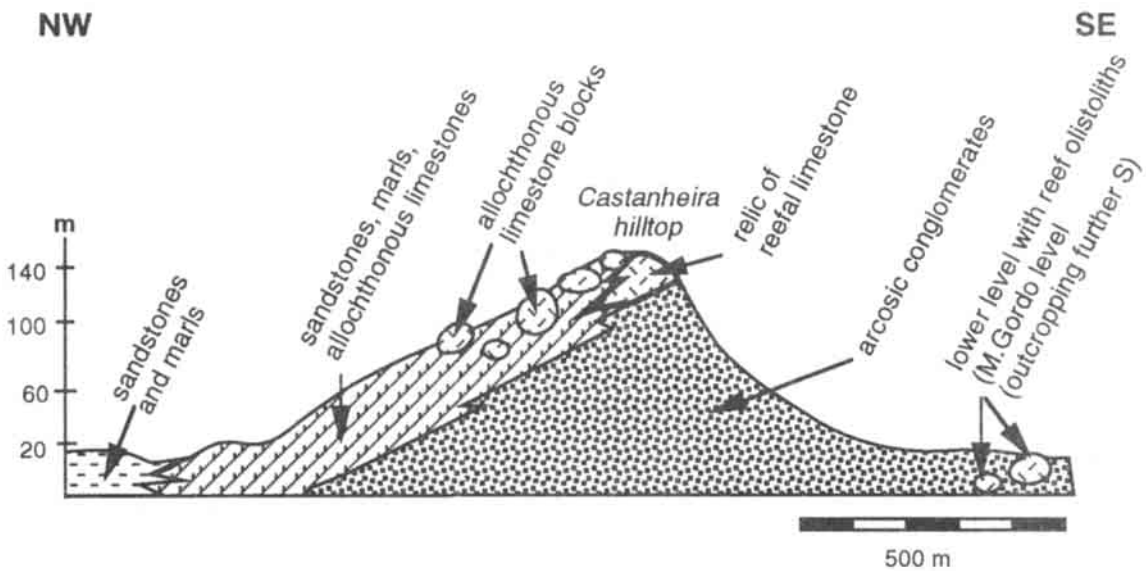

Fig. 145: Geological structure and facies succession around the Castanheira hill (Castanheira fan). Allochthonous limestone blocks are not to scale.

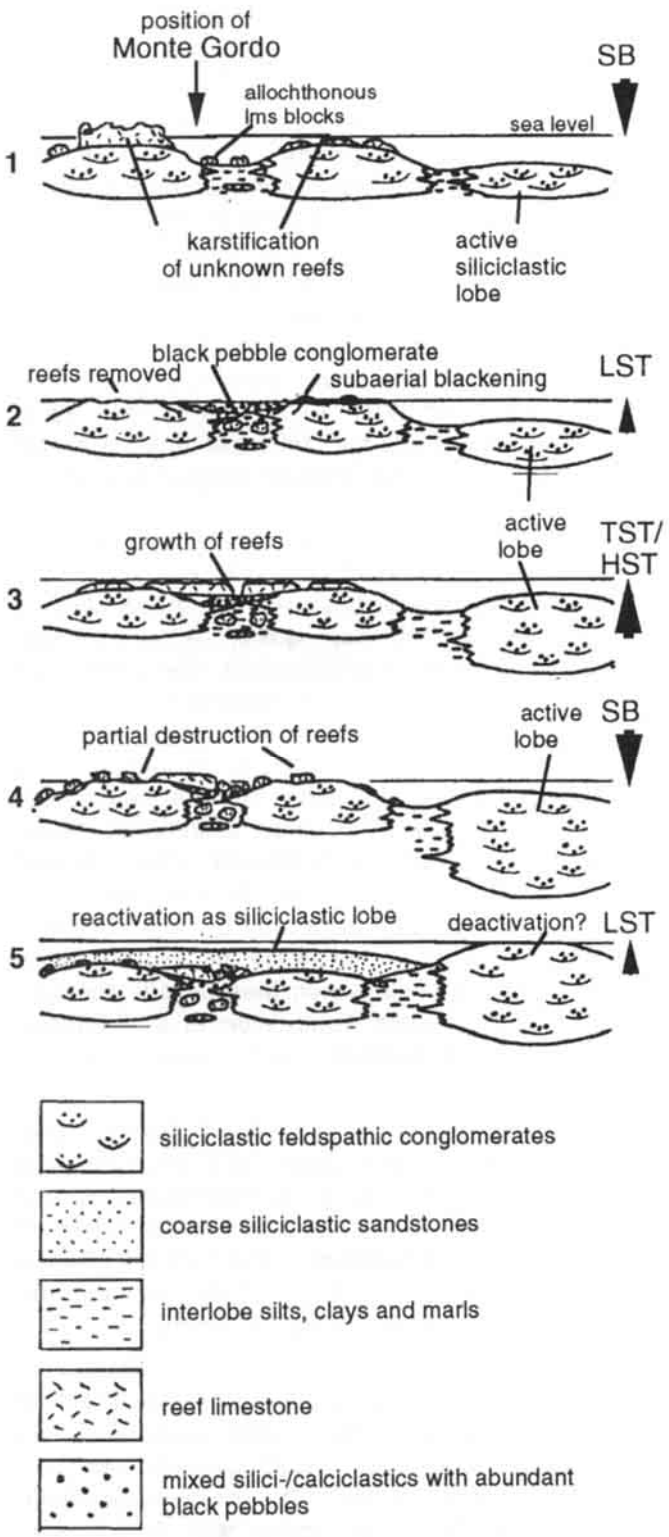

Fig. 146: Interpretation of the development phases of the Monte Gordo area. Changes of relative sea level and local deactivation of siliciclastic lobes are the principal factors. SB, LST etc. are local systems tracts.

(1) Sea level lowstand results in blackening, karstification and block transport of older carbonates towards interlobe areas;

(2) Black pebbles and siliciclastics increasingly fill up interlobe area;

(3) The Monte Gordo reef develops during subsequent sea level rise and highstand. Restriction of reef development to narrow area shows that gravitational siliciclastic sedimentation was active (though probably reduced) in neighboured areas;

(4) Karstification and partial erosion of the Monte Gordo reefs occurs during subsequent sea level fall, after which siliciclastic sedimentation is reestablished (5).

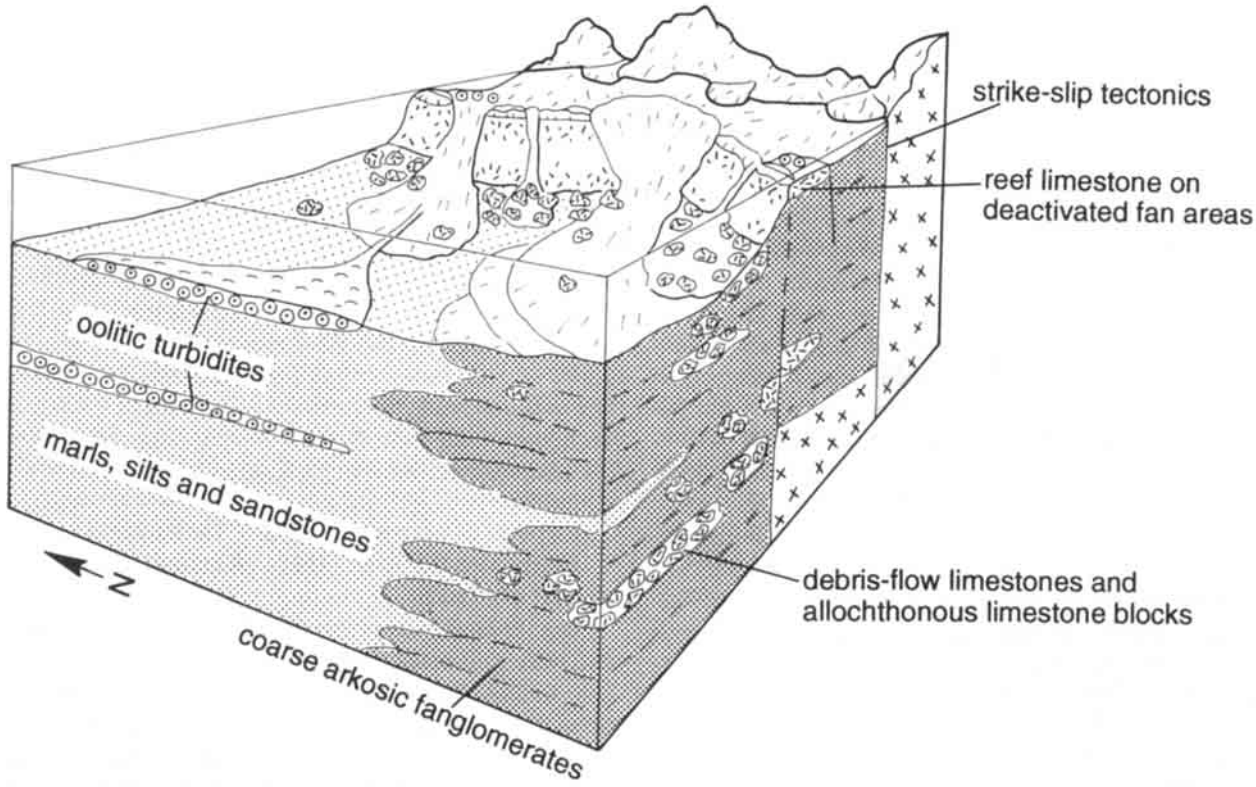

Fig. 147: Generalised depositional model for the mixed carbonate-siliciclastic Castanheira slope-type fan delta. Deposition of autochthonous carbonates was particularly related to two phases of relative sea level rise, but could nevertheless only take over in some autocyclically or allocyclically deactivated fan areas. Collapse events were related to local tectonic activity and drops in relative sea level (see text).

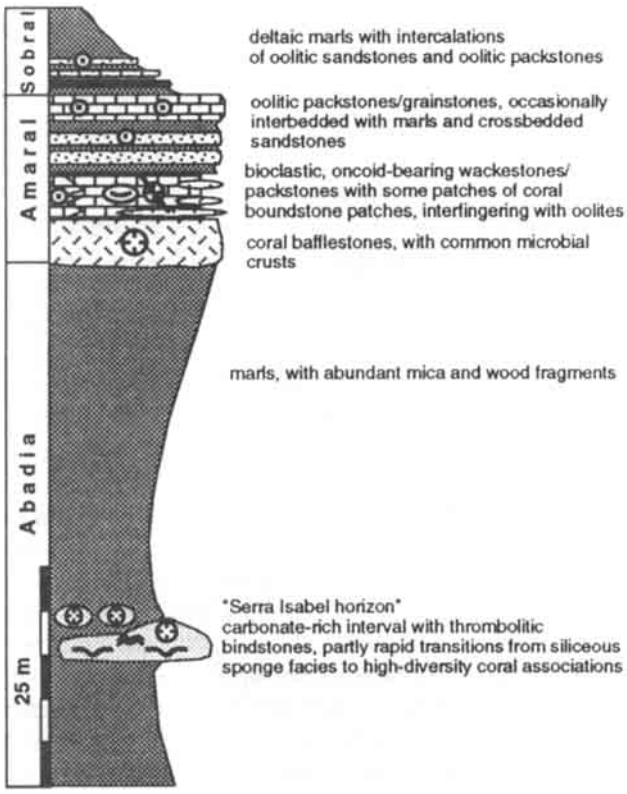

Fig. 148: Simplified section of the upper Abadia beds and the Amaral formation to the east of Arruda dos Vinhos (from LEINFELDER et al. 1993a, slightly modified).

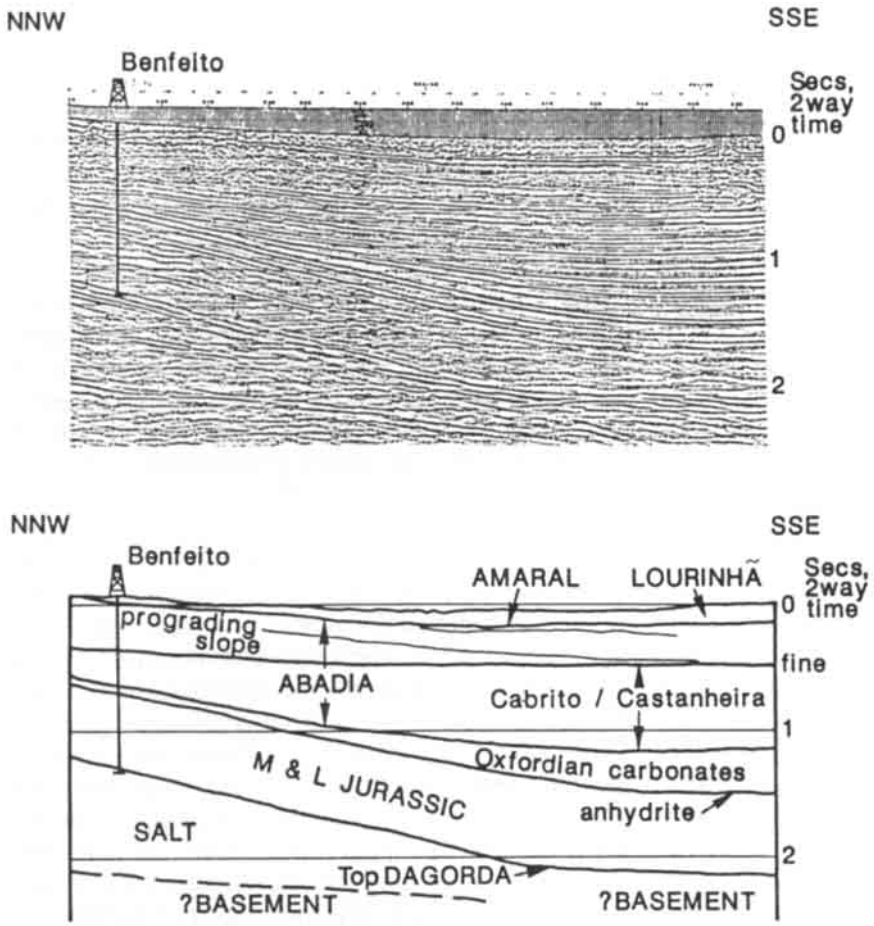

Fig. 149: Seismic line accross the northwestern part of the Arruda Subbasin, to the SE of the Montejunto anticline. Interpretation is supported by results from drillhole Benfeito #1. See Fig. 5 for location. The best reflectors are caused by Upper Triassic and Middle Oxfordian evaporite layers. Note clinoform reflectors in upper part of the Abadia beds. (from LEINFELDER & WILSON 1989)

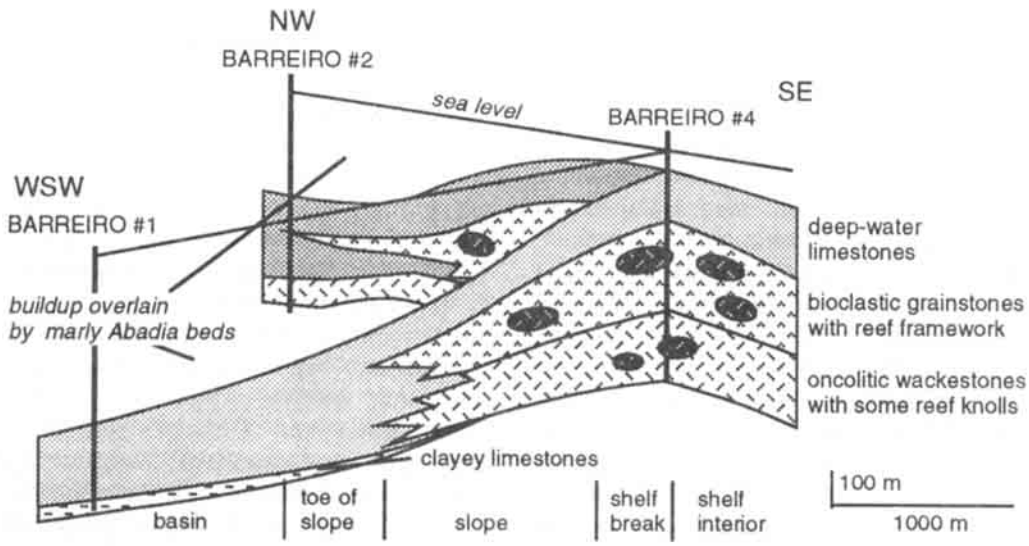

Fig. 150: Interpretative cross-section across the Barreiro buildup. Simplified from ELLIS et al. (1990).

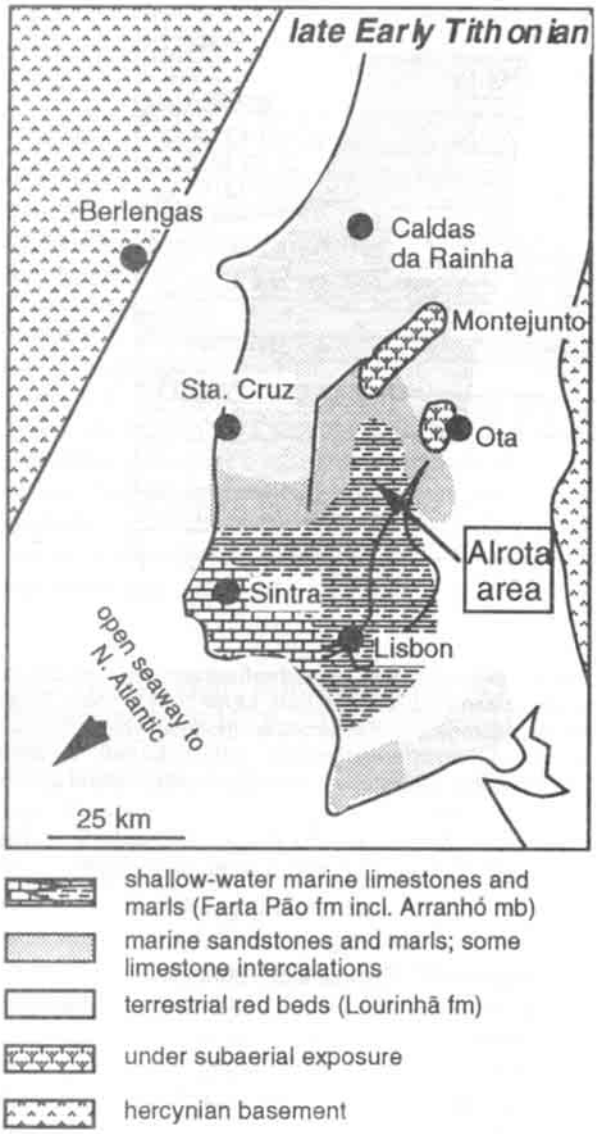

Fig. 151: Paleogeographic map of the middle part of the Lusitanian Basin for the late Early Tithonian (simplified from LEINFELDER 1987a).

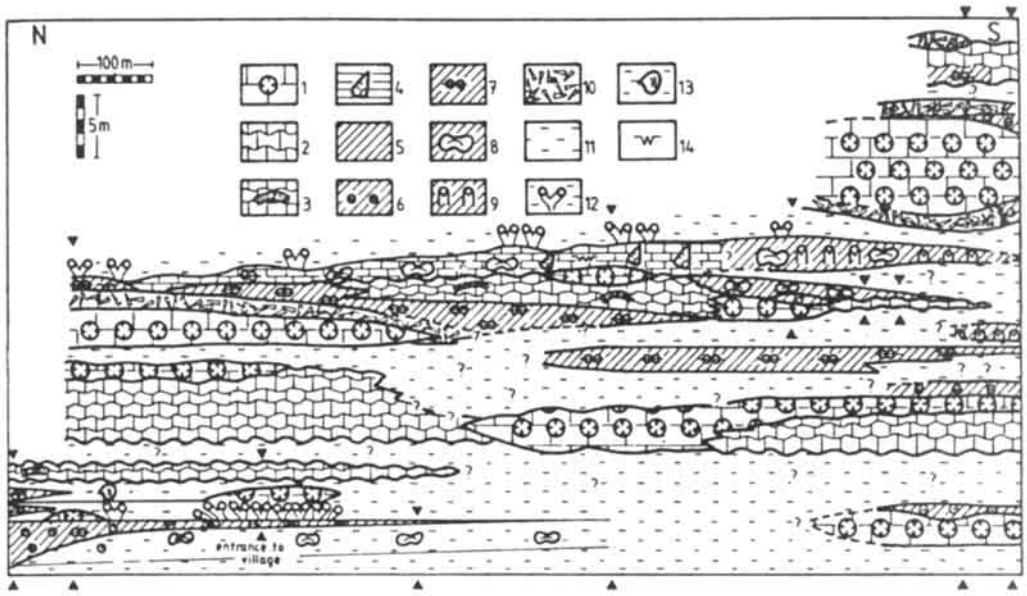

Abb. 152: Die Sedimentkörpergeometrie des Alrota Bereichs: Verzahnung von Korallenfleckenriffen, Korallenbiostromen und assoziierten Schuttkalken mit 'lagunären' mergeligen Kalken und Mergeln (aus LEINFELDER 1986; Pfeile beziehen sich auf dort abgebildete Profilaufnahmen). 1 Korallen Boundstones, 2 Knollenkalke (nodular wackestones), 3 Trichites Kalke/lms, 4 Nerineen Packstones, 5 Pack/Grainstones, undifferenziert/not differentiated, 6 Ooid Grainstones, 7 Cortoid Pack/Grainstones, 8 Onkoid Packstones, 9 Rhodolith Packstones, 10 Riffschuttfazies/reef debris facies.

Fig. 152: Arrangement of facies types in the Alrota area: Coral patch reefs, biostromes and associated bioclastic debris strongly interdigitates with lagoonal marly limestones and marls (Explanation of 1-14 see above) (from LEINFELDER 1986).

3.7 Chapter summary: Other coral reefs and platforms from the eastern part of the Lusitanian Basin

The Upper Oxfordian Montejunto Platform exhibits a facies zonation with considerable similarities to the Ota Platform, although it grew within a carbonate-dominated setting. It developed over an uplifted block modified by the rise of a salt pillow. The buildup is again mud-dominated, but is bordered to the west by a high-energy grainstone shoal. Coral patch reefs developed in front of, within and behind these shoals. Gradual transitions to basinal ammonitic limestones occur, showing the depositional character of the eastern platform margin. The platform passed from a ramp stage to a shoal rimmed carbonate shelf with a depositional margin. Similar to the Ota, the platform largely exhibits aggradational geometry, with slight progradation towards the end of the development. Despite growing in a carbonate-dominated setting, carbonate productivity was lower than in the Ota example, which is shown by the chiefly aggradational character of the MontejuntoPlatform despite the existence of a depositional margin, as well as by the position of the peritidal belt within, and not distal to, the lagoonal zone.

The Kimmeridgian Castanheira-Monte Gordo Fan/Reef System was formed at the eastern margin of the Lusitanian Basin. Coarse arkosic siliciclastics, including basement pebbles, were fed into the basin from the eastern hinterland, filling up local graben structures, created by rift tectonics, with more than 2200 metres of sediments which were drilled in Arruda #1. The fan is exposed in the Vila Franca-Castanheira area with about 350 metres of arkosic conglomerates and sandstones, showing thick amalgamated debris flows, collapse structures, lack of progradation and rapid transition to distal facies, which is diagnostic for a slope-type fan delta. Within and on top of the fan, two levels with autochthonous and allochthonous reef relics occur. The Monte Gordo reef relic, at Vila Franca de Xira represents a 60 m thick coral reef relic which developed in the lower part of the fan conglomerates. It is composed of a basal lithoclastic-black pebble unit, a subsequent deepening-up reef (from coral boundstones to coral-siliceous sponge facies) and a topping shallowing part dominated by coral bafflestones (keep up/give up/catch up/keep up-trend). The reef is truncated by a karstic unconformity. Karstification caused the formation of huge blocks which were transported during a subsequent sea level drop. The Castanheira reef developed on top of the fan, and is represented by a few metres thick carbonate relic showing a rapid give up / catch up trend. Karstic cavities show that the reef

was also truncated by a karstic unconformity, although the reef top is mostly not preserved. Both reef relics are surrounded by a broad zone containing allochthonous carbonates, such as olistoliths, breccia-type debris flows, intraclastic to oolitic grain flows, and turbidites, the latter of which extended far into distal areas of the fan. The growth of the carbonate coral reefs was enabled by a combination of factors (see Chap. 6.4).

The Amaral formation, presumably of mid Late Kimmeridgian age, is composed of coraliferous reefs and oolite-dominated grainstones. It locally contains lenses of oolitic sandstones and marls. Ooids mostly exhibit nuclei of detrital quartz. The Amaral formation, with a thickness of several tens of metres (max. 80 m), covers an area of at least 400 square kilometres. It forms a carbonate cap on top of a fine siliciclastic slope system, the Abadia formation, which prograded southwards. Detection of features relevant for sequence stratigraphic interpretation, such as thrombolitic microbial buildups below the Amaral, karstic horizons within parts of the Amaral and drowning by prodelta sediments shows that the Amaral formation did not develop penecontemporaneously with the underlying prograding siliciclastic slope system, as assumed by ELLWOOD (in ELLIS et al. 1987), but rather developed subsequently during relative sea-level rise (see Chaps. 6.4, 7.7).

The Barreiro buildup, of late Oxfordian to, possibly, early Kimmeridgian age is only known from seismics and drillholes. It developed over an uplifted basement block at the eastern margin of the basin, but unlike the Ota or Montejunto buildup, of similar structural situation, represents the only example where growth was initiated in the deeper water in a clay-rich environment. It developed into a mud mound buildup which then cought up to shallower water, as shown by an association of crustose corals together with microbial crusts. Again contrasting the above examples, the Barreiro buildup was finally drowned and overlain by deep-water sediments.

In marine areas of the Sobral estuarine delta (chiefly latest Kimmeridgian) as well as in the Alrota gulf (early Tithonian), shallow-water, mostly low-energy, euryhaline marls and clayey limestones predominated. Very locally, coral associations developed, which in the Alrota gulf occasionally grew up to water level, facilitating removal of fine-grained, particularly terrigeneous material. This caused positive feedbacks on the development of biohermal, carbonate-dominated patch reefs. Diversities of coral faunas were strongly dependent on the rate of sedimentation. The Alrota area is the key area to calibrate morphological criteria of corals thought to reflect sedimentation rate (see Chap. 6.4).

The above systems are also briefly discussed in the following studies (in english language): ELLIS et al. (1990)(Montejunto, Barreiro), LEINFELDER & WILSON (1989) (Castanheira-Monte Gordo Fan), LEINFELDER (1986)(Alrota, Sobral). A detailed analysis of the Amaral formation will be available in the near future (NOSE in prep., in German).

4 UPPER JURASSIC REEFS FROM THE REST OF THE LUSITANIAN BASIN

For Chapter Summary click here

Figures

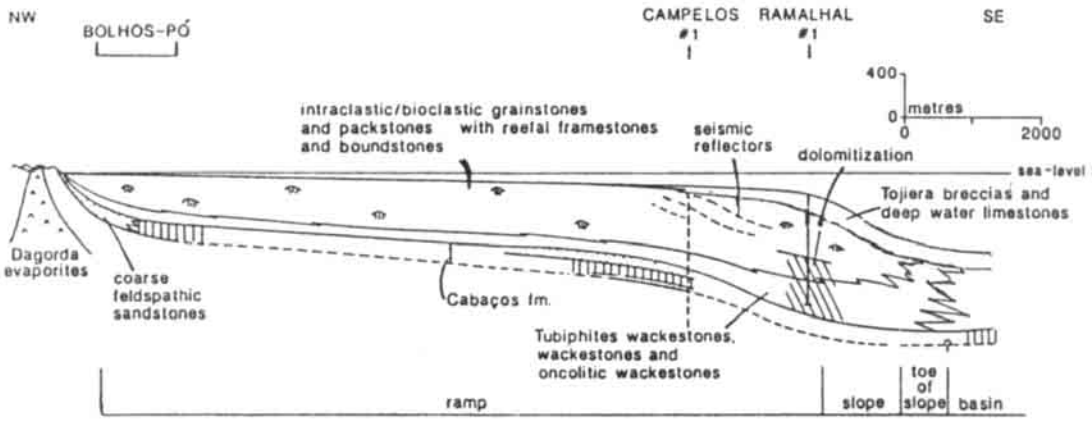

Fig. 153: Interpretative cross-section through the Upper Oxfordian Ramalhal 'buildup', based on seismic and well data. For location of wells see Fig. 5 (from ELLIS et al. 1990).

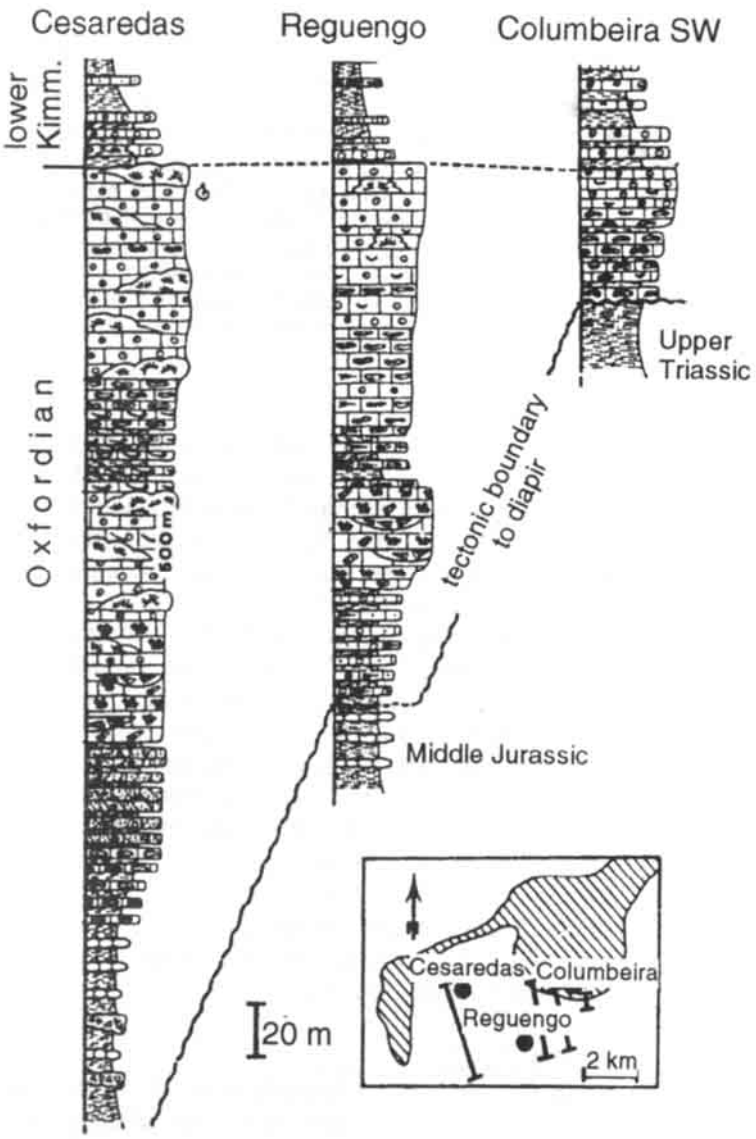

Fig. 154: The Upper Oxfordian shallow-water succession of the Ramalhal buildup as exposed at Cesaredas (from GUERY 1984, slightly modified). See also Figs. 155 and 5 for general location.

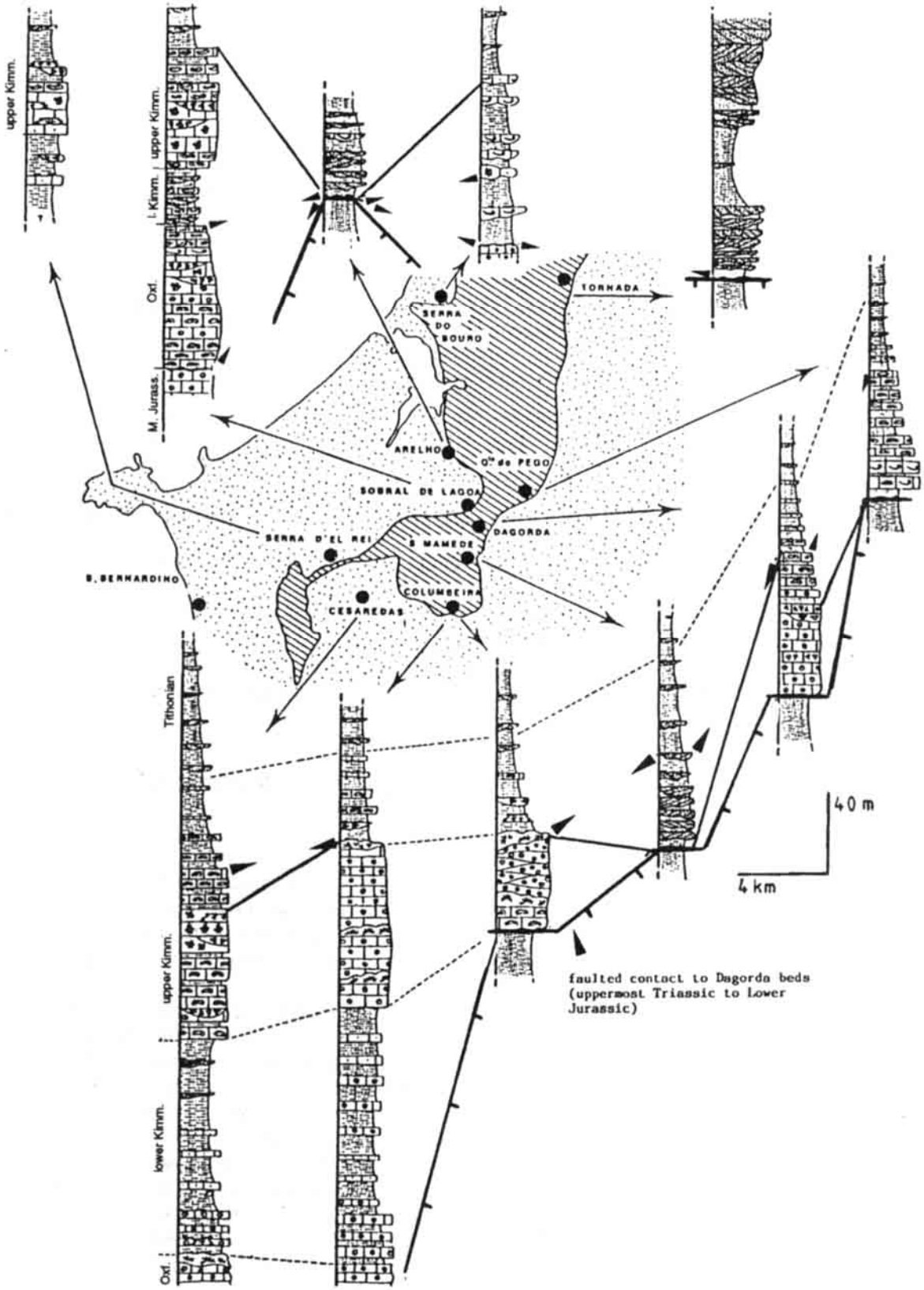

Fig. 155: The Caldas-Bolhos shallow-water carbonate unit (middle part of Alcobaça beds, 'mid' Kimmeridgian age) in the surroundings of the Caldas-Bolhos diapiric structure. The unit disappears towards north and west. For detailed 'Cesaredas`profile see Fig. 163. Lithological profiles are from GUERY (1984, slightly modified), but in part are correlated differently (broken lines and arrows: GUERY´s correlation; solid lines: partial reinterpretation). Contrasting GUERY´s opinion, the contact to the underlying Triassic/lowermost Liassic deposits is interpreted as tectonic.

Figs. 156-161: Giant oncoids at Cesaredas (Caldas-Bolhos-unit, Kimmeridgian)

Fig. 156: Nodular limestone. Nodular texture is caused by compaction of giant oncoids. Length of hammer is 28 cm.

Fig. 157: Coarsening-up oncoid packstone. Oncoids mostly without nuclei. Arrow: nerineid nucleus. Length of bar is 5 cm.

Fig. 158: Oncoids exhibiting in-situ amalgamation. Cortical fabrics outlined with pencil. Length of bar is 10 cm.

Fig. 159: Irregular and amalgamated oncoids. Note domal growth both upwards and downwards within same cortex layer (arrows). Length of bar is 10 cm.

Fig. 160: Thin-section detail from oncoid cortex: with threads of *Bacinella irregularis* crossing birdseye. Length of bar is 1 mm.

Fig. 161: Polished slab of giant oncoid. Note polar development of birdseye fabric suggesting in-situ growth. Length of scale bar is 3 cm.


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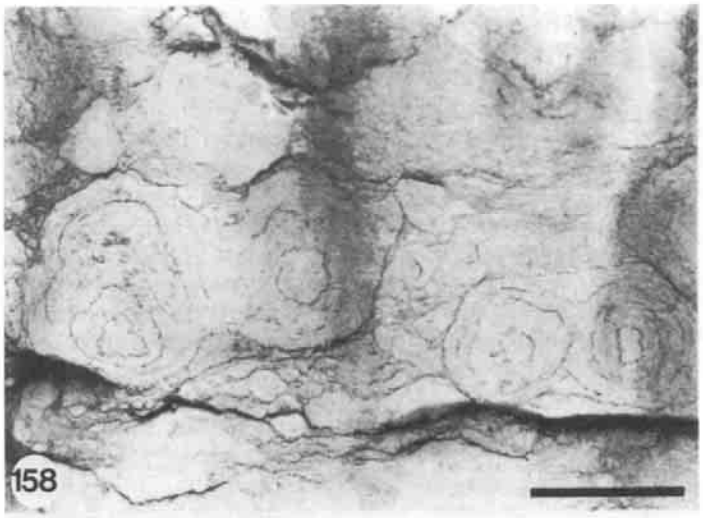
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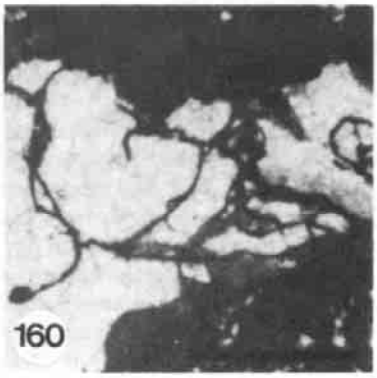
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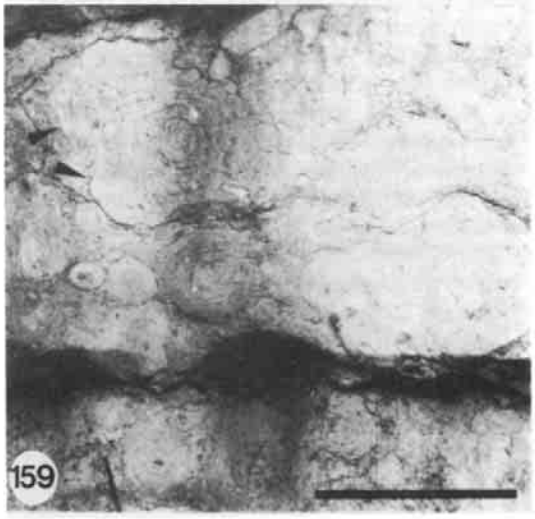
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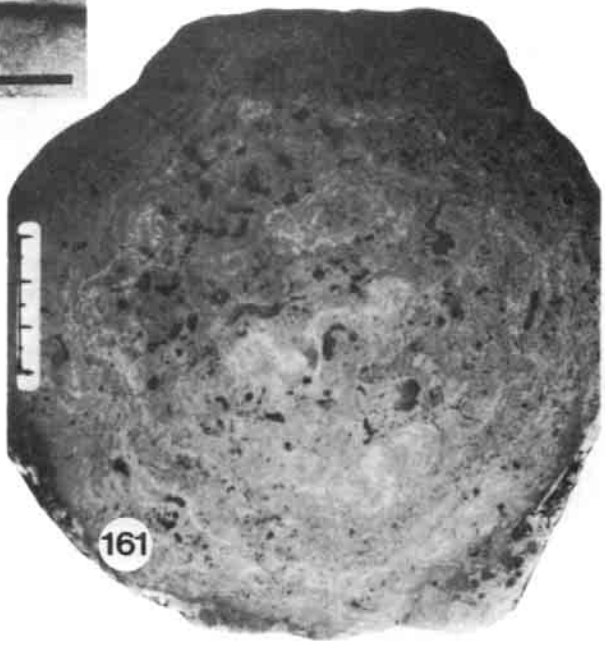
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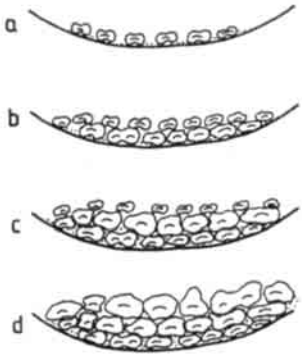

oncoids grow in shallow broad tidal channel under occasional overturning;

after reaching a size too large to be overturned, oncoids keep growing *in-situ*, while a new oncoid population starts growing on top of them;

second oncoid population becomes stable. Underlying oncoids represent a coarse substrate, enabling pronounced *in-situ* growth of second generation oncoids due to large amount of diffuse, reflected light available. Third oncoid population starts growing;

since contaminating fine-grained material may infiltrate the highly porous oncoid substrate, *in-situ* growth of third oncoid population is still more enhanced, resulting in even larger oncoids (up to 15 cm diameter).

Besides the enormous oncoid size, amalgamating of oncoids, polar growth and fitting fabric is also indicative of *in-situ* oncoid growth.

Fig. 162: Model for the in-situ growth of the giant oncoids from the Cesaredas area.

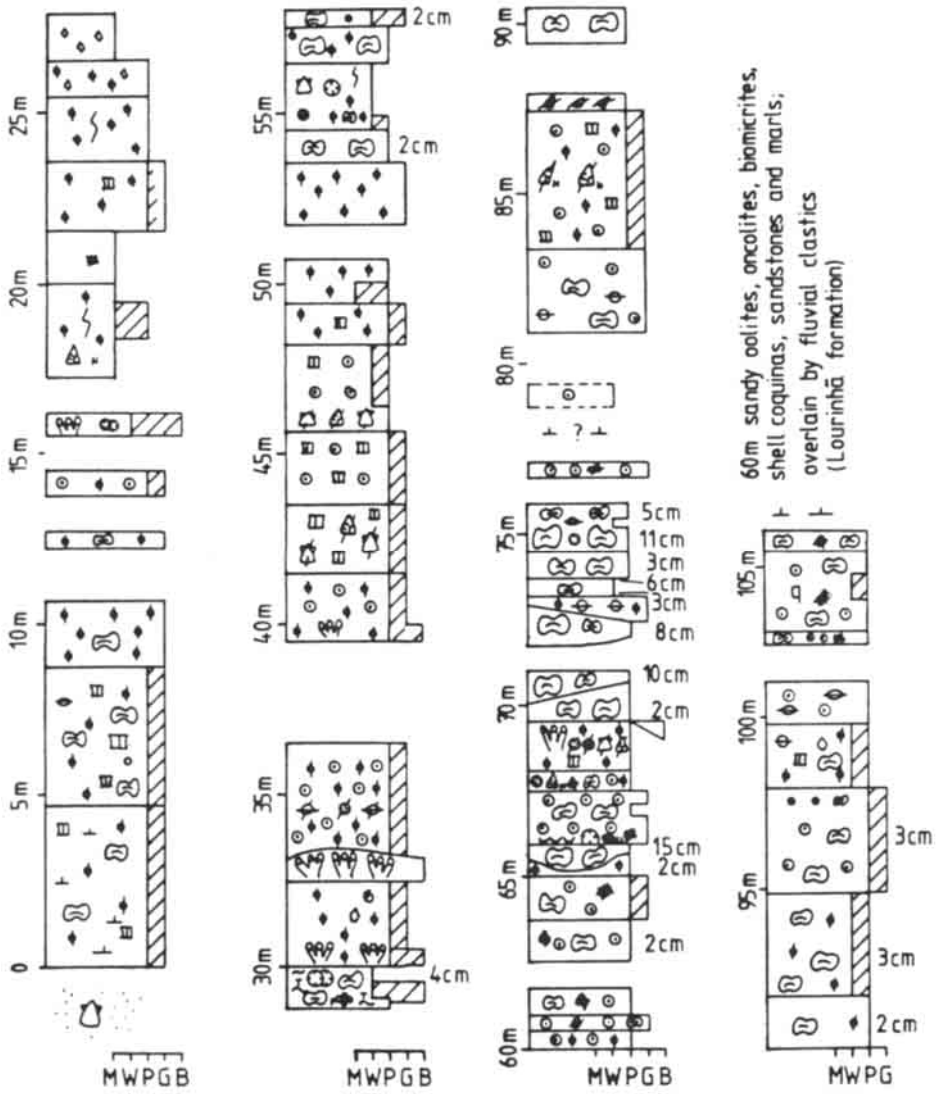

Fig. 163: Profile 'Cesaredas', middle? Kimmeridgian of the Caldas - Bolhos region. For location see Fig. 155. Legend see Fig. 174 (Appendix). Centimetre indications refer to maximum oncoid size (for oncoids > 2 cm).

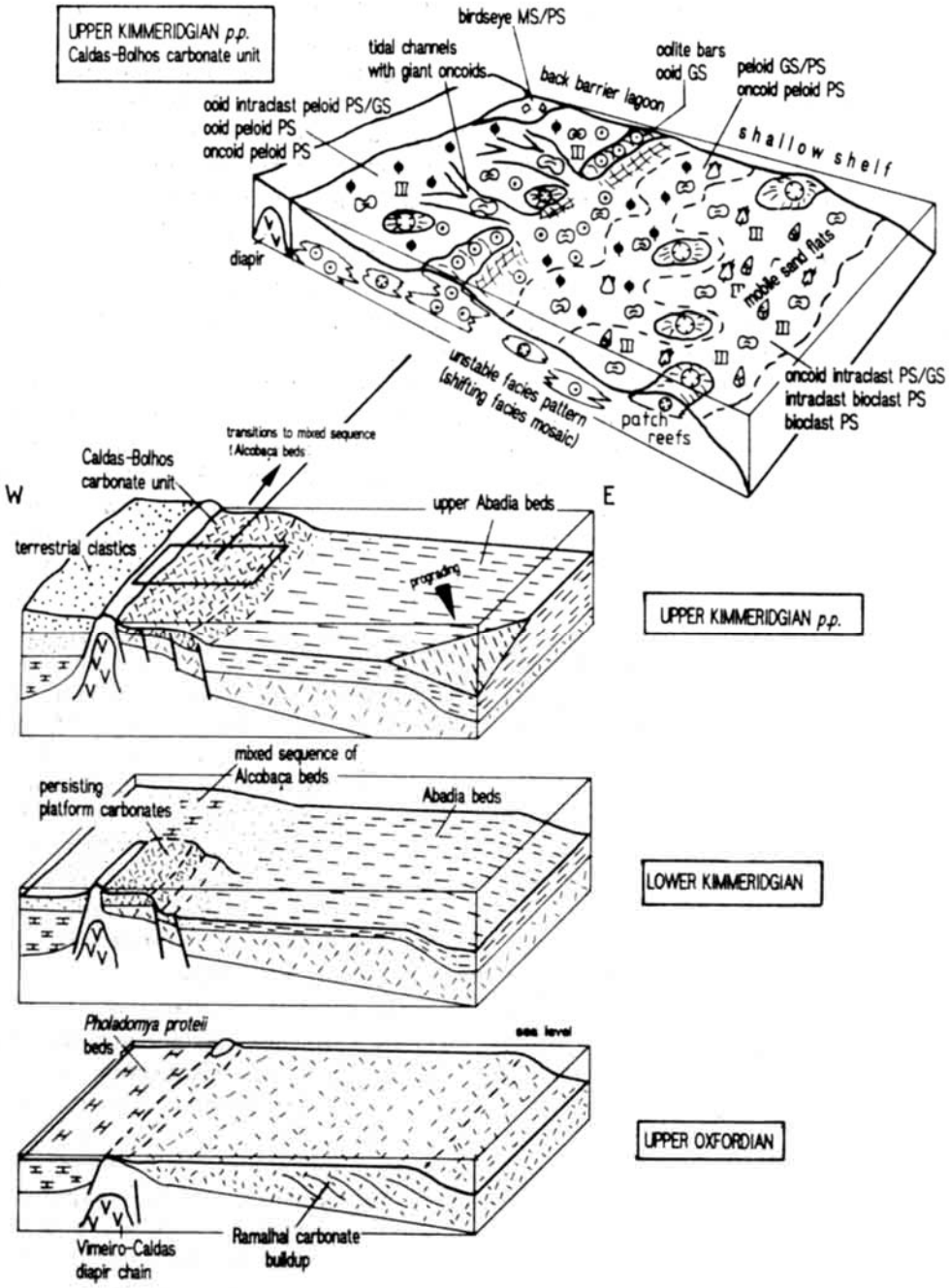

Abb. 164: Depositional models for the Ramalhal - Vimeiro - Caldas da Rainha region, for different time intervals. At the end of the Late Oxfordian the Ramalhal buildup, with the exception of the Vimeiro area, becomes drowned and overlain by Kimmeridgian Abadia deeper water facies (cf. Fig. 153). West-derived siliciclastics largely get screened-off by a subaerial, salt-pillow and/or tectonic uplift. Due to improving protection and, possibly, sea level rise, shallow water carbonates (Caldas-Bolhos unit) expanded northwards to the Caldas area during the early Late (='mid') Kimmeridgian, but were coeval with shallow-water to terrestrial siliciclastic sedimentation further north and west. The facies model for the Caldas - Bolhos carbonate unit is mainly based on the sequences near Dagorda and Cesaredas. The unit represents shallow-ramp-type carbonates, characterised by a facies mosaic superimposing a weak facies zonation.

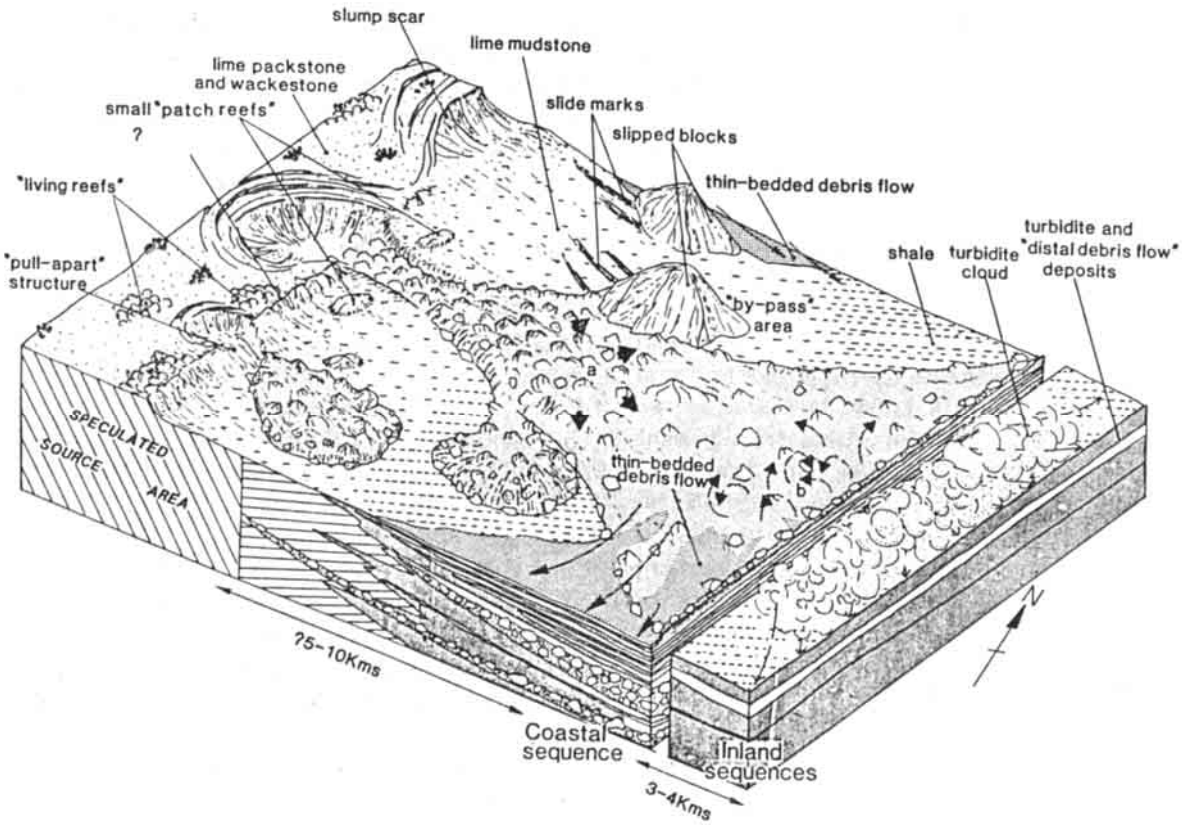

Fig. 165: Depositional model for the Kimmeridgian succession in the Sintra area (from ELLIS 1984, ELLIS et al. 1990).

4.5 Chapter summary: Upper Jurassic reefs from the rest of the Lusitanian Basin

The Ramalhal buildup, of Late Oxfordian to 'mid' Kimmeridgian age, developed in the Bombarral Subbasin, to the North of the Arruda Subbasin where the examples of Chap. 3 were situated. During the Late Oxfordian, a huge, up to 1500 metres thick, grainstone-dominated buildup, which is known both from outcrop and subsurface data, developed to the eastern side of an active salt pillow into the diapiric marginal synkline. The diapiric pillow prevented influx of fine west and northwest derived clastics, which to the west of the diapiric zone were deposited, in shallow water, as mixed muddy limestone - marl succession (Pholadomya protei beds). At the end of the Oxfordian the buildup became mostly drowned and was overlain by the fine siliciclastic Kimmeridgian Abadia slope system, prograding southwards. On the ridge of the salt pillow pure shallow-water carbonates persisted in the Vimeiro area or became reestablished during the 'mid' Kimmeridgian (Caldas-Bolhos carbonate unit), after an early Kimmeridgian phase of mixed carbonate-siliciclastic shallow-water deposition (lower Alcobaça beds). These shallow-water carbonates developed pene-contemporaneously with dominantly terrestrial red beds directly to the west. The analysis of the 'middle' Kimmeridgian Caldas - Bolhos unit, situated at the southern flank of the Caldas - Bolhos diapir, reveals a grainstone to packstone-dominated, frequently shifting facies mosaic which developed on a gently inclined ramp exhibiting indistinct facies zonation. Sediments include coral patch reefs, oncoidal sediments of various settings (including up to 15 cm large in situ oncoids of tidal channels), oolite grainstones, peloidal facies and birdseye limestones. Despite their similarities in age, the facies pattern of this unit is not comparable with the Ota Limestone, which is due to the fact that it is related to a mobile salt pillow, rather than to a stable, steeply bordered, tectonic horst structure as in the Ota example.

Roughly contemporaneous with the lower Alcobaça beds of the Caldas-Bolhos areas, marine sediments developed further west. At the present coastline, at Praia de Consolação, coral meadows, mostly of low diversity, developed in a mixed clayey limestone - marl - sandstone succession, before deltaic and terrestrial sediments took over. Low diversities of coral meadows were due to both fluctuating salinities and elevated sedimentation rates. Similar sediments can be found at Praia do

Salgado. They may be partly coeval with the Caldas-Bolhos carbonate unit further east.

The Sintra carbonate ramp can be only reconstructed by analysing allochthonous sediments shed from this Kimmeridgian to Tithonian, mud-dominated carbonate factory, which was situated in today´s offshore area to the west of Sintra. Despite the carbonate dominance of the area, coral reefs were of fairly low diversity, which must be explained by the the prevalence of deeper settings on the distally steepened ramp and the poorly washed character even in shallow areas. This led to the rapid suffocation of pioneer reef association within carbonate muds. A mixed carbonate - fine siliciclastic succession was created by shedding allochthonous carbonate debrites as well as lime mud far towards the northeast, into areas dominated by basinal, fine-grained, siliciclastic sedimentation.

Further South, in the western Serra da Arrábida situated at the southern margin of the basin Upper Kimmeridgian to Tithonian coral biostromes similar to thosa at Alrota locally developed in a mixed carbonate - siliciclastic succession.

The Oxfordian part of the Ramalhal buildup and the Sintra carbonate ramp are described by ELLIS et al. (1990; in english language). WERNER (1986, in german) analysed the Consolação meadows. The general setting and a brief description of the Arrábida biostromes is given in FÜRSICH & SCHMIDT-KITTLER (1980, in english).

5 REVIEW OF OTHER UPPER JURASSIC REEFS AND BUILDUPS FROM PORTUGAL AND AROUND THE NORTH ATLANTIC MARGIN

Chapter summary: Review of other Upper Jurassic reefs and buildups from Portugal and around the North Atlantic margin

Coral reefs and coral - coralline sponge reefs developed during the Upper Oxfordian and Kimmeridgian in the Algarve Basin of southern Portugal. Often transitions to mixed siliceous sponge reefs and thrombolitic microbial reefs occur (cf. LEINFELDER et al. 1993a, in english language). The reefs include an enormous variety of coral taxa (cf. ROSENDAHL 1985, in german). Most coral reef structures seem to have grown on steepened ramp settings, explaining the rapid transitions to siliceous sponge reefs. In the eastern Algarve, the coral-dominated, laterally persistent Cabeça limestone, chiefly of 'mid' Kimmeridgian age, developed above a marl-dominated succession (Peral Beds), a situation which is similar to the Abadia-Amaral system of the Lusitanian Basin. A coraliferous, grainstone/packstone dominated, isolated platform (São Romão Limestone) developed over a structural or halokinetic uplift and therefore shows similarities with the Caldas-Bolhos carbonate unit of the Lusitanian Basin. In the Western Algarve (e.g. Carrapateira) marly and calcareous coral meadows partly similar to the Alrota and Consolação associations of the Lusitanian Basin occur in a shallow, marl-dominated setting.

Upper Jurassic Moroccan coral-dominated buildups apparently developed during drift phase. They hence are of large dimensions and occur within a carbonate dominated setting (e.g., JANSA et al. 1984, HÜSSNER 1985), showing little similarities with the Lusitanian Basin buildups. On the other hand, buildups within other North Atlantic marginal basins, particularly known from the offshore off North America, occur in mixed carbonate - siliciclastic settings. Known are, for example, carbonate buildups capping fine-grained siliciclastic slopes (cf. Amaral - Abadia System), aggradational buildups (cf. Ota and Montejunto buildup, muddy ramps (cf. Sintra ramp) and grainstone dominated buildups (cf. Ramalhal buildup). (For references on the North American buildups see, e.g., ELIUK 1978, 1981, JANSA 1981, BARIA et al. 1982, GIORDANO et al. 1982, VOGT & TUCHOLKE 1986.) However, buildup sizes were again considerably larger than in the Lusitanian Basin (ELLIS et al. 1990), although it cannot be ruled out that smaller structures are overlooked due to insufficient seismic and drillhole resolution.

6 SYNTHESIS: REEFS AND ‚BUILDUPS' IN MIXED CARBONATE-SILICICLASTIC SUCCESSIONS – CONTROLLING FACTORS EXEMPLIFIED BY THE ‚BUILDUPS' OF THE LUSITANIAN BASIN

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Figures

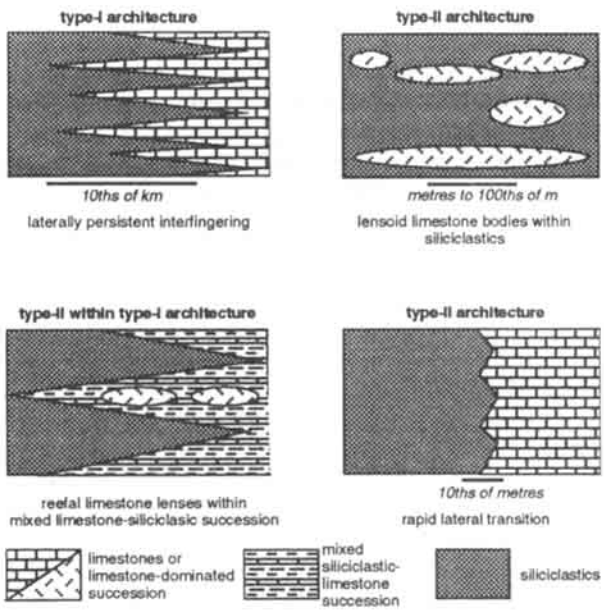

Fig. 166: Basic geometries ('architecture') of Upper Jurassic mixed carbonate - siliciclastic sequences from the Lusitanian Basin. Examples see text.

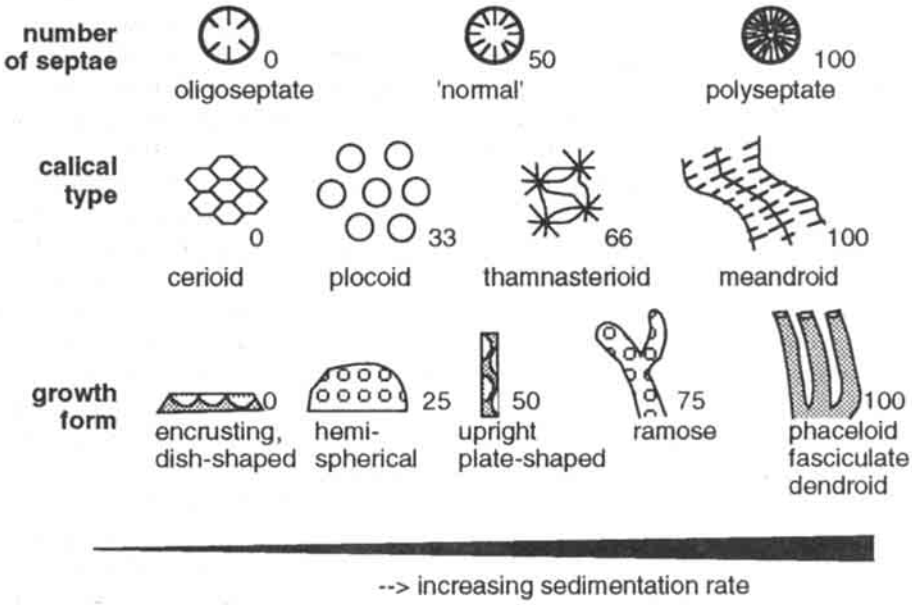

Fig. 167: Morphologic criteria for estimating potential adaption of corals to sedimentation. Values for a given species have to be added, giving the potential sedimentation adaption index SAI. Minimum value is 0 (no morphological hard part adaption in oligoseptate cerioid encrusting corals), maximum theoretical value is 275 (polyseptate maeandroid ramose corals). Phaceloid, dendroid and solitary corals get the calical type value 33 (because adaption is comparable with plocoid calical types), so that polyseptate phaceloid or solitary corals have a SAI of 233. SAI calculation give hints to adaption or non-adaption towards increased background sedimentation, but it has to be kept in mind that morphology of corals is also dependant on other factors. Moreover, some adaptions of corals towards sedimentation (e.g. secretion of mucus) does not leave traces in the morphology of hardparts. When using SAI, calculations must be performed for entire coral associations rather than one species only, with the lowest values obtained being critical for interpretation (see Fig. 168). Calculations should be accompanied by determination of encruster rate. For further explanation see text.

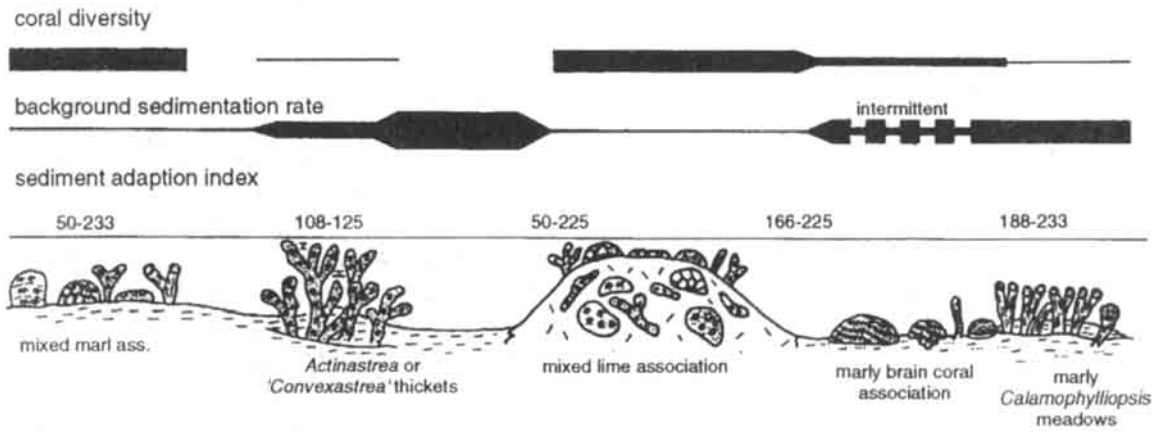

Fig. 168: Estimation of sedimentation rate based on diversity of coral associations and functional morphology of corals using the SAI index: The example of the Alrota patch reefs (Tithonian).

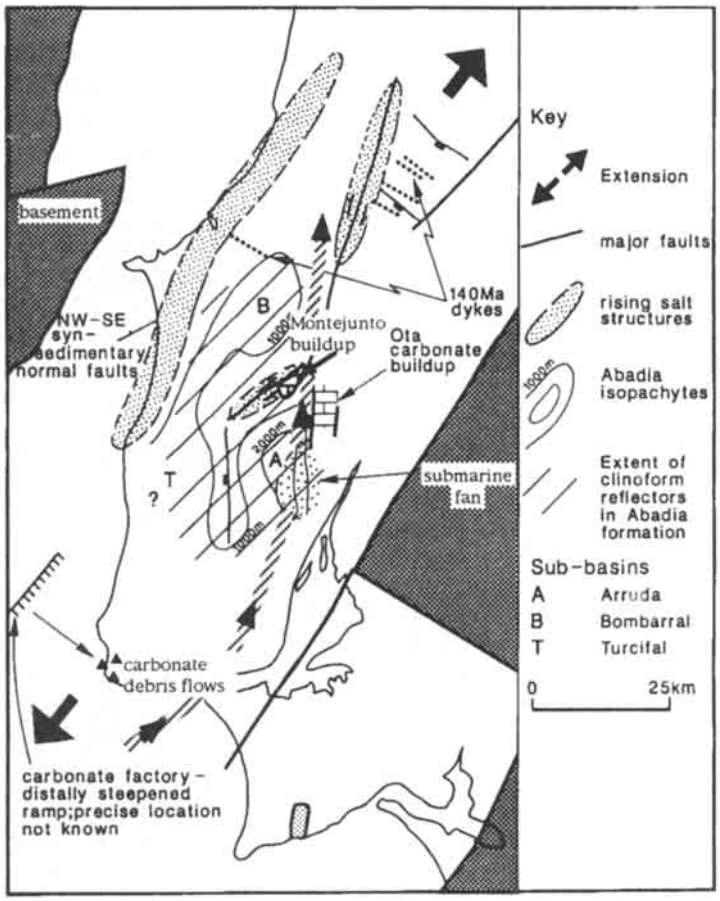

Fig. 169: General configuration of the half-graben, pull-apart-type Arruda sub-basin during the Kimmeridgian and Tithonian (modified from LEINFELDER & WILSON 1989), and dominating factors controlling the various mixed carbonate-siliciclastic depositional systems discussed here. Cross-hatched arrow: supposed Kimmeridgian longshore current system, entering from Atlantic. During the Tithonian, the Arruda Subbasin was influenced by irregular estuarine currents.

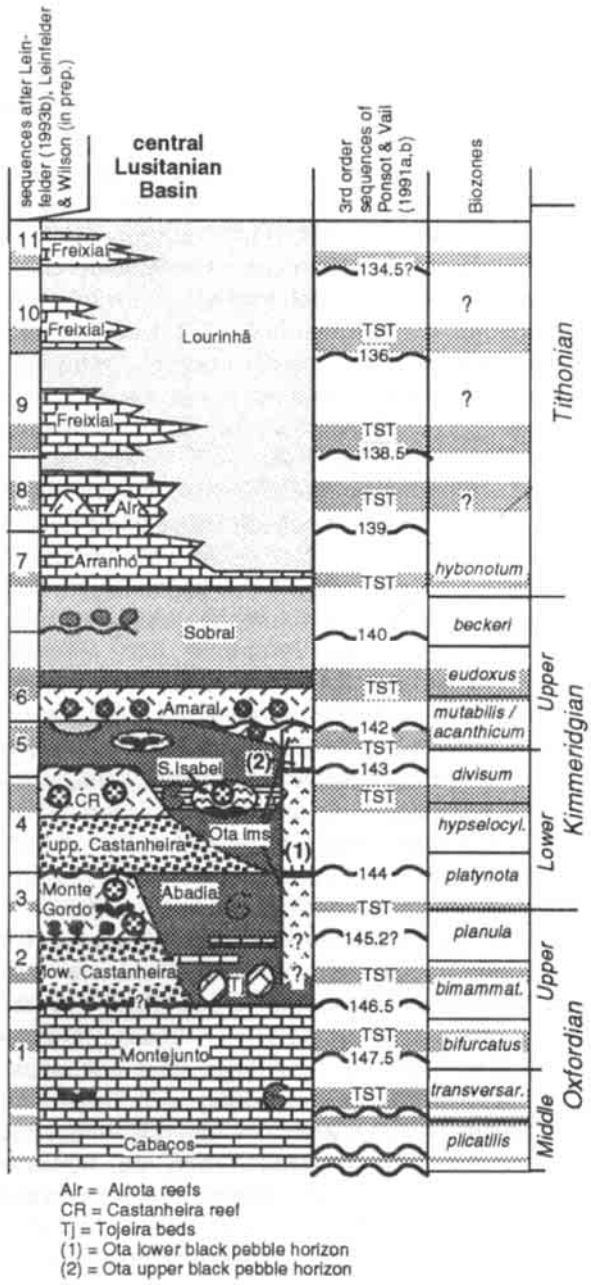

Fig. 170: Sequence stratigraphic interpretation of the Upper Oxfordian to Tithonian succession of the Arruda Subbasin (modified from LEINFELDER 1993b). The development of reefs in the Castanheira fan, calcareous intercalations in the upper Abadia beds, the Amaral formation, and the limestone dominated intercalations in the Arranhó and Freixial beds is correlatable with transgressive intervals. Growth of the Ota-Platform was, however, not interrupted by lowstand siliciclastics. Above the Oxfordian, correlation with depositional third-order sequences of PONSOT & VAIL (1991a,b) is possible.

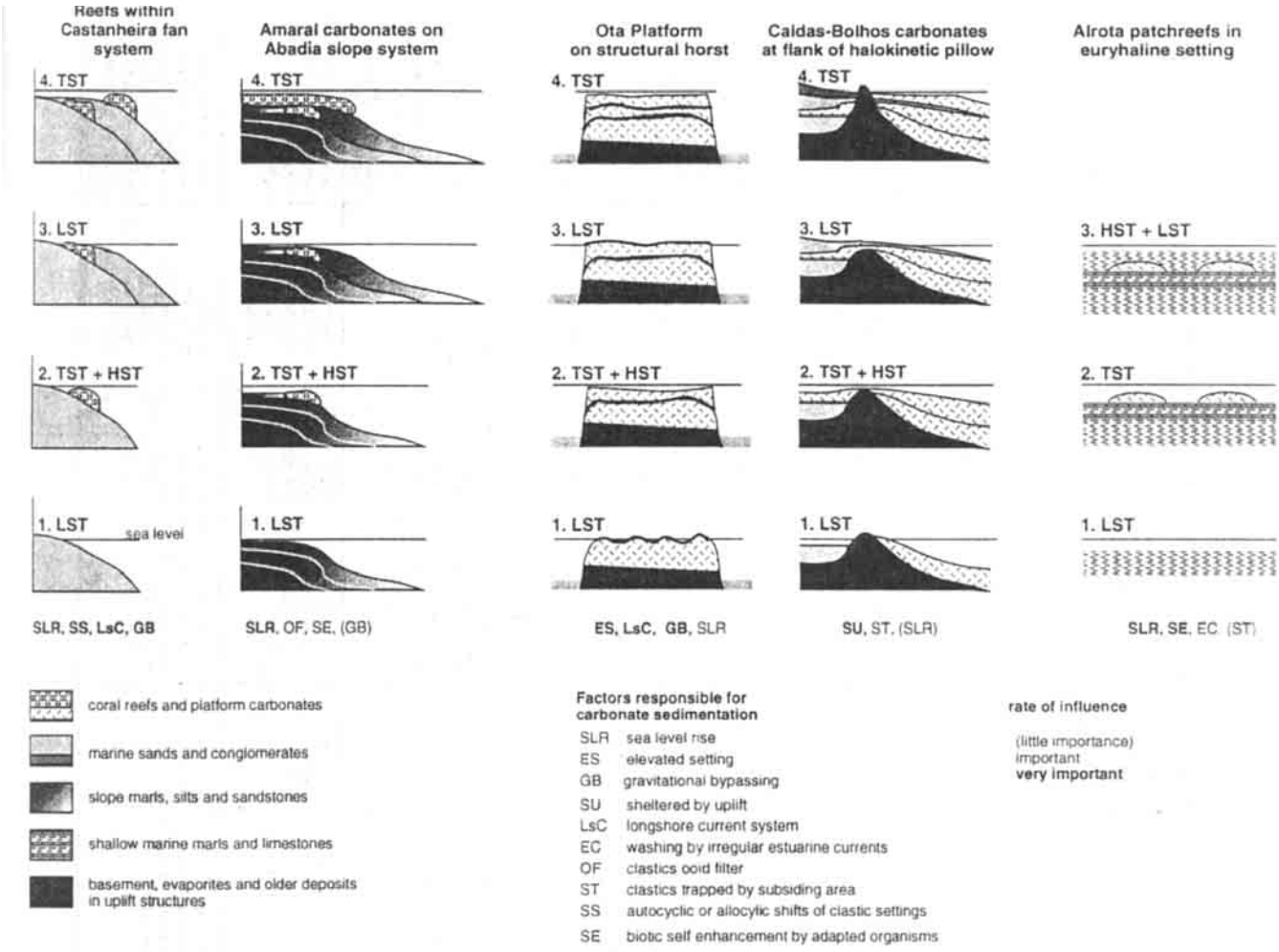

Fig. 171: Evaluation of the influence of sea level change in comparison with other factors controlling the development of mixed carbonate-siliciclastic depositional systems (based on the case studies presented here). Sea level rise is the major prerequisite for many, though not all, systems discussed here, but has to be accompanied by other control mechanisms to result in carbonate deposition within a siliciclastically dominated basin. Structural uplift is another powerful mechanism to support carbonate development within silicilastic basins, but also does not work without other accompanying factors. An 'aridity' factor can be ruled out due to the widespread sediment types indicating vast freshwater areas and semiarid to semihumid climate.

Name	Age	dimension of buildup	buildup type	buildup architecture	coral reef structure	diversity of coral community	buildup or reef initiation	buildup or reef termination	siliciclastic - carbonate mixing type and depositional system	dominant controls
Ota	late Early to Late Kimmeridgian	min 8x2 km, min 160 m thick	mud dominated reef-rimmed shelf, high carbonate content type B (tectonic control)	lateral facies zonation, aggradational, steep by-pass margin	high energy coral-microbial-debris type	high diversity	base not known, probably due to uplift	repetitive subaerial exposure	tpye III, structural buildup within siliciclastic basin (Abadia beds)	basement uplift, longshore current
Montejunto	*Late Oxfordian (to earliest Kimmeridgian?)*	*ca. 400 m thick*	*mud dominated ramp to shoal rimmed shelf, high carbonate content type B (tectonic control)*	*lateral facies zonation, aggradational to slightly progradational, depositional margin*	*low-energy coral microbial type of moderately deep water + back shoal patch reefs*	*medium to low diversity*	*on fold tip over fault zone*	*subaerial exposure*	*(structural buildup within carbonate dominated basin; Montejunto ammonitic lms)*	*basement uplift*
Caldas-Bolhos - Vimeiro buildup	late Early to early Late Kimmeridgian	max. 300 m at surface	grain-dominated buildup type A (halokinetic control)	facies mosaic, within indistinct lateral facies zonation, slightly prograding	low-energy coral bafflestones, high-energy debris pile patch reefs	low diversity	represents relic of large Oxfordian Ramalhal buildup; partly above intercalation of mixed sediments	overlain by shallow-water siliciclastics	type III, ramp buildup adjacent to shallow marine siliciclastics	halokinetic/structural uplift; also resulting in screening off siliciclastics by an island chain
Sintra buildup	*Kimmeridgian to Tithonian*	*unknown, distal slope facies 800 m*	*mud-dominated buildup type B (tectonic control)*	*homoclinal ramp, indistinct facies zonation, prograding*	*low-energy coral-coralline sponge reefs, partly with siliceous sponges, partly crust-rich*	*low to medium diversity*	*unknown, possibly slight uplift of western basin margin*	*unknown, possibly shallowing*	*(probably structural buildup within carbonate-dominated setting; carbonate debrites transported into adjacent fine siliciclastic basin)*	*probably slight basement uplift, overall low energy character due to leeward position of dominating wind)*
Monte Gordo reef	terminal Oxfordian? to Early Kimmeridgian	min. 60 m thick, original extension unknown	mud dominated reefal buildup type C (transgressive buildup)	vertical zonation: pronounced deepening-shallowing trend	low-energy coral reefs and coral-siliceous sponge reefs, abundant crusts	medium diversity	black pebble, quartz and feldspar-rich calciclastic debrites as substrate	subaerial exposure and partial collapse	type II, reef lenses within arkosic slope-type fan delta (Castanheira fan)	sea level rise, autocyclic and tectonic deactivation of siliciclastic fan lobes, longshore current
Castanheira reef	late Early to early Late Kimmeridgian	8 m preserved	mud-dominated reefal buildup type C (transgressive buildup)	indistinct deepening-shallowing trend	low-energy coral reef, occasional siliceous sponges	medium diversity	grainstone level capping siliciclastics serves as substrate	as above	as above	as above
Alrota buildups	Early Tithonian	1-20 m long, 0.2-3 m thick	mud dominated or marly coral meadows and biostromes type C (transgressive buildup)	bafflestones, rarely framestones	low-energy coral meadows and biostromes, partly with oysters	very low to high diversity	oolite-bioclast grainstones form substrate in some examples, otherwise muddy substrates	mostly buried by marls, sometimes by muddy limestones	type II; autocyclic buildups within euryhaline estuarine carbonate-marl setting	reduced but fluctuating sedimentation rate, probably in the coarse of sea level rise; self-reinforcement, many coral associations dapted to sedimentation
Consolação coral meadows	late Early Kimmeridgian	max. 50 cm thick	no true buildup; coral meadows only type C (transgressive)	bafflestones	mostly bafflestones	very low to medium diversity	muddy substrate, occasionally incipient hard ground?	overlain by shallow water siliciclastics	type II; coral meadows in marginal marine setting, in a carbonate dominated unit forming a type I intercalation within siliciclastics	reduction of sedimentation rate, probably due to sea level rise; corals adapted to sedimentation
Amaral formation	mid Late Kimmeridgian (eudoxus Zone?)	10-80 m thick 400 km^2	at base mixed mud-grain-dominated, grading to grain-dominated at top, laterally extensive type C (transgressive buildup)	facies mosaic at base (coraliferous), homogeneous oolites at top	low to high energy coral biostromes, more rarely bioherms partly crust-rich	low to high diversity	overlies fine siliciclastic slope systems with sharp to gradational contact	drowned by prodelta marls or overlain by red beds	type I (persistent intercalataton within prograding siliciclastics); basal coral boundstones partly in type II style (lenses within fine siliciclastics)	major sea level rise; partial channelling of siliciclastics in lower and upper part of buildup, biological adaptions in lower part filtering of quartz sand by ooid encrustation

Fig. 172: Comparison between the principal Upper Jurassic buildups and coral reefs from the Lusitanian Basin. Examples in italics are from pure carbonate regimes, all others are of mixed nature. The comparison reveals also that coral diversity of structures within siliciclastic regimes can be as high as, or higher than, of structures from carbonate settings, provided protecting mechanisms were effective.

6.4 Chapter summary: Reefs and 'buildups' in mixed successions - Controlling factors exemplified by the buildups' of the Lusitanian Basin

Upper Jurassic, mixed carbonate-siliciclastic sediments from the Lusitanian Basin reflecht the combined effects of sea level change, basin structure and configuration, climate, local currents, and adaption of reef biotas. Discrimination of basic architectural types, which may be mixed with each other in different hierarchies, helps interpreting the dominant factors:

Large-scale interdigitation of carbonate-siliciclastic sediments (type I) mostly are due to allocyclic lateral shifts of sedimentary regimes caused by sea level change, with the carbonate-dominated intervals representing the transgressive phases (e.g. Freixial carbonates). The Amaral carbonates, which are sandwiched between the Abadia and Lourinhã siliciclastics, represent one, in other cases two, stacked transgressive intervals. The reduced amount of siliciclastics entering the depositional area of the Amaral was filtered out by oolitic encrustation or was by-passed towards distal slope areas.

Small-scale interdigitation, which cannot be correlated over long distances, may be caused by autocyclic shifts of sediment types triggered by irregular estuarine currents (e.g. marl-limestone bed-to-bed alternation of Arranhó sediments).

Lensoid pure and clayey carbonates within siliciclastic sediments (type II) is the most common type for occurrences of carbonate reefs within terrigeneous deposits (e.g. Alrota reefs, Castanheira-Monte Gordo reefs, buildups directly below Amaral or within Abadia Beds (Serra Isabel unit)). These lenses are particularly caused by a variable combination of autocyclic processes (resulting in channeling of siliciclastics around the structures), effects of local currents, adaptions of corals to elevated sedimentation rate and resulting reinforcement by positive feedback. Local allocyclic (tectonic) processes (deactivation of fan lobes) are additionally assumed for the reefal development within the Castanheira fan. Such autocyclic or local allocyclic formation of reefal or, more rarely, non-reefal carbonates is only possible during phases of reduced terrigeneous input, mostly corresponding to phases of sea level rise. The deepening-shallowing trend together with the termination of growth by subaerial exposure shows that the superimposed control of formation for the Monte Gordo and Castanheira reefs was sea level rise. The lack of clayey terrigeneous material in these examples cannot be explained by strong climatic aridity, since sediment types suggest a semihumid to semiarid climate. Rather, fine suspended terrigeneous material was screened off by a longshore current system along the eastern basin margin. The existence of such a current is substanciated by JANSA´s (1986) assumption of a Upper Jurassic Atlantic palaeo-gulf stream. This current could enter the Lusitanian Basin through the broad and deep Sintra strait.

The younger lensoid Alrota buildups, which also grew in a transgressive setting, suffered more extensively from the influx of fine terrigenous clay. Coarser sand was, however, trapped in a rapidly subsiding, broad estuarine and fluvial lowland, probably caused by withdrawal of salts in the subsurface. The fine terrigenous clays reaching the Alrota area were irregularly deposited under the influence of fluctuating estuarine currents, but locally coral associations thrived. The Alrota area shows how some coral taxa exhibited adaptions towards elevated sedimentation rates and terrigeneous pollution. Density, diversity and incrustation rate of coral associations, as well as morphological features of corals allow an estimation of the tolerated rate of sedimentation. Besides other factors, general growth form, calical type and number of septae can, to a large part, be determined by background sedimentation (cf. LEINFELDER 1986, in english). A combination of these features allows to establish an index of potential adaption towards sedimentation (SAI), which is assumed to be helpful in comparing different associations. Similar adaptions of corals also explain marly, lensoid occurrences of coral meadows and patch reefs in other parts of the Lusitanian Basin.

Rapid lateral transition of larger carbonate settings into siliciclastic domains (type III) is strongly related to structural control. Among the examples are the Ota Platform situated on a horst structure and the Caldas-Bolhos carbonate ramp, situated on a combined tectonic/halokinetic uplift.

In the Ota example, the coarser terrestrial material could be bypassed around the horst, whereas fine clays were again screened off by the longshore current system mentioned above. Sea-level change played no dominant role for reducing siliciclastic input, but resulted in many syn- and postdepositional subaerial exposure phases of the Ota Platform. In the Caldas-Bolhos example, the structural/halokinetic uplift not only provided the elevated position above the basin floor but also resulted in subaerial exposure of parts of the structure, which caused perfect sheltering from west-derived siliciclastics. In this example, sea-level changes played a role in flooding of the uplift and short-lived expansion of carbonates towards the east.

Gradual lateral changes from carbonates into siliciclastics along a broad transition zone would represent a forth architectural type which, though, is only very rarely realised in the Lusitanian Basin (some beds of the Freixial unit). The rarity of this type is explainable by the incompatibility of most carbonate producing organisms, particularly shallow-water-benthic algae, and siliciclastic sedimentation, so that already a small pollution by terrigeneous sediments may lead to the complete breakdown of carbonate production and hence to a fairly rapid transition from carbonates to siliciclastics. The Freixial sediments probably represent subsequent homogenization of interbedded carbonate-siliciclastic horizons caused by bioturbation or storms.

7 CONCLUSIONS

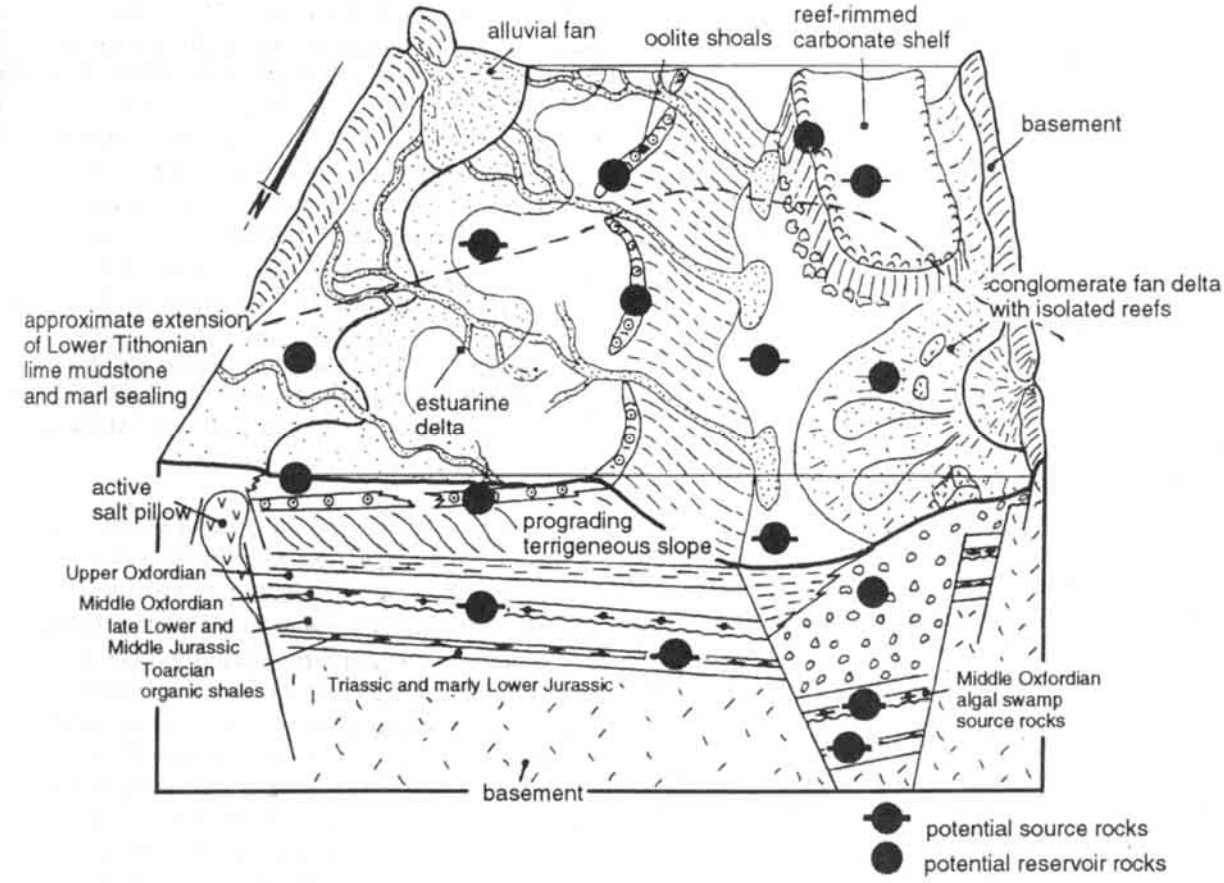

Fig. 173: Strongly simplified reconstruction of the dominant depositional systems of the Arruda Subbasin during the Kimmeridgian, and oil play situations. Potential source and reservoir rocks were abundant, and were connected as well as sealed by structural or sedimentary constellations. Maturation occurrred by continuous subsidence and superposition of younger sediments. During later inversion, these were eroded and hydrocarbons were largely destroyed.

7.8 Chapter summary: Conclusions

New results on carbonate sedimentology based on the Ota-Platform and other 'buildups'

Almost the entire narrow Kimmeridgian Ota Platform, today of max. 11 x 2 km extension, is preserved. Good exposure conditions allow a three-dimensional analysis of the strucuture of this remarkable carbonate platform. It is particularly characterised by well developed facies belts forming an aggradational architecture. From West to East follow a reef, back reef, peritidal and lagoonal belt. In the East, cross-bedded grainstones can be interpreted as relics of a shoal situated at the landward margin of the platform. More general results of facies analysis include:

** Secondarily irregularly blackened sediment horizons and blackened karstic cave fills occur in association with <u>black pebble development</u> in both Ota and Montejunto-Platform. Both blackened horizons and black pebbles may be rich in organic matter. This proves the existence of host rocks for black pebbles and of migrating organic substances, both of which was doubted by SHINN & LIDZT (1988) who rather see black pebble formation related only to fossil fires. The existence of entire sediment layers and the richness in bituminous matter proves the general correctness of the models of black pebble formation by migrating organic substances of various origin (microbial or algal matter, higher land plant material, partly charcoal), as expressed by BARTHEL (1974), STRASSER & DAVAUD (1983) or LEINFELDER (1987b) (see Chap. 2.2.6).*

** <u>Marine giant oncoids</u> up to 15 cm in diameter occur within the Ota Limestone and the Caldas-*

Bolhos unit. Birdseyes and Bacinella structures indicate their very shallow origin. They grew within tidal channels. Amalgamation of several oncoids and growth of cortical protrusions into interparticle cavities proves the in-situ growth of at least parts of them. In-situ growth of oncoids is well known from modern freshwater environments, and can be deduced for some ancient freshwater environments by a set of criteria (LEINFELDER & HARTKOPF-FRÖDER 1990), whereas in-situ growth is rarely discussed for marine oncoids so far (see Chap. 4.1.2).

**Autocyclic small scale shallowing up sequences are widespread in the interior parts of the Ota-Platform. Their character and lateral non-persistence reveal that they were formed by autocyclic shifts of depositional subsystems. Models for their development comprise: Progradation-cementation-erosion system in the back reef zone; progradational wedge and tidal channel system in the peritidal belt, and autocyclic mud ridge development in the lagoonal area (see Chap. 2.2, 2.4).*

** Early karst features of the Ota Limestone include marginal microsparitisation of carbonate grains, early diagenetic solution pipes, honicomb structures and karst cavities. The latter are often filled with residual sediment which became secondarily enriched in echinoderms by selective dissolution of aragonite particles. This is evidence of the very early character of these features, which are thought to be due to mixed-water diagenesis. Partly amalgamated subaerial exposure horizons and karst cavities allow to decipher 14 phases of intraformational and postformational development of the Ota-Platform.*

** The aggradational Ota-Platform is a good example for the inhibition of progradation. Carbonate productivity was doubtlessly high, which is shown by the high rate of infill of the very shallow lagoon and particularly by the position of the intertidal belt directly behind the reef. It is assumed that the tectonic origin of the eastern plarform margin resulted in the development of a steep by-pass escarpment, preventing progradation. This interpretation is in accordance with thewinnowed character of the reef rim (see below) and the detection of marginal faults in seismic lines. In this example, sea level change had no influence on the general architecture (progradation or aggradation) of the buildup. Base-of-slope debris aprons can be postulated but are not exposed. If positioned in an offshore basin and drilled by only one core, as common in offshore basin analysis, the character of this narrow buildup, which does not follow 'WALTHERian' rules, would certainly have been misinterpreted.*

Comparison between Upper Jurassic buildups from the Lusitanian Basin

Three types of buildups exist:

** Halokinetically controlled buildups (type A) developed away from rising salt pillows into the salt rim structures. They hence are mostly of large dimension and show progradational ramp-type to shelf-with-depositional-margin development. The standard example is the grain-dominated Oxfordian Ramalhal buildup. Its Kimmeridgian relics are the Vimeiro and Caldas-Bolhos buildups, which developed close to the structural axis of the salt pillow and show an additional control by tectonics.*

** Most medium sized buildups of the basin fall into the category of tectonically controlled buildups (type B). These are mostly lime-mud dominated or, at least, rich in micritic sediments. According to the degree of structural control they range from ramp to bypass-margin types. Examples are the Sintra, Barreiro, Montejunto and Ota buildups.*

** Transgressive buildups (type C) occur in correlatable levels or units characterised by a reduction in background sedimentation, which came along with sea level rise. The buildups are grain- or mud-dominated or mixed, and may exhibit a clay-rich matrix. They are mostly lensoid, including medium to small-sized bioherms as well as biostromes and marly coral meadows. Examples comprise the Monte Gordo and Castanheira reefs, the Alrota reefs and similar coral associations in the Sobral beds as well as at Consolação and in the western Serra da Arrábida. Transgressive buildups may also be laterally extensive as in the case of the Amaral formation.*

The significance of the buildups from central Portugal for Upper Jurassic reef models

Most reefs from central Portugal match, to a large degree, the Upper Jurassic reef models as given by CREVELLO & HARRIS (1984). An exception is the Ota reef, which despite its high-energy, shallow-water character contains abundant microbial crusts. This is explained by the wave-washed character of the reef, which was facilitated by the existence of a steep bypass margin. This prevented excessive accumulation of carbonate debris within the reef belt, a fate which afflicted most other Jurassic high-energy reef, leading to their eventual suffocation within debris piles.

Thrombolite reefs with partial participation of siliceous sponges and corals, as occurring in the Serra Isabel level and in the topmost part of the Abadia formation, represent another, previously largely unknown Upper Jurassic reef type. Its development is related to fluctiations in

oxygen/nutrient concentrations (LEINFELDER et al. 1993a,b). For a more complete discussion of Upper Jurassic reef types and models see LEINFELDER (1992, 1993a, in english language).

The mixed carbonate-siliciclastic depositional models

During the Kimmeridgian and Tithonian coral reefs and carbonate buildups of the Lusitanian Basin largely grew within siliciclastic settings. The carbonates were largely or completely protected from terrigeneous influence by a variety of sheltering mechanisms. These represent a variable combination of factors, such as elevated position, longshore currents, filtering of quartz by ooid formation, local subsidence traps and sea level rise. In incompletely protected areas, adapted corals could form local patch reefs. The degree of adaption of corals can be estimated by several morphological criteria (number of septae, calical type, growth form) (see Chap. 6.2).

The principal mixed depositional system models are:

(1) Intrabasinal platform horst: The Ota-Platform, situated on a basement uplift, is protected from terrigeneous clastics by this elevated position and by coastal longshore currents, the latter explaining the screening-off of suspended clay and, therefore, the purity of carbonates. Model criteria are: Coeval sedimentation of siliciclastics and carbonates; deep marine character of surrounding siliciclastics, development of aggradational architecture with facies zonation spanning several sea level cycles (indicating tectonic nature of platform uplift), episodic contamination of carbonates by aeolian quartz silt and terrigeneous driftwood pebbles. The Boldos-Caldas buildup was controlled by tectonic and halokinetic uplift, and was additionally protected from siliciclastics by an island chain.

(2) Mixed siliciclastic-carbonate fan delta: The calcarous coral reefs of the arkosic Castanheira slope-type fan delta grew on deactivated fan lobes (see before). Among the sreening-off facors are sea level rise and longshore currents, whereas climate did not play a major role in reducing siliciclastic influx. Diagnostic for the model are: fan-delta sedimentology and architecture; isolated reefs within distinct levels; deepening-shallowing trend of reefs; termination of reef growth by karst phases; allochthonous carbonates.

(3) Prograding, fine-siliciclastic slope system capped by reefal to oolitic carbonates: On top of the Abadia slope system, the Amaral carbonates were formed during reduced siliciclastic input caused by growing distance from the terrigenous source area due to slope progradation and sea level rise. Remaining siliciclastics were partly encrusted by ooids or channelled downslope. Model criteria include: shallowing-up siliciclastic slope succession, with slight deepening trend in topmost part; crust-rich carbonates in transition zone, evidencing strong reduction of sedimentation rate; shallowing-up trend within carbonates, with a final deepening into terrigeneous prodelta sediments, bringing a return to siliciclastic sedimentation. Ramp type carbonates show a general large-scale uniformity, superimposing a small-scale mosaic distribution of reefal subfacies, due to rapid retrogradation and back stepping during sea level rise.

(4) Lagoonal patch reefs within shallow siliciclastic setting are represented particularly by the Alrota coral reefs and biostromes. Sea level rise resulted in general reduction of terrigenous influx, although fine siliciclastics did reach the depositional setting in considerable amounts. Model characteristica are: Lensoid character of reefs; occurrence of reefs within a distinct time interval; reef organisms adapted to background sedimentation; local catch-up trends due to positive feedbacks; frequent termination of reef growth by clayey sedimentation; general reduced sedimentation rates of the low-energy, shallow lagoonal sediments, indicated by a high amount of burrows and other criteria.

Comparison of coral reefs and platforms from siliciclastic and carbonate settings

Mechanisms screening-off siliciclastics can be very effective, so that carbonate productivity and diversity of organisms often can be very high even within carbonate areas surrounded by siliciclastic sedimentation (e.g. Ota-Platform). Examples from pure carbonate settings (Sintra-Ramp, Montejunto-Platform) may even show lower diversity of reef organisms, caused by a deeper position of reefs and elevated sedimentation rate of lime mud. Rate of background sedimentation, both terrigeneous and calcareous, controls the diversity and structure of reef associations at least to, or higher than, the degree exerted by bathymetry/light, water energy and salinity.

Another interesting aspect is that nutrient input during times of dominance of terrigeneous material was probably higher than during times of carbonate dominance. The high diversity of reef organisms in the Ota reef (surrounded by siliciclastics) and their partial high diversity in the Alrota reefs (situated directly within a terrigeneously polluted setting) could indicate that during the Jurassic reef corals were not yet specialised to oligotrophic settings as are modern corals.

Sequence stratigraphy of the Upper Jurassic of the central Lusitanian Basin

It was the rift activity of the basin which dominated the development of major depositional systems (siliciclastic fan delta, prograding slope system, carbonate buildups), part of which occurred penecontemporaneously, with siliciclastics being introduced from geographically different sources. Sea level changes of third order only caused modifications within these systems but did not generally transform them into other ones: Carbonate platforms developed karst and black pebble horizons, hardgrounds, or narrower spacing of small-scale cycles; within siliciclastic systems coraliferous reefs occurred during transgressive phases. Such local third-order cycles are mostly correlatable, despite the strong differences in sedimentary development. Furthermore, a composite sequence stratigraphic interpretation is correlatable with the redefined third order sequences of PONSOT & VAIL *(1991a,b). It is, however, assumed that Lusitanian Basin Upper Jurassic third order sequences are largely controlled by regional tectonics (see* LEINFELDER *1993b,* LEINFELDER & WILSON *,in prep.).*

The discontinuous development of the Upper Jurassic of the Lusitanian Basin, and its significance for the analysis and hydrocarbon exploration of similar marginal basins

Due to later Alpine tectonics the Mesozoic Lusitanian Basin is accessible on land, giving it a model character for most of the other Atlantic ocean marginal basins situated in today's offshore. Of particular importance are: the heterochroneity of many sedimentary units (including structurally controlled carbonate buildups), the narrowness of many buildups, and the development of local graben structures between the buildups, which are filled with siliciclastics.

The great variety of sediment types, architectures and structural styles led to promising oil plays, due to a wealth of Upper Jurassic source, reservoir and seal rocks as well as structural traps and early maturation caused by local strong subsidence. However, later inversion tectonics destroyed most occurrences of exploitable petroleum. Nevertheless, the study of potential oil plays may provide a model for the style of petroleum formation in similar basins: The structure of the Barreiro buildup caused accumulation of petroleum in younger sediments, domed up by the buildup. The partially dolomitised Ramalhal grainstone buildup directly superimposes the dominant source rocks of the basin, the bituminous Cabaços beds, and is sealed by the fine grained Abadia beds. The poorly cemented arcoses of the Castanheira fan are still rich in microbially altered petroleum at places. They originally were sealed by onlapping fine-grained Abadia siliciclastics. Source rocks could be both the Cabaços beds, with good migration paths along deep synsedimentary rift faults, as well as parts of the fine grained Abadia beds, which at outcrop are rich in bitumen at places. The Castanheira conglomerates are an excellent example of a thick, promising reservoir rock developed in a graben, a structure which normally would not be drilled. Relics of bitumen are also visible in karst cavities and grainstones of the Ota and the Amaral buildups, both of which directly border the Abadia beds, as potential source rocks. The Ota-Platform is additionally connected to the Cabaços source rocks by syn- and postsedimentarily active normal faults. Furthermore, bituminous impregnations are common in the Sobral estuarine delta sediments and the Arranhó lagoonal sediments, both of which would show associated reservoir rocks within the same sedimentary systems (Sobral: delta front sands, sealed by prodelta and interbay clays and silts; Arranhó: level-constant, highly compartmentalised but numerous calcareous patch reefs) .

8 ACKNOWLEDGEMENTS

see complete version of paper.

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APPENDIX

Ausführliches Inhaltsverzeichnis / Extended table of contents

LEGEND FOR CARBONATE FACIES LOGS

Macrofauna

- Corals, not differentiated
- massive coral heads (S *Stylina*, T *Thamnasteria*, M *Microsolena*)
- solitary corals
- phaceloid and ramose corals
- stromatoporoids, chaetetids, sponges
- gastropods (N large nerineids, C *Cryptoplocus*)
- bivalves (M megalodontid) / fragmented corals (analogous for other symbols)
- boring bivalves (C in corals, M in mollusks, S in substrate)
- serpulids
- echinoids
- macrofauna, not differentiated and bioclasts (Br brachiopods)
- bio-cortoids and superficial oncoids

Microorganisms

- encrusting algae and alga-like microproblematica, not differentiated (T *Tubiphytes*, Th *Thaumatoporella*)
- *Bacinella / Lithocodium* (B/L)
- encrusting foraminifera (P *Placopsilina*, N nubeculariids)
- foraminifera, mainly lituolids and "textulariids" (Tr *Trocholina*, K *Kurnubia*, M miliolids)
- *Labyrinthina mirabilis*
- dasycladaceans (Cl *Clypeina jurassica*, P *Petrascula*, E *Epimastoporella*)
- *Campbelliella striata*
- algal nodules, mostly of *Rivularia*-type ("cayeuxiid")
- *Marinella lugeoni*

"inorganic" particles

- peloids
- intraclasts (C micritic cortoid-intraclasts = "Rindenintraklasten")
- oncoids
- ooids
- black pebbles (B)
- black pebble main horizon and equivalents
- q detrital quartz

diagenetic and other features

- bioturbation
- marine fibrous cement
- submarine primary cave and topography
- irregular cracks (mostly synaeresis)
- birdseyes / subvertical / laminoid arrangement
- LF-fabric
- mudcracks
- dripstone cement
- microsparitisation
- irregular blackening (S)
- vadose silt (V)
- karst pipes and honeycomb structures
- palaeokarst caves

Limestone fabric and lithology

DUNHAM types: M lime mudstone, W wackestone, P packstone
G grainstone, B boundstone
EMBRY & KLOVAN types (for reefal limestones only): F floatstone,
R rudstone, Bi bindstone, Bf bafflestone, Fr framestone
LF laminated fenestral fabric
cross-hatching indicates transitional or densely intercalated fabrics (*e.g.*: cross-hatchures between P and B = transitions between packstone and boundstone fabric; between P and G = transitions between packstone and grainstone fabric)

- marly limestones

Appendix: Abb. 174: Legende zu den karbonatischen Profilen in Kap. 2.2 und 4.1.2
Appendix: Fig. 174 Legend for carbonate logs in chaps. 2.2. and 4.1.2