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CORAL REEFS AND CARBONATE PLATFORMS WITHIN A SILICICLASTIC SETTING. GENERAL ASPECTS AND EXAMPLES FROM THE LATE JURASSIC OF PORTUGAL.

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ABSTRACT

Both in the Modern and Ancient examples coral reefs and carbonate platforms occur frequently very close to or even directly within areas of siliciclastic sedimentation. Particularly fine grained, often suspended terrigeneous influx is mostly problematic for the reef fauna due to lowering of illumination and oxygenation, increasing nutrient values or directly settling on the organims. The modern examples show that reef growth in such settings is only possible by the existence of sheltering mechanisms such as arid climate, structural and sedimentary traps or longshore currents. If not completely effective, reefs may still prosper under reduced but noticeable siliciclastic sedimentation, but both composition and diversity of the reefs changes drastically. The Ancient examples show that temporal relations are important as well: Autocyclic switches in depositional systems and especially allocyclic events such as tectonic activation/deactivation or sea level change may open and close reef windows through time. Positive effects of siliciclastic sedimentations on reef growth include the availability of suitable substrate morphologies and, in some cases, favourable increases in nutrient concentration, an aspect which appeared to be important particularly for Mesozoic coral reef growth. The Upper Jurassic coral reefs of the siliciclastically dominated Lusitanian Basin of Portugal are a perfect example for the the intimate cooperation and juxtaposition of all these controlling factors.

INTRODUCTION

Although it is frequently thought that coral reefs represent the prototype of pure carbonate environments, many of today's reefs and carbonate platforms grow in close vicinity to, if not directly within, siliciclastic settings (e.g. Northern Great Barrier reef, Red Sea Reefs, Caribbean reefs and platforms off Nicaragua, Abrolhos and Recife reefs off Brazil, and reefs in the Java archipelago; for references see Doyle and Roberts 1988, and contributions of this set of papers). It appears that fossil reef facies may have occurred even more frequently in siliciclastically influenced settings (Tertiary reefs: e.g. Sansisteban and Taberner 1988, Cretaceous reefs: e.g. Steuber 1997, Jurassic reefs: e.g., Leinfelder 1994b, Nose 1995, or Paleozoic reefs, e.g. Nield 1982, Malmsheimer et al. 1996, Long 1997). Thorough study of the reef and siliciclastic interrelationship not only bears a high potential towards a better understanding of the environmental demands, and limitations, of growth of reef organisms, reefs and entire platforms, but additionally allows to use Ancient reefs as valuable paleoindicators of shelf morphology, tectonic activity, local circulation systems, climatic situation and sea level fluctuations.

WHAT'S BAD ABOUT SILICICLASTICS FOR REEFS AND CARBONATE PLATFORMS?

Table 1 lists possible effects of siliciclastic influx on growth of reef organisms and, hence, of reefs and entire carbonate platforms. Whereas occasional influx of coarse siliciclastic material might even improve substrate conditions by providing hard substrates for larval settlement, fine terrigeneous clay, in general, is a very critical factor. Even if influx is not as high as to bury corals completely, the necessity to remove clay particles uses up large amounts of the animal's energy and suppresses rapid growth. Fine clay particles may float several years in suspension before settling down (Kühlmann 1984), a fact which may make even occasional influx a critical factor, because ambient light conditions may be strongly reduced for a long period. Moreover, oxygen is consumed both by the oxidation of organic matter attached to the clay particles and by directly reducing solubility of oxygen in the water (op. cit.). Additionally, terrigeneous influx is mostly accompanied by an unfavourable increase in nutrient and sometimes even freshwater influx.

Table 1: Possible negative effects of terrigeneous influx on reefs:

REEFS AND SILICS? WHAT'S BAD ABOUT IT?

1. Increase of nutrient concentration
2. Freshwater influx
3. Reduction of oxygen concentration
4. Impoverished illumination
5. Loss of hard substrates
6. Pollution / suffocation of reef organisms
7. Burial of reef organisms

COEXISTENCE PATTERNS BETWEEN REEFS AND SILICICLASTICS

The fact that, on one hand, siliciclastic runoff is such a critical factor for the development of reefs and related carbonate platform systems but, on the other, both sedimentary regimes actually may coexist in often very close spatial and temporal relationship, makes these mixed systems a perfect indicator for geological, oceanographic and climatic parameters at work.

Spatial relation of reefs and siliciclastics

The modern example shows that many reefs are perfectly to moderately protected from adjacent coeval siliciclastic influx by a variety of fencing mechanisms, each of which allows a complete or partial sheltering of the disturbing terrigeneous material. There are, however, also examples where reefs are directly smothered by siliciclastic sedimentation.

Arid Climate: Certainly the most effective sheltering mechanism is the position of reefs within an arid climate (Fig. 1). The classic examples are the Red Sea reefs, where reefs are completely surrounded by coeval siliciclastic sedimentation, but due to the aridity sedimentation events are so rare and are almost barren of fine clay particles so that reef growth persists or rapidly rebuilds after sedimentation events. The only constant siliciclastic source is windborn detrital silt which accumulates in certain areas and actually influences the pattern of reef communities (Riegl and Piller 1996). Whereas the arid situation is the most important factor allowing reef growth, there may be a partial additional structural and autocyclic control (see below).

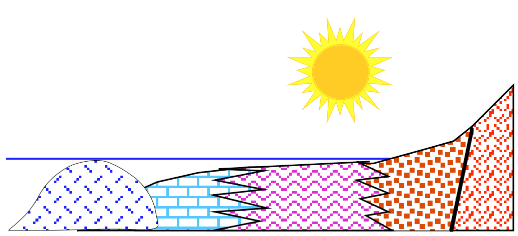

Fig. 1: Reefs and siliciclastics may easily coexist in arid settings.

Shelf structure: Preexisting rugged submarine topography greatly helps reef and platform development under siliciclastic influx. Elevations such as former karst towers, basement uplifts or volcanic seamounts are favorable sites for reef growth, because coarser silics, being transported as bottom load, can be bypassed and stored in morphological depressions. Reef growth may also occur in the shelter of subaerial uplifts (Fig. 2). Shelf structurate may be a sufficient fencing mechanism towards terrigeneous influence in an arid climate or in offshore areas where siliciclastics reach depressions around reefs only in the form of turbidity currents. Modern examples are again from the Red Sea Gulf of Suez (Roberts and Murray 1988) and from the Java Sea (Friedman 1988). However, the Java example shows that shelf structure alone is not sufficient in fencing off all terrigeneous material in nearshore areas under a humid climate where suspended terrigeneous clay is of paramount importance.

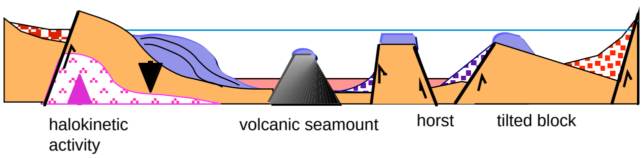

Fig. 2: Frequently, the preferred site of reef growth are tectonic or volcanic uplifts, or sites protected by elevations. Sand-sized silics are trapped in structural and morphological lows. In the fossil example reef distribution may be a good indicator of basin structure.

Longshore currents: Large scale reef and platform development adjacent to siliciclastic coastlines in tropical humid areas demands the existence of another powerful sheltering mechanism, which are longshore current systems (Fig. 3). A well studied example stems from the Caribbean reefs off Nicaragua, where a strong coastal boundary system shelters off the enourmous siliciclastic runoff from the high-rainfall, high-morphology tropical hinterland and allows reef and platform development only a few kilometers off the coast (Roberts 1987).

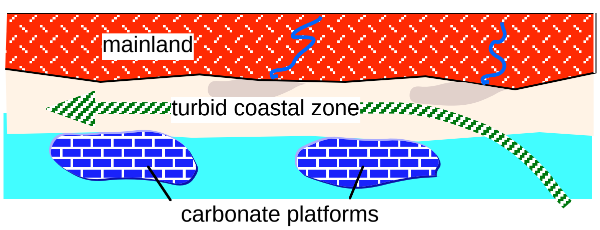

Fig. 3: In humid settings longshore current systems may effectively delimit suspended siliciclastics to a narrow coastal zone.

Depositional trapping systems: Estuaries, estuarine deltas or beach barrier sheltered swamp systems may trap enormous amounts even of fine siliciclastic material (Fig. 4). This is particularly supported if mangroves or seagrass meadows help filtering out the fine clastics. In the Bahia Tapon Bay (Vieques Island, Puerto Rico) mangroves are so effective in trapping silics that shallow-water carbonates develop still within the embayment (D'Aluisio-Guerrieri and Davis 1988). Beach barrier-swamp systems are developed at a large scale along the coast of Brasil but due to natural fill up and human drainage projects are critically close to becoming ineffective (personal obs., see also Leão 1982).

Reefs undergoing direct siliciclastic influx: Sheltering mechanisms might be not efficient enough to keep all terrigeneous influence away from reefs. There are quite some modern examples showing that coral reefs may actually grow under siliciclastic stress. Generally, however, such reefs greatly differ from reefs not smothered by terrigeneous material. The Abrolhos reefs of Brazil are subject to intense terrigeneous sedimentation. Sedimentation is nearly continuous during summer but largely ceases on the reef flats during winter where winter storms remove a major part of the terrigenous matter, causing fairly high bulk carbonate contents in these reefs (Leão 1982) which may mask the high impact of siliciclastics on reef growth. Despite being quite productive, these reefs clearly show a very reduced diversity of reef organisms, with coralline algae and a selection of robust coral taxa dominating (Leão 1982, Leão and Ginsburg 1997). In similar coastal reefs in the state of Pernambuco red algae, corals and other fauna often grow in sheltered cavities rather than on open surfaces (pers. commun. Leão, pers. obs.). Although there are additional biogeographic controls on the diversity (Leão 1982), the Brazilian examples show that both diversity pattern and coral morphologies are strongly dependent on siliciclastic influx, results which can be likewise drawn from fossil examples (see below).

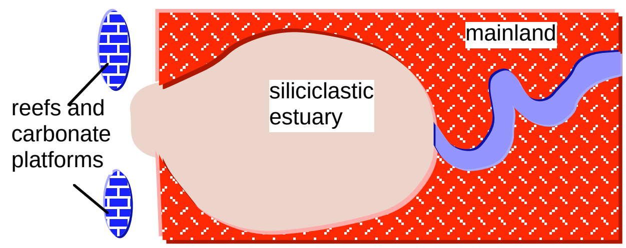

Fig. 4: Depositional systems with a positive accomodation space such as swamps and estuaries may filter off a large amount of siliciclastic material. Since the Tertiary, this is frequently facilitated my growth of mangrove forests.

Temporal relation of reefs and siliciclastics

The fossil record shows that many reefs and carbonate platforms have developed over a duration of many millions of years. However, particularly reefs or platforms growing in a generally siliciclastic environment were often short-lived, and frequently reefal carbonate bodies are intercalated within siliciclastic successions in a repetitive manner. This highlights the importance of temporal autocyclic and allocyclic controls on reef development in such settings.

Autocyclic systems: Despite the low siliciclastic influx in the arid Red Sea setting, the actual position of reefs growing within siliciclastic fan deltas is determined by the availability of abandoned fan lobes (cf. Roberts and Murray 1988). Active fan lobes may become abandoned once accumulation of siliciclastics has resulted in moderate morphological elevations, forcing lateral shifts of siliciclastic around these positive structures (Fig. 5). Similar autocyclic abandonment of depositional siliciclastic areas and capping with reefal carbonate is also known from humid settings (Roberts and Sydow 1997).

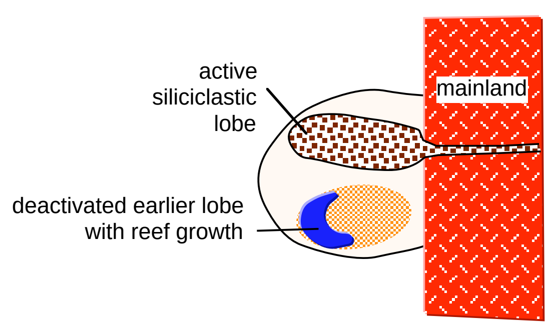

Fig. 5: Fan deltas are characterized by autocyclic shifts of sites of active deposition. Reefs may grow in abandoned areas.

Given a certain subsidence, large prograding silici-clastic slope systems will increasingly change from progradation to aggradation in their distal parts through time. This may give way to the decrease of siliciclastic deposition around the slope break resulting in restriction of siliciclastic transport to a few channels, with reefs growing in between such bypasses. Fossil examples show that ooid formation, which may commence once siliciclastic influx falls short of a critical value, may further reduce siliciclastic grains in the system by filtering them out through incorporation as ooid nuclei (see below).

Allocyclic control by tectonics
Hinterland may switch on and off siliciclastic influx. Particularly in tectonically active areas such as rift basins or compressive plate margins, reef development is strongly related to episodes of tectonic and volcanic quiescence. On the other hand, there are cases where actively rising salt pillows were a prerequisite for the sheltering of reefs from siliclastics (see below). Also, increased subsidence in coastal areas will assure the efficiency of sediment trapping systems such as estuaries and coastal swamps. In such settings episodes of reef development may be correlatable with episodes of increased coastal subsidence.

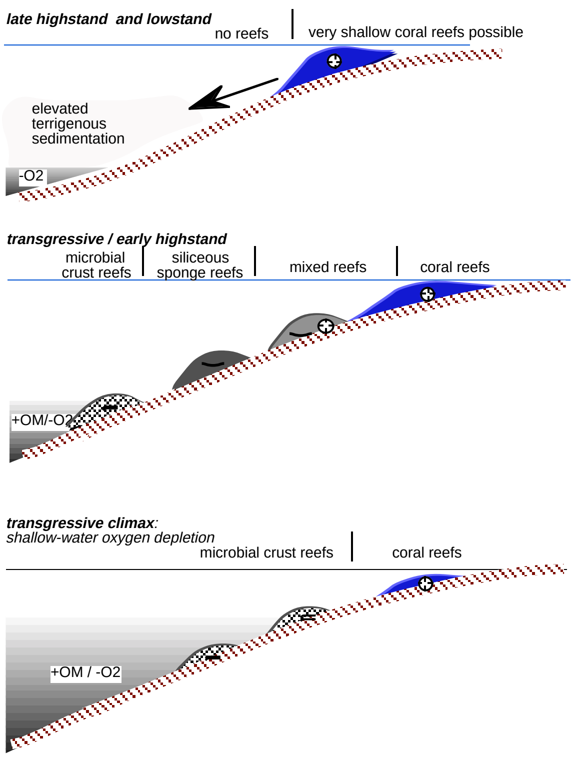

Fig. 6: Sequence stratigraphic model of growth of Upper Jurassic reefs from Iberia. Elevated siliciclastic influx largely inhibited reef growth during falling sea level (top). During rising sea level, reefs of various composition spread across the shelf due to the reduction of siliciclastic influx (middle). Some major transgressions resulted in additional climatic equilibration, accompanied by reduction in water circulation. Oxygen-controlled pure microbolite reefs, normally growing in deeper waters, could then occur in fairly shallow settings. (From Leinfelder 1994a, modified).

Allocyclic control by sea-level change
There is a good evidence that many reefs and carbonate platforms grew preferably during sea level rise and early highstand (e.g. Sarg 1988, Tucker and Wright 1990, Leinfelder 1993, 1994a). This is particularly true of mixed systems where coastal sediment trapping systems such as estuaries will particularly develop during sea level rise. During sea level fall gravitational energy is enlarged and, provided other effective sheltering mechanisms are lacking or of low efficiency, rate of siliciclastic sedimentation increases on the shelf, except for the constantly wave agitated shallowest zone. Examples for reefs from the Late Jurassic show that sea level rise may occasionally come along with climatic buffering and reduction of water circulation, giving rise to the partial substitution of corals reefs by euryoxic microbolite reefs (Fig.6; see also Leinfelder 1993, Leinfelder et al. 1993, Werner et al. 1994).

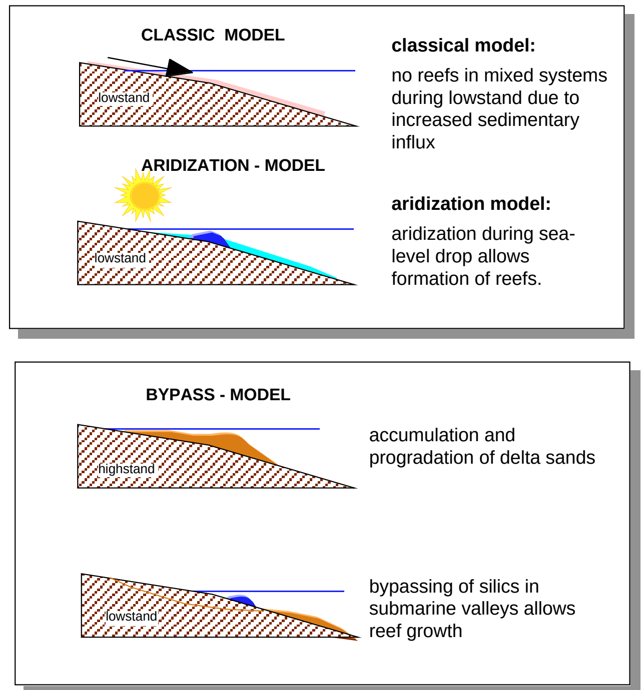

Fig. 7: Sequence stratigraphic context of reef growth in mixed settings: The classical, and frequently occurring situation is that lowstands of sea-level are accompanied by an elevated influx of siliciclastics. However, sea-level lowstand may result in stronger aridization, shutting off silics during lowstand but allowing them during the more humid times of rising or high sea-level. In a setting with restricted accomodation space siliciclastics may be deposited on the shelf only during sea-level rise and highstand whereas bypassing in canyon systems occurs during lowstands, with narrow reef rims developing on the shelf.

There are, however, many exceptions to this transgressive growth model for reefs within silici-clastics (Fig. 7). Provided accumulation space on a shallow shelf is very limited and siliciclastic influx is high, siliciclastics may accumulate and prograde on the shelf during sea level rise and highstand, disabling any reef growth. During sea level drop, canyon systems may develop and siliciclastics can be largely bypassed towards basinal areas. This may allow localized reef growth around the slope break between the canyon areas. Another exception is that sea level rise may cause the change of an arid climate into a more humid situation, causing a higher runoff of freshwater and siliciclastics. As a result, reefs may preferably grow during the more arid lowstand episodes in such settings.

IS THERE ANYTHING POSITIVE WITH REEFS AND SILICICLASTICS?

There are a couple of possible positive effects of terrigeneous influx on some reefs. Wedo not include the following into the positive effects, but want to mention that catastrophic sedimentation events of siliciclastics may be the only way to preserve a delicate reef meadow for the geological record in settings where otherwise such reefs would not have any preservation potential (Freiwald 1996).

Reef foundation by silics

Due to the steep slopes of the Red Sea and its gulfs, many reefs are only developed as very narrow fringing reefs a few meters away from the coastline. More pervasive spatial reef growth is in many places only possible when slope gradients are diminished due to the existence of siliciclastic fan deltas, where abandoned lobes may be taken over by the reefs (see above). Other examples are from Florida, where reefs settle on elevations provided by the underlying siliciclastic depositional systems, such as flooded beach bars (Ginsburg et al. 1989).

Slightly increased nutrient concentration

The oligotrophic Red Sea, with its very limited water circulation, probably benefits from the constant but very low airborne siliciclastic dust which may provide a minimum influx of inorganic nutrients and differences of faunal composition are related to local differencis in this influx (Riegl and Piller 1997). Although increased influx of nutrients due to terrigeneous influx may stimulate the growth of non-skeletal organisms, particularly soft algae, eventually leading to the death of coral reefs (Hallock and Schlager 1986), there are peculiar, though very low diversity stone coral association growing under elevated (anthropogenic) nutrient influx in the Red Sea (Schuhmacher pers. commun.). These differences might be due to the fact that the Red Sea still contains enormous quantities of herbivorous fish.

Many fossil coral associations apparently grew under direct influence of fine terrigeneous sedimentation. Mostly diversities diminish under elevated terrigeneous influx. However, under a only slight terrigenous influx diversities may even increase. This may be explained by the fact that fossil corals were either heterotrophic or the ratio of photoautotrophic (symbiontic) versus heterotrophic energy uptake was smaller than in modern reefs, and coral associations might have benefitted from a moderate increase of both inorganic and organic nutrients accompaniing a moderate terrigeneous influx (see below and Nose and Leinfelder 1997).

APPLICATION: REEFS AND CARBONATE PLATFORMS FROM THE LATE JURASSIC OF THE LUSITANIAN BASIN, WEST CENTRAL PORTUGAL

This chapter will briefly demonstrate how in the Upper Jurassic succession of the Lusitanian Basin of west-central Portugal, many of the above controlling mechanisms cooperated to result in a complex spatial and temporal pattern of both siliciclastic sedimentation and coral reef growth.

The Lusitanian Basin is an Atlantic ocean marginal basin with a complex infill and tectonic history, including two major rift episodes in the Latest Triassic to Earliest Jurassic and Late Jurassic, with episodes of tectonic quiescence in between and afterwards. The basin was slightly compressed in the Tertiary due to Alpine tectonics and therefore escaped incorporation into the present North Atlantic shelf unlike most other Atlantic marginal basins (Leinfelder and Wilson 1989, Wilson et al. 1989). Coral reefs and narrow carbonate platforms developed during the Late Jurassic second synrift and immediate postrift episode (Leinfelder and Wilson in press) and were widespread both during the Oxfordian and particularly during the Kimmeridgian (Fig. 8). The eastern part of the basin was subject to pronounced synsedimentary strike slip movements causing the creation of a transtensional depocenter, the Arruda Subbasin which during the Kimmeridgian was fed by enormous quantitites of siliciclastics from both the Eastern and Northwestern crystalline hinterland. Nevertheless, coral reefs and small carbonate platforms flourished during this time interval allowing the discrimination of spatial and temporal controls of mixed sedimentation (Leinfelder 1994b, Nose 1995).

At the eastern basin margin enormous, but probably point-fed both coarse and fine siliciclastics were shed into the basin from the eastern hinterland, the Iberian Meseta. The eastern basin margin is nowadays partly covered by Tertiary to Modern sediments from the Tagus basin, but its location is indicated both by seismic and borehole interpretation and the position of a huge coarse slope-type siliciclastic fan delta of Early to Late Kimmeridgian age, reaching sediment thickness of more than 2200 meters. Dominance of coarse, mostly amalgamated debris flows and many collapse structures are indicative of intense tectonic activity characteristic of the transtensional strike slip nature of the eastern margin resulting in a strongly subsiding pull-apart-type halfgraben structure (Castanheira fan, Leinfelder and Wilson 1989, Leinfelder 1994b).

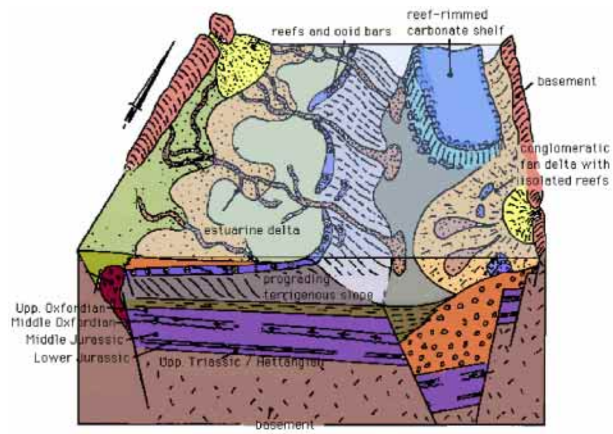

Fig. 8: Simplified sketch of Kimmeridgian mixed depositional systems from the Arruda Subbasin of the Lusitanian Basin, Portugal. Reefs occurred, at various times and places, on an uplifted block, within a siliciclastic fan delta, on top and in the slope of a terrigeneous prograding slope system and within a estuarine delta (from Leinfelder 1994b, modified).

Adjacent to this fan grew the Ota bank, a pure carbonate, coral-reef-rimmed narrow shallow-water carbonate platform which is at least 150 meters thick and developed in an aggradational pattern during major parts of the Kimmeridgian. Both the marginal high-energy coral reef and the entire platform did not suffer from any siliciclastic influx except for some airborne detrital quartz and rare centimeter sized quartz pebbles interpreted as dropstone-type exotic pebbles transported through uprooted trees from the hinterland (Leinfelder 1992, 1994b). Lack of siliciclastics was partly due to the position on an uplifted isolated basement horst, visible in seismic sections (Leinfelder and Wilson 1989), which allowed bypassing of coarse, bottom-transported siliciclastics. However, the existence of lignites, widespread fluvial and freshwater lake deposits of Kimmeridgian age (e.g. Leinfelder 1987), and the enormous amounts of fine terrigeneous material in marine parts of the basin show that the climate in the Lusitanian Basin was humid or rather than arid, suggesting that terrigeneous clay was suspended in the shallow water. While the reef could have been washed by waves, the pure carbonate character of the low-energy tidal flat and lagoon demands the existence of a longshore current system at the eastern basin margin effectively fencing off suspended, east-derived terrigeneous clay. This interpretation is compatible with the general basin configuration which during the Kimmeridgian was open towards the young Atlantic in the southeast and, to a lesser extent, in the north, enabling a current system to parallel the eastern basin margin (Leinfelder 1987, 1992).

The Castanheira fan, to the direct south of the Ota platform, shows two levels with the development of isolated coral reefs, parts of which were not preserved in situ, but as large, parautochthonous to clearly allochthonous, mostly paleokarstified boulders up to house size. Restriction of reef development to only two levels, and the subsequent karstification and partial collapse of the structures shows that reef development was related to the rare episodes of tectonic quiescence, whereas their death and partial destruction is indicative of rejuvenance of tectonic activity (Leinfelder 1994b). Interestingly sequence stratigraphic interpretation of the Upper Jurassic succession of the central Lusitanian Basin shows that these episodes of tectonic quiescence coincided with rises in relative sea level, demonstrating the close relation of sea level fluctuations and tectonic activity, at least for the basin and probably for entire western Europe (Leinfelder 1993, Leinfelder and Wilson in press). Purity of reef carbonates and their isolated distribution even within the reef-bearing levels shows that other controlling factors were aditionally at work: The longshore current system mentioned above was responsible for the lack of fine terrigeneous material in the reefs, whereas their patchlike spatial distribution is evidence of autocyclic and possibly tectonic deactivation of siliciclastic fan sedimentation in parts of the fan (Fig. 9).

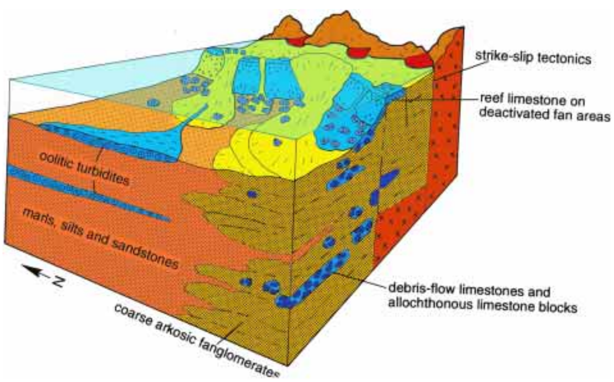

Fig. 9: The Castanheira fan delta of the Kimmeridgian of Central Portugal. The coarse siliciclastic fan delta is the expression of strong tectonic activity and hinterland uplift at the eastern transtensional margin of the Lusitanian rift basin. Autochthonous reefs and allochthonous reefs relics occur in two level, indicating pauses of tectonic activity. However, they still grew coeval with siliciclastic sedimentation highlighting the control by autocyclic shifts of siliciclastic sedimentation (From Leinfelder 1994b, modified)

Both the diminishing grain size towards south and east, and the existence of a seismic clinoform pattern show that a fine to middle grained terrigeneous slope system of Kimmeridgian age prograded from the western crystalline hinterland (relics of which are still preserved in the modern granitic islands of the Berlengas group) towards southeast. Major sediment trapping took place in a rapidly subsiding western subbasin and an adjacent zone of low subsidence or even halokinetic uplift before entering the gentler slope of the Arruda Subbasin half graben (Abadia formation). A major sea level rise interrupted the progradation and probably resulted in the development of sediment trapping estuaries, so that small deeper water coral reefs associated with siliceous sponges and pure, partly dysoxic microbolites could develop in the distal parts of the slope system area, occurring in a discontinuous fashin in one distinct level (Serra Isabel level, Werner et al. 1994; Nose 1995). This happened during the transition from Early to Late Kimmeridgian, the time-interval where the younger reefs within the Castanheira fan delta grew as well. Subsequently, progradation of the siliciclastic slope commenced again, burying this level of reefal lenticular bodies. It was only after the slope system had prograded nearly across the entire subbasin that during stacked episodes of sea-level rises coral reefs occurred again (late Kimmeridgian), first in a variety of coral associations with a clay matrix occurring in lenticular fashion. Quantitative analysis of coral associations and morphological variability of some coral taxa shows that associations within this siliciclastic setting ranged from very low to very high diversity, allowing precise interpretation of habitats and sedimentary dynamics (Nose 1995). Strong diversity reduction is clearly related to elevated rates of terrigeneous fine sedimentation. However, the fact that in still slightly but probably only episodically terrigeneously contaminated settings coral associations diversities were higher than in carbonate settings can be interpreted by the higher demand of nutrients of many Late Jurassic corals due to their still imperfect photosymbiotic relation with zooxanthellae (Nose and Leinfelder 1997).

This level with scattered coral reefs in fine terrigeneous material grades upwards into a nearly continuous carbonate platform system developing during the peaks of two stacked transgressions and rapidly spreading across nearly the entire subbasin (Amaral formation, Nose 1995). Numerous, meter to decimeter-sized, partly still clay-rich, yet mostly carbonate coral reefs grew in close association with bioclastic and oolitic, partly quartz-cored grainstones and packstones. The platform system was crosscut by several siliciclastic channels bypassing the strongly reduced but still occurring siliciclastic material towards the remaining basinal area. Probably due to reactivation of tectonics, siliciclastic influx from the Northwest increased again so that still during sea level rise the very shallow reefal carbonate platform was drowned and covered by prodelta silts and clays. Towards the end of the Kimmeridgian an estuarine delta system prograded over the former carbonate platform which typically gave rise to brachyhaline bivalve associations such as low-diversity oyster reefs and isognomid biostromes (Fürsich 1981, Leinfelder 1986). A peculiar type of coral biostromes, composed of only one coral species in association with oysters and isognomid bivalves was even able to conquer such brachyhaline settings (unpublished results, cf. op. cit.).

CONCLUSIONS

Coral reefs growing in close vicinity or directly within siliciclastic settings indicate that a variety of spatially and temporally active fencing mechanisms must be at work, completely or partially suppressing siliciclastic influx on reefs. Depending on the grain size, quantity and frequency of terrigeneous influx reefs being smothered by siliciclastic may either die (continuous or very frequent and elevated influx), remain productive but change their composition and lower their diversity (continuous or very frequent, but low influx), remain unaffected (very episodic, mostly coarse grained influx), or in some cases even increase their diversity (episodic or continuous, but extremely low influx).

The Upper Jurassic mixed reefal carbonate - siliciclastic succession of the Lusitanian Basin of Portugal highlights the importance of intimate interrelation and juxtaposition of temporally and spatially active fencing mechanisms opening windows for reef growths at different times and places. It is only by the detailed paleoecological and sedimentological analysis of these reef-siliciclastic interrelation that the history of basin development can be dynamically interpreted at a fairly high resolution.

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