Controlling Factors and Environmental Significance of Organomicrite Production and Buildup Development

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Area of Study: Vasco-Cantabrian Basin; N-Spain

Reef Type: Mud Mounds or Organomicrite/Sponge Reefs

Stratigraphy: Early Cretaceous, Albian

Climate: 30°N, Greenhouse interval, subtropical

Reef Organisms: Siliceous sponges, coralline sponges, scleractinian corals together with polychaetes, encrusting foraminifera, thecidean brachiopods and encrusting bryozoans

Depositional Setting: Outer margin of attached carbonate and mixed carbonate/siliciclastic platforms and ramps

Constructive Processes: Mineralization upon non-living organic substrates derived from microbes, biofilms, sponges and possibly other metazoans

Destructive Processes: Downslope transport via olisthostromes. Minor storm wave fetch. Minor bioerosion of lithophagous bivalves and boring sponges. Electrochemical corrosion

Reef Preservation: In most cases intact reef bodies in place. Low grade diagenetic overprinting

Research Topic: Sedimentary dynamics, micrite production, and micrite budget of mud mounds
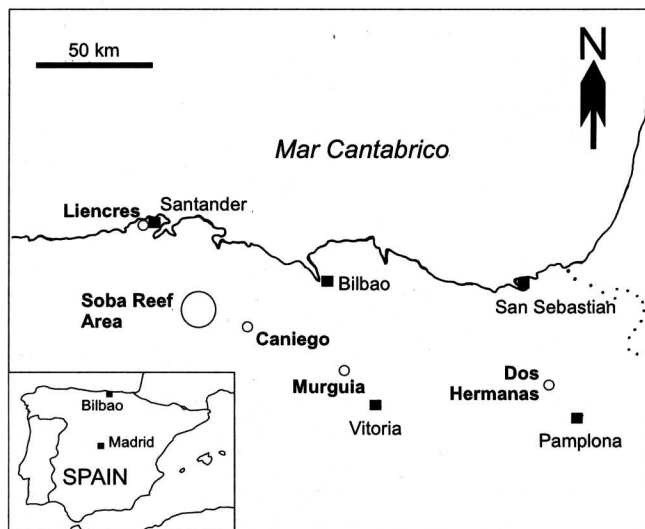

Fig. 1: Locality map indicating main outcrops referred to in the text. Main work was done in the Soba Reef Area (Albian mud mounds).

Abstract

Data obtained from Lower Cretaceous mud mounds provide evidence for organic matrix mediated micrite production in place. Intracrystalline organic macromolecules are typically enriched in Asp and Glu. Mineralization is confined to non-living organic substrates (organomineralization of TRICHET & DÉFARGE 1995) originally derived from microbes, biofilms and/or metazoans. For seeding and epitaxial overgrowth organic substrates and seed crystals need a persistent interaction with the surrounding medium. Therefore, sedimentary starvation is required. Sedimentary starvation is realized via protected space (semi-closed cavities, interstitial pore space, sponge body container), via rapid sealevel rise (TST-confined mud mounds), via rapid drop of sealevel (emersion), and analogue episodes of low carbonate production presumably controlled by eutrophism. Crystal growth also requires an increased carbonate alkalinity. This is provided via sulfate reduction on local scale and/or via continental weathering in the surrounding Paleozoic massifs. Genetically, mud mounds of the Soba Reef Area correspond to organomicrite reefs. These reefs are opportunistic, i.e. their occurrence within the photic zone indicates major crisis of the stenotopic scleractinian coral/calcareous algae community. Mud mounds of the Soba Reef Area share some important features with Albian/Cenomanian hardgrounds (organomicrite related lithification, dominance oft active filter feeding organisms, restriction of sediment supply) but hardgrounds were influenced by stronger submarine dissolution and were exposed to relatively strong current systems.

1 Introduction

Mud Mounds are carbonate buildups with more than 50 vol.-% micrite or pelmicrite (REITNER & NEUWEILER 1995a). These structures are polygenetic ranging from biodetrital to microbial (BOSENCE & BRIDGES 1995), or from biodetrital to allomicritic and automicritic (NEUWEILER 1995). Mud Mound structures are a conspicuous element of the Lower Cretaceous "Urgonian" complex of the Mesozoic Vasco-Cantabrian Basin. Project Re 665/3-1+2 aimed at an integrated approach on a local scale to achieve a new database for the genetic reinterpretation of mud mound structures (NEUWEILER 1995). The follow-up projects Re 665/3-3 and Re 665/7-1+2 dealt with the regional, basinwide significance of mud mound structures, the comparison with bedded hardground sequences related to drowning intervals, and the possible role of diapir-derived brines. All studies refer to the conservative microbial/sponge community which consists of microbial deposits sensu lato associated with siliceous sponges, and coralline sponges e.g. *Acanthochaetetes* and *Vaceletia*. This dim light/aphotic community was found within and adjacent to Albian mud mounds (Soba Reef Area, Dos Hermanas), at marginal areas of diapir platforms (Murguia), and as a major part of a hardground community related to deeper water carbonate ramps (Liencres). Also found within modern and ancient cryptic reef habitats ("telescoping"), this community provides excellent bathymetric control within open waters with a depth

range of 150-100 m. In addition, comparative analyses were carried out with well-preserved facies analogons derived from the Carnian (Triassic) Cassian Formation of the Dolomites (NEUWEILER & REITNER 1995).

2 Aims and Methods

Aims of the projects were 1) to reconstruct the dynamic sedimentary and diagenetic regime associated with mud mound developments, 2) the analyses of benthic mud mound communities (biofacies), and 3) the evaluation of the relative importance of different modes of micrite production and accumulation, i.e. active growth, binding/baffling and internal sedimentation (NEUWEILER 1993, 1995, REITNER & NEUWEILER 1995a, b, REITNER et al. 1995a, b, c).

The applied methods comprise detailed field work with a meter-scaled resolution of vertical and lateral sections, stratigraphic correlation (mapping, marker beds, and type 1 sequence boundaries), microfacies analyses and combined staining techniques (alizarine red S & K-hexacyanoferrate III), epifluorescence microscopy; SEM; microprobe analyses for minor and trace elements (Mg, Fe, Mn, Sr); AAS (Ca, Mg, Fe, Sr, Mn, Na), analyses of stable isotopes (δ^{13}C and δ^{18}O), titration for total organic carbon (TOC) using chromium-sulfuric acid for oxidation; extraction of intracrystalline organic compounds (amino acids), and biomarkers (hydrocarbons, fatty acids; gas chromatography). Statistical methods comprise a checklist with 62 components used for cluster analysis (Q-mode; R-mode). The existence and nature of sedimentary cycles was checked by using Markov-chain analysis (complete results in NEUWEILER 1995).

3 Results

3.1 Soba Reef Area

At the western margin of the Vasco-Cantabrian Basin (Soba Reef Area, Fig. 1) the primary facies architecture of the Aptian-Albian platform/basin transitions are well preserved. Along these zones large-scaled mud mounds reach 70 m in height with a basal diameter of up to 150 m. These mounds were originally described geometrically by RAT (1959) as "mass lenticulaires". PASCAL (1985) illustrated their micritic texture and made general references to mud mounds, reef mounds and algal mounds.

The Aptian/Albian sequence is that of an attached mixed facies platform. Provenance areas of siliciclastic input (Gilbert-type deltas, shoals, coastal sands) are Paleozoic basement rocks of the Asturian Massif (West) and the Ebro Massif in the South. However, there are minor intervals with relatively pure carbonate deposition during the Bedoulian and Clansayesian (Fig. 2).

Stratigraphy

The Upper Aptian (Clansayesian) to Middle Albian interval consists of six sedimentary-diagenetic cycles (System 3-I to VI, cf. Fig. 2) that represent asymmetric transgressive-regressive sequences of. In combination with several marker horizons, these cycles provide a stratigraphic control across the platform/basin transitions based on 18 compiled sections with a total of 1,250 m. Drops in sealevel recorded as paleokarst are documented in the Aptian/Albian boundary interval (II to III) and within the upper parts of the Lower Albian as indicated by the occurrence of *Neohibolites minimus* (ammonite zone: *Douvilleiceras mammilatum*, III to IV).
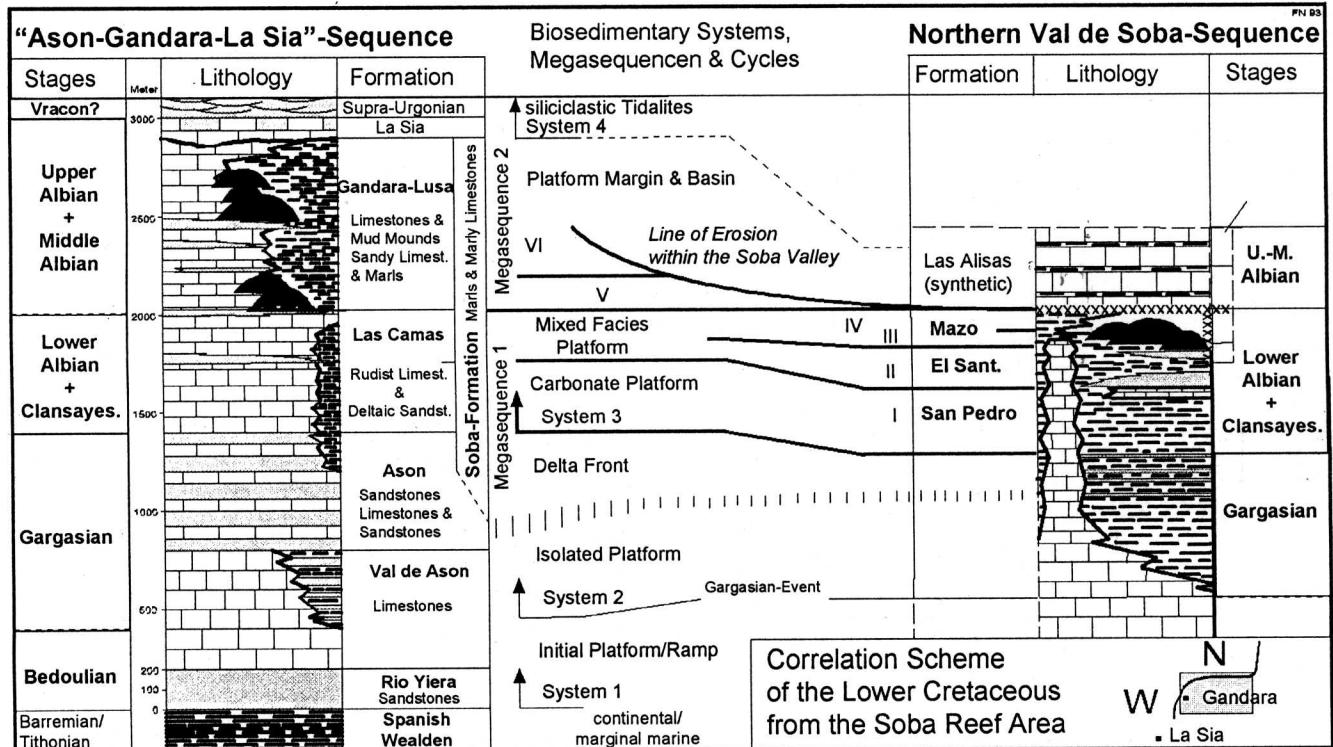

Fig. 2: Correlation scheme of the Lower Cretaceous from the Soba Reef Area. Aptian/Albian deposits are divided into six sedimentary-diagenetic cycles (system 3, cycles I-VI). Note that mud mounds are confined to Albian deposits (modified from NEUWEILER 1995).

Other marker horizons are well defined either by composition e.g. *Barroisia*-beds, first occurrence of Flora Vinport with *Agardhiellopsis cretacea* and *Paraphyllum primaevum* (top of IV) or as depositional events like grainflow-deposits, olisthostromes, debrites and turbidites (e.g. IV to V). The combined application of cyclo- and markerstratigraphy allowed the spatial reconstruction of the depositional regime along specified time slices, thus providing the data base for illustrating dynamic sedimentary processes associated with mud mounds (Fig. 3+4).

Field Observations

At platform margins mud mounds follow transgressive discontinuities of facies. Their size and geometry is highly
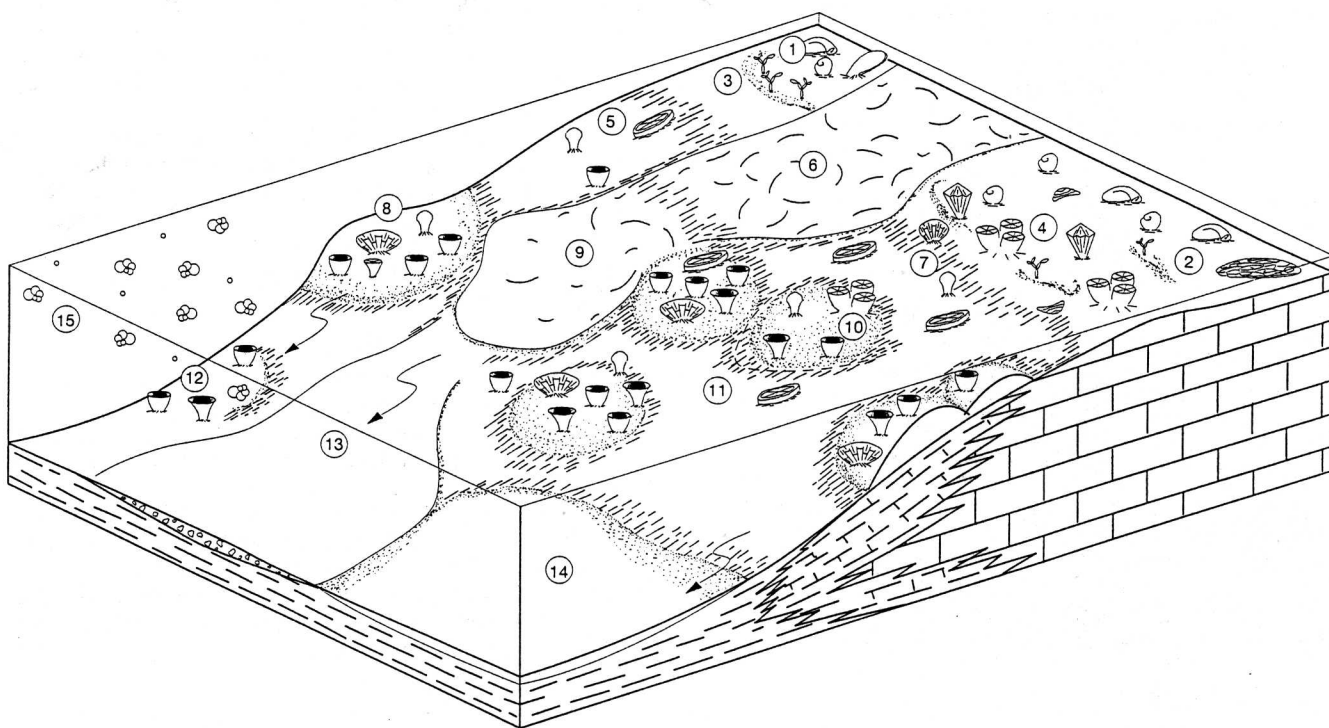

Fig. 3: Establishment of mud mound structures during retrogradation of carbonate platforms. These structures cover different megabenthos zones from the basin up to the platform margin. 8) Mid-slope community with lithistid demosponges, hexactinellid sponges, and coralline sponges (pharetronids, acanthochaetetids). 10) Upper slope community with additional scleractinian corals and calcareous algae (minor). 12) Lower slope community with lithistid demosponges and Hexactinellida (further details in NEUWEILER 1995). Replacements of stenotopic coralgal communities by a "deep water microbial/metazoan community" does not exclude major (seismically traceable?) buildup developments.
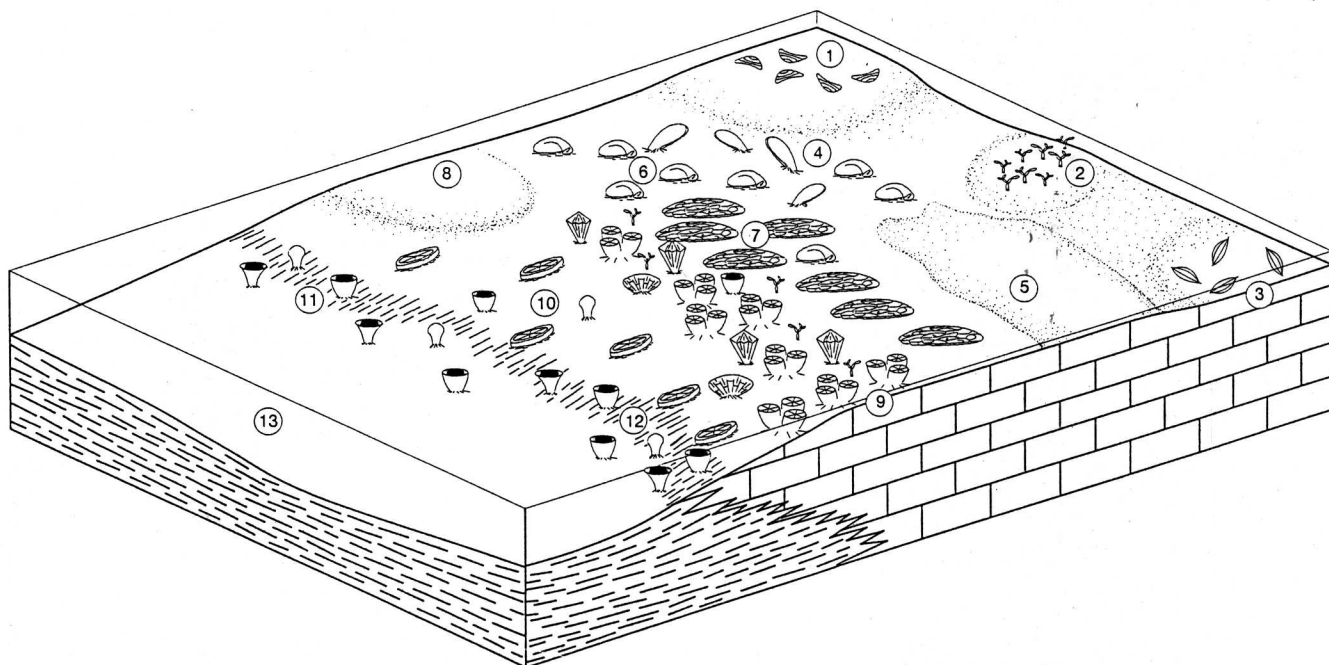

Fig. 4: Lack of mud mound structures during progradation of carbonate and mixed facies platforms. However, there is a narrow zone of automicrite production in close association with microsolenid corals, acanthochaetetid and pharetronid sponges (10), lithistid demosponges, hexactinellids and pharetronids (11) as well as (12) siliceous sponges and microsolenid corals. Dashed lines mark the basinward end of autochthonous carbonate production, i.e. of the "Urgonian carbonate factory" (further details in NEUWEILER 1995).
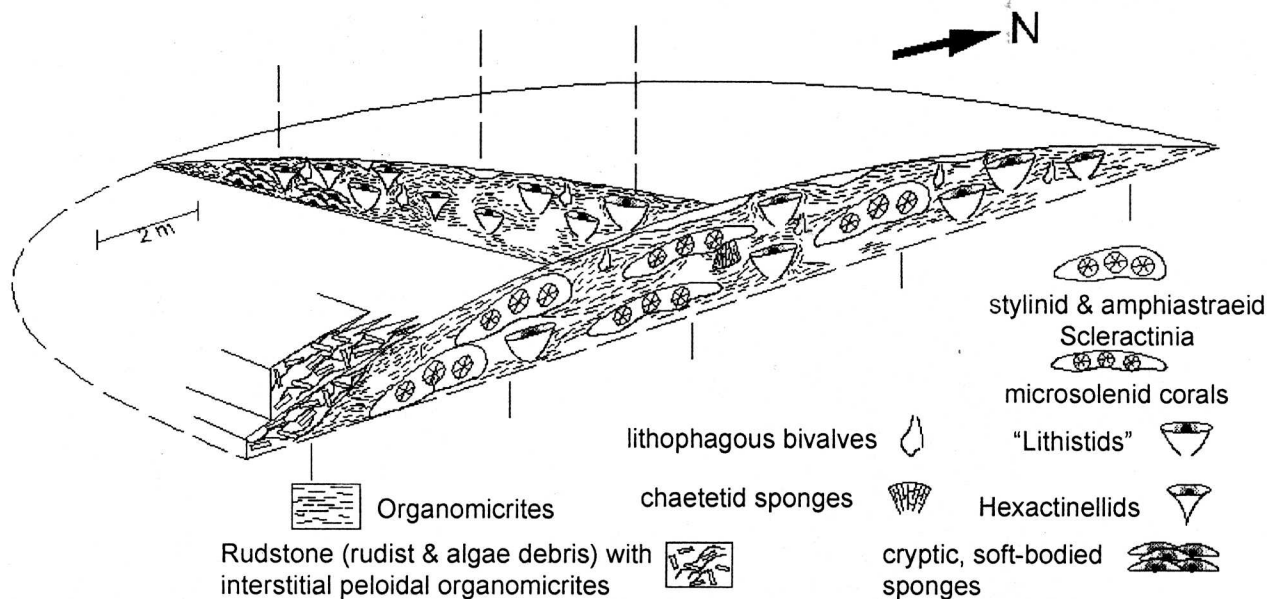
Fig. 5: Systematic sampling on patchy mud mound occurrences revealed zones of distinct subcommunities either dominated by scleractinian corals, by lithistid demosponges or hexactinellid sponges (background). These zones are orientated parallel to the dip of the slope suggesting a major control by longitudinal currents.

Category	Subcategory	Mineralogy	δ^{13}C	Macro- and Microfabric
automicrite	accretionary organomicrite	Mg-calcite	~equilibrium	stromatolites, thrombolites, massive (microfenestrate, peloidal, aphanitic)
	container organomicrite	Mg-calcite	~equilibrium	stromatolites, massive (peloidal, minipeloidal, aphanitic)
	skeletal	Mg-calcite/aragonite	non-equilibr./~equilibrium	controlled by organism (e.g. *Bacinella*, *Vaceletia*)
allomicrite	detritus (bioerosion), mostly platform-derived	mixed Mg-calcite/ aragonite	non-equilibrium	geopetal mud (mostly from rudistid bivalves)

Tab. 1: Categories and major characteristics of micrites as observed within and adjacent to Lower Cretaceous mud mounds.

variable ranging from prominent isolated mounds (70 m thick) to circular patches ca. 5 m thick with a diameter of 20 m and stacked mound complexes with a total thickness of up to 50 m (Pl. 1). These structures are located at both slopes and the upper platform margin acting as a barrier reef complex (Fig. 3). Consequently, different zones of megabenthos communities are covered by mud mound genesis. Small, embryonic mounds (30 cm thick, 80 cm across) occur within marly basin deposits (NEUWEILER 1995: 87-100).

However, there are examples of transgressive discontinuities of facies lacking any mound structures, but bearing narrow zones of facies identical to those observed within mud mounds. In addition, during regressive states distally steepend ramps bear an analogous facies belt corresponding to the basinward endmember of autochthonous carbonate lithofacies, i.e. the carbonate factory. Again, this facies belt is rather narrow (5-10 m) and lacks any mound structures (Fig. 4).

Finally, "mud mound facies" occurs also within cryptic niches of scleractinian coral/red algae reef bodies and interparticle space of coarse-grained biodetrital sediments. In most cases this biogenic pore space reduction precedes cementation by different modes of even rim cements (NEUWEILER 1993, 1995, REITNER et al. 1995b).

Biofacies of Mud Mounds and Related Facies

According to the variety of mud mound occurrences (e.g. Fig. 3), biofacies characteristics are twofold indicating various depositional environments and the mud mound specific biofacies itself. Additional problems derive from possible community replacements resulting in "pseudocommunites" the members of which never lived penecontemperously (coelobites, "drowning").
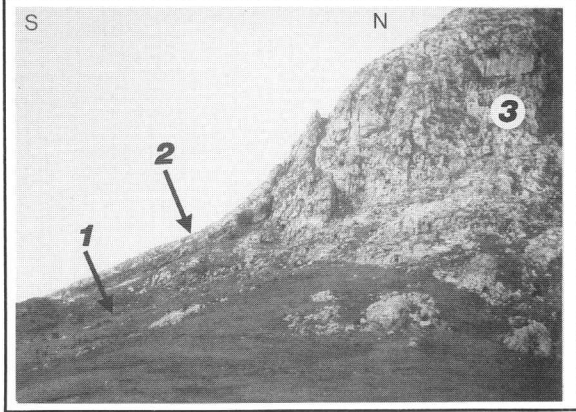
The biofacies crucial for mud mound genesis consists of automicrites, variously developed and preserved (NEUWEILER 1993, 1995) just correlating with the occurrence of thin-walled (cryptic) ostracods (cluster analyses, R-mode).

However, mud mound genesis is restricted to the outer platform margin and the basin covering megabenthos communities consisting of hexactinellid and lithistid sponges (basin, lower slope), siliceous sponges, coralline sponges and microsolenid coral (mid slope) up to the platform margin with additional scleractinian corals and calcareous algae. The main associated elements are encrusting foraminifera, polychaetes, terebratulid, rhynchonellid and thecidean brachiopods, encrusting bryozoans, and pharetronid sponges (Fig. 6). Systematic sampling on patchy mud mound occurrences revealed a narrow zonation within these mounds facing current systems along the slope (Fig. 5).

Despite the fact that automicritic rims might occur within carbonate shoal deposits (NEUWEILER 1993), major occurrences of automicrites are generally excluded from lagoonal and littoral environments.

Plate 1: Stacked mound complex, Lower Albian, Soba Reef Area
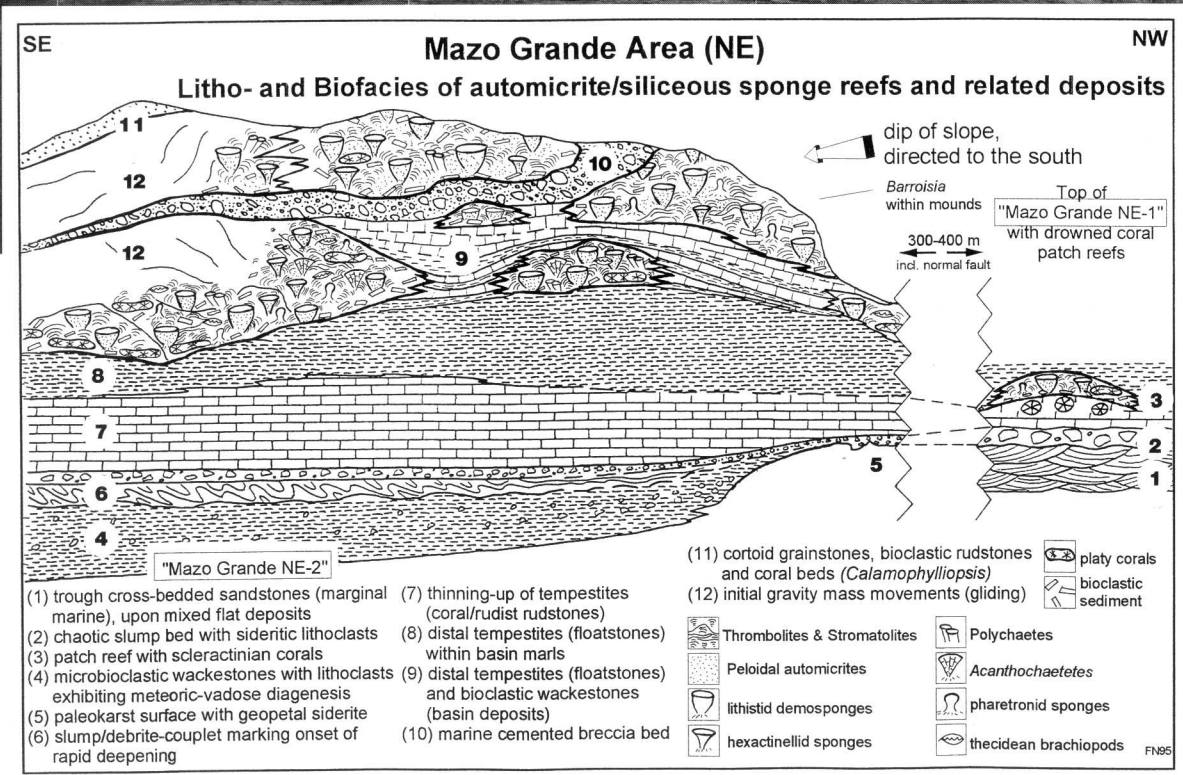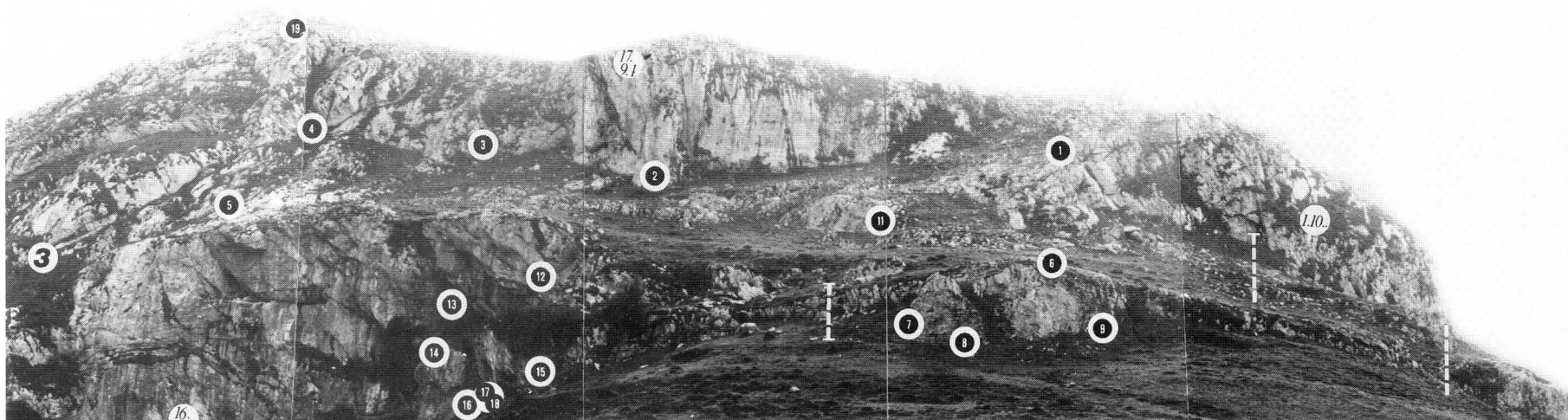
Mound front with biodetrital flanking beds within Hexactinellid-marls (1) and mound cover beds (2). 3=S-margin of mound complex (cf. composite overview)
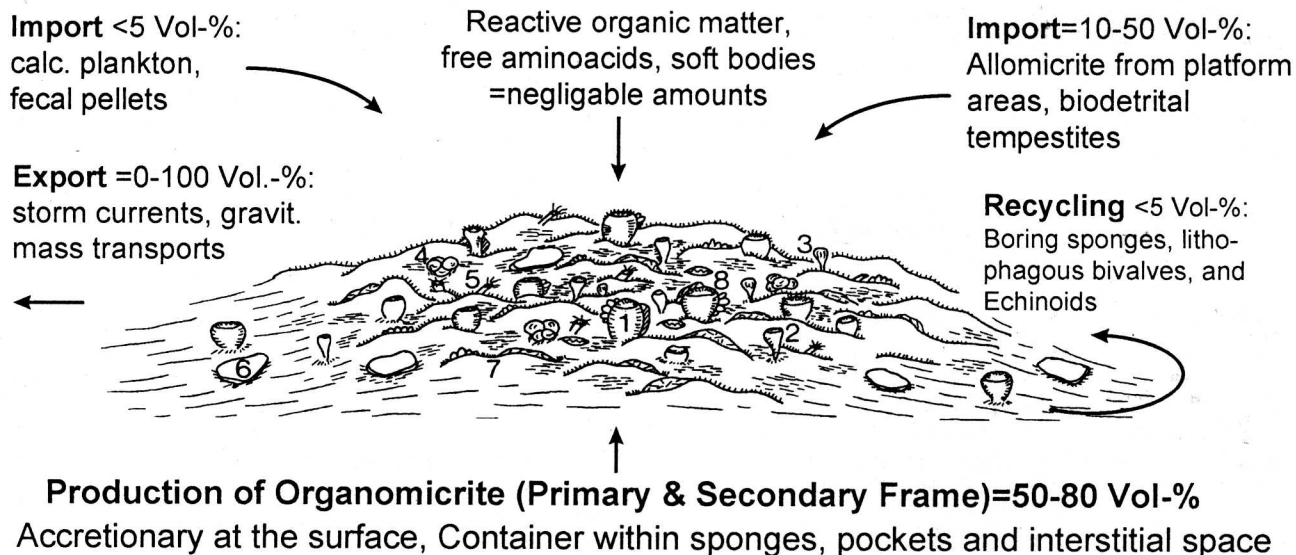
S · N

Mazo Grande Area (NE)
Litho- and Biofacies of automicrite/siliceous sponge reefs and related deposits

SE · NW

dip of slope, directed to the south

Barroisia within mounds

Top of "Mazo Grande NE-1" with drowned coral patch reefs

300–400 m incl. normal fault

"Mazo Grande NE-2"

(1) trough cross-bedded sandstones (marginal marine), upon mixed flat deposits
(2) chaotic slump bed with sideritic lithoclasts
(3) patch reef with scleractinian corals
(4) microbioclastic wackestones with lithoclasts exhibiting meteoric-vadose diagenesis
(5) paleokarst surface with geopetal siderite
(6) slump/debrite-couplet marking onset of rapid deepening
(7) thinning-up of tempestites (coral/rudist rudstones)
(8) distal tempestites (floatstones) within basin marls
(9) distal tempestites (floatstones) and bioclastic wackestones (basin deposits)
(10) marine cemented breccia bed
(11) cortoid grainstones, bioclastic rudstones and coral beds (*Calamophylliopsis*)
(12) initial gravity mass movements (gliding)

Thrombolites & Stromatolites
Peloidal automicrites
lithistid demosponges
hexactinellid sponges
Polychaetes
Acanthochaetetes
pharetronid sponges
thecidean brachiopods
platy corals
bioclastic sediment

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Import <5 Vol-%: calc. plankton, fecal pellets

Reactive organic matter, free aminoacids, soft bodies =negligable amounts

Import=10-50 Vol-%: Allomicrite from platform areas, biodetrital tempestites

Export =0-100 Vol.-%: storm currents, gravit. mass transports

Recycling <5 Vol-%: Boring sponges, lithophagous bivalves, and Echinoids

Production of Organomicrite (Primary & Secondary Frame)=50-80 Vol-%
Accretionary at the surface, Container within sponges, pockets and interstitial space

Fig. 6: Micrite budget and reconstruction of a mud mound community with associated zones of organomicrite production (dashed lines). 1) lithistid demosponges (container automicrite), 2) hexactinellid sponges (container automicrites), 3) pharetronid sponges, 4) acanthochaetetid sponges, 5) polychaetes, 6) microsolenid corals, 7) encrusting foraminifera together with encrusting bryozoans and soft demosponges (container automicrite), and 8) thecidean brachiopods. Dashed lines at the surface correspond to sites of accretionary automicrite production (stromatolites, thrombolites and massive fabrics).

Micrite Production in Place

Tab. 1 provides general aspects of micrite subcategories found adjacent to and within mud mounds. As mud mounds may form isolated "carbonate islands" within marly basin deposits, micrites are predominantly local in origin. In addition, borings by lithophagous bivalves and sponges (*Aka*) demonstrate that most parts of micrites were initially indurated.

Petrographic and biofacies analyses made evident that automicrite production occurs independent of light, thus excluding photoautotrophic organisms (e.g. cyanobacteria). Despite the fact that most of automicrites represent "classical" microbial fabrics, there was no direct evidence for microbes at all, contrasting co-occurring bacteriosponges with well preserved outlines of former symbiotic bacteria!

The primary mineralogy of the automicrites is high Mg-calcite with residual $MgCO_3$-contents between 1.2 and 3.6 mole-%. The composition of stable isotopes ($\delta^{13}C$ and $\delta^{18}O$ ‰ vs. PDB) goes along with inorganically precipitated marine cements ($\delta^{13}C$: 2.9 to 3.8, $\delta^{18}O$: -1,5 to -4). The comparative analysis of intracrystalline amino acid quantity reveals relative maxima of glutamine and asparagine, pyruvates and glycine as well as tyrosine. The relative amounts of amino acids are very similar to those obtained from modern automicrites of Lizard Island reef caves (GBR) and are clearly separated from skeletal automicrites of *Bacinella*. In addition, biomarker analysis of accretionary automicrites resulted in a specific n-alkane pattern comparable to literature data of modern marine thrombolites (Lizard Island) and Upper Jurassic spongiolites. In addition, gas chromatograms of the hydrocarbon fraction provide evidence for the role of biodegradation (cf. THIEL et al. this volume; REITNER et al. this volume).

3.2 Diapir Platforms

Within the Vasco-Cantabrian Basin diapir-related carbonate platforms range from the Aptian to the Campanian (Keuper evaporites, cf. REITNER 1987). Their distribution is linked to the active strike-slip-fault system. The Late Albian Murguia Diapir is part of the southern Cantabrian Diapir Zone. Influences of diapir-derived brines were concluded

from aragonitic ooids and sulfide ores in fractures and fissures of the reef (REITNER 1986). Therefore the Murguia Diapir was selected to check the opportunistic nature of organomicrites (drowning, low carbonate productivity) and the possible influence of diapir-derived brines.

Organomicritic beds occur within the Late Albian/Cenomanian boundary interval. They are characterized by phosphatic ooids, hardground lithoclasts and a general trend towards pelagic conditions as indicated by planktonic foraminifera, pithonelloid calcispheres and ammonoids. Autochthonous organisms are agglutinating foraminifera, coralline and lithistid sponges as well as brachiopods, irregular echinoids, bivalves and gastropods. Typically, thin-shelled ostracods are present. The beds are of lowermost Cenomanian age (*Rotalipora brotzeni*, *R. appeninica*; *Mantelliceras saxbii*, *M.* cf. *mantelli*).

Relative high residual Mg-contents in the range of 4,000-6,000 ppm combined with relatively depleted Sr-contents around 400 ppm suggest a high Mg-calcite precursor mineralogy of organomicrites. The prominent Na-anomaly reported by REITNER (1987) cannot be confirmed albeit the same beds were analyzed. The values of stable isotopes ($\delta^{13}C$ and $\delta^{18}O$ ‰ vs. PDB) were strongly effected by meteoric-phreatic diagenesis. Values of $\delta^{18}O$ are in the range of -5.53 to -8.01 and those of $\delta^{13}C$ of +0.04 to -1.93. So far, geochemical data provide no direct evidence for diapir-derived brines.

However, the low diversity of organisms, pseudomorphs possibly after evaporitic minerals and resedimented Keuper material point to fluctuating salinities during the Upper Albain/Lower Cenomanian. Of special interest are low relief mounds which might develop from even hardgrounds surrounded by *Thallassinoides* beds and dark marls. They reveal a community replacement of orbitolinid foraminifera and coralline red algae by a deep-water sponge community consisting of lithistid demosponges, coralline sponges (*Acanthochaetetes*, *Vaceletia*), rhynchonellid and terebratulid brachiopods in association with patchy occurrences of automicrites. This community structure is very similar to those observed within some mud mounds of the Soba Reef Area, is found within cryptic niches of Late Albian/Cenomanian coralgal reefs, and reveals close taxonomic relationships with modern communities from the Pacific realm
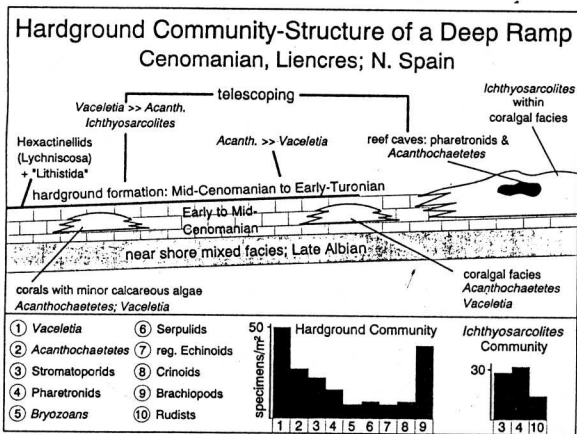
Fig. 7: Facies model during hardground development, Cenomanian of Liencres, Biscay coast (after REITNER et al. 1995).

(REITNER 1993). Apart from initially indurated organomicrites, the occurrence of muddy substrates is indicated by cerioid solitary corals. Analogous to some organomicrite occurrences of the Soba Reef Area, organomicrite production induced hardground conditions and was linked to sedimentary starvation. The diapir-related Caniego-Limestone (diapir of Villasana de Mena) shows analogous features, i.e. coupled occurrences of constructive organomicrites, sedimentary starvation and hardground recruitment (Late Albian, Vraconian).

3.3 Carbonate Ramps

An analogous benthic community dominated by the coralline sponges *Acanthochaetetes* and *Vaceletia* is found within a Cenomanian/Turonian hardground succession cropping out at the coastal area of Santander (Liencres, cf. Fig. 1). This system was established during the drowning of a distal carbonate ramp during the early Middle Cenomanian (Fig. 7, *A. rhotomagense* zone, details in REITNER et al. 1995c).

Biofacies: Besides coralline sponges, which cover 70-80 % of the community, lychniscose hexactinellids, desmabearing lithistid demosponges, thecidean brachiopods, small ahermatypic scleractinians, bryozoans, gastropods and serpulids are present. This sponge community is associated with organomicrites, microbialites and thin mineralized limonitic biofilms. The latter had a strong electrochemical corrosive ability resulting in distinct submarine dissolution patterns.

Biofacies dynamics: The entire benthic hardground community consists of species with long life expectancy and extremely reduced reproduction rates (K-strategists). This metazoan community is most likely associated with external microbial biofilms as deduced from their modern relatives (REITNER 1993). Many organomicrites and thrombolitic/stromatolitic structures are induced by these films. Within the hardground succession the sponge dominated community is replaced by limonitic stromatolites associated with the foraminifera *Miniacina* and colonies of the problematic iron bacterium *Frutexites*. This biofacies discontinuity indicates a fundamental change in the oceanographic conditions rather than a continued deepening of the ramp. The collapse of a community dominated by K-strategists was replaced by a community dominated by r-strategists thus possibly indicating eutrophic conditions. This change occurred during the basal Late Cenomanian.

4 Conclusions

Biological-organic control: Data obtained from Lower Cretaceous mud mounds strongly support the crucial role of organic matrix mediated micrite production in place (cf. REITNER 1993, NEUWEILER 1993, 1995, organomicrite in REITNER et al. 1995b). Initial seeding of crystals is controlled by Ca^{2+}-binding organic macromolecules typically enriched in Asp and Glu. Mineralization is therefore confined to dead organic substrates (organomineralization) which may be originally derived from microbes, biofilms and metazoans, respectively. Additional supply from the water column is negligible as concluded by fluorescence behavior of Triassic counterparts (NEUWEILER & REITNER 1995).

Physical control: For seeding and epitaxial overgrowth organic substrates and seed crystals need a persistent interaction with the surrounding medium. Therefore, sedimentary starvation is required. Sedimentary starvation is realized via protected space (semi-closed cavities, interstitial pore space, sponge container), via rapid sealevel rise (TST-confined mud mounds), via rapid drop of sealevel (emersion), and analogue episodes of low carbonate production presumably controlled by eutrophism (environmental drowning sensu HALLOCK & SCHLAGER 1986).

Chemical control: Crystal growth also requires an increased carbonate alkalinity. This is provided via sulfate reduction on local scale and/or via continental weathering in the surrounding Paleozoic massifs. Possibly, a local control was provided by diapir-derived brines (NEUWEILER 1995: 168-169).

Genetically, mud mounds of the Soba Reef Area correspond to organomicrite reefs dominated by active filter feeding organisms (Fig. 6). These reefs are opportunistic, i.e. their occurrence within the photic zone indicates major crisis of the stenotopic scleractinian coral/calcareous algae community (Middle Albian of the Soba Reef Area; Late Albian of "Dos Hermanas"). Mud mounds of the Soba Reef Area share some important features with studied hardgrounds (organomicrite related lithification, benthic community dominated by active filter feeding organisms, restriction of sediment supply). However, the hardgrounds were influenced by stronger submarine dissolution and were exposed to relatively strong current systems inhibiting active vertical growth.

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