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Early Sinemurian hardgrounds in the Ligurian Alps, Northwestern Italy (Prepiemontese domain, Arnasco–Castelbianco unit)

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ABSTRACT

The Rhaetian–Liassic boundary in the Ligurian Alps (Prepiemontese domain, Arnasco–Castelbianco tectonic unit) is characterized by an apparent sharp passage from tidal to pelagic environment. The interposed layers show features of slow sedimentation, condensed ammonite-rich surfaces (*johnstoni/rotiforme* Zones = Lower Hettangian/Early Sinemurian), bored surfaces and Fe-oxide nodules. A detailed facies analysis suggests that at least two hardground horizons are present above the condensed ammonite-rich surface. An *initial* hardground can be distinguished from a *terminal* one by the intraformational reworked Fe-oxide pebbles lying on a sparsely bored surface. Little or no sedimentation, condensed ammonite fauna, early lithification horizons with bored surface, oxidic staining, suggest that during the Lower Lias the southern part of the Arnasco–Castelbianco unit was an uplifted block with its own identity and environment, already cut off from the contiguous and pre-existing platform. A submarine rise such as an offshore shallow shelf area or a wide seamount seems to be the best model for the reconstruction of the depositional environment where these hardgrounds formed.

RÉSUMÉ

La limite Rhétien–Lias, dans les Alpes Ligures (domaine prépiémontais, unité d'Arnasco–Castelbianco), apparaît caractérisée par un brusque changement de milieu qui passe de littoral à pélagique. Les niveaux intercalés montrent toutefois les caractères d'une sédimentation avec les lacunes comme des surfaces à ammonites condensées (zones à *johnstoni* et à *rotiforme* = Hettangien inférieur/Sinémurien basal), des surfaces à borings, des galets d'oxydes de fer, etc. Une analyse de faciès détaillée a révélé la présence d'au moins deux hardgrounds au-dessus de la surface condensée à ammonites. Un hardground initial est séparé par un autre terminal, constitué par la plupart des produits de remaniement intraformationnel comme les galets d'oxydes de fer disposés sur une surface avec quelques rares borings. Peu ou pas de sédimentation, une faune à ammonites condensées, des horizons à lithification précoce avec surface à borings, des marques d'oxydation amènent à conclure que, pendant le Lias inférieur, la partie méridionale de l'unité d'Arnasco–Castelbianco était un bloc soulevé possédant sa propre dynamique et déjà détaché de la plate-forme contiguë préexistante. Une ride sous-marine, comme une *offshore shallow shelf area* ou un très vaste *seamount*, pourrait être le meilleur substratum pour la formation de ces hardgrounds.

RIASSUNTO

Il limite cronostratigrafico Retico–Lias nelle Alpi Liguri (dominio Prepiemontese, unità di Arnasco–Castelbianco) è marcato da un brusco passaggio da facies tidali a pelagiche. Gli strati interposti sono contrassegnati da orizzonti di non-deposizione, livelli ad ammoniti condensate (zona a *johnstoni* e zona a *rotiforme* = Hettangiano inferiore e Sinemuriano basale), superfici a *borings* e a noduli ad ossidi di ferro. L'analisi di facies condotta ha rivelato l'esistenza di almeno due *hardgrounds* al di sopra della superficie ad ammoniti condensate. Un *hardground*

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iniziale è stato distinto da uno *terminale* costituito da ciottoli mineralizzati di origine intraformazionale deposti su una superficie a sparsi *borings*. La scarsa o nulla quantità di materiale sedimentata, la fauna ad ammoniti condensate, i livelli a litificazione precoce con perforazioni e le mineralizzazioni diffuse, unitamente all'evidenza di eventi distensivi sin-deposizionali, portano alla conclusione che durante il Lias inferiore la porzione meridionale dell'unità di Arnasco–Castelbianco costituiva una zona di «alto» topografico con una sua propria dinamica, già isolata dalla contigua e pre-esistente piattaforma-madre. Un rialzo sottomarino come una piattaforma del largo a bassa profondità o un ampio *seamount* possono costituire un ambiente deposizionale adatto alla formazione ed alla configurazione di questi *hardgrounds*.

1. Introduction

In the Ligurian Alps the Prepiemontese domain is represented by allochthonous units lacking their original ante-Triassic substratum.

The Arnasco–Castelbianco tectonic unit (Vanossi 1971, 1980, Royant & Lanteaume 1973) is a wide Prepiemontese *klippe* overlying either another thrust-sheet of the same domain (Case Tuberto unit) or the external part of the Ligurian Briançonnais. The Arnasco–Castelbianco unit consists, in its lower element (Vanossi 1971), of a typical Norian–Rhaetian–Lower Lias triplet made up of carbonate rocks, followed by a thick complex of breccias of Upper Liassic–Dogger age with a small rhyodacite outflow (*Brecce di M. Galero*, Cortesogno et al. 1981, Dallagiovanna & Lualdi 1985). The Arnasco element consists of pelagic sequences of Malm–Neocomian age *(Radiolariti di Arnasco, Calcari di Menosio)* and siliciclastic layers of Middle Eocene age.

Recent studies of this unit (Cantaluppi & Lualdi 1983, Lualdi 1983, 1984) have shown that the Rhaetian–Lower Liassic sequence is far from complete and that the previous doubts as to the presence of part of the Lower and the whole Middle and Upper Hettangian are confirmed.

The aim of this paper is to describe part of this condensed succession from a sedimentary and partly paleoecological point of view, and to explain the genesis of this particular event.

Comments on the complexity of the pre-spreading mechanism and the coincident drowning of the Upper Triassic carbonate platform are beyond the scope of this work which only deals with a relatively short time span, essentially included between a regressive and a transgressive phase.

2. Geological setting

The evolution of the Upper Triassic carbonate platform in the Arnasco–Castelbianco unit shows a fairly constant and slightly positive subsidence/sedimentation ratio. On a dolomitic complex of Norian (–Carnian p.p.?) age (*Dolomie di M. Arena;* thickness: 250–300 m), making up the oldest formation of this tectonic unit (see Lualdi 1983), lies a shaly carbonate succession of Rhaetian–Hettangian age (*Calcari di Veravo;* thickness: 40–60 m). Three main series (from west to east: M. Nero, M. Arena and Pizzo Ceresa) (Fig. 1) are picked out as the most significant to illustrate the features of the boundary between the last few meters of the Calcari di Veravo and the Liassic formation.

The figure shows their location, lithology, the sampled horizons and the faunal data. The Rhaetian succession is essentially composed of peritidal sequences with a *Retiophyllia clathrata* (Emm.) bioherm within the lowermost third of the series. The sedimentary evolution is marked by a transition from inner tidal flat facies (Dolomie di M. Arena) to

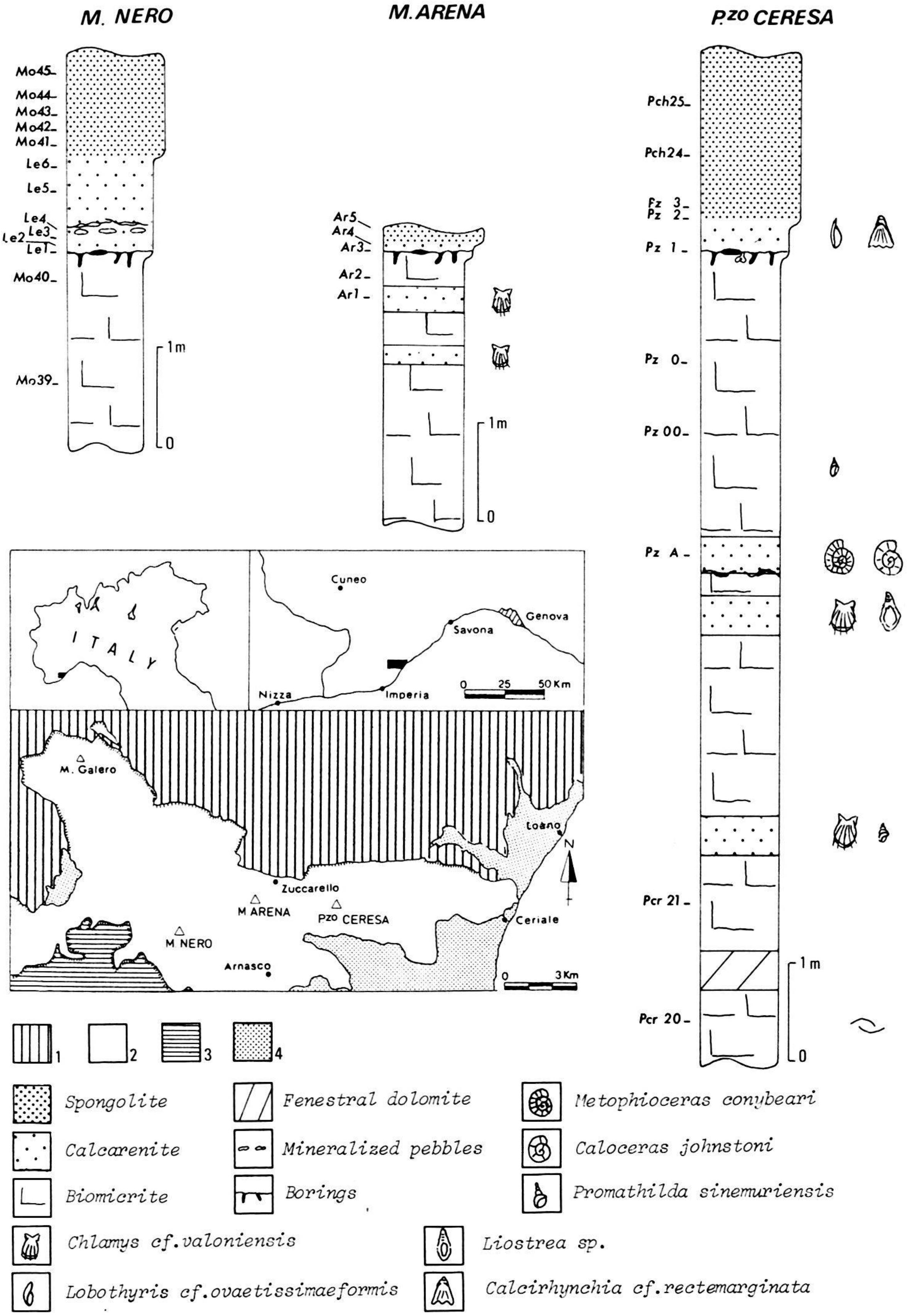


Fig. 1. Stratigraphic sections, location map and tectonic sketch (after DALLAGIOVANNA & VANOSSI 1983, modified). 1: Briançonnais and Prepiemontese (C. Tuberto) units: 2: Arnasco–Castelbianco unit. 3: Borghetto d'Arroscia element. 4: Pliocene and Quaternary.

an external (Calcari di Veravo) one. Almost up to the top of the Veravo limestones inter-supratidal features such as algal laminated dolomites with *fenestrae* and shrinkage cracks are found.

The last few meters of this latter succession (with a max. of 6–7 m at Pizzo Ceresa) – made up of burrowed biomicrites and by three biomicrudite/calcarenite layers, very fossiliferous – show sign of condensed sedimentation, with at least two discontinuity surfaces holding a condensed ammonite fauna (see further).

The upper boundary of the Calcari di Veravo is delimited by a continuous bored surface encrusted by Fe–Mn oxide minerals with concentrically laminated nodules and irregular staining.

The overlying *Calcari di Rocca Livernà* (Sinemurian–Middle Lias?) consists of a thick sequence mostly of siliceous limestones (thickness: 200–250 m), with chert nodules and microbreccia lenses interbedded with thin calcarenites and calcisiltites. In all the examined series the Rocca Livernà limestones begin with biocalcarenites (crinoid ossicles, bivalves) without chert nodules (thickness: 10–90 cm). The lower stratigraphic boundary of this formation is always sharp, with small morphological steps on the topographic surface. Beds are 10 to 20 cm thick, ash-grey, rough, with closely spaced tectonic foliation also marked by discontinuous and irregular mineral staining (hematitic) of a red-brown color. In the whole sequence the fauna, which is not very abundant, contains mostly crinoids, belemnite rostra (*Nannobelus* sp.), a few bivalves, sponge spicules and, *fide* ZACCAGNA (1892), *Vermiceras spiratissimum* QUENST., found in the Pennavaira valley. Particularly significant, whether for the fauna or the sedimentary characters, is the Le4 level at M. Nero (see Fig. 1), lying 40 cm above the bored surface, containing externally mineralized flat pebbles with small borings on the whole surface, indicative of rolling and overturning on the seafloor. These pebbles encrust abundant echinoidal debris and a mixed microfauna with *Triasina hantkeni* MAJZ. and *Involutina liassica* (JONES). Encrusting forams, as *Planiinvoluta carinata* LEISCHNER, are also present.

3. Lithologic description and data interpretation

3.1 The peritidal substrate

The Calcari di Veravo Formation forms the substrate on which the condensed succession rests. Two lithozones are separated by a biohermal horizon (bafflestone with *Retiophyllia clathrata* (EMM.), *Microphyllia* sp., *Thamnasteria* sp.): the lower one is composed by marly limestones and black shales (with *Rhaetavicula contorta* PORTLOK and *Frondicularia woodwardi* HOWCHIN) probably formed in pond or marsh environments; the upper one, better developed, consists of subtidal burrowed mudstones, packstones and grainstones interbedded with inter-supratidal dolomites (LUALDI 1983).

The faunal assemblage is composed (Fig. 6A) by brachiopods (*Rhaetina gregaria* (SUESS)), bivalves (*Modiolus* sp., *Atreta intusstriata* (EMM.), *Cardita munita* (STOPP.), *Cardita cloacina* (QUENST.), etc.), gastropods (fam. *Pleurotomariacea* and *Cerithiacea*), crinoids (*Isocrinus* sp.), echinoids (*Plegiocidaris* sp.), and a rich microfauna (*Triasina hantkeni* MAJZ., *Involutina sinuosa pragsoides* (OBERH.), *Trocholina* sp., *Ammodiscus* sp., *Glomospirella friedli* KRISTAN-TOLLMANN, *Trochammina almtalensis* KOEHN-ZANINETTI, *Frondicularia woodwardi* HOWCHIN, *Agathammina austroalpina* KRISTAN-TOLLMANN

&TOLLMANN, *Planiinvoluta ?mesotriassica* BAUD, ZANINETTI & BRÖNNIMANN). In general the depositional theme shows cyclothems with slight deepening trend. Subsidence is a little faster than deposition. Regressive cycles are nevertheless present, as shown in the Pizzo Ceresa section, just 7 m below the top of the formation.

3.2 The condensed ammonite-rich surfaces

In the Pizzo Ceresa and M. Arena sections, above the peritidal complex, there follows bioturbated biomicrites (Pcr21, Pz00, Pz0 levels) with vertical burrows. Three biomicrudite layers are interbedded, the youngest of which is fossiliferous, with ammonites in a condensed horizon. Ammonites belonging to the *johnstoni* Zone (Lower Hettangian, higher part; ELMI & MOUTERDE 1965, ELMI et al. 1971) and the *rotiforme* Zone (Early Sinemurian) are here found together. The biostratinomic features have already been discussed in CANTALUPPI & LUALDI (1983).

In short, two discontinuity surfaces (a, b, Fig. 2) have been identified (see also Fig. 6B); the more important of these (b) contains *Caloceras johnstoni* (SOW.) and *Caloceras torus* (D'ORB.) badly fossilized, only the *lower part of the shell being preserved.* Less frequently only the imprint is preserved, marked on the underlying layer. This fauna indicates the upper part of the Lower Hettangian (*johnstoni* Zone).

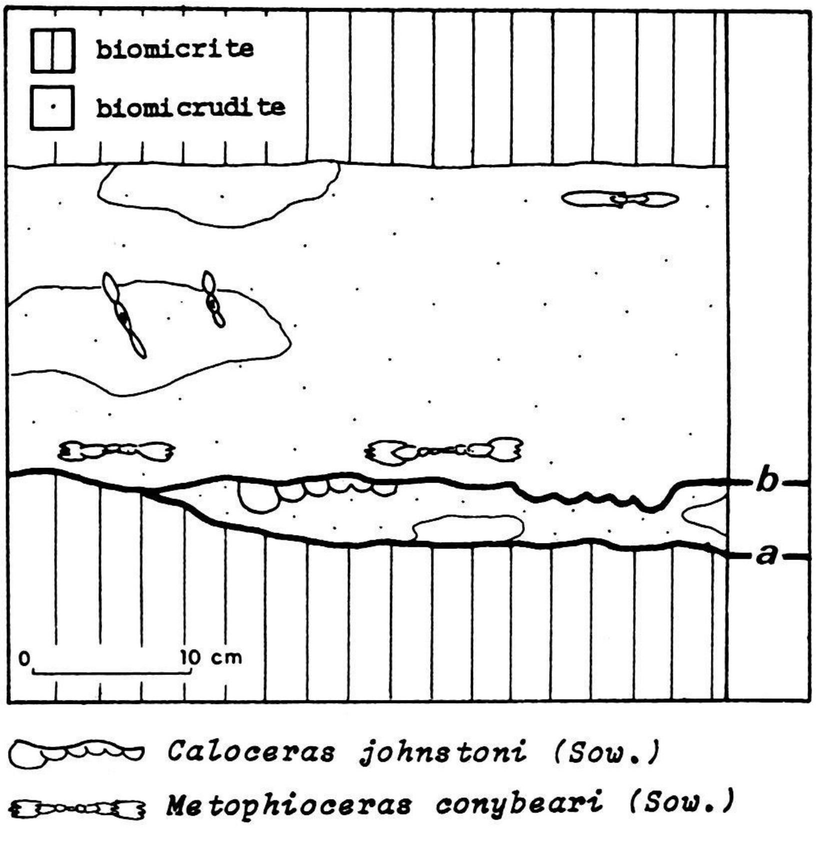


Fig. 2. Two discontinuity planes (a, b) separate badly-preserved Lower Hettangian ammonites (*Caloceras johnstoni* (SOW.), *C. torus* (D'ORB.)) from well-preserved Lower Sinemurian ones (*Metophioceras conybeari* (SOW.)). A Middle–Upper Hettangian fauna (*Schloteimiidae*) is reworked. Pizzo Ceresa outcrop. (After CANTALUPPI & LUALDI 1983, modified.)

Immediately above this surface *Metophioceras conybeari* (Sow.) is found in good preservation. This species characterizes the Lower Sinemurian (*rotiforme* Zone).

In the middle of the bed are found (badly preserved and evidently reworked) *Waehneroceras* sp. and *Charmasseiceras* sp. or *Boucalticeras* sp., indicating a Middle–Upper Hettangian age. Elsewhere bivalves (*Chlamys* cf. *valoniensis* (DEFR.), *Plagiostoma* sp., *Plicatulidae)*, gastropods (*Promathilda* ex. gr. *sinemuriensis* MAR.) and small underterminable ammonites are present.

Discussion. All the above-mentioned features indicate a shallow water but pelagic deposition without emersion, with biochemical sedimentation and lag deposits (PzA level with limonitic staining) interbedded with bioclastic layers. The micritic matrix indicates an extremely moderate energy, at least till its complete lithification.

The sedimentological and faunal evidences suggest a seamount or an offshore shelf as depositional environment, sometimes with high energy condition, being able to erode the ammonites and to rework the sediment with its fauna. It's worth recording the scarcity of terrigenous detritus, the wide Fe-oxide stainings and the considerable sedimentary gap.

3.3 The hardground layers

Few meters above the ammonite-rich surface (max. 3 m at Pizzo Ceresa), just beneath the biocalcarenite layers (Le1–6, Ar3–4, Pz1–2 levels) lies a bored surface that marks the beginning of another condensed sequence. Two main breaks in the sedimentary sequence are recognizable: an *initial* one and a *terminal* one.

The first (Le1, Ar3, Pz1 levels) is formed by a boring surface (Fig. 3) on a muddy sediment with Fe-oxide concentrically laminated nodules. Horizontal bioturbation is moderately developed.

The second (Le4 level) rests between a calcarenite and a micrite layers and has sparse borings and mineralized pebbles from intraformational origin.

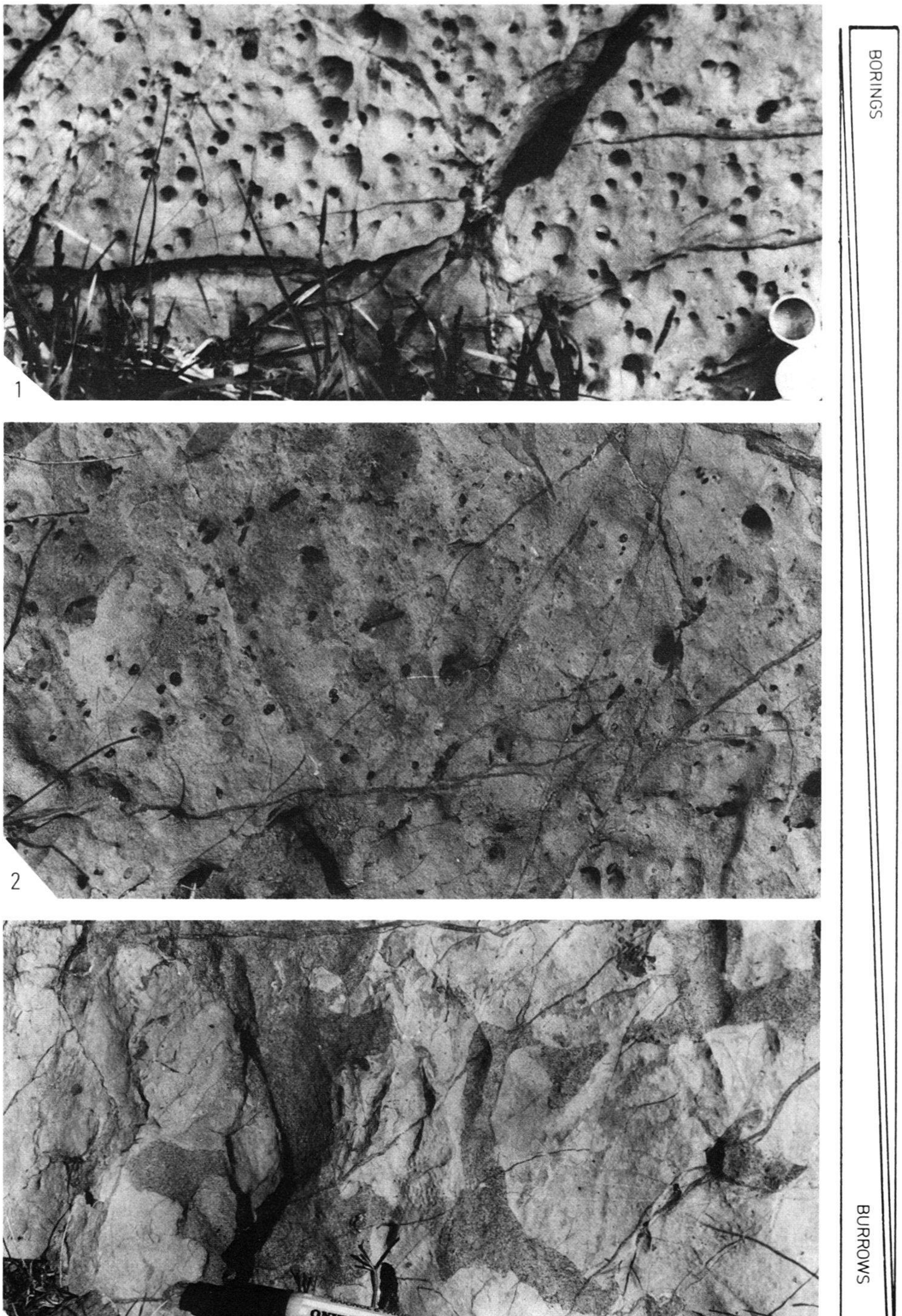
These omission surfaces are true *hardgrounds* (sensu BROMLEY 1975) in that they indicate synsedimentary lithified seafloor (as opposed to rock grounds). The intraformational pebbles of the second hardground may be also compared with the *hiatus concretions* (sensu VOIGT 1968).

In this paragraph, the single horizons are described and briefly discussed with reference to their composition, morphologic characters and genetic significance. *Symbols are referred to Figure 1.*

From bottom to top:

Le1, Ar3, Pz1 levels (Fig. 1, 3, 4, 6C, 7): Lithologically these levels consist of bio- and pelmicrites with gastropods, echinoderms and forams. They show a very irregular surface, sometimes densely bored (up to 1–1.5/cm^2) with small neptunian dykes cutting through *Spongeliomorpha* cavities. They can reach from the lower surface down to 40 cm.

Fig. 3. Morphological changes on the initial hardground surface (Pz1 level). 1: heavily pitted surface, mostly by *Lithophaga* and *Trypanites*. Lens is 17 mm in diameter. 2: less heavily pitted surface with P_2O_5-infilled holes and *Spongeliomorpha paradoxica* burrows. 3: *Spongeliomorpha paradoxica* burrows filled by bioclastic calcarenite. Note the absence of borings on the whole surface. Felt pen is 10 cm long. From point 1 to point 3 there is a 100-m distance.


1
2
3
ONYX MARKER
BORINGS
BURROWS

Fe-oxide nodules and mineral staining are present. In the surface layer the distribution of boring is not regular: intensely bored areas (usually without *Spongeliomorpha* burrows) are flanked by others completely uncolonized, marked by a strong activity of suspension-feeding organism. There is a considerable variability in boring size: they are from 1 to 5 mm in diameter and from 0.2 to 4 cm long.

At present borings are often entirely or partly filled by phosphatic mineralization, standing out against the rocky matrix.

Three kinds of borings are recognizable here, divided on size and morphology:

a) *cylindrical-shaped* borings, with circular or slightly elliptical section, from 3 to 5 mm in diameter, 1–4 cm long, sometimes curvilinear and with decreasing diameter going to the extremities. Some specimens are concentrically filled by micrite alternating with mineralized envelopes; the coated sectors start form the external part and go toward the middle of the cavity (cf. KRAJEWSKI 1984);

b) *clavate* borings with flask-shaped or conical cavities, circular cross section, 1 mm in diameter, 2–3 mm long, rectilinear, without branches;

c) ∞-*shaped* borings, max. diameter about 3–5 mm, some centimeters long.

The genera *Trypanites* MÄGDEFRAU (a) and *Gastrochaenolites* LEYMERIE (b, c) are recognizable. The flask-shaped *Gastrochaenolites lapidicus* KELLY & BROMLEY 1984 (Fig. 3A, 4A–B of their work), the conical *G. turbinatus* KELLY & BROMLEY (op.cit., Fig. 3G, 8C), *G. dijugus* KELLY & BROMLEY with flattened U-shaped chamber and figure-of-eight entrance (Fig. 3C, 6A–B) and *Trypanites weisei* MÄGDEFRAU may be differentiated.

Larger borings, probably made by a bivalve (*Lithophaga*) are present too; they are up to 10 mm in diameter and 20 mm long. No traces of the shells were found in situ inside the cavities.

Careful examination of bedding planes in the Pizzo Ceresa outcrop has revealed borings penetrating upwards into the base of overlying beds (*inverted boring* surface). The borings are the cylindrical-shaped and the U-shaped types described above.

On the surface layer small dykes and sills with a calcarenite infill are present. The size of the dykes ranges from 2 to 10 cm wide and from 5 to 40 cm deep. Frequently the infilling sediment reaches the underlying surface without cutting it. Dykes have an irregular shape, often crossing themselves, and anastomosing. Sometimes their vertical section is coarsely U-shaped; in this case the dike remodels the cavity of the burrows (*Spongeliomorpha, Thalassinoides*). In the sedimentary fill echinoderm debris and brachiopods (*Lobothyris* cf. *ovaetissimaeformis* (BÖCKH.) and *Calcirhynchia* cf. *rectemarginata* (VECCHIA)) are present in a microsparitic matrix or in a sparry cement.

Discussion. Zones of early lithification from soft- to firmground may be differentiated; local difference in substrate lithology (e.g. clay contents, ZANKL 1969), long time grain-to-grain contact, presence of low rounded mounds, often heavily bored, as a result of volume increase owing to growth of early cement (SHINN 1969, PALMER & PALMER 1977) may have produced "islands" on which a good variety of organism could colonize. The frequency of inverted borings is conditioned by the bottom morphology; they were probably associated with local excavations (burrows made mostly by crustacean and fishes) creating small caverns beneath rock layers that, post-lithification, were inhabited by boring organism (SHINN 1969, FÜRSICH & PALMER 1975). Both borings and the uniform grain truncation (bioclasts, coated grains, etc.) show early lithification as does the absence (in fine-grained sediments) of deformed crypts, indicating a pre-existent cementation (cf. GOLDRING & KAZMIERCZAK 1974). The passage from the soft- to the hardground stage could have been developed at different times from point to point, depending on the local sediment composition, the organic matter, water depth and energy, etc. (see PURSER 1975, BAIRD & FÜRSICH 1975, SHINN et al. 1977).

Borings represent the last colonization phase of the sediment/water interface when lithification was complete. Exactly what was the *pre-lithification* biocoenosis is problematic. The following paleoecological conditions are recognizable: above a gradual hardening softground lived a well-developed microfauna (*Involutina liassica* (JONES), *Frondicularia, Ammodiscus,* Ostracods). Their good variety and normal individual size indicates a favourable biotope. Peloids are present too, mostly faecal pellets and coprolites (*Favreina*) with good sorting. The macrofauna, only gastropods and echinoderms, shows normal environmental conditions, with individual size above normal (gastropods). Colonization by deposit-feeders is also quite well developed.

Where the lithified crust was relatively thin and underlain by only weakly cemented sediment, mechanical erosion has frequently enlarged the burrows to form cavities and dykes. No lamination or graded scallop-like arrangements (indicating an injective phase, CASTELLARIN 1966 and references therein) or lithoclasts are present. The absence of these features could exclude stages of forced injection and suggests the fill as due to the gravity and water transport.

In the gap between two or more erosive phases, substrate colonization is often developed, mostly by borers. The main reason for the lack of a rich encrusting fauna and flora (algae, forams, serpulids, microproblematica, etc.) may be a *high degree of abrasion* of the surface by sediment particles moving across it, at least just before burial of the hardground. In this way, an earlier stage of colonization by encrusters could have been removed.

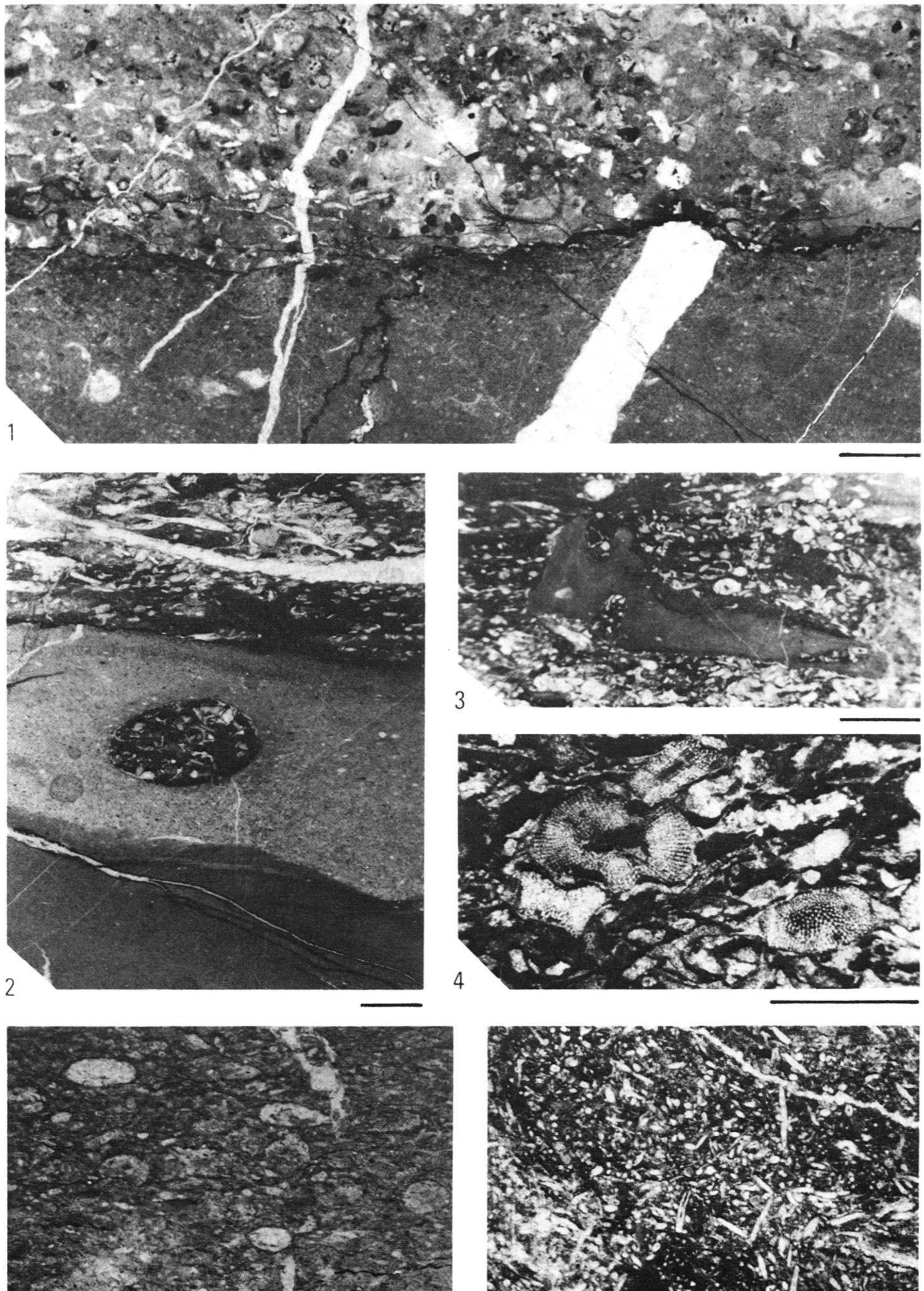
Le2–3, Ar4, Pz2 levels (Fig. 1, 4): these layers represent the *renewal of deposition;* intraclastic biomicrites, crinoidal biocalcarenites, oomicrites and spongolites are alternately present. Sorting is always high, showing a good selective power. High-energy deposits with an allochthonous fauna (broken and rolled columnals, fragmented spicules, etc.) are interbedded with low-energy deposits with pelagic bivalves, forams and echinoidal micrites. It is worth recording the preferred orientation of allochems (silica-filled oolite molds) shows in Le2 level, immediately lying on the bored surface.

Discussion. Every "oolitic" facies found in a pelagic environment should be properly described. Recent works on micrite "oolitic/micro-oncolitic" facies in open marine sediments, in fact, have shown how quite common and indicative they are, not only for the sedimentological but also for the paleogeographic significance (e.g. JENKYNS 1972, MASSARI 1979, 1983). Unfortunately the examined microfacies shows only molds of the original ooids or microoncoids, now completely filled by secondary silica. No thin cortical envelops or tangential structures may be found, except an heavy micritic (or micritized?) halo. Grains in origin were between 0.2 and 0.4 mm in diameter but now they appear strongly flattened in one direction. According to SARKAR et al. (1980), similarly oriented deformations of allochems may serve as signals for the presence of hardgrounds and emersion surfaces with early lithification. Overburden stresses, in fact, in the presence of a rigid substrate may be locally amplified until they exceed th elimit required to cause deformation of allochems earlier than usually possible. By this way the degree of deformation decreases upward. Even at the microscale, in the examined series such a graduality is unfortunately not evident, only the allochems of the lower layer being flattened. On the other hand, the experiments on compaction of ooids and lime mud made by BHATTACHARYYA & FRIEDMAN (1979) show the importance of lime mud-content in deforming allochems. The linear relationship between increasing proportion of mud content and proportion of undeformed ooids is in that paper demonstrated. In the Le2 micrite level with 7.5% of ooids, deformation due to overburden stress on rigid surface could be too high to justify itself. BHATTACHARYYA & FRIEDMAN (op.cit.) show in fact in a grain breakage log that in a mud-supported fabric (ooid:mud = 25:75) 88.5% of the ooids is undeformed, 6.4% is split and 5.1% have diagonal fractures. Hence the cause of the Le2-level ooid deformation is not clearly identifiable, above all in a relatively strong tectonized area.

Le4 level (Fig. 1, 4, 5, 6D, 7): In the M. Nero outcrop this level corresponds to a sparsely bored concretions horizon. These concretions occur about 40 cm over the bored surface of the Le1 level. Lithologically, the concretions are small flat-pebbles of brown color usually 2–6 cm in diameter and consist of micrite. The perimeter of such concretions is heavily covered by a mineralized crust with concentric fabric. A mixed fauna with Rhaetian (*Triasina hantkeni* MAJZ., *Trochammina almtalensis* KOEHN-ZANINETTI) and Liassic (*Involutina liassica* (JONES)) forams has been found in perfect preservation within the oxide crust. Encrusting forams, mostly *Planiinvoluta carinata* LEISCHNER, are present too. On the lamina where the concretions lie, sparse small borings occur together with limonitic staining. Sometimes (as showed in Fig. 5C) a subsequent mineralization links up the pebbles together or covers the sediment particles (mostly bioclasts). Thanatocoenosis is completed mostly by echinoid debris and subordinately by crinoids and gastropods. In addition, both the upper and the lower surfaces of the concretions are bored, indicating rolling and overturning on the seafloor before complete burial.

Discussion. There is not a complete relationship between these pebbles and the early diagenetic nodules defined as "hiatus concretions" by VOIGT (1968) and later described by several authors (HALLAM 1969, KENNEDY & KLINGER 1972, KAZMIERCZAK 1974, GOLDRING & KAZMIERCZAK 1974, KENNEDY & GARRISON 1975b, BAIRD & FÜRSICH 1975, BAIRD 1976, FÜRSICH 1979). This term was introducted for concretions which underwent exhumation and colonization before renewed burial. Almost all the AA. agree with a synsedimentary genesis of these nodules though different conditions were described for their early sedimentary history. HALLAM (1969) and KENNEDY & KLINGER (1972) hypothesized an early diagenetic event occurring a little distance below the sediment/water interface; then, after erosion of the unconsolidated sediment and exhumation on seafloor

Fig. 4. 1: biocalcarenite infilling in a *Spongeliomorpha* burrow. The rim of the micritic substrate is covered by Fe–Mn oxides. On the right the early thick calcite vein is truncated by the infill of the burrow. A second calcite generation is weakly dislocated by differential compaction. Pz1. 2: boring section in a micrite/biocalcarenite alternance. The hole is filled, as the biocalcarenite layer, by Fe-oxides and phosphates. Le4. 3: micrite intraclast with normal and inverted borings. Le4. 4: echinoid spine and plates in the biocalcarenite bed. Le4. 5: allochems-deformed micrite with oolite molds (silica-filled). Le2. 6: sponge spicule wackestone. Belemnite rostra (not in fig.) are associated. Mo44. Scale bars 1 mm.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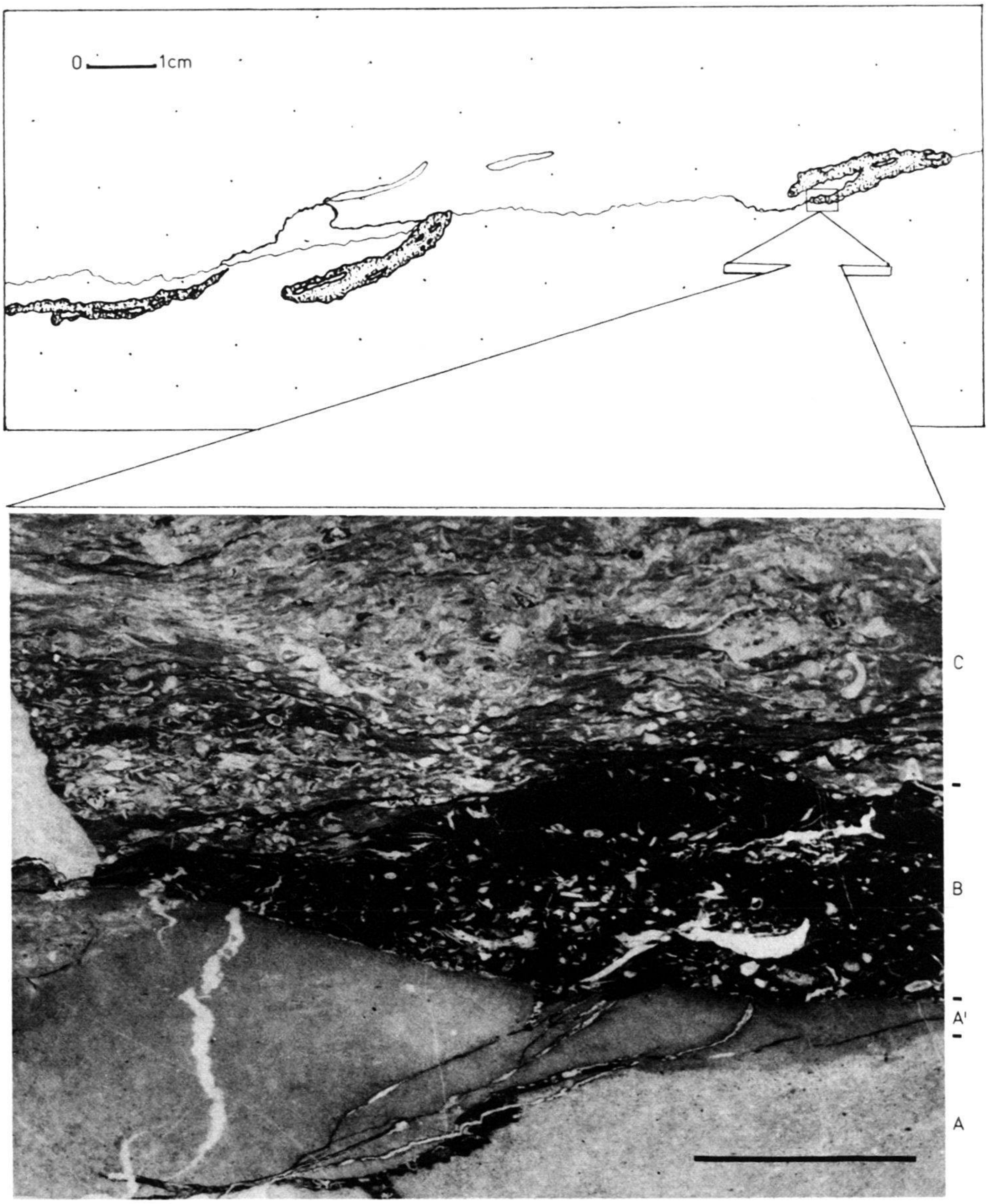


Fig. 5. Terminal hardground (Le4 level) drawn from a weathered surface. A: coarse biomicrite with echinoidal debris; A′: micrite; B: Fe-oxide concretion encrusting a mixed fauna; C: biocalcarenite with thin Fe-impregnated films. Scale is 1.5 mm.

of the concretions, they were bored, encrusted, winnowed and reburied again. FÜRSICH (1979, "Genetic Sequence VI") proposed close relationship between burrows (mostly made by crustaceans) and nodule formation, the latter being placed at the bottom of *Spongeliomorpha* bioturbation. The here examined concretions differ from the above mentioned ones in diameter (average 3 cm vs 20–40 cm), degree of mineralization (much stronger) and depositional history. Pebbles must in fact have been exposed for a long time on the seafloor: substrate colonization, indeed, occurs before the complete burial of the pebbles (Fig. 7, point 4). In addition, extensive mineralization links the concretions with the substrate, still encrusted by living organisms (mostly forams). Besides pebbles seem to be formed during an early precompaction phase, as the organisms are seldom crushed. Their genesis and depositional history may be explained through the "Genetic Sequence IV" ("Reworked shallow marine hardgrounds", FÜRSICH 1979). During the change from soft- to hardground (see Fig. 7, right part, points 1–3) the open burrow system in the firmground stage (point 2) shows early lithification. The exposed hard surfaces are closely space, colonized by borers and weakly by encrusters (point 3). This irregular surface is broken up and the hardground has been reworked into pebbles (point 4). After a transport the pebbles are sometimes entirely colonized and finally buried in a high-and-low energy environment (point 5). Subsequent mineralization occurs after the burial of the pebbles.

High-energy deposits are thus interbedded with low-energy ones. Omission periods occur, favouring synsedimentary lithification processes and the formation of iron-manganese crusts on the water/sediment interface (cf. "temporary solution hard bottoms", FABRICIUS 1968) or within the uppermost layers.

The overlying beds (*Le5–6 levels,* Fig. 1, 6E, 7) consist of the same lithological alternation, the molluscan biomicrites becoming more frequent. In Le6 level *Involutina liassica* (JONES), *Ophthalmidium triadicum* (KRISTAN) are also present. Toward the top, sponge spicules increase, indicating a progressive deepening of the environment. Vertical transition with spongolites is very rapid, showing in a short time open-marine condition (Mo 43–45, Ar5, Pch24–25 levels). Together with porifera, crinoids and belemnites (*Nannobelus* sp.) are present.

4. Sequence of events

The depositional history of the soft-hardground substrate, as shown especially in the M. Nero outcrop, shows a good affinity with the Genetic Sequence I ("Fully marine hardgrounds generally formed in shoal environments") of FÜRSICH (1979). Outlining its most important points it can be synthetized as follow (see Fig. 7):

0. A strong bioerosive activity dominated by suspension-feeders (*Spongeliomorpha paradoxica, S. suevica = Thalassinoides*) develops at the firmground stage (and partially softground, after a weak bioturbation made by deposit feeders).
1. On a progressively hardening sustrate, a first hard surface suspension feeders colonization establishes *(Trypanites, Gastrochaenolites, Lithophaga)* with normal and locally inverted borings. Lithification goes on (allochems are fractured by borings). Omission phase. Erosive activity, in a following time, increases and remodels the bioturbation of the deposit feeders filling the cavities with crinoidal biocalcarenites and brachiopods (cf. PURSER 1969, FÜRSICH 1971, BAIRD & FÜRSICH 1975). *"Initial hardground".*
2. Omission carries on; genesis of the Fe-oxide nodules and stainings and boring filling – totally or in part – by phosphate. Such a different composition may occur during a subsequent mineralization time.

3. Renewal of deposition with crinoidal biocalcarenites interbedded with oomicrites. Allochems show an iso-oriented deformation probably due to plastic stresses (see SARKAR et al. 1980).
4. Deposition becomes episodic; stages with transport (from contiguous area, "Genetic Sequence IV") and deposition of externally mineralized flat pebbles plus substrate bored fragments alternate with omission stages. Second hard surface suspension feeders colonization and second mineralization (in situ) (cf. "temporary solution hard bottoms" FABRICIUS 1968). "*Terminal hardground.*"
5. Higher environmental energy: crinoidal biosparites with mollusca debris and abundant microfauna are present.
6. By metric, transitional boundary, sponge spicule mudstone appears, corresponding to a deeper low-energy environment. Silica is very abundant.

Features of pelagic but shallow water environment in the lower part of the condensed cycle (ammonitic surface) and the evidence of early lithification with boring surface in the upper one therefore show the persistence, until the Early Sinemurian, of shallow-water offshore areas and raised sectors.

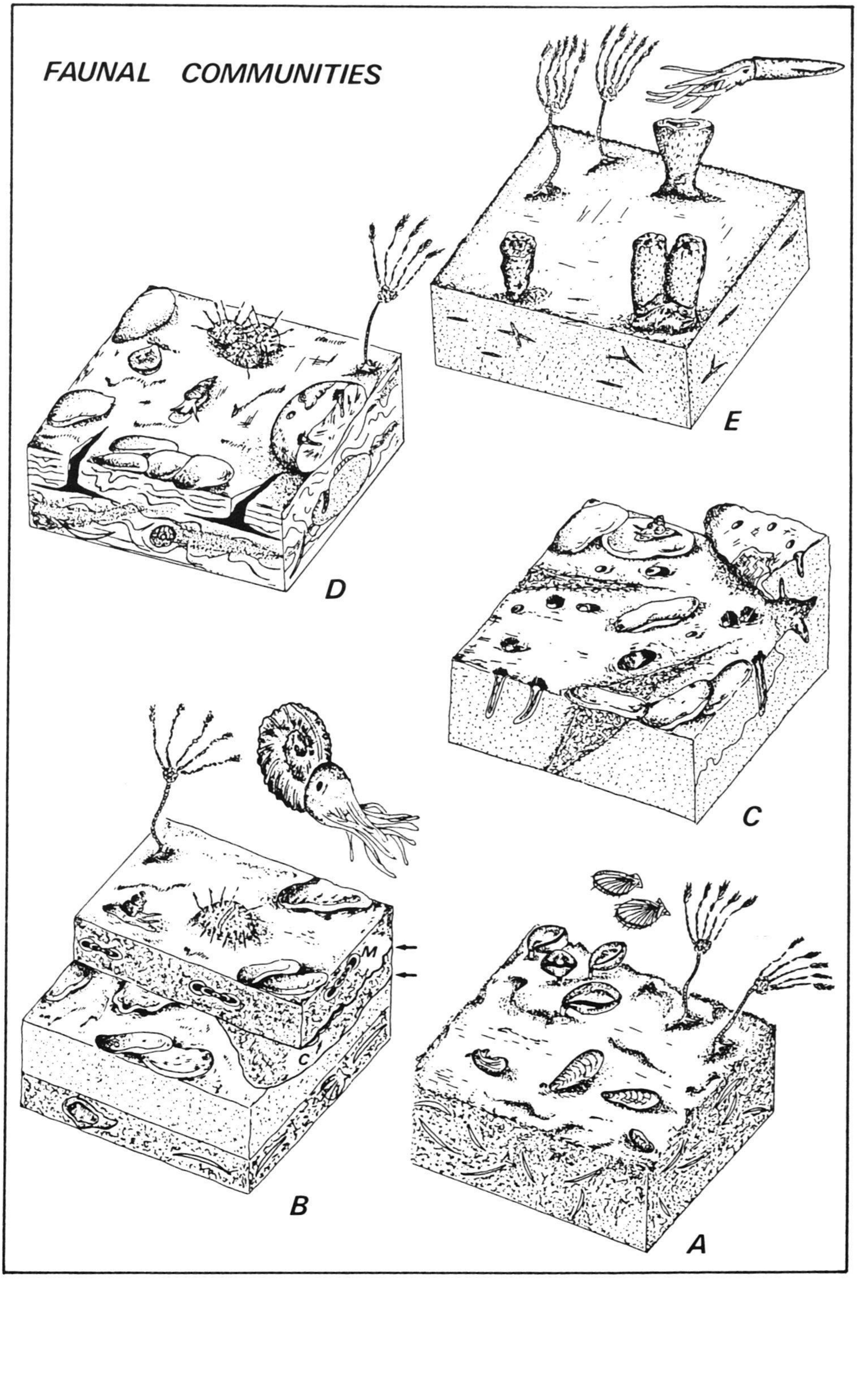
5. Evidences for distensional events in the Upper Triassic and Lower Lias

Some indications for synsedimentary tectonic events are found in the Arnasco–Castelbianco unit since the Norian–Rhaetian boundary. Three main stages of tectonic activity may be identified: a) at the Norian–Rhaetian boundary; b) during the Late Rhaetian; c) in the Lower Lias (Hettangian and Early Sinemurian).

a) An unconformity between the Dolomie di M. Arena and the Calcari di Veravo is marked by a 5° to 7° angular unconformity (Pizzo Ceresa) indicating slightly but early crustal movements. At M. Castellermo (west of the M. Nero section) a dolomite breccia (floatstone) is interbedded between dolomites and limestones (2 m thick) about 10° in discordance (ROYANT & LANTEAUME 1973, LUALDI 1983).

b) At Pizzo Ceresa and less frequently in the M. Nero sections, small clastic dykes (max. 20 cm depth) cut the supra-intertidal units in the upper part of the Rhaetian sequence. Sometimes even the subtidal unit is affected. It seems more likely that they derive from a tensional effect – during an advanced lithification phase (angular clasts are present) – rather than they be the infill of sun cracks that do are present in other emersion surfaces of the same sequence.

Fig. 6. Reconstruction of five faunal communities through times (Rhaetian–Sinemurian). A: *peritidal substrate community* (Veravo limestone). Interbedded argillitic layers within microsparitic ones contain *Rhaetavicula contorta* and *Atreta intusstriata*. The whole assemblage is formed by brachiopods *(Rhaethina gregaria)*, bivalves *(Modiolus, Cardita munita, C. cloacina, Chlamys)* and crinoids *(Isocrinus)*. B: *condensed ammonite community*. Note the two discontinuity surfaces (arrows) separating badly-preserved Lower Hettangian *Caloceras* (C) from well-preserved Lower Sinemurian *Metophioceras conybeari* (M). C: *initial hardground community* and sedimentary features (Le1, Pz1, Ar3). Note the normal and inverted borings, the bioerosive dikes and the Fe-oxide mineralization. D: *terminal hardground community* (Le4). Mineralized pebbles (bored and forams encrusted) lie on a micrite/calcarenite alternance. Echinoids, *Isocrinus* and small *Promathilda sinemuriensis* are present. E: *siliceous sponges community*. Silica-rich muddy floor is colonized by porifera, crinoids and *Nannobelus* sp. Diagrams are inspired by MCKERROW (1978).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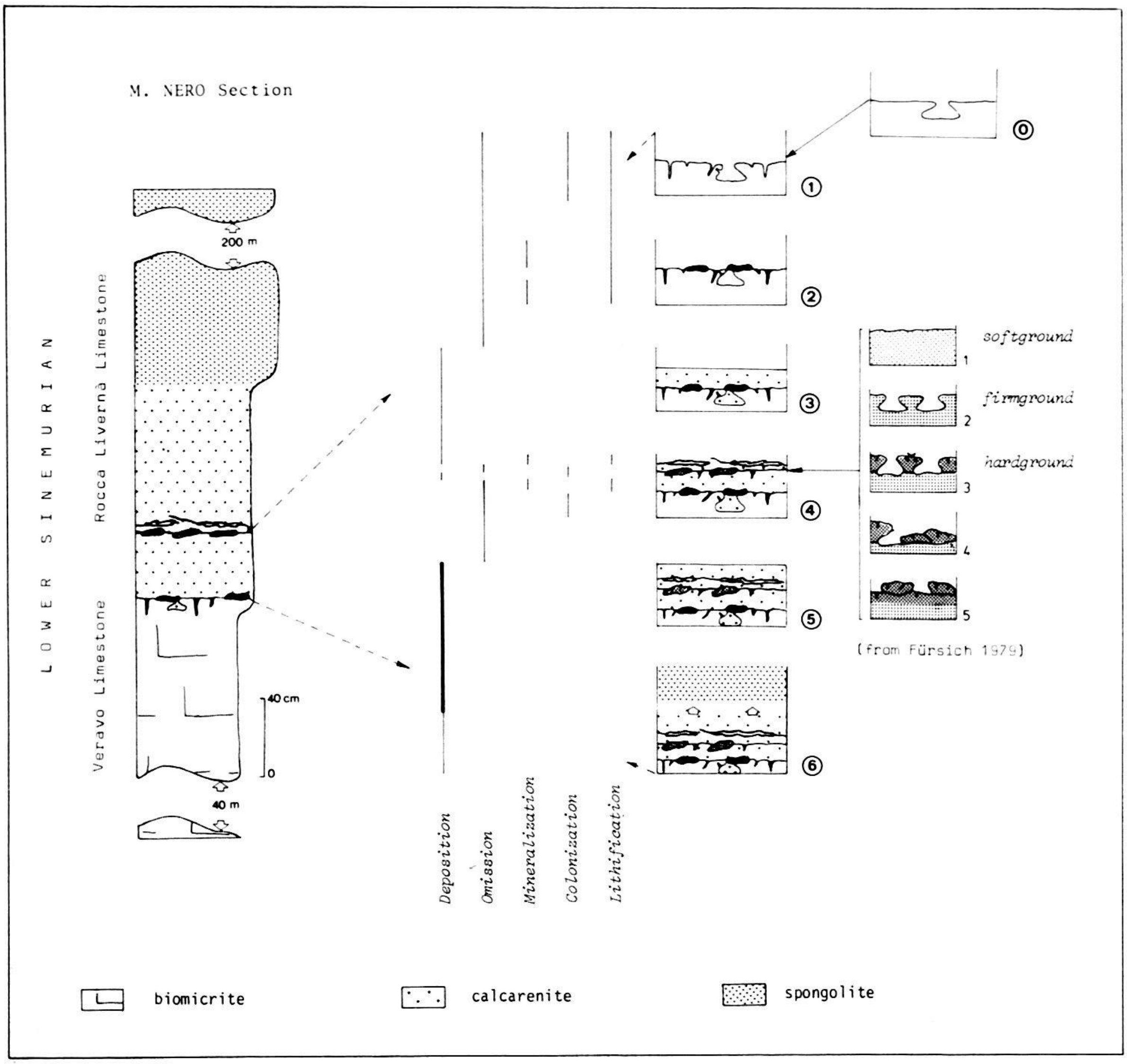

Fig. 7. Flow diagram of the sequence of events at the Veravo Formation–Rocca Livernà Formation boundary. For explanation see text.

c) At Pizzo Ceresa two synsedimentary normal faults with a 2 meters offset sever the beds at the top of the Veravo limestones, being the spongolitic mudstones of the Calcari di Rocca Livernà unaffected.

A strong erosion cutting part or the whole Rhaetian sequence is proved in some place where the Liassic spongolitic mudstones directly overlie the Norian peritidal dolostones.

In the Arnasco–Castelbianco unit there is no evidence for a clastic deposition interfingered with these syntectonized layers, but it is worth recording that this unit is completely allochthonous and the original connection with the neighbouring units is unknown. Better field analysis in the inner part of the Prepiemontese domain and in the Piemontese s.s. one (M. Sotta unit, and partly M. Gazzo–Isoverde unit) could find crucial evidence in this connection.

The distensional tectonic activity is thus recorded, in this sector of the continental margin, from Late Norian where small-scale movements produced block tilting connected with a local Norian rifting recently known also for the Southern Calcareous Alps

(JADOUL 1984, LUALDI & TANNOIA 1985 and references therein). Pre-rifting mechanism seems to be dominant during Rhaetian. Rifting effects are for the most part manifested during Hettangian age where large crustal blocks tilted, parted from the original platform in progressive subsidence, and with fault-system control, produced uplifted sectors. A tectonic stasis established during Sinemurian, when an open-marine siliceous limestone deposition is linked to rapid basin subsidence.

6. Paleogeographic setting

As indicated, the hardgrounds and the discontinuity surfaces are peculiar to the Arnasco–Castelbianco tectonic unit (*Prepiemontese ligure* domain). In this unit the hardground spread out in all the sequences where the boundary between the Calcari di Veravo and the Calcari di Rocca Livernà Formations is exposed. On a 5–7 km distance the hardground features are quite similar. Apart from various substrate colonizations, owing to differential early lithification areas, even in a single outcrop lateral changes are not visible (for hundreds of meters, i.e. at Pizzo Ceresa). No hardground has on the contrary been found until now in other Prepiemontese units (as C. Tuberto unit) that still have Triassic and Liassic sequences. However, in the M. Sotta unit (inner side of the *Piemontese* s.l. domain) thin limonite films are present in the *Calcari di M. Sotta* ("Membro dei Calcari a lumachelle", Rhaetian–Lower Lias, OXILIA 1978). In the best developed *Ligurian Briançonnais* tectonic units (like the Ormea unit, external part of this domain) a generalized emersion, joined with a subsidence standstill, takes place from Ladinian–Carnian(?) age to Aalenian. Only locally did the Rhaetian transgression occur (VANOSSI & GOSSO 1983). Triassic deposits were largely removed during the emersion and chemical degradation, with red chloritoide metapelites ("Siderolitico" *auct.*) was quite widespread. Sedimentary dykes and karst-cavities infilling imposed on the Middle Triassic carbonate deposits feature the top of the Ladinian beds. Such a subaereal weathering, probably connected with an increasing uplift of the "Briançonnais high" towards the European continental margin (VANOSSI & GOSSO 1983, CORTESOGNO & VANOSSI 1985) could represent during Lower Lias a synchronous event of the sedimentary stasis of the Prepiemontese units (Middle Hettangian–Early Sinemurian) just before the platforms drowning. At the Upper Triassic–Sinemurian boundary (during which a Jurassic "rifting phase" leading to a "pre-oceanic rifting phase" is recognizable) the paleogeographic arrangement is therefore as follows (for details see VANOSSI 1980, VANOSSI & GOSSO 1983, VANOSSI et al. 1984):

- The "Briançonnais ligure high" is emerged – except by local transgression – in the Middle Triassic and its carbonate platform begins to be eroded away.
- The nearest of the Prepiemontese units – such as C. Tuberto – interposed between the Briançonnais ligure and the oceanic-crust-bearing Piemontese s.s. domains shows thin calcareous deposits (sometimes nodular) probably related to submarine rises rimming the Briançonnais margin. No hardground has been found till now.
- The Arnasco–Castelbianco unit – more internal than C. Tuberto – becomes a drowned area within which several uplifted blocks are isolated.

Good conditions for the hardground formation coexist with little or no deposition. The Early Jurassic pre-rifting phase in the inner Prepiemontese units is therefore represented by a sedimentary crisis beginning in the Early Hettangian. The episodic deposition continued till the Lower Sinemurian.

Other inner Piemontese units, like the "Montenotte Trias–Lias *auct.*" and the M. Gazzo–Isoverde seem to have drowned during the Late Rhaetian or the Early Hettangian. On the contrary the general deepening of the Arnasco–Castelbianco unit began during the Lower Sinemurian (*bucklandi* Zone).

7. Conclusion

The Arnasco–Castelbianco unit, in the Prepiemontese domain, played an important role during Rhaetian through Sinemurian time. The peritidal platform of the Upper Triassic passed to the open-marine spongolitic Sinemurian limestones through condensed ammonite-rich surfaces, early lithification beds with borings, hardgrounds with iron-manganese crusts, indicating particular depositional condition with slow or no sedimentation during the Lower Lias.

A detailed field investigation enables a sequence of events to be outlined, and to describe the depositional history of these interbedded layers, where the sharp transition between the last shallow-water pre-rifting deposits and the beginning of the Ligurian Tethys is recorded.

Synsedimentary evidences of distensional events – such as angular unconformities, small clastic dykes, erosional surfaces – mark *since the Norian,* but more considerably *during the Rhaetian,* moderate crustal stretching just before the Liassic rifting phase. *During the Hettangian* (probably Medium and Upper, according to the ammonite fauna) part of the platform foundered and tilted. A fault control kept some blocks uplifted from the drowning European margin and the Arnasco–Castelbianco unit hardgrounds lay on the top of them.

No important tectonic events characterized the Sinemurian hemipelagites. A fast subsidence allowed deposition of more than 200 m of cherty limestones in a monotonous sequence.

Other Prepiemontese units – more external than the Arnasco–Castelbianco one – rimming the Briançonnais microcontinent (emerged and progressively eroded away) showed little sedimentation from Norian to Lias, therefore featuring in part the sedimentary crisis of the Upper Triassic–Lower Liassic boundary.

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