

BURROW DECREASING-UPWARD PARASEQUENCE (BDUP): A CASE STUDY FROM THE LOWER JURASSIC OF THE TRENTO CARBONATE PLATFORM (SOUTHERN ALPS), ITALY

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Abstract. A study of the Trento carbonate platform (Southern Alps, Italy) identified a different type of parasequence named “burrow decreasing-upward parasequence” (BDUP). This important type of bioturbated shallowing-upward sequence, 2.3-2.9 m thick, developed in a warm lagoonal environment and characterizes the Pliensbachian interval of the Calcarei Grigi Formation. The study of surficial bioturbation and three-dimensional, Y-shaped deep burrows in the BDUP (produced mainly by crustacean decapods) defined taphonomical characteristics and resulted in the identification of four types of *Thalassinoides suevicus* (Types I, II, III, IV). A detailed analysis of the burrows focused on the enlargement at the bifurcation point, on the development of the vertical burrow and on the coarse-grained skeletal debris infilling of the burrows. Surficial bioturbation affected only the first centimeters of the substrates and did not produce preservable trace fossils; it is recognizable by the taphonomic dislocation of shell beds and reorientation of skeletal remains. Bioturbation-burrowing analysis resulted in the identification of 19 “burrow decreasing-upward” parasequences (BDUP). They are ichnologically, taphonomically and sedimentologically well characterized, and represent a useful type for sequence stratigraphy in a carbonate platform environment dominated by biogenic activity.

Riassunto. L'analisi della piattaforma carbonatica di Trento (Alpi Meridionali) ha permesso di individuare un nuovo tipo di parasequenza qui denominata “burrow-decreasing upward parasequence” (BDUP). Questo tipo di sequenza “shallowing upward”, estremamente bioturbato e spesso in genere 2,3-2,9 m, si è sviluppato durante il Giurassico inferiore in ambiente lagunare subtidale e caratterizza l'intervallo Pliensbachiano della Formazione dei Calcarei Grigi. La bioturbazione superficiale ed i burrows profondi (a forma di Y e con reticoli sviluppati in tre dimensioni prodotti in gran parte da crostacei decapodi) sono abbondanti nella porzione inferiore della BDUP e sono stati studiati definendone le caratteristiche tafonomiche salienti. Lo studio ha permesso di individuare quattro tipi di *Thalassinoides suevicus* (tipi I, II, III, IV). L'analisi di questi burrows è stata condotta osservando l'allargamento al punto di biforcazione delle ramificazioni della traccia, lo sviluppo di tunnel verticali ed il riempimento bioclastico a granulometria grossolana talvolta presente nelle tracce. La bioturbazione superficiale, diversamente da quella profonda, coinvolge solo i primi centimetri di substrato, non producendo tracce fossili preservabili, ma è riconoscibile per la

dislocazione di letti conchigliari e la riorientazione di resti scheletrici. L'analisi della bioturbazione ha permesso di individuare 19 parasequenze “burrow-decreasing upward”; la BDUP è quindi ben caratterizzabile dal punto di vista icnologico, tafonomico e sedimentologico e rappresenta un utile strumento nello studio di ambienti di piattaforma carbonatica dominata da attività biologica e pertanto può essere considerata una nuova metodologia di supporto alla stratigrafia sequenziale.

Introduction and study area

This study is part of a more complex taphonomical and ichnological analysis of the Sinemurian - Pliensbachian interval of the Calcarei Grigi Formation (for biostratigraphy see Bassi et al. 1999; Fugagnoli & Loriga Broglio 1996), carried out to review previous sequence stratigraphy and paleoenvironmental models (Monaco 1999; 2000a, b; Monaco & Giannetti 2001, 2002; Masetti et al. 1998).

The Jurassic shallow-water carbonate platform system of the Calcarei Grigi Formation in the Trento Platform (Western Venetian Pre-Alps) is well-known, and the sedimentological, paleontological and stratigraphical characteristics of all its four members (Lower, Middle, Upper, or Rotzo, and the Massone Oolite) have been studied in detail (for extensive discussion on geological settings, sedimentary stratigraphy, paleontology, taphonomic stratigraphy and paleoenvironmental models, see Bosellini & Broglio Loriga 1971; Clari 1975; Broglio Loriga & Neri 1976; Beccarelli Bauck 1988; Fugagnoli & Loriga Broglio 1996; Masetti et al. 1998, Monaco & Giannetti 2001, 2002 and references therein). All sections studied in this paper belong to the fossiliferous Rotzo Member, the only member that shows regular networks of decapod crustaceans, developed in a quite complex lagoonal system.

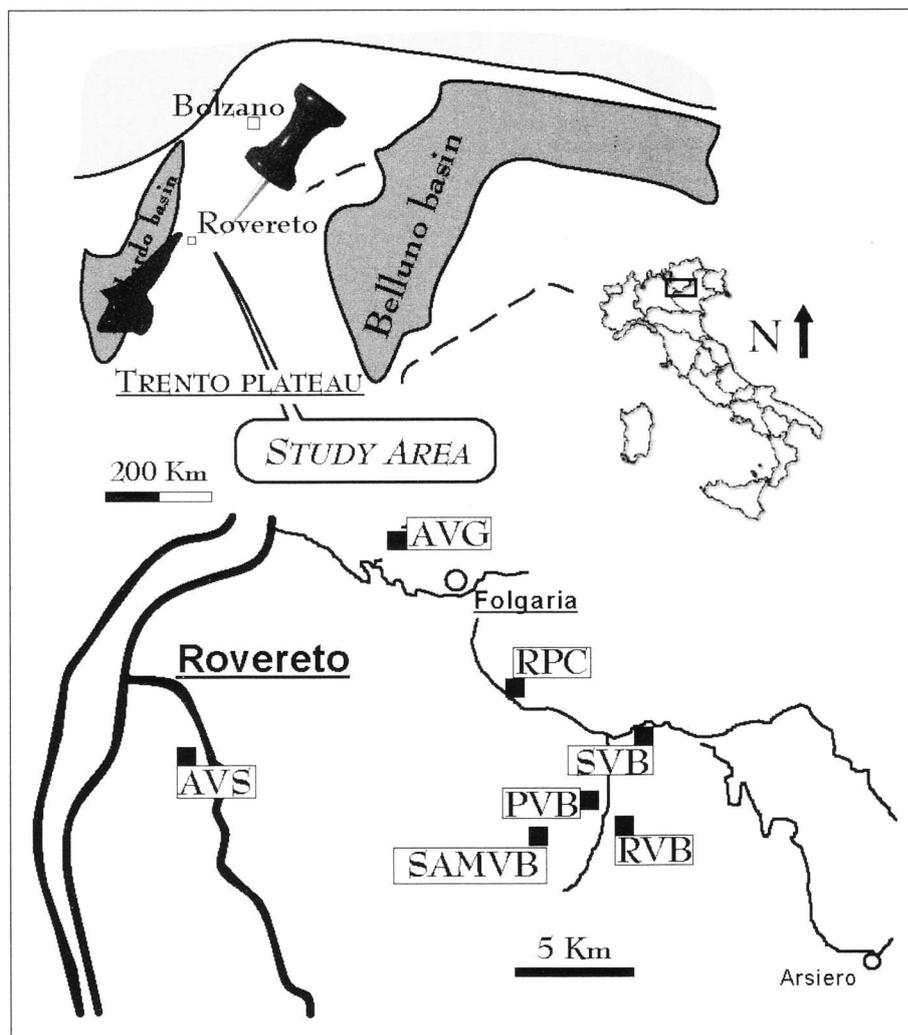


Fig. 1 - Schematic map of the Trento carbonate platform and location of the studied sections.

Different types of *Thalassinoides suevicus*, observed from the smallest to the largest form (Type I and IV, respectively), associated with rare *Ophiomorpha* and *Thalassinoides* isp., dominate the ichnocoenosis in the Pliensbachian interval (Monaco & Garassino 2001). These trace fossils are organized in a three-dimensional burrow system, which gradually decreases upward and forms a new type of a shallowing-upward sequence named here “burrow decreasing-upward parasequence” (BDUP). Its description and interpretation are one of the most important parts of this paper.

The analysis of trace fossils gives important information on the changes of paleoecological parameters, because tiering, development of networks, size of burrows and other geometrical characters are strictly related to depth, oxygenation of the environment, faunal abundance and characteristics of the substrate. In the last three years an accurate analysis has been carried out on skeletal remains and their sedimentological context, resulting in the description of different skeletal concentrations (SkC) and taphofacies, each related to a different depth range and hydrodynamic conditions (Monaco & Giannetti 2001, 2002).

Seven stratigraphic sections were analyzed (RVB, SVB, PVB, SAMVB, RPC, AVG, AVS sections 23 m, 27.15 m, 39.90 m, 34 m, 24 m, 26 m and 25 m in thickness, respectively), to define the lithostratigraphy of the Rotzo Member in the Folgaria – Rovereto area (Fig. 1). These sections cover a wide area, from the margin (AVS section) to the inner part (RVB, SVB, PVB, SAMVB, RPC sections) of the ancient carbonate platform, and show different sub-environments (Fig.1, 2).

Biogenic structures in the “burrow decreasing -upward parasequence” (BDUP) of Calcari Grigi

A careful analysis of biogenic structures and of their relationship with physical structures (e.g. combined flow- and storm-induced) reveals a strong biogenic activity in the Pliensbachian interval of the Calcari Grigi Formation (Fig. 3 and Pl.1, figs. a-f). Biogenic structures of the burrow decreasing-upward parasequence (BDUP) were produced by endo- and epibenthic organisms and reflect changes in environmental parameters such as depth (subtidal to intertidal), characteristics of

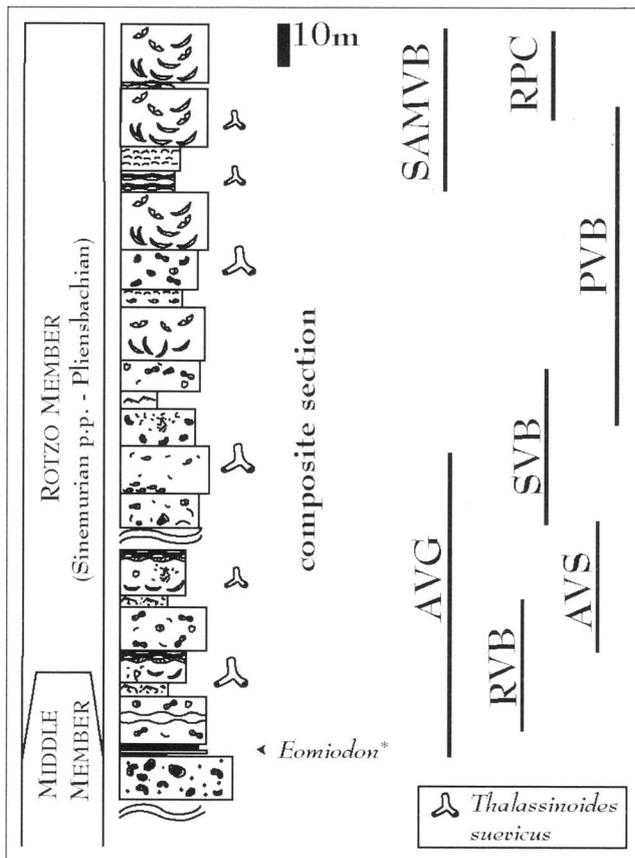


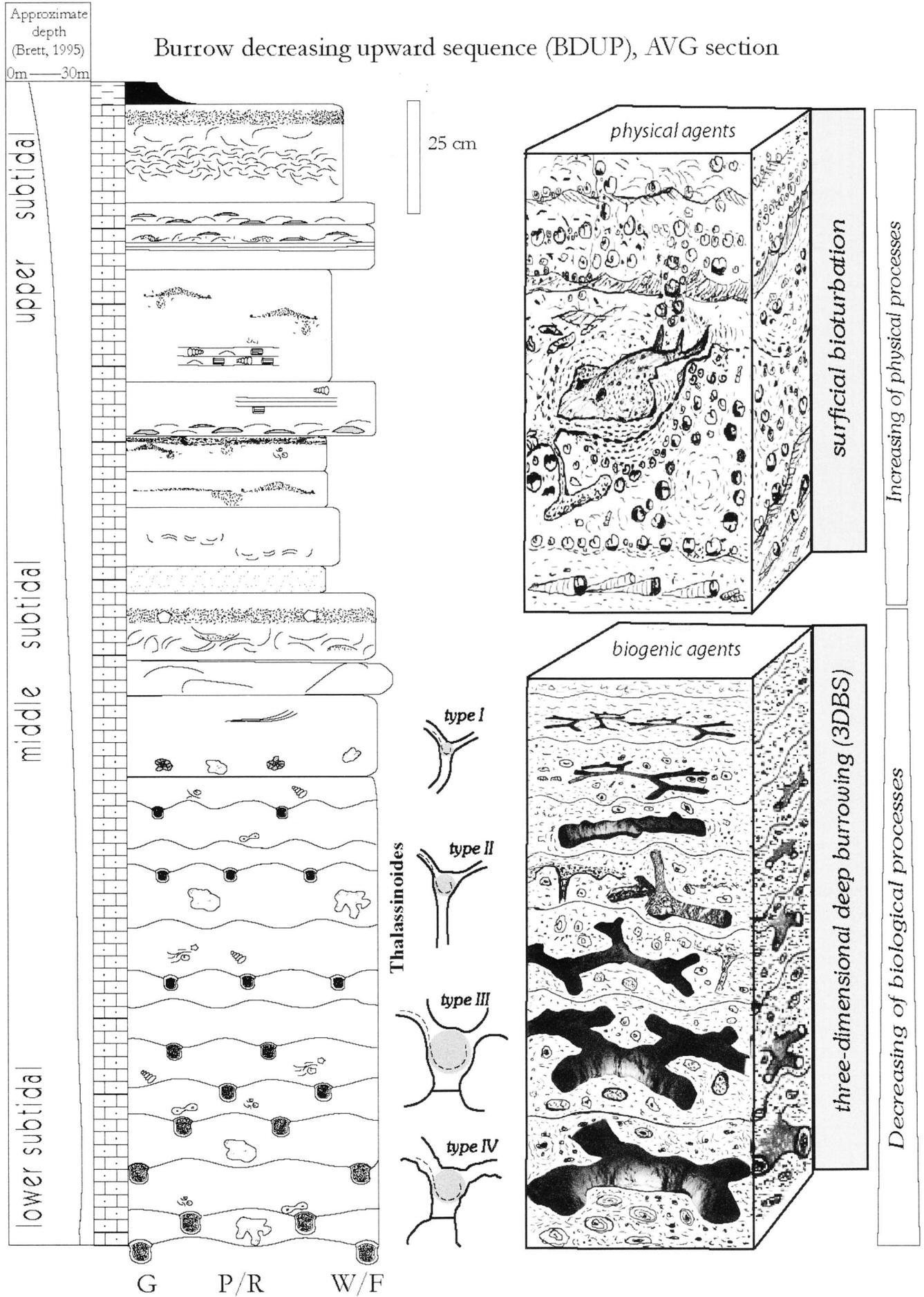
Fig. 2 - Composite stratigraphic column formed by the sections of the Valbona area. Asterisk (*) indicates the interval analogous to the ostracod- and bivalve-bearing (*Eomiodon* sp.) black shale of Bassi et al. (1999) at the top of Sinemurian, which marks the base of the Rotzo Member (see Monaco & Giannetti 2001).

the substrate, energy, salinity, oxygenation, productivity, which are typical of the lower, middle and upper parts of the parasequence (BOF, MOP and TOP following Brett 1995). A detailed sedimentologic and taphofacies analysis in all parasequences permits to reconstruct paleoenvironmental changes in the Trento area (Monaco & Giannetti 2001; 2002). The relationship among biogenic-induced taphocharacters suggests that the Pliensbachian interval was characterized by different generations of burrow systems showing remarkable biostratigraphic features (Monaco & Garassino 2001). Therefore, as revealed also by neoichnology (Bromley 1996), the taphonomy of burrows may be considered as one of the most important methods for the reconstruction of biogenic processes in shallow-water environments. Taphofacies distribution and taphonomic stratigraphy in the Trento area were largely discussed in Monaco & Giannetti (2001, 2002).

Endobenthic activity causes movement and redistribution of skeletal grains. Therefore, it is necessary to propose a distinction between "surficial bioturbation" and "deep burrowing", due to different trace-makers and ecological conditions. Surficial bioturbation is characterized

by the absence of preserved walls or networks: it is quite well recognizable on the outcrops by the homogenization of the deposits, the dislocation of continuous shell beds, like those produced by currents, waves or storms, and by the reorientation of shells (well visible in the case of geopetal structures). It is not possible to attribute exactly the different forms of surficial bioturbation to the organisms that generated them, because of the general lack of specific structures such as walls, linings, tubes and chimneys typical of many burrows. Anyhow, it may be suggested that this type of bioturbation in the Calcarei Grigi is due to nektic/epibenthic organisms, which episodically (like fishes) or incessantly (such as worms or mollusks do) interact with the substrate. Surficial bioturbation produces a lot of taphocharacters like crushing, reorientation of shell fragments, disarticulation, mottled concentration of skeletal remains and biogenic advection, frequently superimposed on structures produced by physical agents (Monaco 1999).

On the contrary, the geometry and taphonomy of the deep burrowing in the Pliensbachian of the Trento area are better characterized (e.g. intersection of different generations of burrows). The greatest part of the networks observed in the studied sections is constituted by tiered levels of quite regular burrows having a smooth external wall (*Thalassinoides* gr. *suevicus*). Each level is composed of mazes very well developed in the horizontal plane (Pl. 1, fig. d, f). Locally, vertical tunnels are also preserved. Burrows of *Thalassinoides* are characteristically Y-shaped with a typical enlargement at the point of bifurcation of the branches. This enlargement is located in correspondence of the turning chamber of the crustacean, produced by the burrower in order to change the direction of locomotion by 180° performing a somersault followed by a roll around the body axis (see the shrimp *Callinassa*, Stamhuis et al. 1996). The degree of enlargement is very different in the four *Thalassinoides suevicus* forms identified: in type I (the smallest one) the enlargement is very poorly developed (from 2 to 4 cm) and its diameter is quite similar to the diameter of the branches, while in type II it ranges from 6 cm to 10 cm, a little larger than the branches, having a width of 4-7 cm; its maze is very regular, with cylindrical branches up to 25 cm in length, and it appears more complex than that of type I. The largest forms observed in the Calcarei Grigi are type III and type IV: type III shows very large turning chambers, from 14 to 22 cm, it has very short branches narrowing progressively up to 9-10 cm in diameter and distributed symmetrically in the horizontal plane; type IV is distributed in irregular networks and turning chambers are loosely developed (swollen turnaround), ranging from 15 cm to 17 cm, while the diameter of branches varies slightly between 14 cm to 16 cm. Type IV was observed mainly in the PVB section, while type III is present particularly in the AVG and RVB sections. Type II and I are present in all the studied sections



and are observed most frequently in the AVS section, where other types of *Thalassinoides* are not present. In the analysis of the enlargement of the turning chamber, besides its absolute dimensions, also its proportions compared to the geometry of the whole network are important (Pl. 1, fig. f). In some rare cases it was possible to observe vertical tunnels, close to the entrance on the seafloor, still preserved.

Five conical mounds were observed in the studied sections. Probably mounds were made by the animals transporting the sediment out of the horizontal galleries through the vertical tunnels, as observed in present environments; the vertical tunnels were useful to promote ventilation of the burrows and to permit access to the seafloor.

An exceptional discovery is represented by the end of a vertical tunnel with the entrance very well preserved, which passes frontally to the rippled sea-floor, flattened by a repetitive moving and surfacing of the animal from the entrance of the burrow. The mound close to the burrow's entrance passes laterally to symmetric wave ripples, and both structures are covered by a coarse-grained deposit (see Monaco & Garassino 2001, fig. 3f).

In some beds it is possible to observe mottles of coarse-grained sediment, subcircular in shape, very similar to the "tubular tempestites" recorded in modern tropical carbonate storm systems (Caicos islands, see Wanless et al. 1988). Tubular tempestites, quite frequently observed in the RVB, SVB and AVG sections, represent infillings of burrows by coarse-grained skeletal debris during storm or hurricane events. The infilling of skeletal debris is different from the sediment of the bed: in fact, being transported by physical events, it contains a lot of coarse-grained bioclastic remains, fragmented by transport. The shape of these tubular tempestites is quite rounded, depending on the shape of the burrows that in the Calcarei Grigi are mainly represented by *Thalassinoides*. Frequently, a tubular tempestite cross cuts a burrow system, and therefore may be considered as the latest biogenic event.

A great importance was given to the analysis of skeletal remains recovered inside the burrows: in fact, these are present only in the largest forms of *Thalassinoides* (type III-IV) and in the central part of the burrows, belted by a muddier sediment. These bioclastic

grainstones, located in correspondence of the lumen of the burrow, may represent remains of the crushing activity of the animal or constitute a second bioturbation phase. Gastropods, bivalves, foraminifers (*Orbitopsella*) and pellets, generally attributable to crustaceans, are well visible in thin section.

Burrow Decreasing-Upward Parasequence

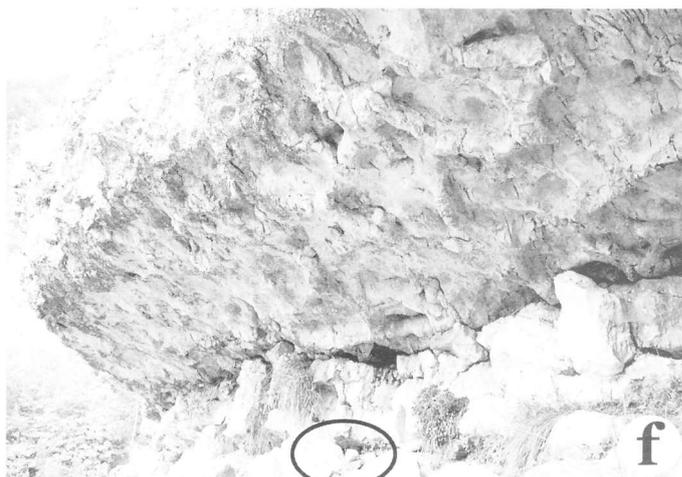
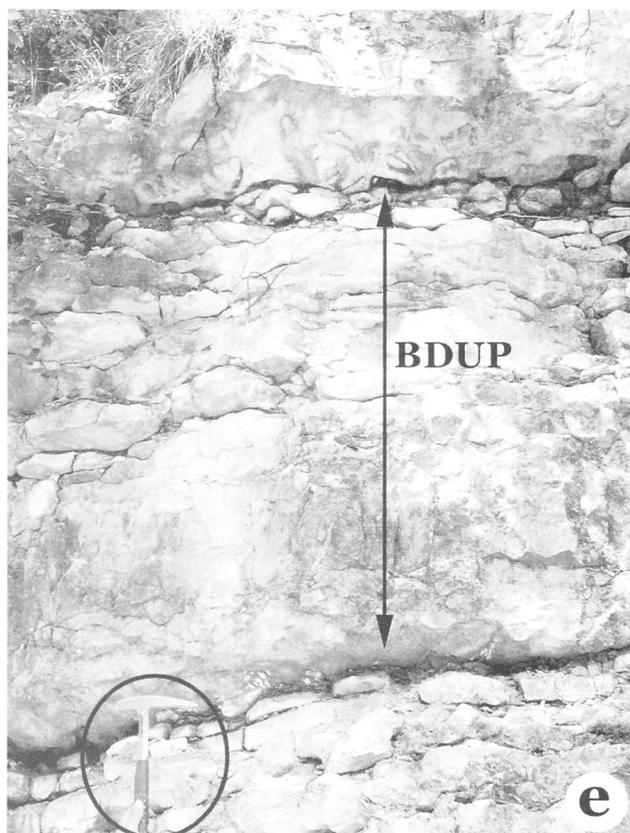
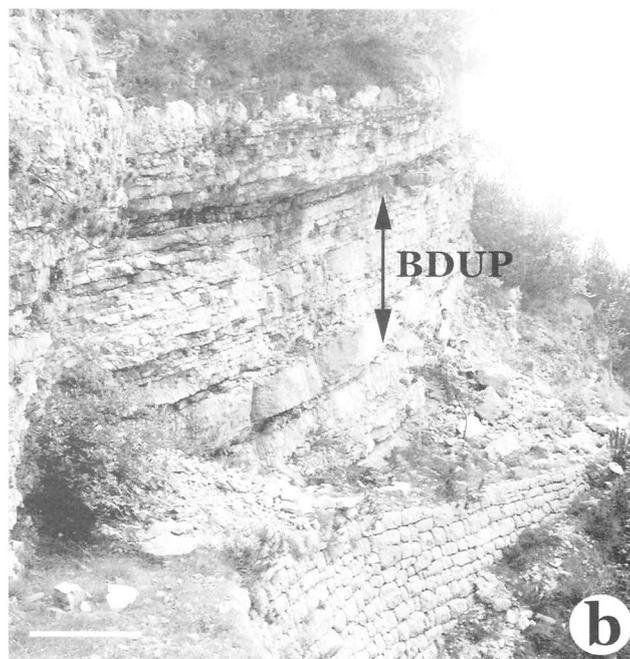
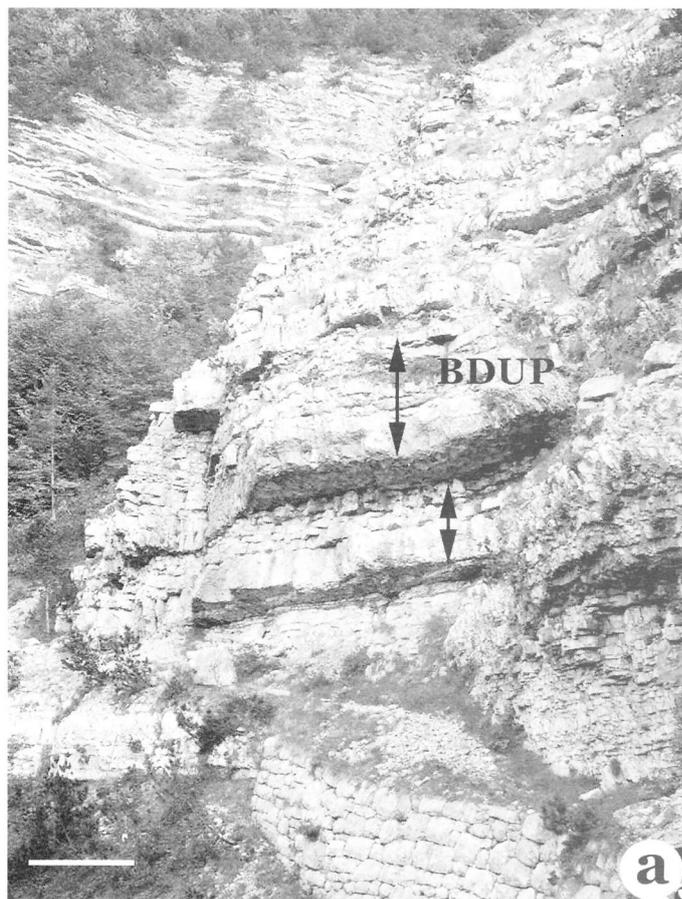
Taphonomic and ichnologic analyses permitted to individuate a new type of sequence: the "burrow decreasing-upward" parasequence (BDUP, see Fig. 3; Pl. 1, fig. a, b, e). It is about 2.3-2.9 m thick and it strictly corresponds to the taphonomic parasequence of Brett (1995). Besides the shallowing-upward trend, the two sequences have in common the presence of shell beds induced by storm waves in the middle part, and a bioclastic cap, constituted by disarticulated and winnowed shells, several centimeters or decimeters thick, in the top.

The BDUP is described following the vertical distribution of different facies from the lower, to the middle and upper parts, as follows.

Base and lower part of the BDUP

While middle and upper intervals of the BDUP have different characteristics in the studied sections, the base-lower part of the sequence is quite similar in all the identified sections. It is characterized by an intensely bioturbated nodular limestone bed, 60-100 cm thick, made of pure carbonate, that protrudes from the adjacent layers (Pl. 1, fig. a-f). It reveals a dominance of deep biological activity, represented by the networks of burrows described above, forming a "three-dimensional burrow system" (3DBS, Monaco & Giannetti 2002). Both size and tiering of burrows decrease from bottom to top (from large *Thalassinoides* type III or IV, to type II and I, Fig. 3), conferring a typical trend also to nodularity, which in these sections is completely due to biogenic activity. Because each nodule coincides with a burrow's section, nodularity decreases upward both in size and density, creating a cyclical pattern in the base-lower part of the BDUP, well recognizable in the field (Pl. 1, fig. e). Taphonomic analysis reveals characters related to biogenic activity (like trace fossil cutting, shell crushing and active burrow infilling, peloid concentration, boring, encrusting and mottled concentrations of bioclastic packstone, see category C in Monaco & Giannetti 2001), even if some differences between sections exist. In the AVG and AVS sections the three-dimensional burrow system is particularly well developed, reaching 80 cm-1 m in thickness (*Thalassinoides* type IV is not present, while type III, and type II in particular, are very abundant and developed in tiers). Usually, limestone beds of 3DBS show shell concentrations deposited by physical transport (storm currents) and many of such skeletal remains are affected by burrowing. These layers were probably formed by high-energy processes at the storm wave base during crustacean activity, inducing reworking, abrasion, grouping and fragmentation (physical taphocharacters of category D, see Monaco & Giannetti 2001). In the RVB, SVB and PVB sections all burrows of crustaceans contain skeletal remains, like shells of bivalves (recognizable valves of the genus *Gervilleioperma*) and of foraminifers (mainly *Orbitopsella*) which are encrusted by biogenic (like algal enveloping) and inorganic processes. Encrustation, therefore, affects commonly the skeletal remains involved in burrow activity, and thin mm layers of calcium carbonate surround shells which are placed inside the burrow or laying around the burrow's rim. On the contrary, boring seems to affect shells of gregarious communities of bivalves (like *Lithioperma*, some specimens in life position) and of terebratulacean

Fig.3 - Sketch of the burrow decreasing-upward sequence (BDUP). Deep burrowing at the base of the sequence is characterized by different types of *Thalassinoides suevicus* (type I to IV), while surficial burrowing is preserved in the middle-upper part of BDUP. Note that nodularity and burrowing decrease upward in size and complexity.



brachiopods, frequently encrusted too, which are distributed outside the burrow system. Boring has been referred to the activity of several groups of organisms like sponges, boring algae and polychaete annelids (Neumann 1966; Bromley 1996 and references therein).

In some sections (PVB, SAMVB) the top of the lower part of BDUP reveals limestones with brachiopod and gastropod gregarious communities (facies of 40 to 80 cm in thickness, see Broglio Loriga et al. 1996; Broglio Loriga & Fugagnoli 1997) which are not burrowed. Sparry calcite cements and geopetal structures (category B in Monaco & Giannetti 2001; Monaco 1999) are present; a poor degree of fragmentation, abrasion and grouping of these skeletal remains indicates the very low energy conditions affecting some sub-environments. These protected environments were colonized only by specialized gregarious groups of organisms, proliferating in bottom conditions totally disadvantageous to active burrowers such as crustaceans and, therefore, to the development of any burrowing activity.

Middle and upper part of the BDUP

Toward the middle and upper part of the BDUP, the size and density of burrows decrease and only *Thalassinoides* type I is still present. Therefore, it is not possible to recognize a completely developed three-dimensional burrow system (Pl. 1, fig. b).

This part reaches 80 cm-1m in thickness and is generally characterized by an increase of surficial bioturbation affecting physical structures. A lot of structures like coarse-grained, bioclastic ripples (Leckie 1988), cross laminations, HCS and carpets of fragmented skeletal remains, containing autochthonous and allochthonous bioclasts, suggests high-energy processes like combined flow, storm or tsunamis events, that induce a strong, but short-lived stress on the seafloor. Fragmentation, orientation, grouping and disarticulation are the most common taphocharacters, because of the very high degree of transport. Coarse-grained ripples are formed by fragmented skeletal remains, in some cases oriented and aligned on the foresets. Frequently, the interaction between physical and biological agents is visible: continuous shell beds induced by currents are often interrupted by surficial bioturbation, shells are reoriented and mottled concentrations of bioclasts fragmented by transport and crushing are present. Therefore, biological activity on the substrate is due mainly to surficial bioturbation and limitedly to deep burrowers.

Many of the physical processes are dominated by combined flows. These are formed by the interaction between normal wave motion and currents close to the fair-weather wave base (Harms 1969).

According to several authors, this induced a very strong total stress on the seafloor, of greater magnitude than wave and current stresses combined (Grant & Madsen 1986). Generally, bioclasts are minutely fragmented, and it is not always possible to attribute them to a precise group of organisms. In other cases, robust gastropod shells such as nerineaceans (*N. norigliensis*) are preserved whole, but grouped together with minutely fragmented bioclasts. In the upper Pliensbachian whole shells of gastropods are concentrated in levels 3-4 cm thick, laterally continuous, sometimes associated with symmetrical ripples of bioclasts. Combined flow concentrations were crushed and reworked by burrowing and scavenging organisms that interrupted the continuity of bioclastic levels forming mottled concentration of bioclasts.

Generally, the top of the "burrow decreasing-upward" sequence (BDUP) is the thinnest portion, about 20-35 cm thick, and, in the Rotzo Member, deposited mainly in subtidal conditions, is not always present. When present, it consists of the upper subtidal part of the sequence, but sometimes (two cases in the Middle Pliensbachian) it may contain intertidal/supratidal deposits as well (10-15 cm thick, PVB and RPC sections). Upper subtidal deposits are formed by tightly packed shell beds, composed of convex-up oriented bivalves, which in some cases show shelter porosity filled by sparry calcitic cement. Shell orientation may be referred to the action of uni- or bi-directional fair-weather and tidal currents, with enough strength to orient, but not transport, bivalve shells. Bivalves, completely disarticulated, represent an endobenthic fauna, often monospecific, and form shell beds extended laterally up to tens of meters, typically found in carbonate-dominated para-sequences (Kidwell et al. 1986; Aigner 1985; Fernández López 1997a, b; Brett 1995). In some areas surficial bioturbation affects these levels, favouring shell crushing, reorientation and concentration of fecal pellets close to the shells, while deep burrowing is completely absent or very poorly developed.

The intertidal/supratidal portion of the sequences, where present, reveals typical characters of subaerial exposure: bubble-like and planar bird's eyes, oxidized shells, reddish films indicative of soil processes and flat pebbles of mud, desiccation cracks, and in the RPC section root structures and plant remains of *Equisetites* sp. Locally, it is possible to observe flat pebble breccias (very common instead in the Lower and Middle Members) and mud-cracked polygons rounded by transport: these layers were probably induced by storms or hurricanes that affected the substrate. An intertidal hurricane deposit was observed in the SVB section: this is few cm thick and is composed of pelleted lime mud, showing tubular voids due to gas escape. Skeletal remains are rare and deep burrowing is not visible.

Conclusions

In the Pliensbachian sections of the Trento carbonate platform 19 burrow decreasing-upward parasequences were identified: they show different features, but they all have in common a decrease in biogenic structures, accompanied by an increase in physical processes toward the top of the sequence. Moreover, the "burrow decreasing-upward" parasequence (BDUP) may be considered a synonymous of "nodular (biogenically-induced) decreasing-upward" parasequence. The BDUP represents a type of the well-known shallowing-upward parasequence in carbonate platform environments, mainly defined through the study of bioturbation and taphonomic observations. The burrow activity of crustaceans may be sensitive to sea-level variation, oxygenation and carbonate production. As a new carbonate sequence begins, the crustacean activity breaks out, decreasing progressively together with the shallowing-upward trend towards restricted (poorly oxy-

PLATE 1

The burrow decreasing-upward sequence (BDUP) in the Calcari Grigi Formation, Rotzo Member, Folgaria and Lessini areas.

- Fig. a, b - Examples of thinning-upward sequence, here defined as BDUP, in the Folgaria area (AVG section); note a thicker limestone bed corresponding to the "three-dimensional burrow system" which characterizes the lower part of BDUP.
- Fig. c - The base of BDUP which abruptly overlays dark marly levels (black arrow).
- Fig. d, f - The base of BDUP is represented by regular mazes of branched burrows of *Thalassinoides suevicus* type III-II (black arrow; hammer for scale).
- Fig. e - another example of the BDUP in the Lessini area (hammer for scale).

genated) conditions of the lagoonal environment. Therefore, the study of burrowers gives the possibility to refine the knowledge about periodical sea-level and oxygen variations in a parasequence. Some authors suggest that a global environmental stress affected shelves during the Lower Jurassic due to a rapid rise in CO₂ since the end of the Triassic. It warmed shallow waters, damaging temperature-sensitive organisms (corals) and favouring the global proliferation of the opportunistic and tolerant species in the Lower Jurassic. In fact, during this period large bivalves of the “*Lithiotis*” facies formed buildups, replacing coral reefs typical of the end of Triassic (Fraser et al. in press); also, the cyclic development of decapod crustacean burrowers may reflect these peculiar conditions of the lagoonal environment.

The lower part of BDUP, corresponding to the “three-dimensional burrow system” described in Monaco & Giannetti (2002), forms a thick limestone bed, strongly burrowed and nodular, easily identifiable in the field. Therefore, the parasequence boundary may be easily detectable also looking at the outcrop from a distance. Deep biogenic structures, distributed in tiers and classified as several types of *Thalassinoides* (type IV, III, II, I, from largest to smallest), result into/are the cause of the nodularity trend of the parasequence. The evolution of the transport of skeletal particles induced by burrowers (both surficial and deep) through time may be recog-

nized studying the biostratigraphy or genetic taphonomy (Brett 1995). Therefore, genetic taphonomy of trace fossils helps to define taphofacies and burrowing activities, to highlight/to identify the variations of ecological parameters (e.g. carbonate productivity, nutrients, hydrodynamic conditions) and the shallowing-upward trends typical of the studied sequences, although a more precise modeling of these relationships is still in progress.

The middle and upper part of the BDUP are dominated by characters suggesting physical transport and, secondarily, surficial bioturbation. As a consequence, this type of crustacean burrowed parasequence may surely be an important tool to investigate cyclicity in fossiliferous and burrowed carbonate platform environments, revealing also the paleoecological variations. The identification of BDUP may represent a helpful method also in sequence stratigraphy. In fact, starting from BDUP, an ichnological and taphonomical characterization of sequences of higher order would be possible.

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