Facies (2007) 53:389–400
DOI 10.1007/s10347-007-0115-3

ORIGINAL ARTICLE

# Depositional environment and biofacies characterisation of the Triassic (Carnian to Rhaetian) carbonate succession of Punta Bassano (Marettimo Island, Sicily)

**Rossana Martini · Simonetta Cirilli · Céline Saurer · Benedetto Abate · Gaetano Ferruzza · Giovanna Lo Cicero**

Received: 26 October 2006 / Accepted: 24 May 2007 / Published online: 15 June 2007


**Abstract** The aims of this study are to reconstruct the geological setting of the Punta Bassano series (Marettimo Island, Egadi Archipelago, western Sicily) and its palaeogeographic evolution. The reference section for the Upper Triassic of Marettimo shows an alternation of marl and limestone beds together with brecciated levels. The limestones are both homogeneous mudstones with evaporite pseudomorphs and laminated with fenestrae. Foraminiferal, palynomorph, and ostracod associations constrain the Punta Bassano sequence to the Carnian-Rhaetian interval. The Punta Bassano succession represents a shallow inner ramp, ranging from open-marine environment with good water circulation to lagoonal and peritidal protected environments. Freshwater input from rivers or groundwater on the carbonate ramp is indicated by the ostracod microfauna. The comparison of facies and microfauna with those from other sequences of the Mediterranean Upper Triassic (Pyrenees, Corsica, Sardinia, and Tunisia) allows us to confine the Punta Bassano sedimentation to the northern margin of the Tethys, between the Corsican and the Pyrenean depositional setting. These new results indicate that Marettimo Island, which is considered a single structural element being formed by four tectonic units, is a piece of the southern margin of the European Plate, displaced over a longer distance to become part of the other Egadi Islands, when the Corso-Sarde block made its rotation and successive collision with the North African Margin.

**Keywords** Upper Triassic · Sedimentology · Foraminifers · Ostracods · Palynomorphs · Palaeogeography · Sicily · Marettimo Island

R. Martini (✉) · C. Saurer
Department of Geology and Palaeontology,
University of Geneva, 13, Rue des Maraîchers,
1205 Geneva, Switzerland
e-mail: Rossana.Martini@terre.unige.ch

S. Cirilli
Dipartimento di Scienze della Terra, University of Perugia,
Piazza Università, 06100 Perugia, Italy

B. Abate · G. Ferruzza · G. Lo Cicero
Dipartimento di Geologia e Geodesia, University of Palermo,
Via Archirafi 22, 90123 Palermo, Italy

## Introduction and geological setting

The Egadi Archipelago, and thus Marettimo Island (western Sicily), are located on the mega-suture between the African and the European lithospheric plates and represent remnants of an old submarine orogenic belt linking the Apennine-Maghrebian and the Sicilian mountain chains (Fig. 1). The Apennine-Maghrebide chain, as a whole, is characterised by the superposition of two major units that configured a regional west-dipping thrust system with an east-verging duplex structure, separated by a low angle fault.

The Sicilian chain, of which Marettimo represents the westernmost area, includes the Trapani, Palermo, and Peloritani Mountains, from west to east, respectively. These mountains are composed of a Meso-Cenozoic stratigraphic succession belonging to the external domain, mainly accumulated along the Adria-Africa passive continental margin. The oldest deposits, representing a long Late Triassic depositional phase of evaporitic to restricted-marine environments, directly onlap Permian continental deposits (Elter et al. 2003). The marked deformation which affected this succession began during the Middle to Late Miocene. From the Late Miocene, the geometry of the thrust belt was strongly modified by several processes

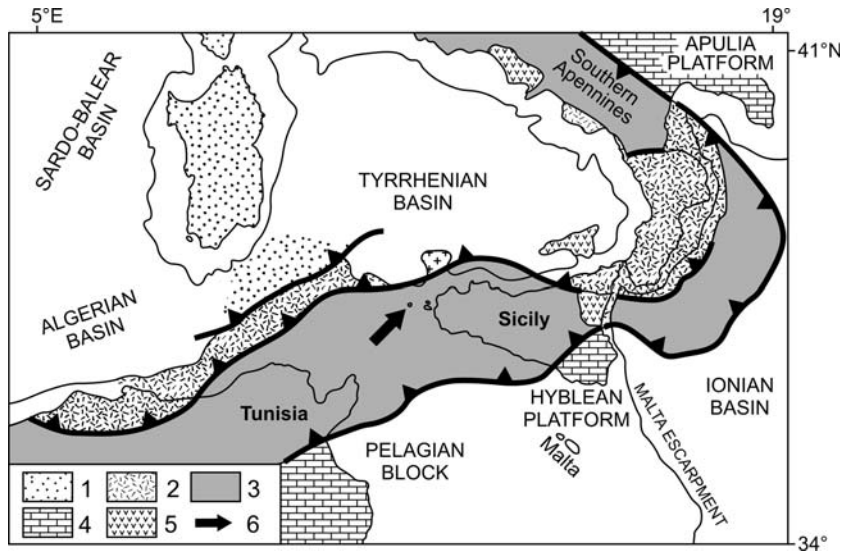



**Fig. 1** Tectonic sketch of the central Mediterranean area (after Catalano et al. 1995). *1* Corso-Sarde block. *2* Kabylo-Peloritanian Unit. *3* Apennine-Maghrebian Unit and deformed foreland. *4* Foreland and less deformed foreland (Tunisia, Iblean Platform). *5* Plio-Quaternary volcanism. *6 Arrow* indicates the position of Marettimo Island and hence of the Egadi Archipelago

(e.g. extensional faulting, volcanic activity, crustal thinning) correlated with the development of the Tyrrhenian Basin (Elter et al. 2003). The main cause is attributed to the anticlockwise rotation of the Corso-Sarde block and its successive collision with the North African margin (Catalano et al. 1995). In the Egadi thrust belt, the present ramp-flat duplex geometry results from the detachment of the sedimentary cover.

The western Mediterranean palaeogeographic reconstructions for the Triassic period (Stampfli and Borel 2004, with bibliography) generally show a crustal thinning of North Africa in relation to the Neo-Tethyan opening. The highly rifted nature of the Mesozoic African continental margin during the Tethyan spreading and its compartmentalisation into a number of sub-basins, brought about deposition in foredeep settings that remained deep marine through much of the early Middle Miocene.

From the Triassic up to the Tertiary (Paleogene), three main palaeogeographic domains have been recognised in western Sicily: the pelagic Imerese-Sicani domain with basinal deposits, the neritic Hyblei-Saccense domain characterised by carbonate platform deposits and the neritic Panormide domain with evaporite deposits (Di Stefano et al. 1997).

The Upper Triassic succession of Punta Bassano has been deposited on the inner part of the Panormide platform (Abate et al. 1999).

Marettimo Island is considered a single structural element formed by four tectonic units settled during the Late Miocene to Pliocene. They are, from NW to SE and from lower to upper: the Punta Bombarda, the Punta Troia-Marettimo, the Monte Falcone and the Punta Bassano units (Abate et al. 1982, 1995, 1996) (Fig. 2).

The sedimentological and biostratigraphic analyses of the Upper Triassic succession of Marettimo Island is based on the study of a geological section located on the Punta Bassano promontory in the south of Marettimo Island at an altitude of about 120 m. Here, the Middle? to Upper Triassic shallow-water carbonate platform deposits of the Punta Bassano unit crop out in a recumbent northwest-verging anticline, which tectonically overlaps the Punta Troia-Marettimo Unit (Fig. 2).

While a few previous studies have focused on geology, lithostratigraphy and macropalaeontology (Jacobacci 1955;

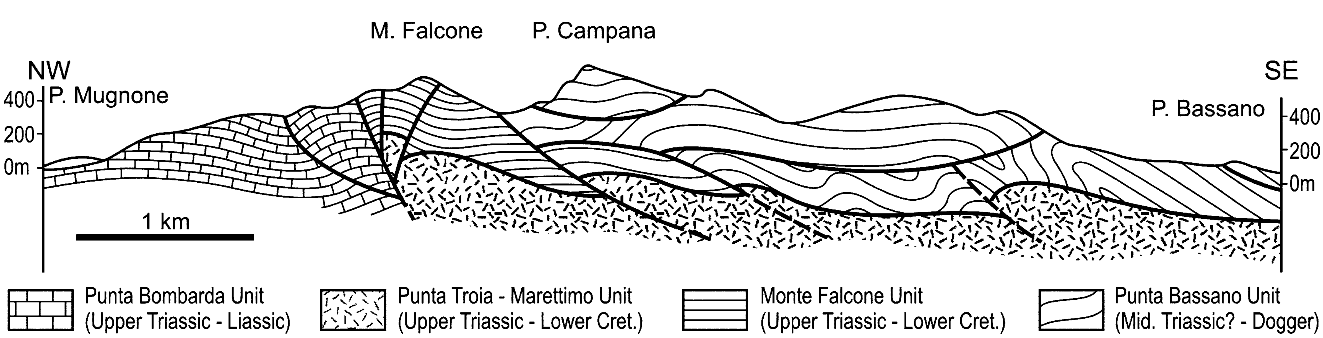



**Fig. 2** Schematic NW/SE tectonic cross section of the Marettimo Island (after Abate et al. 1982)

Malatesta 1964; Giunta and Liguori 1973; Abate et al. 1996, 1999), only one detailed investigation on sedimentological aspects has been attempted (Abate et al. 1982). In the current paper, a sedimentological and biostratigraphic approach is used to understand the relationship between palaeoenvironmental parameters and change of sedimentary facies.

## Materials and methods

Microfacies and foraminifers analysis was performed through the polarised light on 60 thin sections sampled in the limestones.

Palynological processing was employed on 20 samples mostly of clayey marls and marls. Out of these samples, five were provided palynological assemblage. Organic matter was extracted applying standard palynological techniques (Monteil 1985). Samples were crushed to a fraction comprised of between 200 µm and 2 mm, and attacked using diluted hydrochloric (HCl 32%) and hydrofluoric (HF 71–75%) acids to destroy, respectively, carbonate and silicate components. The organic residue was sieved at 11 µm in order to remove finer particles. To prevent organic matter degradation, the residue was not oxidised with nitric acid ($HNO_3$), a process generally used to remove amorphous organic matter and mounted on slides using polyvinyl alcohol and Eukitt glue. The palynological slides were examined under transmitted light.

Concerning the ostracods, 15 samples of limestone were processed using the seldom method of acetolysis (Crasquin-Soleau et al. 2005). After the processing, four of them produced ostracods, which have been observed with a scanning electronic microscope.

The acetolysis allows us to isolate ostracods, and/or others microorganisms (e.g. foraminifera, brachiopod larvae, conodonts) varying from small (0.2 mm) to large (2–3 mm) size, from highly lithified rocks. The four steps of this technique are briefly presented as follows: (1) Crushing: in order to increase the reaction surface, 400–500 g of rock is reduced to pieces of several $cm^3$. (2) Dehydration: to avoid a later acid attack, the crushed sample must be dried, but the temperature should not exceed 100°C. (3) Acetolysis: when the sample has cooled down, it is completely covered with pure acetic acid. No effervescence must occur; it is either a result of impure acid or incomplete drying. (4) Settling and washing: when sufficient muddy deposit is present, even before the complete disaggregation of the sample, the acid is filtered off and the sample is then washed. For ostracods, three sieves are used: the 2-mm mesh retains non-disaggregated sediment, the 0.5-mm mesh retains adults and large forms, and the 0.1-mm sieve retains small specimens and larvae.

## Facies description

The reference section of the Upper Triassic of Punta Bassano Unit shows a 124-m-thick stratigraphic succession of carbonate rocks limestone (often dolomitised) with intercalations of marls, clayey marls and brecciated levels. The limestone, which is characteristically poor in microfauna, is both micritic with pseudomorph of evaporites and laminated with fenestrae. Six main lithologies and nine microfacies have been recognised. The most frequently occurring litho- and microfacies types are described and illustrated in Figs. 3 and 4.

### Lithofacies type 1

Gray homogeneous limestone medium to thickly bedded (30 cm up to 1 m), showing stratification cycles as described by Schwarzacher (2000) (Fig. 3a). Abundant gypsum pseudomorphs identified by characteristic lath-like crystal shape are present within the limestone and are evident on the weathering surface (Fig. 3b), which on the field sometimes displays yellow patina. Frequently, the evaporitic minerals have been completely leached to form distinct moldic porosity.

Three microfacies have been recognised:

*MF 1* The most abundant microfacies is *mudstone* with very rare bioclasts, exclusively composed of ostracod shells and foraminifers. Rounded quartz grains might be abundant and concentrated in thin levels. Organic facies mostly contain amorphous organic matter, which percentage ranges between 40 and 60% of the total content. Subordinate amount of small equidimensional inertinite is also present associated with rare sporomorphs and vitrinite.

*MF 2* Fine-grained peloidal *wackestone/packstone*, is found alternating with the above described facies. Miliolid type of foraminifers (i.e., *Hoyenella inconstans*) and *incertae sedis* of parathuramminacean type usually occur, while ostracod shells are rare. Cloudy calcite pseudospar replacements of evaporite nodules (up to 5 mm) and/or gypsum crystals, has been observed. This fabric became progressively more common towards the top of the section.

*MF 3* *Bioclastic packstone* is subordinately present in this lithofacies. Coarse bioclastic grains consist of bivalve shells and ostracods. Various types of lithoclasts are abundant, including mudstone with rounded quartz grains and finely laminated wackestone (probably of microbial/algal origin). In places, packstone exclusively composed of crinoidal fragments and minor fine-grained mud peloids also occur. This microfacies shows evident stylobedding-type diagenetic structures (sensu Logan and Semeniuk 1976).

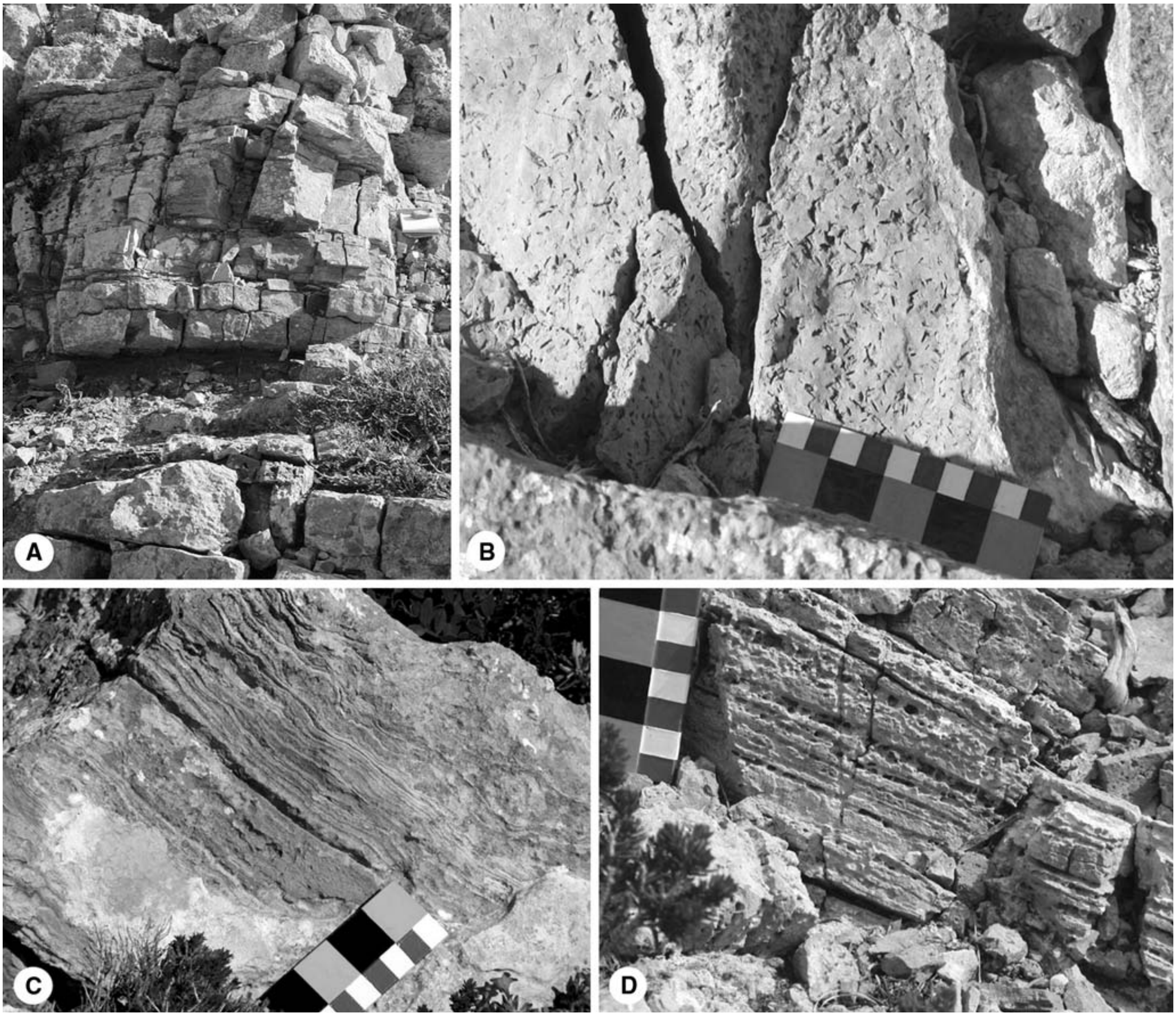



**Fig. 3** Facies from the Carnian to Rhaetian Punta Bassano carbonate succession. **a** Gray homogeneous limestone medium to thickly bedded. **b** Abundant gypsum pseudomorphs on the weathering surface of the grey limestone. **c** Beige to whitish laminated mudstone with fenestrae. **d** Large fenestrate structures occurring towards the top of the succession

Lithofacies type 2

This lithofacies represents a well-stratified beige to whitish laminated mudstone with fenestral fabrics (Fig. 3c). These beds, 2–20 cm thick, are generally intercalated to the homogeneous limestone (lithofacies type 1), at the top of the shallowing-upward cycles. The fenestrae are flattened and almost parallel to the bedding and to the undulate millimetre laminae. Towards the top of the succession, the voids size increases, up to 5 mm (Fig. 3d). The laminated structures are sometimes discontinuous, interrupted by trough stratification underlined by mud drapes.

Two energy-controlled microfacies, normally alternated, have been recognised.

*MF4 Microbial laminated wackestone* is the low-energy facies (Fig. 4). The laminae are composed of alternating layers of mudstone and very fine-grained peloidal packstone, in places grainstone. Fenestrae are abundant and often also include geopetal fabrics. The more thick laminae contain flattened ostracod shells and remnants of echinoderms. Framboidal pyrite and bedding-parallel irregular microstylolites are also observed.

*MF5 Ostracod/peloidal packstone to grainstone* is the more high-energy facies (Fig. 4). These are made up of alternating layers of almost exclusively double-valved ostracods, lying parallel to the stratification, and of dense micritic peloids of variable size. Other bioclastic grains are

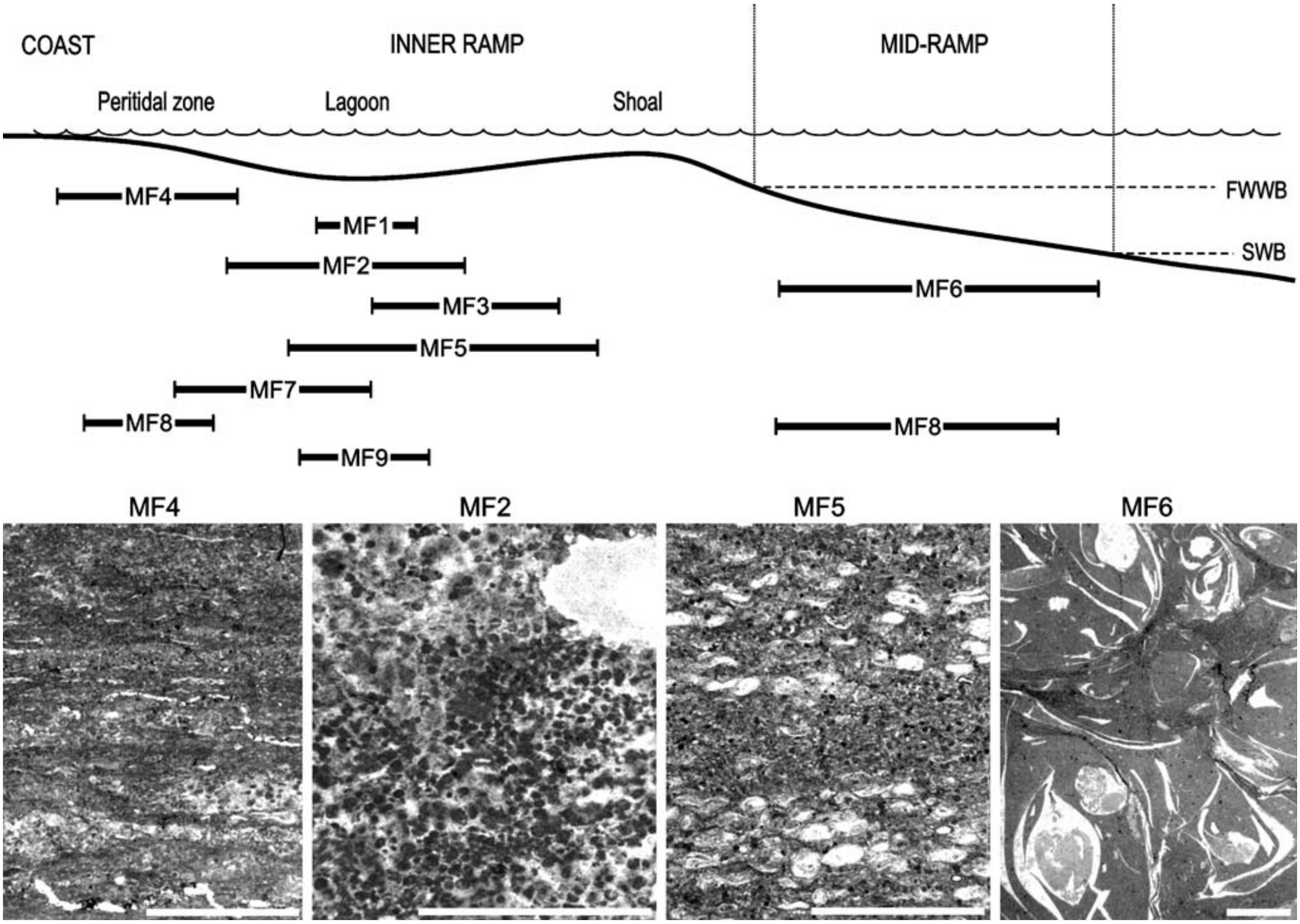



**Fig. 4** Microfacies from the Punta Bassano carbonate succession and interpretation of their distribution along the Upper Triassic (Carnian to Rhaetian) carbonate ramp (*MSL* mean sea level; *FWWB* fair-weather wave base; *SWB* storm-wave base) (modified from Flügel 2004). Photographs show the more characteristic microfacies: *MF5* Ostracod/peloidal packstone to grainstone, made up of alternating layers of almost exclusively double-valved ostracods, lying parallel to the stratification, and of dense micritic peloids. *MF4* Planar fine microbial laminated wackestone with fenestrae, composed of alternating layers of mudstone and very fine-grained peloidal packstone, in places grainstone. *MF6* bioclastic packstone/floatstone with bivalves and gastropods. *MF2* Fine-grained peloidal wackestone/packstone showing (*top-right corner*) cloudy calcite pseudospar, which has replaced evaporite nodules. *Scale bar* is 200 µm

subordinate and include foraminifers, bivalve shells, echinoderms and microbial/algal aggregates. Thin bioturbation trails are observed as well as low-amplitude stylolites, which interrupt the layers, frequently.

Organic matter content is dominated by large debris of vitrinite, frequently amorphised by fungi, algal spores and subordinate amount of equidimensional inertinite. Sorting and rounding of organic debris are low.

### Lithofacies type 3

Shelly limestone consists of thin (up to 15 cm) beds of grey coarse bioclastic limestone. The bioclasts are essentially represented by large (more than 2 cm) bivalve and brachiopod shells, showing a coarsening-up arrangement. This lithotype normally occurs interbedded with yellow-ochre clayey marl intervals.

*MF6* The microfacies is a *bioclastic packstone/floatstone* (MF6). It contains bivalves, brachiopods and gastropods (Fig. 4), locally showing micritic envelopes (sensu Bathurst 1966). Ostracods, foraminifers and echinoderm remnants are sporadically present.

### Lithofacies type 4

Thin layers of grey-beige limestone, 2–3 cm thick, characterised by yellow to orange patina due to late burial dolomitisation, which makes it well recognisable in the field. The levels presently appear as undulating weathering crusts, strongly fractured, on top of the homogeneous limestone beds (lithofacies type 1).

*MF7* The homogeneous microfacies is *fine- to coarse-grained packstone/grainstone*, containing very small subrounded or subangular mud peloids and ostracods, heavily impregnated with iron oxides.

The total organic matter content is very low and mostly consisting of small particles of inertinite and fungal remains.

### *Lithofacies type 5*

Along the *Punta Bassano* succession, 10 cm–1 m thick, often discontinuous layers of intraformational breccias are present showing flat-lying clasts orientation.

*MF8* The microfacies is a *rudstone* characterised by a low percentage of carbonate matrix, often dolomitised, and angular limestone clasts (2–20 cm). The texture of clasts is quite homogeneous, represented by mudstone (MF1) and laminated wackestone (MF4).

### Lithofacies type 6

Clayey marl and marl intervals, which vary in thickness from a few centimetres to several metres, are irregularly distributed along the succession (Fig. 5).

*MF9* The dark grey clayey marls and marls, yellow to ochre on the weathering surface, are characterised by poor and less diversified microfauna consisting of ostracods. Sporadically, thin-shelled bivalves occur.

The total organic matter content is quite high and mostly represented by vitrinite, amorphosed phytoclasts, fungal hyphae, cutinite (leaf remains) and less abundant inertinite. The percentage of sporomorphs varies from low within the lowest clayey marls intervals to quite abundant upwards. The maximum is reached around 30 m where the sporomorph assemblage is dominated by circumpolles frequently in tetrad status.

## Facies interpretation

In the following discussion, the microfacies characterising the Punta Bassano succession are interpreted in terms of palaeoenvironment. Their lateral distribution along a carbonate ramp is reconstructed, extending from a peritidal setting to a shallow subtidal zone passing over a high-energy shoal facies (Fig. 4).

The laminated fenestral wackestone (MF4) can be interpreted as algal or microbial mat deposits related to upper intertidal to supratidal environment of a tidal flat (peritidal zone; Flügel 2004), swept by gentle tidal currents. Fenestral fabric results from grain bridging and/or gas bubble formation associated with decomposition of organic material. In addition, most peloids of this facies are thought to have been formed by shrinking of originally cryptalgal and muddy laminae owing to desiccation and/or salinity variations (Fischer 1964; Martini et al. 1989; Carillat et al. 1999).

**Fig. 5** Stratigraphic section of the Upper Triassic Punta Bassano carbonate succession showing sample locations, biostratigraphically diagnostic organisms and depositional systems ▶

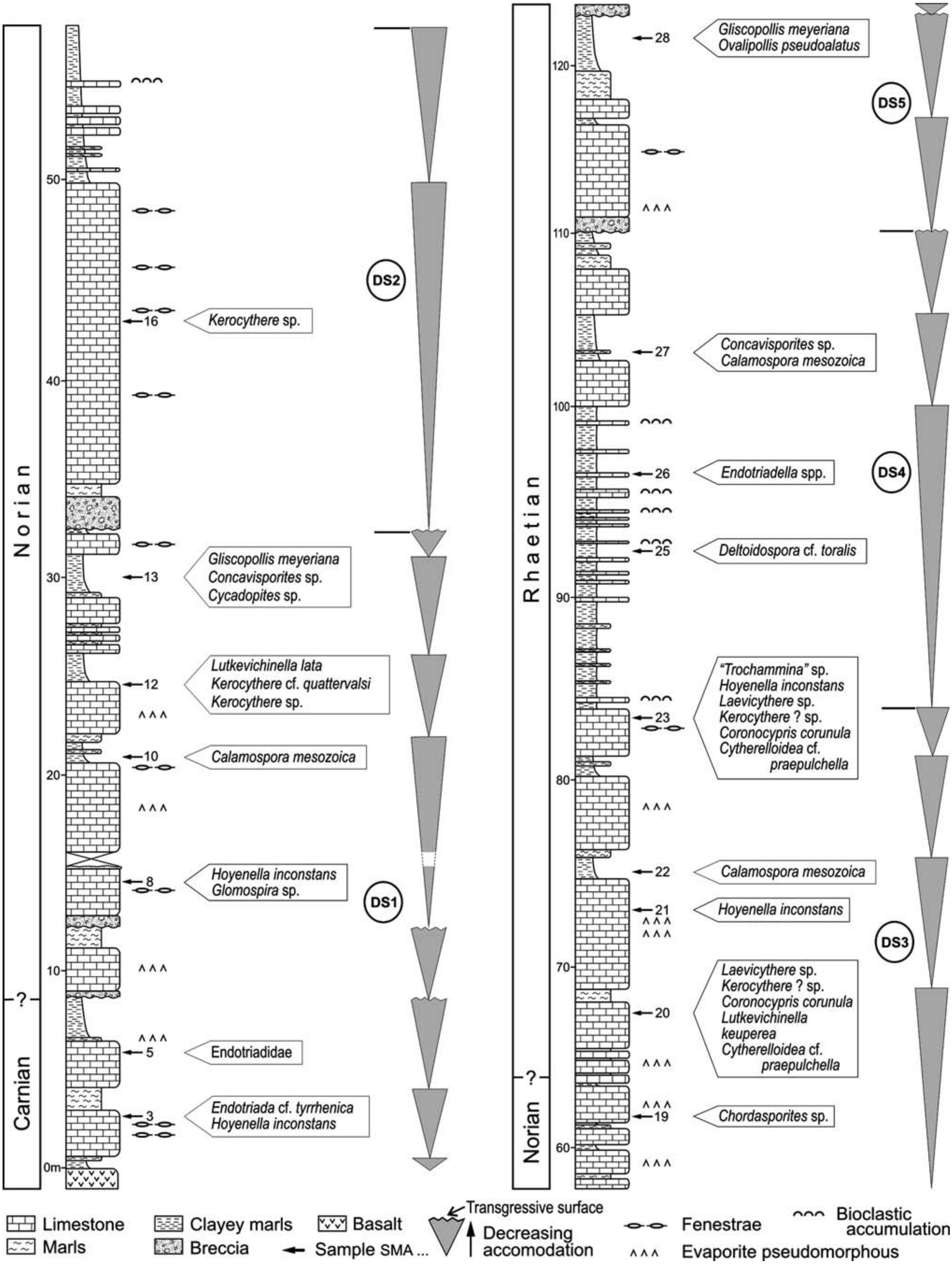
Mudstone (MF1) and fine-grained peloidal wackestone/packstone (MF2) occur in lagoonal-peritidal environment. The low biotic diversity of foraminifers and ostracods indicates high-stressed habitat in very shallow restricted areas, where great fluctuations in salinity and temperature probably occurred. Under such conditions, short-term exposures with evaporite precipitation may have taken place as testified by corresponding mineral molds.

The bioclastic packstone (MF3) and the ostracod/peloidal packstone to grainstone (MF5) are considered to have originated as a storm deposit in the backshoal lagoon on the carbonate ramp. The main textural criteria to validate our interpretation is the presence of distinct differences in grain sizes of these layers and of under- and overlying beds (i.e. mudstones and wackestones) (Aigner 1985). These storm layers are flat-bedded, bioclast-dominated and coarse grained. In MF3 redeposited, crinoids are present, which are derived from open-marine environments. The relative abundance of lithoclasts (MF3), comprising distinctly microfacies, and rounded grains point to high-energy events and erosion in a peritidal environment. The concentrations of mixed lagoonal and open inner-ramp marine biota together with abundant peloids reinforce the proposed depositional model.

The lumachelles microfacies (MF6) may originate from short-term events (Kidwell 1991). Based on the packing of skeletal elements, which is mud-supported, the deposition takes place in an open-marine setting on a carbonate mid-ramp. A low-energy environment below the wave base is proposed. The presence of coated bioclasts with micrite envelopes indicates that during the decline of storm intensity, the material coming from very shallow environments was transported by offshore-directed bottom currents.

In the fine- to coarse-grained non-laminated packstone/grainstone (MF7), restricted diversity of bioclasts (only ostracods) and dominance of micritic peloids indicate deposition in the inner ramp, perhaps peritidal, settings with poor connection with the middle ramp. The absence of laminations, evaporitic signature and of subaerial exposure may exclude deposition in evaporitic arid platform interiors, where this facies would also occur.

In the Punta Bassano succession, peritidal intraformational breccias (MF8) are interpreted to have formed by synsedimentary deposition of eroded carbonates probably related to storm events. However, the more thick and discontinuous brecciated bodies may result from the


Norian
Carnian
?
0m
10
20
30
40
50
3
5
8
10
12
13
16
Endotriada cf. tyrrhenica
Hoyenella inconstans
Endotriadidae
Hoyenella inconstans
Glomospira sp.
Calamospora mesozoica
Lutkevichinella lata
Kerocythere cf. quattervalsi
Kerocythere sp.
Gliscopollis meyeriana
Concavisporites sp.
Cycadopites sp.
Kerocythere sp.
DS1
DS2
Rhaetian
Norian
?
60
70
80
90
100
110
120
19
20
21
22
23
25
26
27
28
Chordasporites sp.
Laevicythere sp.
Kerocythere ? sp.
Coronocypris corunula
Lutkevichinella
keuperea
Cytherelloidea cf.
praepulchella
Hoyenella inconstans
Calamospora mesozoica
"Trochammina" sp.
Hoyenella inconstans
Laevicythere sp.
Kerocythere ? sp.
Coronocypris corunula
Cytherelloidea cf.
praepulchella
Deltoidospora cf. toralis
Endotriadella spp.
Concavisporites sp.
Calamospora mesozoica
Gliscopollis meyeriana
Ovalipollis pseudoalatus
DS3
DS4
DS5
Limestone
Marls
Clayey marls
Breccia
Basalt
Sample SMA ...
Transgressive surface
Decreasing accomodation
Fenestrae
Bioclastic accumulation
Evaporite pseudomorphous

solution-collapse of beds (e.g. evaporites) because even though the evaporites were not directly observed in the field, algal mats, evaporite pseudomorphs and cellular structures provide evidence for evaporites (Eliassen and Talbot 2005).

Finally, the clayey marls and marls (MF9) are interpreted as being deposited in restricted lagoonal areas (e.g. in a back-ramp) under low-energy conditions. The reduced diversity of shallow-water biota, which are only represented by non-disarticulated ostracods with high number of individuals, confirms this interpretation.

Facies types and assemblages of the Punta Bassano succession are closely comparable to those of other Alpine Upper Triassic carbonate settings, pointing to similar peritidal depositional conditions. Typical examples are the Lofer sequences in the Northern Calcareous Alps (e.g. Flügel 1981; Enos and Samankassou 1998), the Fatric Unit in the West Carpathians, Slovakia (Tomasovych 2004), the Kössen Formation in the Northern Calcareous Alps (Kuss 1983) and the Calcare di Zu Formation in the Southern Calcareous Alps (Lakew 1990). However, the Punta Bassano facies indicate more restricted position of the intra-platform environments from the open ocean, as demonstrated by the complete absence of patch-reefs and derived skeletal grains, as well as by the poor diversity of the microfaunal assemblages.

## Biostratigraphy

Biostratigraphically (foraminifers and palynomorphs) as well as palaeoecologically (ostracods) significant microfossils, occur all along the Upper Triassic Punta Bassano succession. Foraminifers have been studied on thin sections (SMA: 3, 5, 8, 9, 11 to 14, 16, 18, 19, 21, 23, 24, 26 and 27; the significant samples are: SMA: 3, 5, 8, 21, 23 and 26).

Samples for palynological slides (SMA: 2, 3/1, 5/1, 7/1, 8/1, 10, 11/1, 12, 13, 15, 17, 19/1, 22, 25, 27, 27/1, 27/2 and 28; the significant samples for the palynomorphs are: SMA: 13, 19/1, 25, 27 and 28) and for ostracod extractions (SMA: 12, 16, 20 and 23; all samples are significant) were collected both in limestones and in clayey marls and marls (Fig. 5).

### Foraminifers

The investigation of thin sections in the Punta Bassano section evidenced monotonous associations of foraminifers, represented by a low number of individuals. They are most abundant in the peloidal wackestone/packstone (MF2) where the foraminifers sometimes co-occur with abundant ostracods as well as bivalve and echinoderm fragments. Preservation of microfauna is quite poor due to strong recrystallisation, which affects the entire succession.

The biostratigraphically significant species of benthic foraminifers are *Hoyenella inconstans* (Fig. 6a, b) and *Endotriada* cf. *tyrrhenica* (Fig. 6c). They have been found in association with *"Trochammina"* (Fig. 6e), *Endotriadella* (Fig. 6f, g) and *Glomospira*.

*Hoyenella inconstans* is a reliable marker for the Upper Triassic Alpine Tethys (Kamoun et al. 1994 with synonymy; Martini et al. 1998). It occurs at different levels of the sequence (Fig. 5), in the lower and in the middle part, respectively (SMA: 3, 8 and 21), and allows us to attribute this interval to Late Triassic (Carnian-Norian to Rhaetian).

We notice that the stratigraphic range of this species is corroborated by its occurrence with the zone marker *Triasina hantkeni* in many Upper Triassic successions, like in the *Raetavicula contorta* beds in the Northern Apennines (Ciarapica et al. 1987) and in the Briançonnais Domain in the Western Alps and in the Préalpes Médianes (Zaninetti et al. 1986).

### Palynomorphs

The palynological study was carried out on both limestone and clayey marls and marls intervals (Fig. 5). The palynological assemblage is not too much differentiated across the Punta Bassano succession but the percentage of sporomorphs increase upwards, reaching its maximum at around 30 m from the base of the succession (SMA13).

The most common and biostratigraphically significant species is *Gliscopollis meyeriana* (Fig. 6h, i), which occurs at 30 m from the base of the section (SMA13) to its end (SMA28). Other accessory elements are present, such as *Ovalipollis pseudoalatus* (Fig. 6j), *Concavisporites* sp., *Deltoidospora* cf. *toralis, Calamospora mesozoica, Cycadopites* sp. and *Chordasporites* sp. This assemblage can be assigned to the Norian-Rhaetian (Schuurman 1977, 1979; Morbey 1975; Morbey and Dunay 1978; Visscher and Brugman 1981; Warrington 1996). This age assignment is in agreement with the foraminifer's distribution.

### Ostracods

Ostracods are the most abundant and most common microorganisms in the whole Punta Bassano succession, as is expected due to the restricted depositional environment of the sequence. Combined with both the microfacies and the micropalaeontological analyses, the study of the ostracods helped to refine the depositional environment of the Punta Bassano succession.

The most representative genera and species, belonging to five families are *Laevicythere*, *Kerocythere* cf. *quattervalsi* (Fig. 6k, l), *Lutkevichinella lata* (Fig. 6m, n), *Cytherelloidea* cf. *praepulchella* (Fig. 6o, p), *Lutkevichinella keuperea* (Fig. 6q, r), and *Coronocypris corunula*.

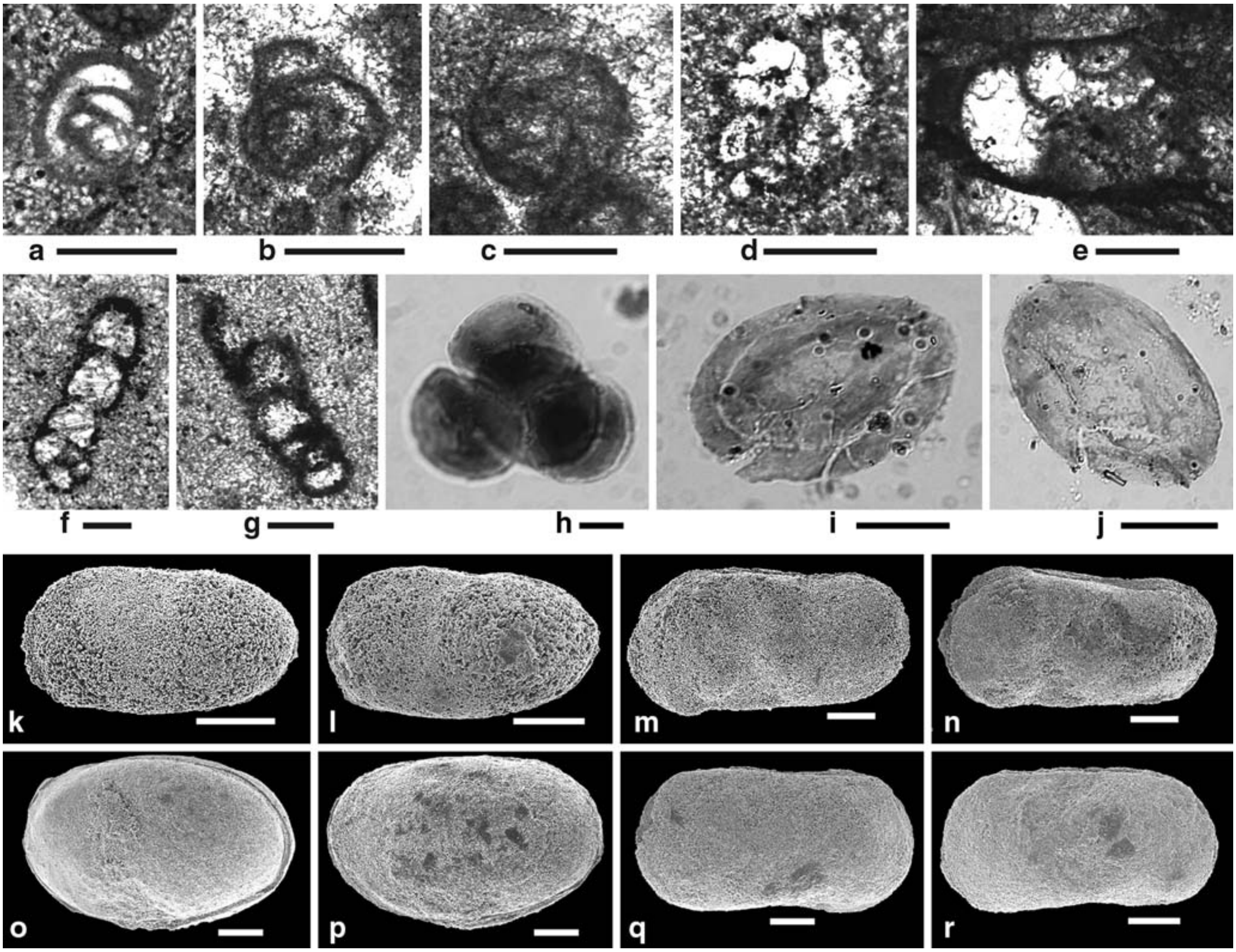



**Fig. 6** Characteristic microfauna and microflora of the Punta Bassano carbonate succession. Foraminifers: **a**, **b** *Hoyenella inconstans* (**a** SM23; **b** SM3). **c** *Endotriada* cf. *tyrrhenica* (SM3). **d** Endotriadidae (SM5). **e** "*Trochammina*" (SM12). **f**, **g** *Endotriadella* spp. (SM26). For the foraminifers, the *scale bar* represents 100 µm. Palynomorphs: **h**, **i** *Gliscopollis meyeriana* (**h** as tetrad status SM13; **i** SM28). **j** *Ovalipollis pseudoalatus* (SM28). For the palynomorphs, the *scale bar* represents 10 µm. Ostracods: **k**, **l** *Kerocythere* cf. *quattervalsi* (SM12). **m**, **n** *Lutkevichinella lata* (SM12). **o**, **p** *Cytherelloidea* cf. *praepulchella* (SM20). **q**, **r** *Lutkevichinella keuperea* (SM20). For the ostracods, the *scale bar* represents 100 µm

The association *Lutkevichinella lata*/*Kerocythere* cf. *quattervalsi*, found in sample SMA12, is in agreement with a Ladinian-Norian age. The associations *Coronocypris corunula*/*Lutkevichinella keuperea*/*Cytherelloidea* cf. *praepulchella* and *Cytherelloidea* cf. *praepulchella*/*Laevicythere*/*Kerocythere*, found in the samples SMA20 and SMA23, respectively, point out a Carnian-Rhaetian interval.

## Depositional environment

The depositional environment of the Punta Bassano series can be divided into five depositional systems, DS1 to DS5, displaying shallowing-upward trend (Fig. 5). They have been defined and interpreted in terms of palaeoenvironmental evolution, based on micro-, bio-, and palyno-facies analyses. The following steps are suggested to explain the facies superposition and depositional patterns across the section.

### DS1

The first system covers the early 30 m of the succession. It is composed of eight shallowing-upward cycles from homogeneous limestone (lithofacies type 1) to clayey marls and marls (lithofacies type 6), which underline the end of each genetic unit. The limestone intervals of each cycle normally start with mudstone (MF1), sometimes containing intermittent-energy storm deposits (MF3 and MF5), and end either with laminated mudstone (MF4) or with peloidal wackestone/packstone with evaporite pseudomorphs (MF2). Fenestral fabrics and peloids, interpreted to by largely derived from in situ mechanical deformation of disjointed cryptalgal laminae, occur at different levels. The shallowing-upward cycles end with clayey marls and marls (MF9), reflecting a decrease of accommodation space related to a fall in relative sea level.

The first five cycles are indicative of accumulation in very shallow restricted lagoonal-peritidal environments under low water-energy conditions, and probably submitted to salinity fluctuations, as attested by the presence of abundant evaporite pseudomorphs.

In the last three cycles, the higher-energy facies (e.g. MF6 and MF7) become more abundant, indicating a better connection to the open sea. The ostracods association also confirms this trend by the presence of the small ostracod genus *Kerocythere* (Fig. 6k, l), associated with the large genus *Lutkevichinella* (Fig. 6m, n), which indicates a saline to brackish environment. We consider that this genus is allochthonous here.

Two levels of intraformational breccias (MF8) are present in this depositional system, directly overlaying the third and the fourth genetic units. As recorded in many other shallow shelf settings (Baum and Vail 1988), lowstand system tracts are absent in the Punta Bassano series. Consequently, these breccias, which correspond to transgressive surfaces, may point to sequence boundaries.

DS2

This depositional system, represented by two cycles, is 28 m thick. The first one starts with 2-m-thick intraformational breccias (MF8), which indicate a transgressive system tract. Afterwards, the depositional conditions remain constant on the first genetic unit, composed by successive shallowing-upward facies. This trend includes the microfacies MF1 to MF7 of which, the laminated fenestral wackestone is well developed. This sequence is interpreted as having formed in the upper intertidal to supratidal environment of a tidal flat (e.g. peritidal "island") on which deposition/subsidence rate seems to be constant, according to the regular alternation of the facies. Connections to the open sea were ensured, as attested by the genus *Kerocythere*, a species being characteristic for an open-marine environment.

The second cycle indicates slightly deepening conditions. It is richer in clayey marls and marls, deposited in a backshoal lagoon, under very low energy conditions. The limestone is only represented by few intercalations of isolated beds of mudstone (MF1). Only one bioclastic-rich level, exclusively composed of crinoid fragments (MF3), indicates a storm-influenced depositional setting.

DS3

This depositional system records deepening and more open-marine influences. It reaches a thickness of 26 m, and is made by four shallowing-upward cycles ending with decimetre-thick clayey marls and marl intervals. The microfacies of each cycle reveal higher energy depositional conditions and the deposition of bioclastic/peloidal wackestone/packstone to grainstone took place (MF3, MF5 and MF7). Occasionally, lumachelle layers (MF6) also occur as crinoidal grainstone. The environmental setting of the sequence refers to a shallow-marine shoal environment, under medium to high energy. Two ostracod associations have been found in this interval; both contain the genera *Cytherelloidea* and *Laevicythere* which characterise a shallow and warm-water setting. The presence of the species *Coronocypris corunula* in the ostracod association from the last cycle clearly indicates more open-marine influences on the shallow-marine environment.

DS4

This sequence, 24 m thick, is subdivided into three distinct cycles. The thicker, lower cycle is quite similar to the second cycle of DS2. It is mostly composed of clayey marls and marls and reflects quiet and sheltered water conditions in a backshoal lagoonal setting. Thin levels of bioclastic wackestone/packstone (MF3 and MF5) and shelly packstone (MF6) are commonly intercalated, indicating shallower, higher-energy conditions.

The two following shallowing-upward cycles start with mudstone (MF1), sometimes containing intermittent-energy storm deposits, and end with decimetre-thick beds of clayey marls and marls, similarly to the basal cycles of DS1. Mudstone deposited in the very shallow restricted lagoonal environment, and storm layers accumulated during increasing hydrodynamic activity.

DS5

The last sequence is surely incomplete, because of a distinct fault. The recognised lower cycle starts with a 1-m-thick intraformational breccia (MF8) level, followed by a limestone interval and then by thin marls. The microfacies of the limestone are peloidal wackestone/packstone (MF2), which gradually passes into a laminated wackestone (MF4) with fenestral fabrics. This sequence is interpreted as an upper intertidal to supratidal environment of a tidal flat, likewise the first genetic cycle of DS2. The breccias might indicate the sequence boundary.

The second cycle shows a low-energy facies, from laminated wackestone (MF4) to clayey marls and marls (MF9). It results from deposition on lagoonal/peritidal protected areas.

The studied sequence ends with a decimetre-thick bed of intraformational breccia (MF8), representing a transgressive surface.

Conclusively, the depositional setting of the Punta Bassano succession was a carbonate ramp with very low topographic relief and hence created extremely large homogeneous facies tracts. As shown above, the accommodation space created sufficient palaeobathymetry to generate more open higher hydrodynamic conditions by both wave and tidal action. The increase of accommodation space was probably initiated by subsidence, followed by platform flooding and hence transgression. Inversely, sea-level falls could quickly isolate the ramp interiors reducing the hydrodynamic energy levels, and creating widespread lagoonal-peritidal restricted environments and fresh water circulation.

## Conclusions

The Upper Triassic Punta Bassano succession at Marettimo Island (Egadi Archipelago, Sicily) provides valuable sedimentological and palaeontological data for the interpretation of the depositional environment and to precise the palaeogeographic scenario.

- Biostratigraphy, based on foraminiferal and palynological data, indicates a Carnian-Norian to Rhaetian age for the Punta Bassano section. This range is consistent with the indications given by ostracod associations.
- The whole succession has been deposited in a shallow inner ramp zone, including open-marine as well as lagoonal and peritidal protected environments. Low- and high-energy shoal facies have been recognised and their lateral distribution along the carbonate ramp has been reconstructed. Periodic storm activity influenced the distribution and preservation of textural components. Depositional systems analysis revealed the existence of five cycles, displaying shallowing-upward trend.
- Facies types and biostratigraphic content are closely comparable to those known from the Upper Triassic epeiric carbonate platform on the northwest to northeast margin of the Tethys Ocean (e.g. Lofer sequences and Kössen Formation in the Northern Calcareous Alps; Fatric Unit in the West Carpathians; Calcare di Zu Formation in the southern Calcareous Alps). However, the Punta Bassano facies indicate a more restricted position of the intra-platform environments because (1) patch-reefs and derived skeletal grains are missing, and (2) by the poor diversity of the microfaunal assemblages.
- The comparison of facies and microfauna with those from other Mediterranean coeval sequences (Pyrenees: Fréchengues et al. 1990, 1993; Peybernes et al. 1988; Corsica: Peybernes et al. 1991; Sardinia: Carillat et al. 1999; and Tunisia: Kamoun et al. 1994) allow us to confine the Punta Bassano's sedimentation on the northern margin of the Tethys Ocean, of the European crust between Corsica and Pyrenees. Before this study, Marettimo Island was considered as located in the internal part of the Panormide carbonate platform, during the Late Triassic (Abate et al. 1978a, 1978b, 1982).
- These new results refine the existing regional tectonic model and indicate that Marettimo Island, which is considered as a single structural element, is a piece of the southern margin of the European Plate displaced further to the detachment of the Corso-Sarde block and incorporated within the Egadi Archipelago.

**Acknowledgments** The authors wish to thank the reviewers (Prof. A. Munnecke and an anonymous reviewer) for their very constructive remarks, and express their sincere gratitude to Dr. S. Crasquin-Soleau (CNRS-Université Pierre et Marie Curie, Paris, France) for help with the determination of the ostracods. We are grateful to J. Metzger (University of Geneva) for the help in computer drafting. This work was financially supported by the Swiss National Science Foundation.

## References

Abate B, Catalano R, D'Argenio B, Di Stefano P, Lo Cicero G (1978a) The Panormide-Saccense evaporitic-carbonatic embayment. A Triassic sedimentary domain of western Sicily. In: Sixth meeting of carbonate sedimentologists, Liverpool, Abstract

Abate B, Catalano R, Renda P (1978b) Schema geologico dei Monti di Palermo. Boll Soc Geol It 97:807–819

Abate B, Lo Cicero G, Renda P (1982) Facies carbonatiche ed evaporitiche del Trias superiore di Marettimo. Rend Soc Geol It 5:71–76

Abate B, Feruzza G, Incandela A, Renda P (1995) Tettonica trascorrente nelle Isole Egadi (Sicilia occidentale). Studi Geologici Camerti Vol Spec 2:9–14

Abate B, Incandela A, Renda P (1996) Lineamenti strutturali dell'Isola di Marettimo. Mem Soc Geol It 51:23–33

Abate B, Incandela A, Renda P (1999) Geologia dell'isola di Marettimo (Arcipelago delle Egadi, Sicilia occidentale). Naturalista sicil S. IV-XXIII 1–2:3–41

Aigner T (1985) Biofabrics as dynamic indicators in nummulite accumulation. J Sediment Petrol 55:131–134

Bathurst RG (1966) Boring algae, micritic envelopes and lithification of molluscan biosparites. Geol J 5:15–32

Baum GR, Vail PR (1988) Sequence stratigraphy concepts applied to Paleogene outcrops, Gulf and Atlantic basins. In: Wilgus CK, Hastings BS, Kendall CGStC, Posamentier HW, Ross CA, Van Wagoner JC (eds) Sea-level changes: an integrated approach. Soc Econ Paleont Min Spec Publ 42:309–327

Carillat A, Martini R, Zaninetti L, Cirilli S, Gandin A, Vrielynck B (1999) The Muschelkalk (Middle to Upper Triassic) of the Monte di Santa Giusta (NW Sardinia): sedimentology and biostratigraphy. Eclogae geol Helv 92:81–97

Catalano R, Di Stefano P, Nigro F, Sulli A, Vitale PF (1995) Evoluzione paleogeografica e strutturale della Sicilia e dei mari adiacenti. Naturalista sicil série IV-XIX 3–4:143–187

Ciarapica G, Cirilli S, Passeri L, Trincianti E, Zaninetti L (1987) "Anidriti di Burano" et "Formation du Cetona" (nouvelle formation), biostratigraphie de deux series-types du Trias supérieur dans l'Apennin septentrional. Rev Paléobiol 6:341–409

Crasquin-Soleau S, Vaslet D, Le Nindre Y-M (2005) Ostracods as markers of the Permian/Triassic boundary in the Khuff Formation of Saudi Arabia. Palaeontology 48:853–868

Di Stefano P, Avellone G, Basilone L, Mallarino G., Nicchitta D (1997) Upper Triassic reef to back-reef lagoon facies in the Panormide Platform. Eurobasin Euroconference 8th Workshop of ILP Task Force "Origin of sedimentary basins" Palermo, Italy, 7–13 June, 1997, pp 26–30

Eliassen A, Talbot MR (2005) Solution-collapse breccias of the Minkinfjellet and Wordiekammen Formations, Central Spitsbergen, Svalbard: a large gypsum palaeokarst system. Sedimentology 52:775–794

Elter P, Grasso M, Parotto M, Vezzani L (2003) Structural setting of the Apennine-Maghrebian thrust belt. Episodes 26(3):205–211

Enos P, Samankassou E (1998) Lofer cyclothems revisited (Late Triassic, northern Alps, Austria). Facies 38:207–228

Fischer AG (1964) The Lofer cyclothems of the Alpine Triassic. Kansas Geol Surv Bull 169:107–149

Flügel E (1981) Paleoecology and facies of Upper Triassic reefs in the northern Calcareous Alps. SEPM Spec Publ 30:291–359

Flügel E (2004) Microfacies of carbonate rocks. Springer, Berlin Heidelberg New York, p 976

Fréchengues M, Martini R, Peybernès B, Zaninetti L (1990) Mise en évidence d'associations de foraminifères benthiques dans la séquence de dépôt ladino ?-carnienne du "Muschelkalk" des Pyrénées Catalanes (France, Espagne). CR Acad Sci Paris t.310 série II 667–673

Fréchengues M, Peybernès B, Martini R, Zaninetti L (1993) Les foraminifères benthiques ladino-carniens du "Muschelkalk" des Pyrénées françaises à l'Est de la Garonne. Rev Micropal 36:111–120

Giunta G, Liguori V (1973) Evoluzione paleotettonica della Sicilia Nord-Occidentale. Boll Soc Geol It 92:903–924

Kamoun F, Peybernès B, Martini R, Zaninetti L, Vila J-M, Trigui A, Rigane A (1994) Association de foraminifères benthiques dans les séquences de dépôt du Trias moyen?-supérieur de L'Atlas tunisien central et méridional. Geobios 31:703–714

Kidwell SM (1991) The stratigraphy of shell concentrations. In: Allison PA, Briggs DEG (eds) Taphonomy-releasing the data locked in the fossil record. Plenum Press, New York, pp 211–290

Kuss J (1983) Faziesentwicklung in ein proximales Intaplatform Becken: Sedimentation, Palökologie und Geochemie der Kössen Schichten (Ober Trias, Nördliche Kalkalpen). Facies 9:61–172

Jacobacci A (1955) Primi risultati dei rilevamenti geologici effettuati durante l'anno 1954. Boll Serv Geol It1954 LXXVI/2:491–495

Lakew T (1990) Microfacies and cyclic sedimentation of the Upper Triassic (Rhaetian) Calcare di Zu (southern Alps). Facies 22:187–232

Logan BW, Semeniuk V (1976) Dynamic metamorphism; process and products in Devonian carbonate rocks: Canning Basin, eastern Australia. West Austral Geol Soc Spec Publ Canning, Basin 6, p 138

Malatesta A (1964) Trias fossilifero a Marettimo nelle Isole Egadi. Atti Soc Tosc Sci Nat 71:187–199

Martini R, Gandin A, Zaninetti L (1989) Sedimentology, stratigraphy and micropaleontology of the Triassic evaporitic sequence in the subsurface of Boccheggiano and in some outcrops of southern Tuscany (Italy). Riv It Paleont Strat 95:3–28

Martini R, Girod F, Zaninetti L (1998) Découverte de foraminifères et confirmation de l'âge Norien et Rhétien du Trias des Préalpes Médianes Plastiques (Massif des Cornettes de Bise, Préalpes du Chablais, Suisse et France). Eclogae geol Helv 91:69–74

Monteil E (1985) Les dynokystes du Valanginian du Bassin du Sud-Est (Ardèche, France). Doctoral thesis, Pierre et Marie Curie, Paris 6, p 314

Morbey SJ (1975) The palynostratigraphy of the Rhaetian Stage, Upper Triassic in the Kendelbachgraben, Austria. Palaeontographica (B) 152:1–75

Morbey SJ, Dunay RE (1978) Early Jurassic to Late Triassic dinoflagellate cysts and miospores. In: Thusu B (ed) Distribution of biostratigraphically diagnostic dinoflagellate cysts and miospores from the Northwest European continental shelf and adjacent areas. Continental Shelf Inst Publ 100:47–59

Peybernes B, Martini R, Taugourdeau-Lantz J, Zaninetti L (1988) Caractérisation micropaléontologique du Rhétien dans les Pyrénées française entre Garonne et Méditerranée. Rev Paléobiol 7:137–161

Peybernes B, Martini R, Zaninetti L (1991) Les foraminifères benthiques du Trias carbonaté (Ladinien ? - Carnien et Rhétien) de Corse. Geobios 24:683–696

Schuurman WML (1977) Aspects of Late Triassic palynology. 2. Palynology of the "Grès et Schiste à *Avicula contorta*" and "Argiles de Levallois" (Rhaetian) of northeastern France and southern Luxemburg. Rev Palaeobot Palynol 23:159–253

Schuurman WML (1979) Aspects of Late Triassic palynology. 3. Palynology of latest Triassic and earliest Jurassic deposits of the Northern Limestone Alps in Austria and southern Germany, with special reference to a palynological characterization of the Rhaetian Stage in Europe. Rev Palaeobot Palynol 27:53–75

Schwarzacher W (2000) Repetitions and cycles stratigraphy. Earth-Sci Rev 50:51–75

Stampfli GM, Borel GD (2004) The TRANSMED transects in space and time: Constraints on the paleotectonic evolution of the Mediterranean domain. In: Cavazza W, Roure F, Spakman W, Stampfli GM, Ziegler P (eds) The TRANSMED atlas: the Mediterranean Region from crust to mantle. Springer, Berlin Heidelberg New-York, pp 53–80 & CD ROM

Tomasovych A (2004) Microfacies and depositional environment of an Upper Triassic intra-platform carbonate basin: the Fatric Unit of the West Carpathians (Slovakia). Facies 50:77–105

Visscher H, Brugman AW (1981) Ranges of selected palynomorphs in the Alpine Triassic of Europe. Rev Palaeobot Palynol 23:1–117

Warrington G (1996) Triassic spores and pollen. In: Jansonius J, McGregor DC (eds) Palynology: principles and applications. Am Assoc Stratigr Palynol Found 2:755–766

Zaninetti L, Martini R, Salvini-Bonnard G, Ciarapica G, Dumont T (1986) Sur quelques foraminifères du Trias supérieur du Domaine Subbriançonnais (Alpes occidentales et Préalpes Médianes); comparaison avec des microfaunes de l'Apennin septentrional et des Carpates occidentales; découverte de *Triasina hantkeni* dans le Domain Subbriançonnais. Rev Paléobiologie 5:261–268