ORIGINAL ARTICLE

Adam Tomašových

Microfacies and depositional environment of an Upper Triassic intra-platform carbonate basin: the Fatric Unit of the West Carpathians (Slovakia)

Abstract Facies associations of the Rhaetian Fatra Formation from the Veľká Fatra Mts. (West Carpathians) were deposited in a storm-dominated, shallow, intra-platform basin with dominant carbonate deposition and variable onshore peritidal and subtidal deposits, with 21 microfacies types supported by a cluster analysis. The deposits are formed by bivalves, gastropods, brachiopods, echinoderms, corals, foraminifers and red algae, ooids, intraclasts and peloids. A typical feature is the considerable variation in horizontal direction. The relative abundance and state of preservation of components as well as the fabric and geometric criteria of deposits can be correlated with depth/water energy-related environmental gradients. Four facies associations corresponding to four types of depositional settings were distinguished: a) peritidal, b) shoreface, above fair-weather wave base (FWWB), c) shallow subtidal, above normal storm wave base and d) above maximum storm wave base. The depositional environment can be characterized as a mosaic of low-relief peritidal flats and islands, shoreface banks and bars, and shallow subtidal depressions. The distribution and preservation of components were mainly controlled by the position of base level (FWWB), storm activity and differences in carbonate production between settings. Poorly or moderately diverse level-bottom macrobenthic assemblages are dominated by molluscs and brachiopods. The main site of patch-reef/biostrome carbonate production was located below the fair-weather wave base. Patch-reef/biostrome assemblages are poorly diverse and dominated by the branched scleractinian coral *Retiophyllia,* forming locally dm-scale autochthonous aggregations or more commonly parautochthonous assemblages with evidence of storm-reworking and substantial bioerosion by microborings and boring bivalves.

A. Tomašových (✉)
Institut für Paläontologie, Würzburg Universität,
Pleicherwall 1, 97070 Würzburg, Germany
e-mail: adam.tomasovych@mail.uni-wuerzburg.de
Tel.: +49-931-312512
Fax: +49-931-31 25 04

Facies types and assemblages are comparable in some aspects to those known from the Upper Triassic of the Eastern and Southern Alps (Hochalm member of the Kössen Formation or Calcare di Zu Formation), pointing to similar intra-platform depositional conditions. The absence of large-scale patch-reefs and poor diversity of level-bottom and patch-reef/biostrome assemblages with abundance of eurytopic taxa indicate high-stress/unstable ecological conditions and more restricted position of the Fatric intra-platform setting from the open ocean than the intra-platform habitats in the Eastern or Southern Alps.

Introduction

The Upper Triassic epoch represents the start of the modern coral-reef community type (Wood 1999) and the onset of coral-zooxanthellae symbiosis (Stanley 1988; Stanley and Swart 1995), the establishment of first Mesozoic epibiont communities (Lescinsky 2001), the appearance of abundant bivalve macroborers (Perry and Bertling 2000), and the Norian and Rhaetian stages correspond to the global reef bloom (Flügel 2002). However, the end-Triassic mass extinction event represents a period of significant paleobiological and paleoenvironmental change, when nearly 40% of invertebrate genera did not survive into the Jurassic (Raup and Sep-koski 1982, 1986) and reef ecosystems were affected by a significant drop in the global carbonate production (Flügel and Kiessling 2002).

In the Fatric Unit of the West Carpathians, relatively well-preserved Rhaetian-Hettangian marine successions occur (Gadzicki et al. 1979; Michalík and Gadzicki 1983). Although the precise position of the Rhaetian-Hettangian boundary is questionable in these sections due to absence of biostratigraphic-valuable taxa, the reconstruction of the Rhaetian depositional environment of the Fatric Unit can

be very useful in understanding the nature of pre-extinction benthic associations on local and regional scales.

Sedimentological features and paleontologic content of the uppermost Triassic strata of the Fatric Unit are relatively well-documented (Michalík 1973, 1974, 1977, 1979, 1980, 1982; Michalík and Jendrejáková 1978; Gadzicki 1974, 1983), with some detailed information on brachiopods (Michalík 1975), corals (Roniewicz and Michalík 1991a, 1991 b, 1998), bivalves (Kochanová 1967; Gadzicki 1971) and vertebrates (Duffin and Gadzicki 1977). The results of these studies show a high variation in the composition and preservation of the deposits. However, detailed microfacies and paleoenvironmental analyses on a small-scale level are rare and depositional models are mostly absent.

Paleoenvironmental reconstruction of the whole depositional setting of the Fatric Unit was performed by Michalík (1977) who recognized ten facies areas on an approximately 300-km-long transect through the West Carpathians. The scale of observation in this study includes only a small portion of this intra-platform depositional setting, which is now preserved in a 25-km-long transect in the Veľká Fatra Mountains (central Slovakia). This area is characterized by the presence of relatively well-exposed sections and was therefore chosen for this study.

The goals of this study are a) to define particular microfacies types, based on 5 lithologic sections, their spatial and temporal distribution and the relationship between components, and b) to interpret of the depositional setting and its comparison with coeval settings on the NW-Tethyan carbonate platforms. The first aspect is necessary as it provides high-resolution framework for understanding the horizontal facies variation. These deposits contain fossil assemblages with abundant taxa like corals, bivalves and brachiopods that were substantially affected by the end-Triassic extinction (Hallam 1996, 2002; Hallam and Wignall 1997) and can therefore provide important information about distribution patterns and habitats of these fossil groups at the end of the Triassic.

Geologic Setting

During the Upper Triassic, the West Carpathians were situated on the extensive epeiric carbonate platform on the northwestern margin of the Tethys Ocean in the subtropical climatic belt (Michalík 1994; Gawlick 2000) (Fig. 1). The Upper Triassic carbonate platform of the West Carpathians had been subdivided into several shore-parallel depositional settings, now preserved in various paleotectonic units. In a simplified scheme, the most proximal nearshore zone was formed by extremely shallow or continental deposits, followed seaward by intra-platform mixed carbonate-siliciclastic or predominantly carbonate basins (this is the position of the Fatric Unit), a Dachstein carbonate platform and finally rimming Dachstein-reefs (Haas et al. 1995). The Rhaetian
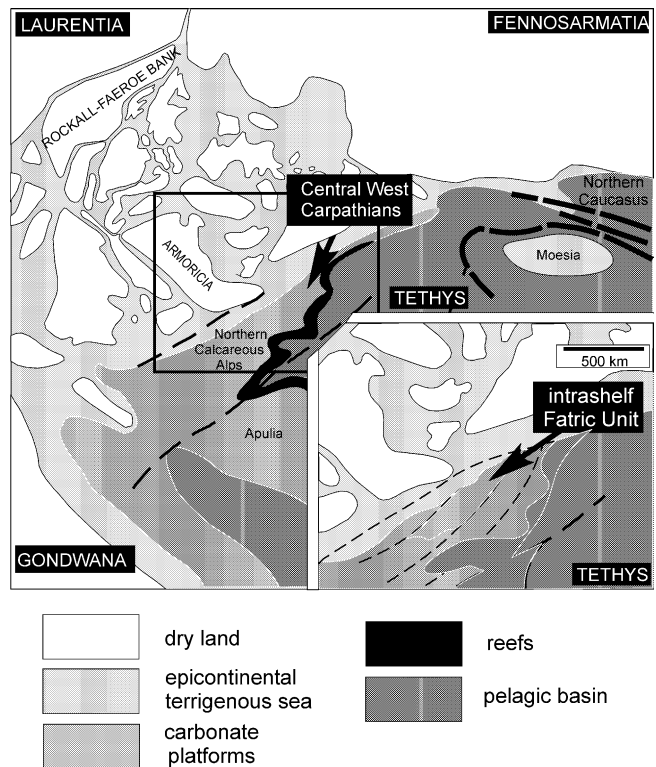

Fig. 1 General paleogeographic position of the Fatric Unit (Central West Carpathians) in the Upper Triassic (Norian/Rhaetian). After Michalík (1994), modified

Fatra Formation was deposited in a shallow-water intra-platform, marine, predominantly carbonate setting of the Fatric Unit (West Carpathians) (Michalík 1982) (Fig. 2). Only in the southernmost part of the Fatric Unit depositional area, restricted peloidal bars/shoals of the Svätý Jakub Formation were deposited (Tomašových and Michalík 2000). In the Fatra Formation, the Rhaetian age is confirmed by the first appearance of foraminifers *Triasina hantkeni* and *Glomospirella friedli* (Gaździcki 1983) and brachiopod *Austrirhynchia cornigera*.

Carbonate deposition took place under a low subsidence regime. The proportion of siliciclastic admixture is mostly very limited. The studied area of the Fatric Unit was most probably connected with the Tethys Ocean either via the shallow Dachstein platform top, or perhaps through a system of deeper intra-platform basins formed by the depositional settings of the Hronic (West Carpathians), Bajuvaric and Tirolic Unit (Eastern Alps). At the beginning of the Jurassic, the depositional regime in the Fatric Unit was abruptly replaced by the terrigenous sedimentation of the Kopienec Formation (Hettangian-Early Sinemurian, Fig. 2). In the overlie of the basal clastic member of the Kopienec Formation, ammonites *Psiloceras psilonotum* (Quenstedt) and *Caloceras* cf. *torus* (d'Orbigny), equivalent to the Early Hettangian *Psiloceras planorbis* Zone, were documented (Rakús 1993). Therefore, the age of lowermost part of the Kopienec Formation,
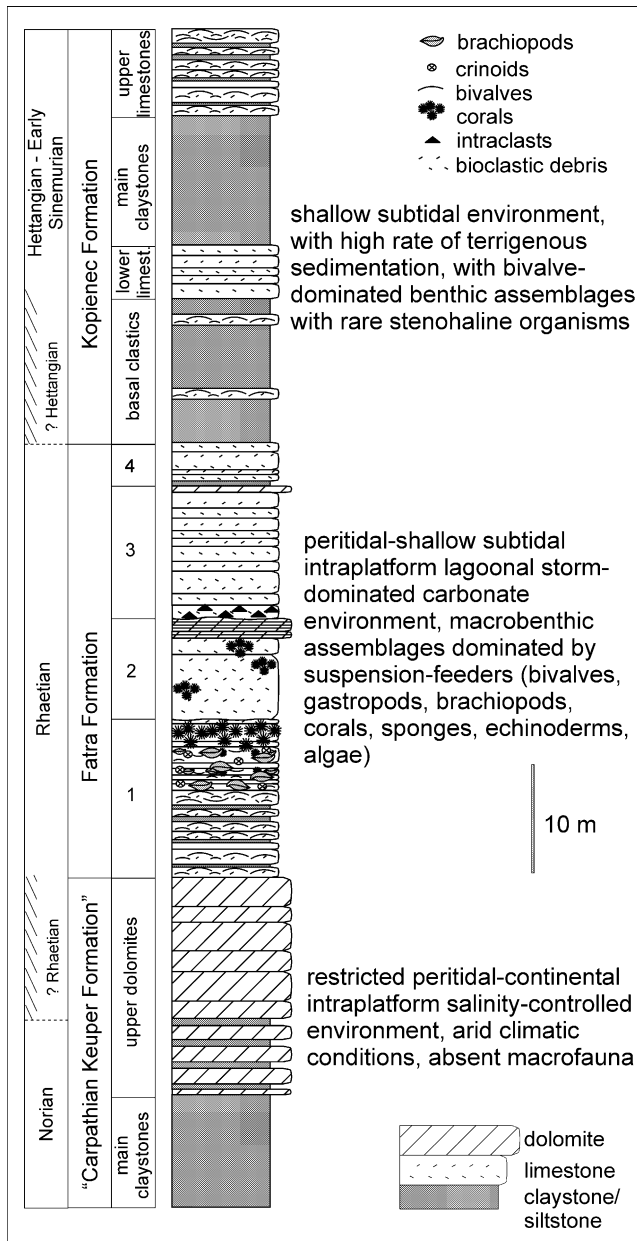
Fig. 2 Basic lithostratigraphic scheme of the uppermost Triassic-lowermost Jurassic strata in the Fatric Unit, Central West Carpathians. The subdivision of the Fatra Formation into four intervals corresponds to four large-scale sequences bounded by three unconformities

Fig. 3 A. Overview map with the study area. **B**. Geographic location of studied lithologic sections of the Fatra Formation in the Veľká Fatra Mts., Slovakia. *1* – Dedošova, *2* – Sviniarka, *3* – Belianska-Borišov, *4* - Bystrý potok, *5* – Ráztoky, *6* – Krížna, *7* – Revúcky Mlyn, *8* - Balcierovo, *9* – Borišov-farm, *10* – Malá Ramžiná, *11* – Žarnovka, *12* - Zelená-Brnovské, *13* – Šoproň

formed by approximately 5- to 20-m-thick barren siltstones/claystones, is unknown.

Methods

The database includes 5 stratigraphic key sections of the Fatra Formation (Figs. 3, 4, 7, 10). In addition, 8 sections exposing only parts of the Fatra Formation were studied for comparative purposes (Fig. 3). Sedimentologic, taphonomic and paleobiologic features at the bed level were described in the field. Sections have been measured bed-by-bed an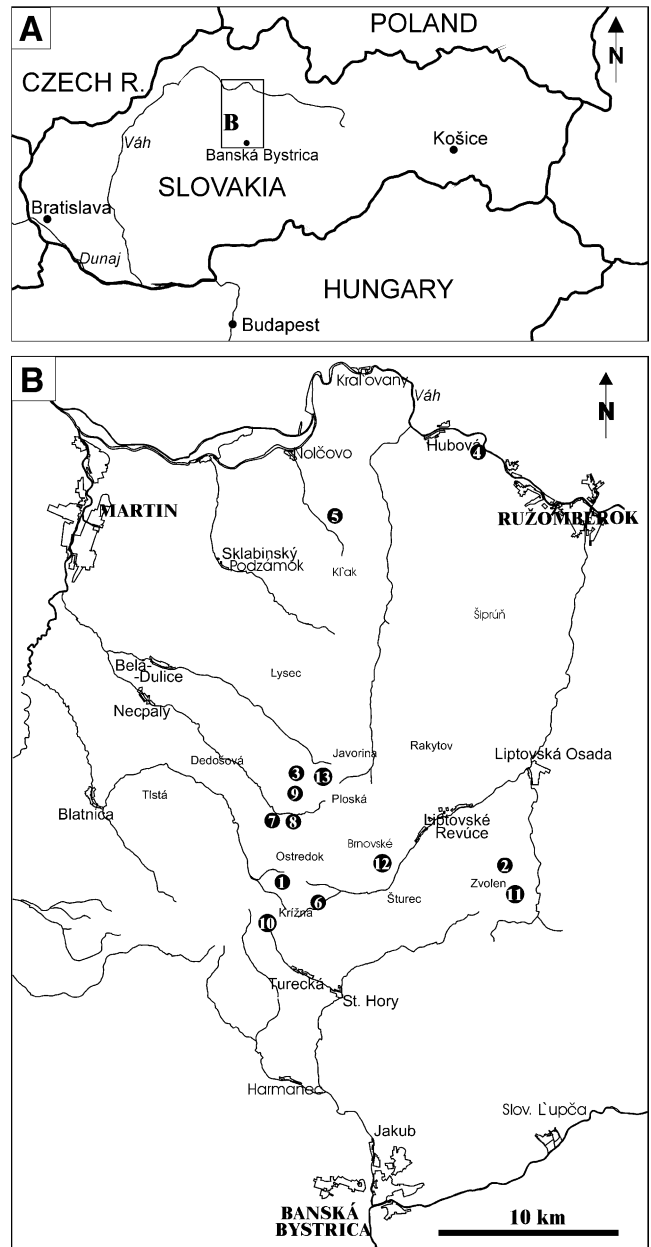d numbered from bottom to top. Samples for thin sections have been obtained from 2-m-distant intervals. In addition, denser sampling of up to 20-cm-distant intervals was performed in segments which exhibit high facies variation. In the lower part of Dedošova – Frčkov locality, several parallel sections were measured in horizontal direction in order to map a spatial variation of the patch reef/biostrome facies (Fig. 15A). The textural classification of Dunham (1962) and Embry and Klovan (1972) was used with modifications for the description of microfacies types.

The term "biostrome" is used for dm-scale, sheet-like autochthonous or parautochthonous deposits with relatively high proportion of constructors, bafflers and binders (corals, algae and/or sponges). The term "patch-reef" is used for meter-scale, mound-
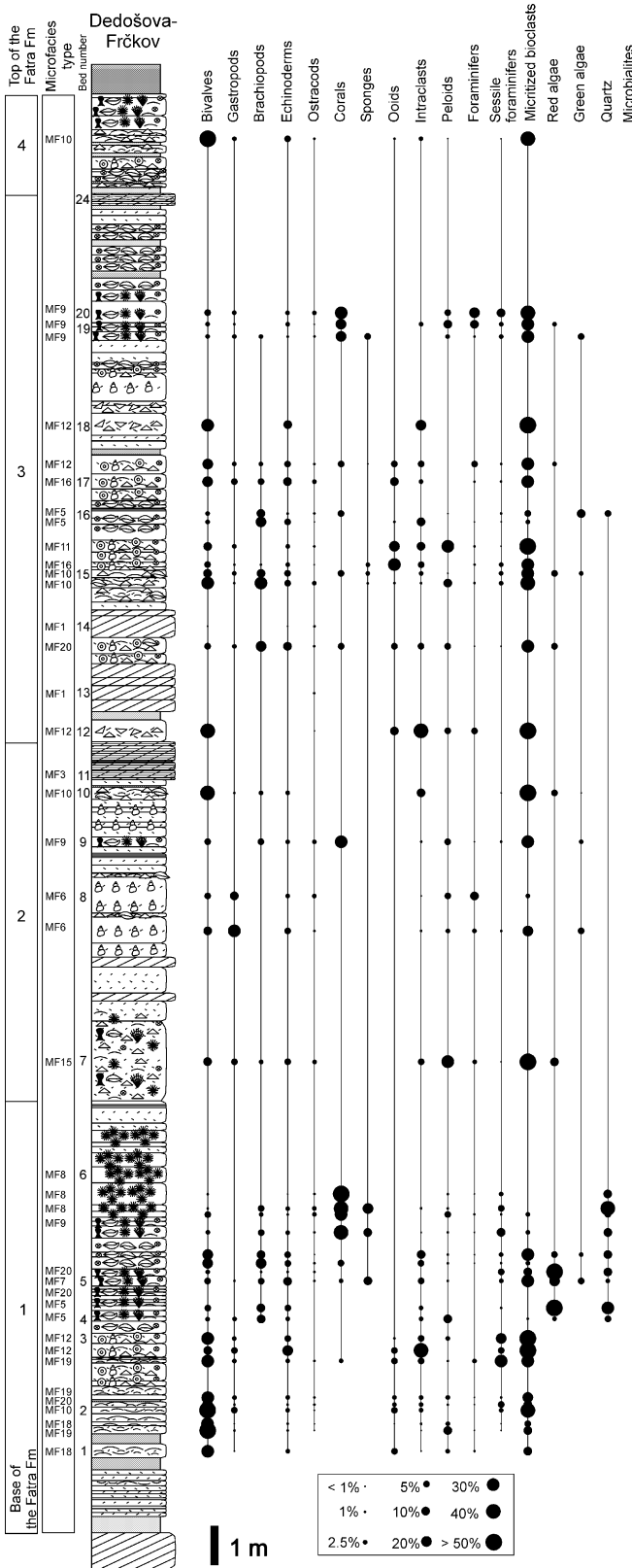
Fig. 4 Lithologic section of the Fatra Formation in Dedošova - Frčkov. Explanations: See Fig. 8

like or flat-topped deposits consisting of autochthonous or parautochthonous remains of constructors, bafflers and binders that can be composed of several stacked biostromes. All together, 209 thin sections were studied. Relative abundance of 14 components (bivalves, gastropods, brachiopods, echinoderms, ostracods, corals, calcareous sponges, red algae, green algae, foraminifers, sessile foraminifers, ooids, intraclasts, and peloids) was estimated using comparative chart method of Bacelle and Bosellini (1965) and Schäfer (1969). These quantitative data formed the basis of a data matrix for a Q-mode cluster analysis using the squared Euclidean distance and the Ward method as the clustering technique (see Appendix). Individual clusters were named after the dominating components.

As the composition of samples is described by percentage values that represent dependent parts (Reyment and Savazzi 1999), standard exploratory multivariate techniques prone to the unit-sum constraint (e.g. PCA) cannot be used. In order to reduce the overall complexity of the data by extracting hypothetical variables (dimensions) accounting for the maximum correlation between sample and component scores, correspondence analysis can be used for percentage data (Kowalewski et al. 2002). Correspondence analysis allows observing the simultaneous representation of samples and taxa within the same system of coordinate axes. The arch effect and compression of the ends of the gradient were eliminated by applying a detrended correspondence analysis (DCA, Hill and Gauch 1980).

In order to decrease data heterogeneity and exclude outliers, samples with allochem content below 10% were excluded from data analysis. This data matrix (exhaustive data set) for DCA comprises 14 components as variables and 152 thin sections as objects. In order to see a primary ecological relationship between individual organism groups, the data matrix was minimized by excluding microfacies types with evidence of high alteration (high-proportion fragmentation, disarticulation and abrasion) and transport/reworking (good sorting, presence of intraclast and ooids). This data matrix (reduced data set) for DCA contains 11 bioclast types and 78 thin sections as the objects. The reduced data set contains seven microfacies types (MF 4 - bio-wackestone, MF 5 - brachiopod floatstone, MF 6 - gastropod floatstones/packstone, MF 7 - solenoporacean framestone, MF 8 - coral framestone, MF 9 - bio-floatstone with micritized corals and MF 18 - bivalve floatstone).

Results

Sections

Five lithologic sections of the Fatra Formation are presented in Figures 4, 7–10. The meter-scale spatial variation in coral patch-reef/biostrome facies types in Dedošova-Frčkov section is shown in Fig. 15A. As the Fatra Formation in the Veľká Fatra Mts. can be subdivided into four main intervals (large-scale sequences) bounded by laterally extensive unconformities (Tomašo-

Fig. 5 Coral patch-reef/biostrome facies types: *1*. Massive coral *Astraeomorpha* sp., strongly bored with bivalves (1), and encrusted by oysters (2). Some free spaces are occupied by small terebratulids (3). Sample DD4.4. Scale: 1 cm *2*. Coral colony of *Retiophyllia paraclathrata*, with terebratulid *Rhaetina gregaria* (arrow) between corallites. Sample S82. Scale: 1 cm *3*. Small branching bush-shaped solenoporacean alga, bored with bivalves (arrow). Sample DD5.2. Scale: 1 cm *4*. Stacked, 10–20 cm thick coral colonies of *Retiophyllia gosaviensis*. Dedošova – Frčkov A (beds 4.15–4.18). Scale: 10 cm *5*. Toppled coral colony of *Retiophyllia gosaviensis*. Dedošova – Frčkov E (bed 5). Scale: 10 cm
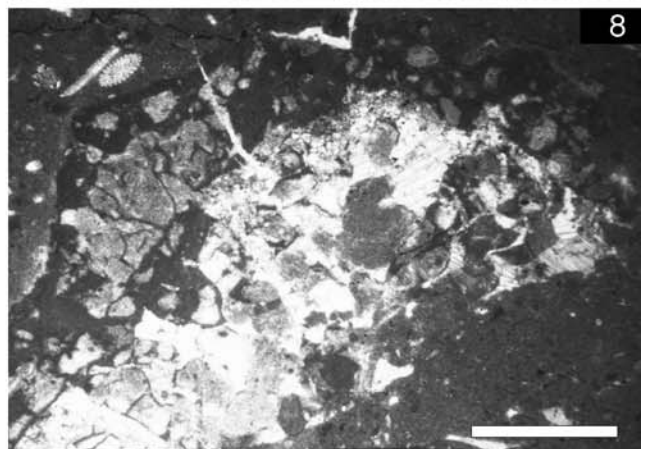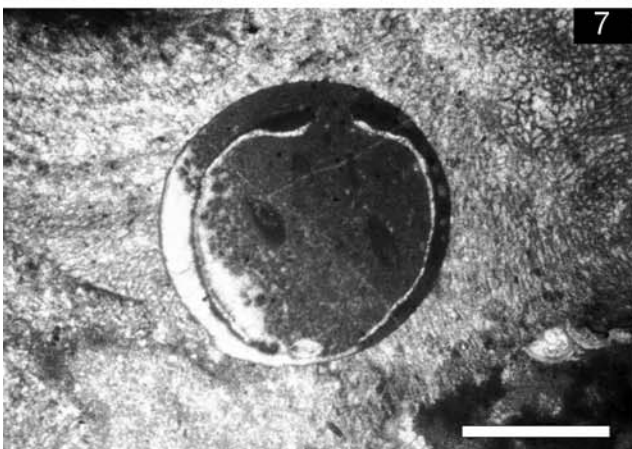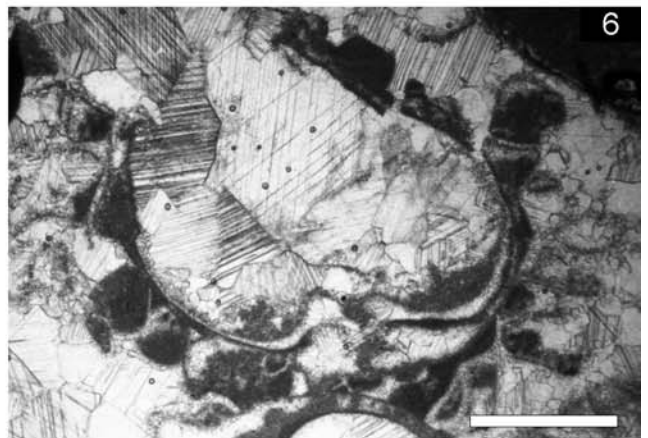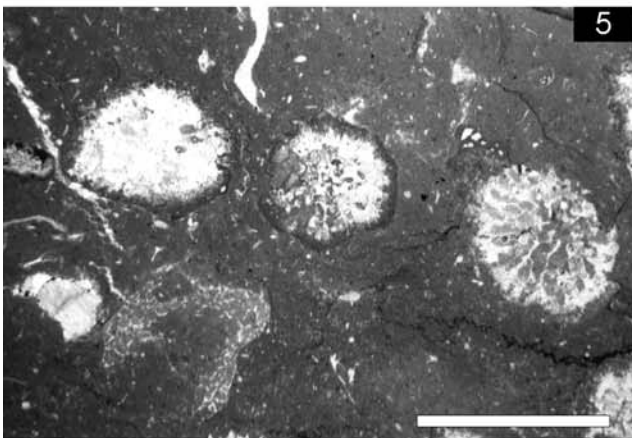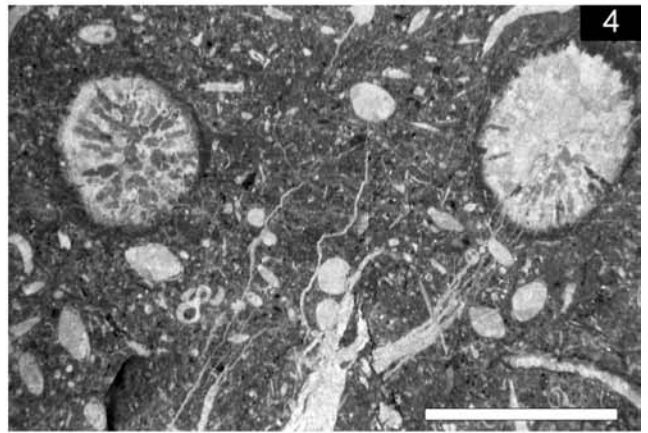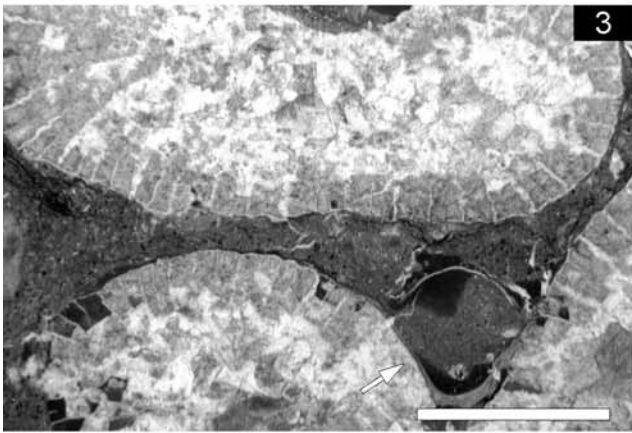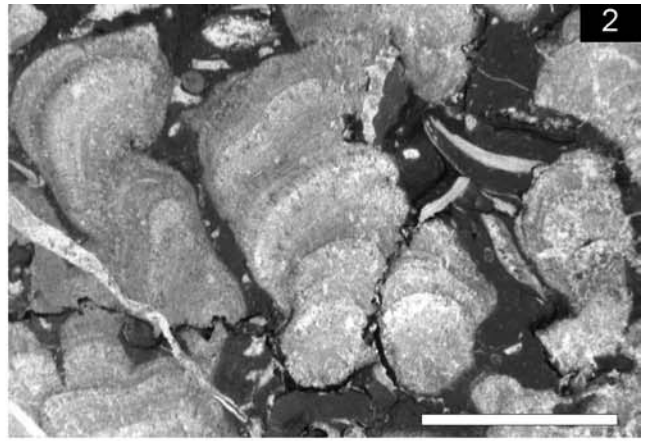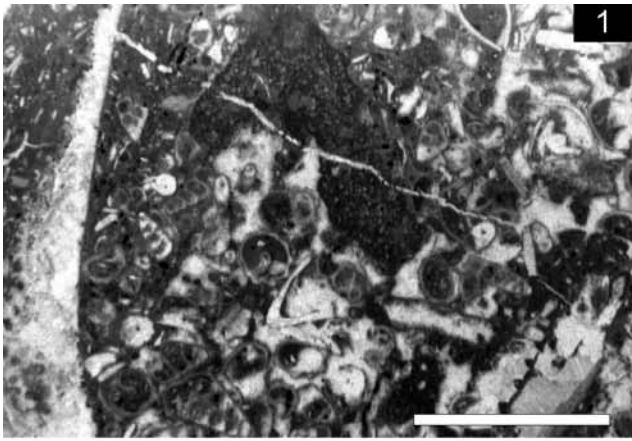
vých 2002), the following description of the sections is based on this subdivision. The correlation of the first large-scale sequence and spatial variation of coral-patch reef/biostrome facies types on km-scale is presented in Figure 15B.

1. Dedošova – Frčkov (Fig. 4) represent outcrops in the forest which are situated on the steep SW slope of the Frčkov hill (1585 m), in the closure of the Dedošova dolina valley, NW of the Krížna (1574 m). The Fatra Formation is completely exposed together with upper-most part of the underlying "Carpathian Keuper Formation". The upper boundary is observable only at some places because of tectonization and weathering of the basal siltstones and claystones of the Kopienec Formation.

In the lowermost 11.5 m thick interval of the Fatra Formation (1st large-scale sequence), small-scale coarsening-upward sequences are preserved (beds 1–3). Limestones are characterized by a complex internal structure formed by cm-scale alternation of poorly sorted floatstones with well-preserved bivalves (*Placunopsis alpina, Atreta intusstriata, Chlamys valoniensis*) and well-sorted packstones/grainstones with erosional bases and poorly preserved bioclasts. These beds are abruptly replaced by brachiopod floatstones with *Rhaetina gregaria* and bioclastic packstones with bivalve, echinoderm, brachiopod and coral fragments (bed 4). In detail, horizontal and vertical distribution of individual facies types and benthic taxa is variable in this part of the section (Fig. 4). Locally, isolated coral colonies of massive (*Astraeomorpha*) and branching (*Retiophyllia*) corals or solenoporacean algae are present in life or overturned/toppled position (Fig.5–5) and form meter-scale aggregations. Both massive and branching corals and algae in these beds are strongly encrusted with oysters (*Atreta*) and bored by bivalves (Fig.5–1, 3, Fig.6–6, 7). Upwards, they are replaced by a 2-m-thick patch-reef/biostrome complex formed by coral framestones with complete colonies of *Retiophyllia gosaviensis* (beds 5–6) with rare intercalations of intraclastic limestones. 10–50 cm high fan or dome-shaped *Retiophyllia* coral colonies, with diam-

Fig. 6 Shallow subtidal facies types, above normal storm wave base: *1.* Gastropod packstone with foraminifers and algae (MF 6). Sample DD7.7. Scale: 5 mm *2.* Framestone with solenoporaceans (MF 7). Sample DD5.2. Scale: 5 mm *3.* Coral framestone (MF 8) with *Retiophyllia gosaviensis* (corallites with local dark automicritic coatings and encrusting bivalve - *arrow*). Sample DD5.12. Scale: 5 mm *4.* Floatstone with micritized corals (MF 9) containg *R. paraclathrata* and abundant involutinid foraminifers. Sample DD19.2. Scale: 5 mm *5.* Floatstone with micritized corals (MF 9) (*R. paraclathrata* with bioerosions and encrustations of *Baccinella* sp. and *Lithocodium* sp. and calcareous sponge). Sample DD18.10. Scale: 5 mm *6.* Bivalve macroboring with recrystallized valves in the retiophyllid coral (MF 9). Sample DD5.8. Scale: 1 mm *7.* Bivalve macroboring in solenoporacean alga (MF 7). Sample DD5.2. Scale: 1 mm *8. Bacinella* sp., boring and encrusting recrystallized coral fragment (MF 9). Sample DD18.10. Scale: 1 mm
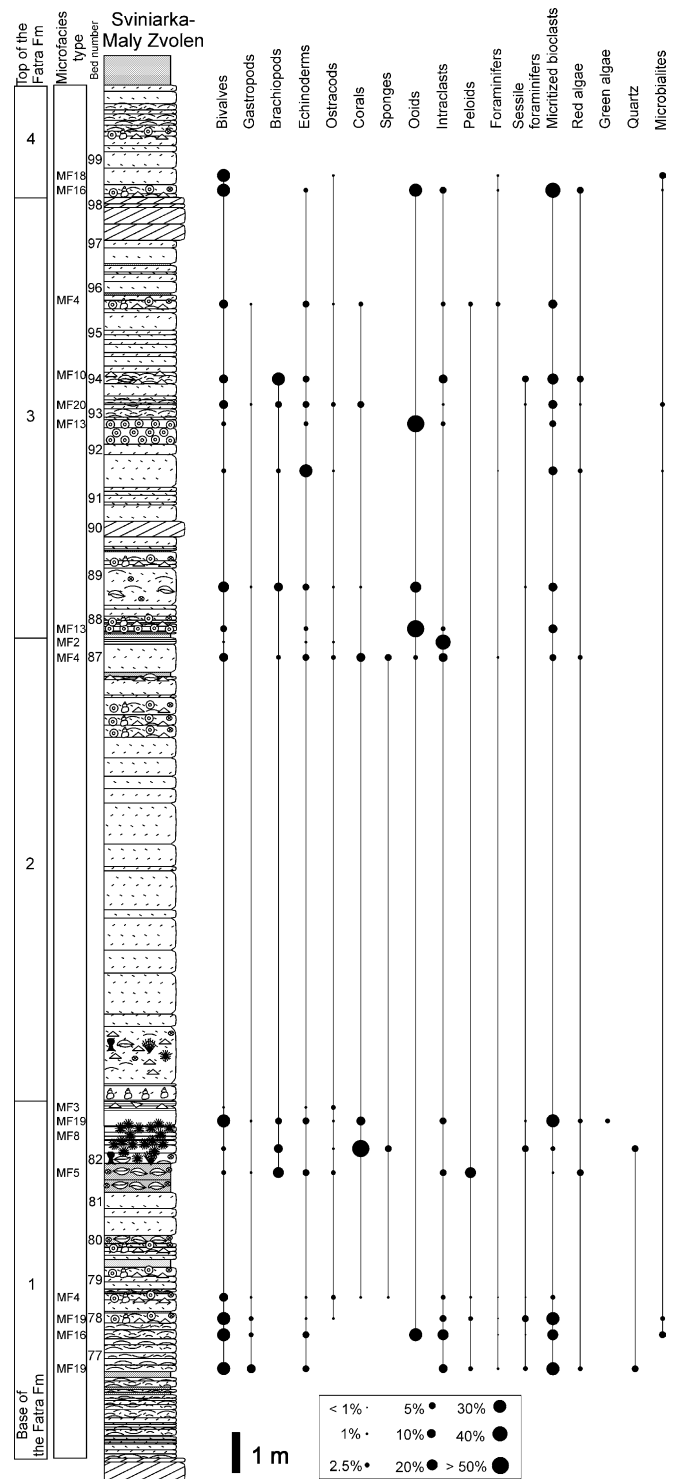

Fig. 7 Lithologic section of the Fatra Formation in Sviniarka – Malý Zvolen valley. The section is tectonically disrupted. Explanations: See Fig. 8

eters between 20 and 100 cm (Fig. 5–4), are still preserved in growth position, with corallites (5–10 mm in diameter) radiating in upward direction. The proportion of borings and encrustations is relatively low.

Coral framestones are capped by laminated bindstones with an erosional unconformity at the top.

In the middle 9.7-m-thick interval (2nd large-scale sequence), thick packstones with intraclasts occur (bed 7), passing upwards into gastropod floatstones (bed 8) and capped by laminated bindstones (bed 11), at the top with an erosional unconformity with well sorted grainstone (bed 12). Above this unconformity, a 14.7-m-thick interval (3rd large-scale sequence) consisting of dolomites with fenestral pores and sheet cracks and well- or bimodally sorted grainstones, packstones and rudstones with brachiopods, bivalves and gastropods is preserved (beds 14–18), passing into brachiopod floatstones (bed 16), ooidic packstones (bed 17) and well-sorted intraclastic grainstone (bed 18). Upwards, bioclastic floatstones with *Retiophyllia* coral fragments (beds 19–20) are capped by laminated bindstones (bed 24).

In the uppermost 2.7 m thick interval of the Fatra Formation (4th large-scale sequence), bioclastic packstones and rudstones with bivalves (*Rhaetavicula contorta, Placunopsis alpina, Chlamys* sp., *Modiolus minutus, Palaeocardita austriaca*) and bioclastic-oolitic limestones with calcitic, chamositic and ferrigenous ooids, and coral, echinoderm, bivalve and brachiopod (*Rhaetina gregaria*) fragments are preserved. Isolated coral colonies (*Retiophyllia* sp.) are locally present.

2. Svinarka - Malý Zvolen (Fig. 7) represent outcrops in the creek in the Svinarka valley and smaller exposures in the forest east of the creek, SE of the Malý Zvolen hill (1372 m). In the creek, the lower and upper boundary of the Fatra Formation is exposed; the middle part is tectonically disrupted. The correlation with the forest exposures allowed to discern a complete stratigraphic column of the Fatra Formation at this locality. In the lowermost, 9.4-m-thick interval of the Fatra Formation (1st large-scale sequence), metre-scale coarsening-upward sequences prevail, consisting of dark claystones, coquinal floatstones with bivalves (*Rhaetavicula contorta, Placunopsis alpina*) and well-sorted packstones/grainstones (beds 77–79). These beds pass into coquinal floatstones with abundant brachiopods (*Rhaetina gregaria, Zugmayerella uncinata*) and bivalves (*Plagiostoma punctatum, Modiolus minutus, Pteria* sp., *Antiquilima* sp., *Atreta intusstriata, Chlamys* sp.) (beds 80–81) and small dm-scale coral framestones with *Retiophyllia paraclathrata* (bed 82, Fig. 5–2). Here, 30- to 40-cm-high coral colonies with corallites 5 mm in diameter are mostly toppled. These beds are overlain by fenestral and cryptalgal bindstones with a capping erosional unconformity. In the middle 12-m-thick interval of the Fatra Formation (2nd large-scale sequence), thick-bedded bioclastic and gastropod limestones are preserved, capped by laminated limestone with rip-up clasts, fenestral pores and sheet cracks (bed 87). In the upper 11.5-m-thick interval (3rd large-scale sequence) consisting of ooidic grainstones and packstones, bio-rudstones and crinoid floatstones is present (beds 88–96), capped by mudstones and dolomudstones (beds 97–98) with an unconformity at the top. In the uppermost, about 3-m-thick interval of the Fatra Formation (4th large-scale sequence), rudstones, grainstones and packstones with micritized bivalves, echinoderms and coral fragments are preserved. Biomicritic wackestone with *in-situ* corals is present as a 15-cm-thick interbed. The uppermost bed of the Fatra Formation is formed by well-sorted grainstone with strongly micritized bivalves and crinoids.

3. Belianska – Borišov (Fig. 8) represent exposures in the forest pathway leading from the Havranovo to the cottage below Borišov hill, 300 m below the cottage, east of the Borišov hill (1509 m). The upper part of the "Carpathian Keuper Formation" and lower and middle parts of the Fatra Formation are exposed here. The uppermost part of the "Carpathian Keuper Formation" is formed by light grey thick-bedded dolomudstones. In the first large-scale sequence of the Fatra Formation (12 m), small-scale shallowing-upward sequences occur (beds 1–11). In their lower part, they are formed by bioclastic limestones with complex internal stratification (mm- or cm-scale alternation of floatstones with packstones) and bivalves (*Bakevellia praecursor, Placunopsis alpina*) and laminated mudstones (beds 1–6). In their upper part, bioclastic floatstones are replaced by well-sorted packstones/grainstones (beds 7–10). Upwards, these beds pass into bioclastic wackestones/floatstones with brachiopods (beds 13–15) and higher-up into well sorted packstones and grainstones with erosional boundaries (beds 16–17). These are overlain by thick packstones/floatstone with coral fragments and intraclasts (bed 18). In the middle 6-m-thick interval (2nd large-scale sequence), laminated dolomites are capped by an erosional unconformity, with well sorted packstones (bed 23). Up-section, brachiopod floatstones with internal stratification, well-sorted packstones and oo-grainstones are preserved (beds 27–30).

4. 4. Bystrý potok – Ružomberok (Fig. 9) represent exposures in the road cut from Ružomberok to Martin, between the village Černová and Hubová, near the entry of the Bystrý potok creek into the Váh River. The locality had been mentioned by Stur (1859) and partially described by Michalík (1985) and Tomašových (2000). The middle and upper part of the Fatra Formation are exposed. In the lower part of the section (7.5 m), two shallowing-upward sequences capped by laminated mudstones/bindstones are preserved (beds 1–6). The second one is capped by an unconformity and overlain by well-sorted packstones with intraclasts and micritized bioclasts. This forms the base of a coarsening-upward sequence and passes upward into thick packstones with megalodonts, brachiopods, algae, coral fragments and echinoderms and oobiograinstones at the top (beds 7–9). In the middle part of the section (4 m), alternation of coquinal limestones with marls with abundant brachiopods (*Rhaetina gregaria, Zugmayerella uncinata, Austrirhynchia*

Fig. 8 Lithologic section of the Fatra Formation in Belianska-Borišov

Fig. 9 Lithologic section of the Fatra Formation at the Bystrý potok locality near Ružomberok. Explanations: See Fig. 8

intraclasts and bioclasts prevail (beds 18–23), passing into dolomitic mudstones in the uppermost part of the section.

5. Ráztoky – Nolčovo (Fig. 10) represents exposures which are situated in the forest pathway on the left slope of the valley above the Ráztoky creek, south of the Ostré hill (786 m), above the Nolčovská dolina valley. This section was described by Michalík and Sýkora (1979). In the first large-scale sequence of the Fatra Formation (12 m), metre-scale shallowing-upward sequences (beds 1–3) are overlain by brachiopod and crinoid floatstones (beds 4–7). Higher, a coral limestone with *Retiophyllia* (bed 8) passes into thick grainstones and packstones (beds 9–10). In the second large-scale sequence of the Fatra Formation (11.5 m), an alternation of dolomites with bioclastic limestones is preserved, finally capped by laminites with an erosional unconformity at the top (beds 21–22). In the third large-scale sequence (11.5 m), three small-scale shallowing-upward sequences occur (beds 32–40). They consist of laminated limestones with foraminifers and ostracods, well-sorted intraclastic grainstones, coquinal floatstones with brachiopods (*Rhaetina gregaria, R. pyriformis*) and floatstones with bored/encrusted coral fragments (*Retiophyllia paraclathrata*) and are capped by a dolomite (bed 40). In the uppermost, fourth large-scale sequence, about 1 m of mudstone interval (bed 45) is overlain by floatstones with abundant megalodonts, gastropods and foramini-

cornigera, Discinisca suessi) and bivalves (*Actinostreon haidingerianum, Atreta intustriata, Modiolus minutus, Plagiostoma punctatum, Chlamys* sp., *Antiquilima* sp., *Pteria* sp., *Liostrea* sp.) occur (beds 9–10). They pass into dm-scale alternations of packstones with mudstones (beds 11–16). In the upper part of the section (3.7 m), packstones and grainstones with ooids,
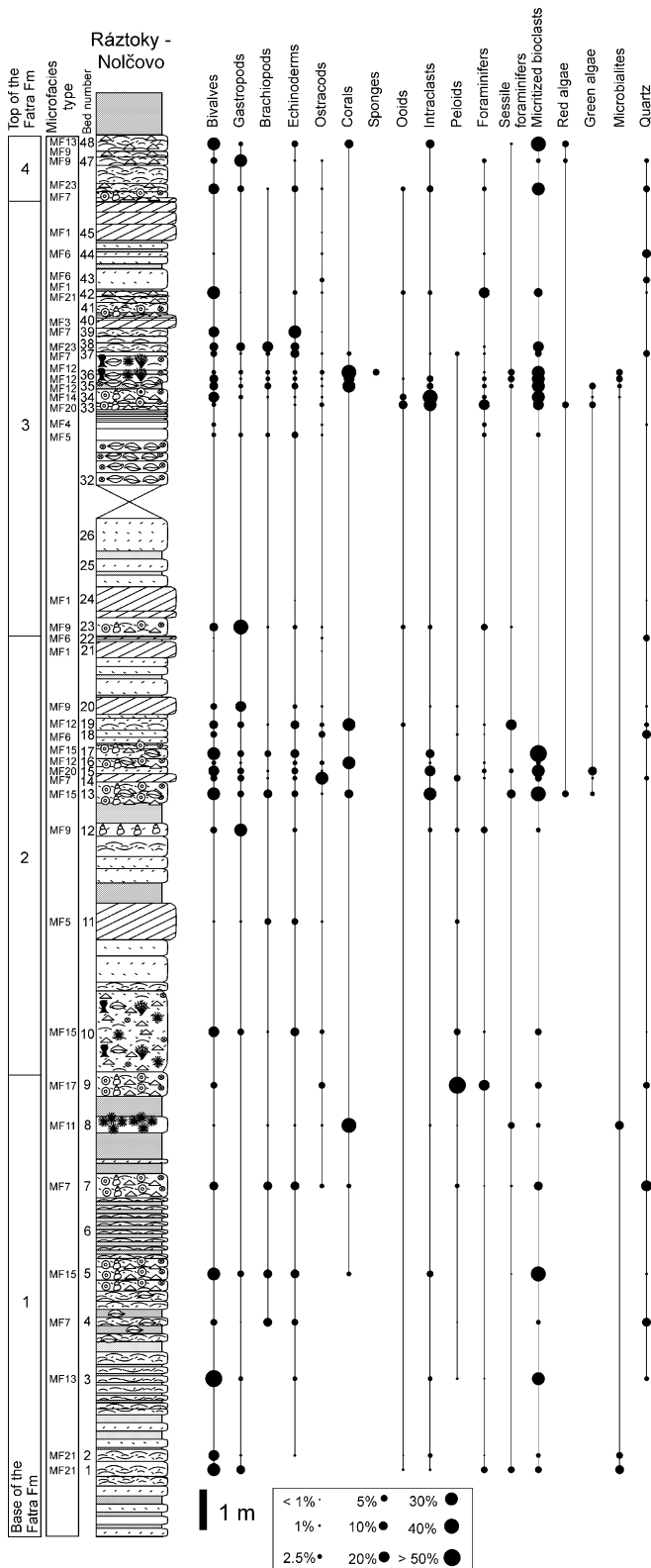
Fig. 10 Lithologic section of the Fatra Formation in Ráztoky - Nolčovo. Explanations: See Fig. 8

fers. The uppermost bed of the Fatra Formation is formed by coquinal biointra-rudstone with well-sorted, concordantly oriented and strongly micritized fragments of bivalves, brachiopods and echinoderms (bed 48).

Microfacies types

In the Q-mode cluster analysis performed at the sample level and based on relative frequencies of components, 20 cluster types have been recognized (see Appendix). However, the final distinction of microfacies types was also based on fabric criteria (sorting, packing and orientation), bed geometry and internal stratification and does not strictly reflect the results of the cluster analysis. Therefore, some clusters were subdivided and all together 21 microfacies types are described in the following part. The samples within the first cluster were subdivided into mudstones (MF 1) and laminated bindstones (MF 3). Clusters 7 and 8 were fused in one MF type (MF 9 - biofloatstone with micritized corals). Clusters 9–11 were assigned to MF 10 and 12 according to the dominating size of components. In spite of the drawbacks due to subjective assignment of some samples, it is suggested that a cluster analysis can be useful as a first step in microfacies types demarcation in settings with high facies variation. Mean values with standard deviations of relative abundances of components are summarized for each microfacies type in histograms (Fig. 11). The DCA ordination of the exhaustive and reduced data set is shown in Fig. 16.

MF 1 – Mudstone

This type (Fig. 12–2) is represented by light grey, thick-bedded (25–60 cm) dolomudstones and dolomitized mudstones, spatially associated with laminites or intraclastic limestones. They often display fenestral fabric and internal sediment filling. Fenestral pores form discontinuous, concordant, irregularly-shaped sparitic laminae, locally passing into continuous sheet cracks. In some beds, agglutinated foraminifers (*Glomospirella*), ostracods and calcarenous green algae (*Halicoryne*) are common.

MF 2 – Intraclastic breccia (floatstone)

This facies type (Fig. 12–1) is characterized by a bioturbated matrix and dark angular and irregular micritic intraclasts (several mm to 2–3 cm). Fenestral pores with internal sediment may be locally present. Ostracod shells and disarticulated valves may occur, along with small fragments of echinoderms and bivalves.
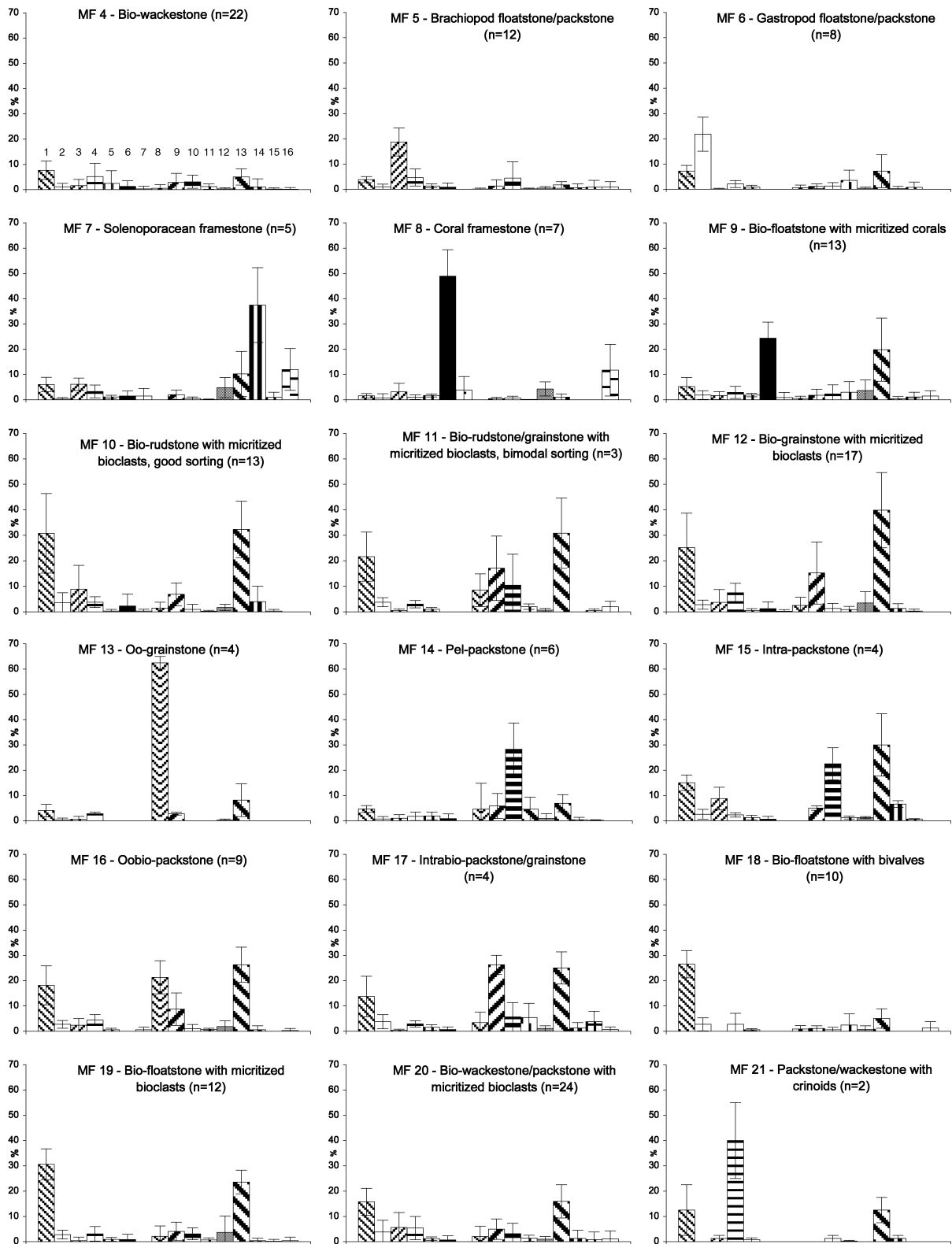
Fig. 11 Histograms of microfacies types showing mean values and standard deviations of individual components. The first three microfacies types are not shown because of rare or absent components. Explanations: 1–Bivalves, 2–Gastropods, 3–Brachiopods, 4–Echinoderms, 5–Ostracods, 6–Corals, 7–Calcareous sponges, 8–Ooids, 9–Intraclasts, 10–Peloids, 11–Foraminifers, 12–Sessile foraminifers, 13–Micritized bioclasts, 14–Green algae, 15–Red algae, 16–Microbialites
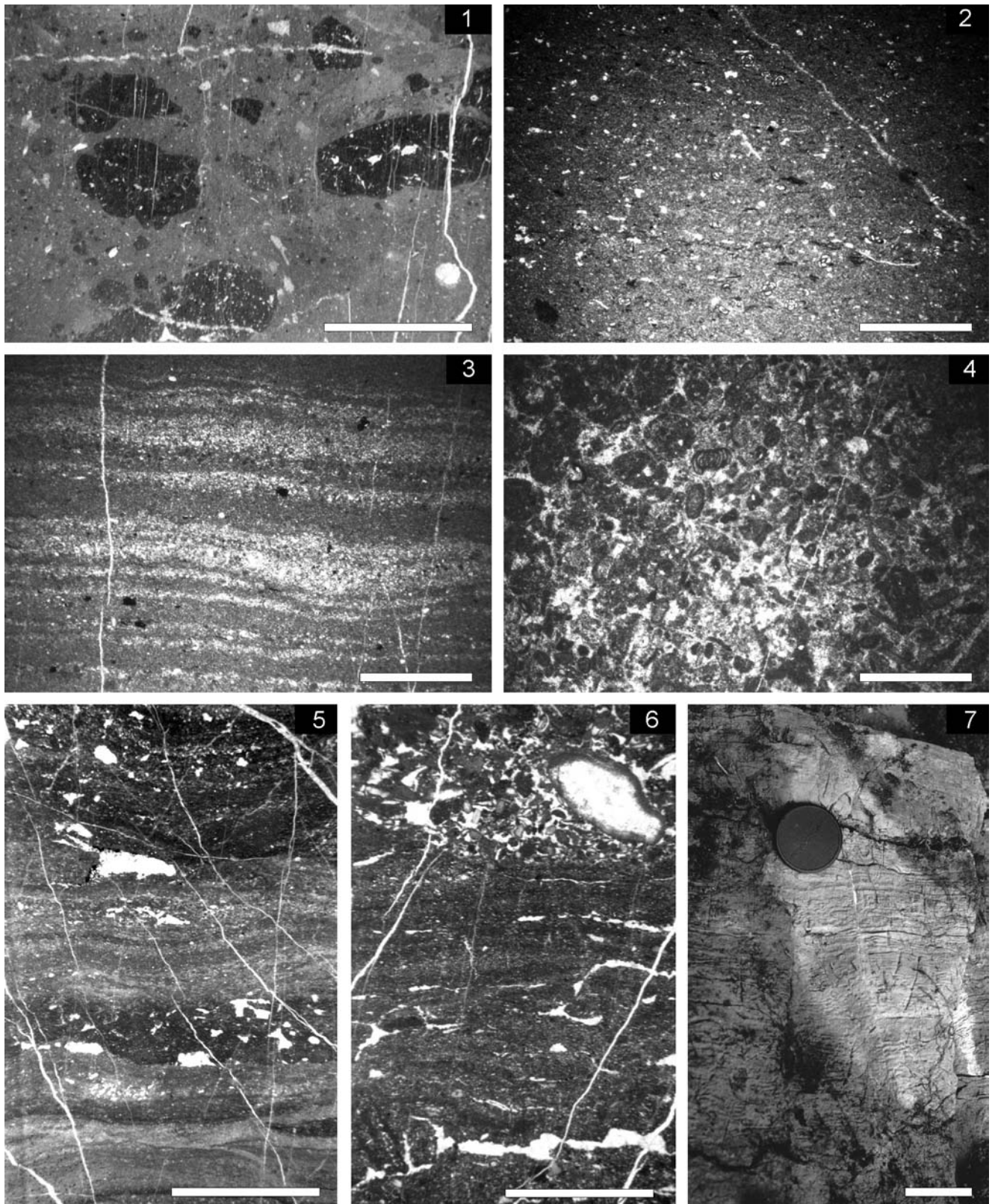
Fig. 12 Peritidal facies types: *1*. Intraclastic breccia (MF 2). Sample S87. Scale: 5 mm *2*. Mudstone with foraminifers (*Glomospirella*) (MF 1). Sample R32. Scale: 1 mm *3*. Cryptalgal bindstone (MF 3). Sample DD11. Scale: 1 mm *4*. Pel-packstone with foraminifers (MF 14). Sample BP5. Scale: 1 mm *5*. Fenestral bindstone (MF 3). Sample NR8. Scale: 5 mm *6*. Fenestral bindstone (MF 3). Sample S11.2. Scale: 5 mm *7*. Fenestral bindstone (MF 3). Sample NR8. Scale: 5 cm

MF 3 – Laminated bindstone

1. Fenestral bindstone (Fig. 12–5–7) with millimetre-scale wavy horizontal lamination formed by micritic laminae and more or less continuous or discontinuous fenestral sparitic laminae with irregular lower and upper boundaries.

2. Cryptalgal bindstone (Fig. 12–3) with finely or moderately crinkled horizontal lamination consisting of alternation of calcilutitic laminae and very well-sorted calcisiltic bioclastic-microintraclastic laminae, locally with micrograding.

3. Planar or low-angle cross-stratified, mm-scale lamination formed by less regular alternation of micritic laminae with dispersed bioclastic debris and calcisiltic to calcarenitic laminae with densely packed fragments of foraminifers, bivalves and crinoids, often with concordant orientation.

MF 4 – Bio-wackestone

This type shows the presence of moderately sorted, ran-domly oriented, and mostly poorly preserved bivalve fragments, gastropods, echinoderm ossicles and brachiopods. Complete macroscopic remains are very scarce. Microfossils are represented by ostracods, nodosariid and glomospirellid foraminifers, globochaetes, dasycladacean algae (*Halicoryne*) and holothurian sclerites.

MF 5 – Brachiopod floatstone/packstone

This type (Fig. 13–7) is preserved in dark grey, thin-bedded (5–25 cm) limestone beds. It commonly displays bioturbated and pelletized micritic matrix and contains predominantly well-preserved terebratulid brachiopods (*Rhaetina gregaria*), with very rare traces of micritization or bioerosion. In some beds, shells with geopetal infillings are frequent. The biofabric is dispersed or loosely packed, less commonly densely packed, with poor sorting and mostly random orientation of brachiopods.

Fragments of bivalves, crinoid ossicles, echinoid spines, juvenile gastropods, ostracods and sessile foraminifers are common. Nodosariid, glomospirellid and trochamminid foraminifers, serpulids, corals, cyanobacteria (*Cayeuxia*) and fragments of calcareous red (Solenoporaceae) or green (Codiaceae) algae may be locally present. In some cases, stratification formed by alternation of brachiopod floatstones with 5–10 mm thick, redeposited, well-sorted, calcarenitic laminae with basal erosional surfaces is recognizable.

MF 6 – Gastropod floatstone/packstone

This type (Fig. 6–1) is dominated by poorly/moderately sorted, non-micritized, well-preserved, complete or frag-mented gastropods (5–30%), usually with geopetal structures. Involutinid (*Aulotortus communis* and *A. tumidus),* glomospirellid and nodosariid (*Frondicularia woodwardi)* foraminifers (2.5–10%), green calcareous algae (Codiaceae), cyanobacteria (*Cayeuxia*), bioeroded and micritized fragments of megalodonts and other bivalves and fragmented or complete, non-micritized echinoderm ossicles are common. The microfossils are additionally represented by *Halicoryne, Globochaete,* ostracods and ophiuroid fragments, and microproblematic *Earlandia* (Flügel 1972; Borza 1975).

MF 7 – Solenoporacean framestone

It forms dark grey, 20–50 cm thick lensoidal patches in the limestone beds in the lower part of the Fatra Formation (Dedošova-Frčkov and Krížna). This type (Fig. 5–2, Fig. 6–2) contains predominantly well-preserved solenoporacean algae that are not affected by fragmentation and micritization. They are often bored by bivalves and endolithic microborers (Fig. 6–7). Apart from red algae, the diversity of frame builders is very poor, calcareous sponges are only locally present. Brachiopods, bivalves and crinoid ossicles are commonly dispersed in the matrix in the interspaces between algae.

MF 8 - Coral framestone

This type is characterized by the dominance of branching corals (*Retiophyllia gosaviensis, R. paraclathrata,* and *R. fenestrata*) which represent primary framework builders (Fig. 6–3). They are commonly encrusted by oysters (Fig. 6–3), calcareous sponges, sessile foraminifers and serpulids. In the micritic matrix, fragments of brachiopods, bivalves, crinoids, algae, ostracods and microbial intraclasts and peloids are commonly dispersed in spaces between corals. Tabular corals (*Astraeomorpha*) are rare, forming only locally small-scale, 30–50 cm thick monotypic aggregations. Two basic types of micritic matrix are present. The more common is gravity-controlled allomicrite, it has a grey colour and locally unhomogenous structure (pelletized or bioturbated) in thin sections. It forms infillings of cavities and interspaces between components. The second type is represented by automicrite, which includes gravity-defying deposits in the form of coatings, crusts, layers on the surfaces and in the internal cavities of bioclasts. In the thin sections, automicritic coatings are dark brown to black, homogenous and mostly structureless. Allochems are absent in these gravity-defying automicritic coatings, in contrast to allomicritic type with diverse assemblage of bioclasts.

MF 9 – Bio-floatstone with micritized corals

This type is characterized by the presence of degraded retiophyllid corals (Fig. 6–4, 5, 6). Bioclasts are randomly
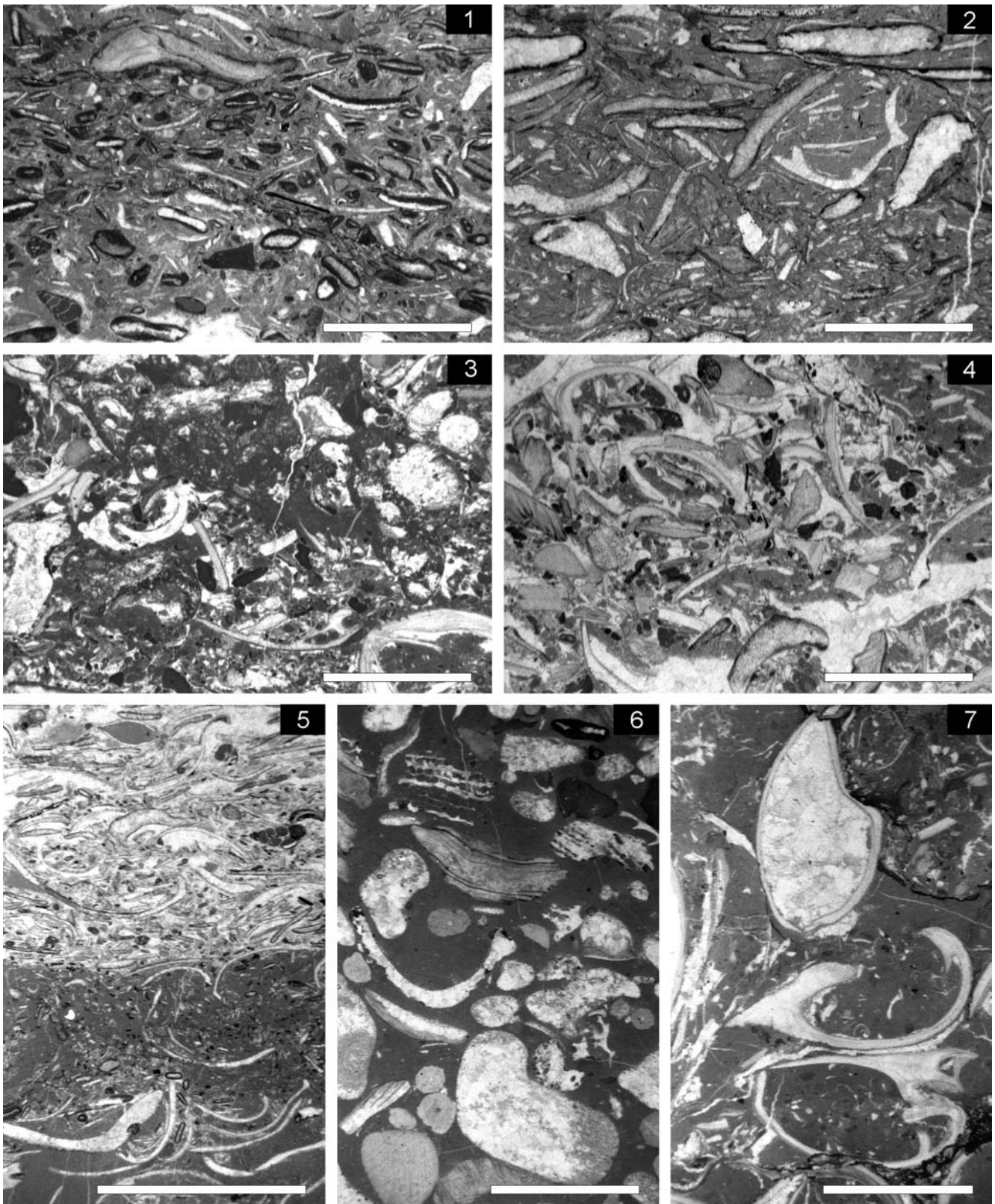
Fig. 13 Shallow subtidal facies types, above normal storm wave base: *1*. Floatstone with micritized bioclasts (MF 19). Sample DD2.7. Scale: 5 mm *2*. Floatstone with micritized bioclasts (MF 19). Sample B12. Scale: 5 mm *3*. Packstone/wackestone with micritized bioclasts (MF 20). Sample DD5. Scale: 5 mm *4*. Packstone/wackestone with micritized bioclasts (MF 20). Sample DD5.3. Scale: 5 mm *5*. Storm-reworked deposit – in the basal part with bivalve floatstone (MF 18), in the upper part with bio-rudstone (MF 10). Sample K2.10. Scale: 5 mm *6*. Packstone/wackestone with micritized bioclasts (MF 20). Sample DD5a. Scale: 5 mm *7*. Brachiopod floatstone (MF 5). Sample DD4.2. Scale: 5 mm

oriented and poorly sorted. Fragments of coral colonies or isolated corallites (*Retiophyllia paraclathrata*) are commonly strongly destructively micritized, microbored and encrusted (common sessile foraminifers, *Thaumatoporella* sp., *Baccinella*, *Lithocodium*, (Fig. 6–8), cf. Kołodziej 1997) and/or covered with automicritic coatings. Bivalve macroborings are common (Fig. 5–1, Fig. 6–6). Calcareous (nodosariids, involutinids, *Ophthalmidium*) and agglutinated (*Glomospirella*, *Trochammina*, *Tetrataxis*) foraminifers, ostracods, globochaetes, cyanobacteria (*Cayeuxia* sp.), sponges, fragments of bivalves, gastropods, brachiopods and echinoderm ossicles are common.

MF 10 – Well-sorted bio-rudstone with micritized bioclasts

10–40 cm thick beds of this type commonly display good sorting, dense packing and concordant, edgewise/nested or random orientation of bioclasts (Fig. 14–7, 8). Grading in the proportion of matrix and size and density of allochems is locally preserved. High proportions of fragments of bivalves, echinoderms, gastropods and brachiopods are degraded (abraded, micritized and bioeroded). In several cases, certain proportions of bioclasts are, in contrast, relatively well preserved, without traces of bioerosion and abrasion. Encrustations by sessile foraminifers are rare.

MF 11 – Bimodally sorted bio-rudstone/grainstone with micritized bioclasts

This type (Fig. 14–5, 6) consists of concordantly oriented, convex-up bivalves with drusy sparitic shelters and local mud-infiltrations, and well-sorted calcarenitic debris (up to 2 mm). Rudite-size bivalve fragments with micritic rims are mostly encrusted by sessile foraminifers, bored and abraded. Bio- and oomicritic intraclasts, peloids and radial ooids (with fragments of bivalves, crinoids, foraminifers and peloids as nuclei) are common.

MF 12 – Bio-grainstone with micritized bioclasts

This type (Fig. 14–2) is characterized by well-sorted and densely packed fabric, only locally with micrite, and usually contains abraded, fragmented and strongly bioeroded bioclasts with micritic rims and sessile foraminifers (*Tolypammina*, *Planiinvoluta*). Debris of bivalves, gastropods with exotic micritic infillings, echinoderm ossicles (locally with syntaxial rims) and brachiopods are abundant. Fragments of corals and calcareous algae can occur locally. Bio- and oomicritic intraclasts, peloids and radial ooids are present.

MF 13 – Oo-grainstone

10–50 cm thick beds of this type are characterized by good sorting of ooids (approximate diameter: 1–1.5 mm), with oval, circular or elongate outline and radial structure showing several cortical layers (Fig. 14–1). Intraclasts and micritized and abraded bioclasts are less common (2.5–5%). Ooid nuclei consist of recrystallized bivalve fragments, brachiopods, crinoids, foraminifers, micritic and biomicritic intraclasts or peloids.

MF 14 – Pel-packstone

This type (Fig. 12–4) is characterized by the dominant presence of well-sorted peloids (maximum size 1 mm) and agglutinated foraminifers (*Glomospirella*), and less common fragments of echinoderms, micritized bivalves, and ostracods.

MF 15 – Intra-packstone

This facies type typically occurs in dark grey massive and thick-bedded limestones (50–200 cm) in the middle part of the Fatra Formation. They display bimodal sorting consisting of well-sorted intraclastic-peloidal debris and poorly sorted rudite-size bioclasts, with no preferred orientation. A micritic matrix may be locally absent. Ooids can also be present. Bioclasts are abraded, encrusted (*Tolypammina*, *Planinvoluta*, *Thaumatoporella*) and bored/micritized (endolithic microborings). Some bioclasts are in contrast relatively well preserved without signs of bioerosion and abrasion. Recrystallized bivalve fragments are dominant, gastropods, corallite fragments or fragments of coral colonies and solenoporacean algae, echinoderm ossicles and brachiopod valves are common. The microfauna is characterized by a relatively diverse assemblage of foraminifers (*Triasina hantkeni*, *Tetrataxis inflata*, *Trochammina alpina*, *Frondicularia woodwardi*, *Glomospirella*), globochaetes, *Earlandia*, green algae (*Halicoryne*), and ostracods.

MF 16 – Oobio-packstone

Beds of this type contain calcarenitic debris with abundant well-sorted ooids (0.5–1 mm) with radial structure and oval outline. The ooid nuclei are formed by fragments of bivalves, crinoids, intraclasts or peloids. Micritized bivalve fragments and micritic intraclasts are common; gastropods, brachiopod fragments, echinoderm ossicles and green algae (*Halicoryne*) are present in varying proportions. In general, bioclasts are mostly poorly preserved. In one subtype, components (1–1.5 mm) completely encrusted by sessile foraminifers (*Tolypammina*) are very common.
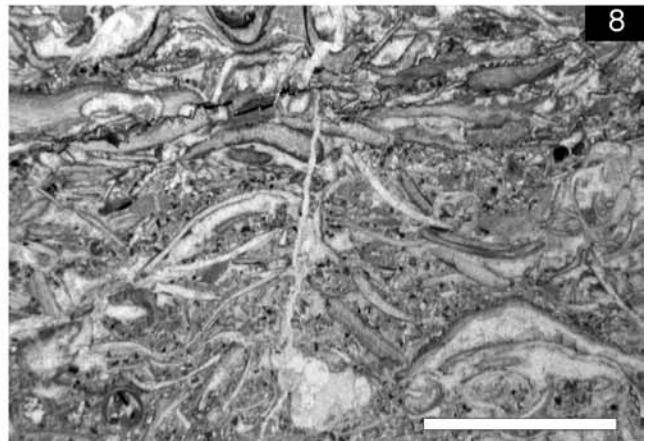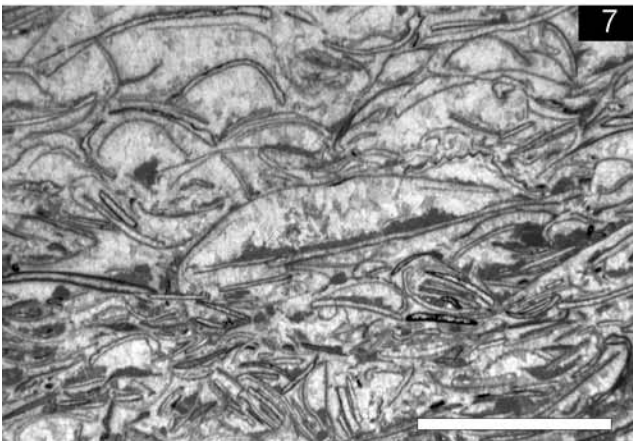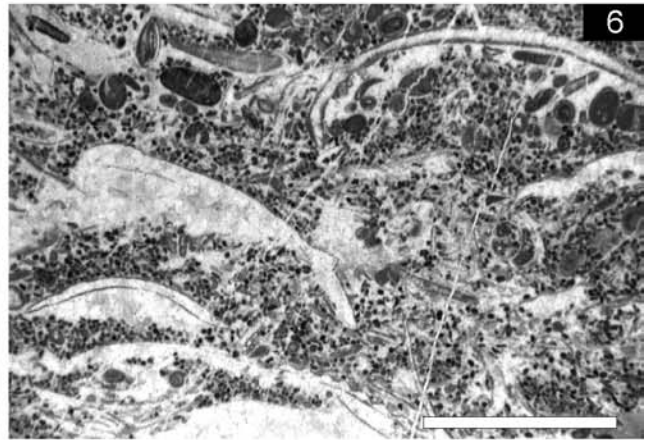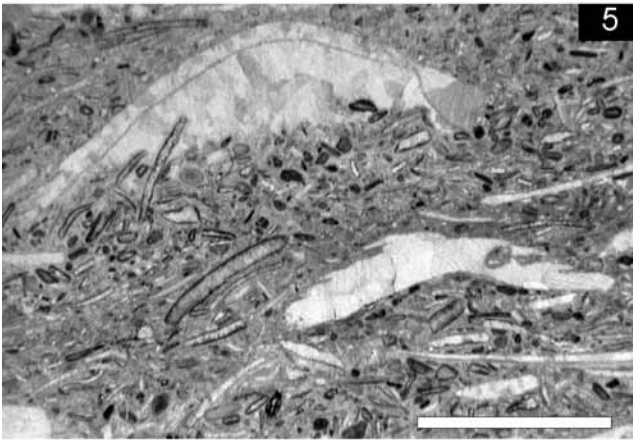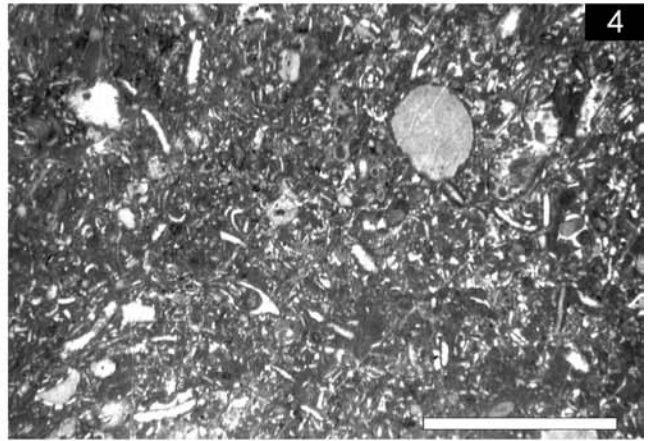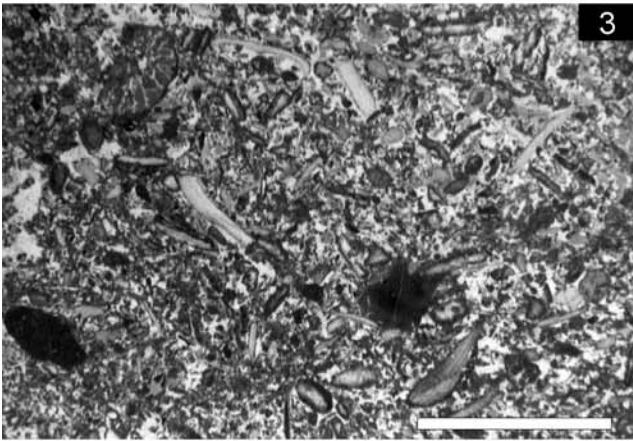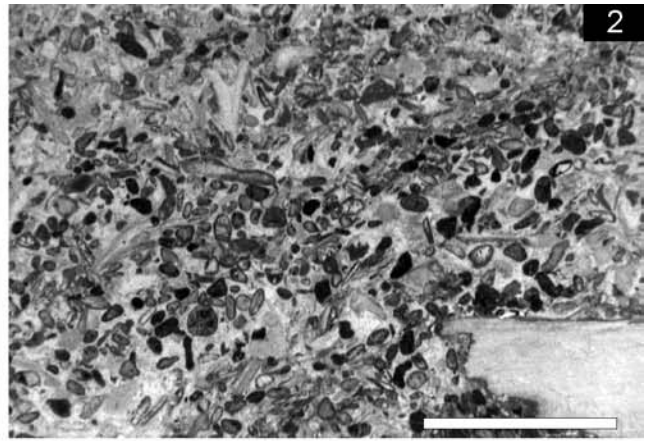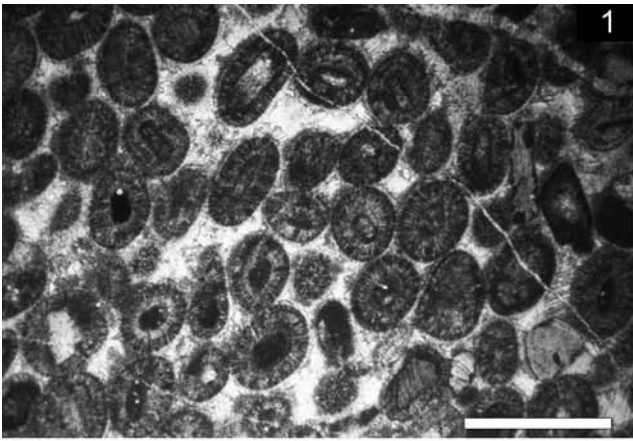
MF 17 – Intrabio-packstone/grainstone

Beds of this type usually display a basal erosional surface, good sorting (below 1 mm) and dense packing of angular or oval microintraclasts and micritized/bored or abraded bioclasts (bivalves, echinoderms). Calcareous (*Triasina, Aulotortus*) and agglutinated (*Glomospirella*) foraminifers, globochaetes, green algae (*Halicoryne*) and thick-shelled ostracods are locally abundant. Mostly they occur in the direct overlie of mudstones (MF 1) or laminites (MF 3).

MF 18 – Bivalve floatstone

Dark grey, 5–10 cm thick beds of this type (Fig. 13–5) commonly alternate with 1–10 cm thick bio-floatstones (MF 19) or bio-wackestones/packstones with micritized bioclasts (MF 20). They contain poorly sorted and dispersed/loosely packed, complete or fragmented bivalves (*Placunopsis alpina, Rhaetavicula contorta, Bakevellia praecursor, Gervillaria inflata, Chlamys valoniensis*), mostly randomly or less commonly concordantly oriented/nested. Sparitic shelters or geopetal textures are scarce or absent. Valves are commonly encrusted by sessile foraminifers. However, the proportion of bioerosion and micritization due to activity of microborers is much lower in comparison to floatstones and wackestones/packstones of the MF 22 and 23.

MF 19 – Bio-floatstone with micritized bioclasts

5–20 cm thick beds of this type are characterized by the abundance of bivalves and high degree of destructive micritization and bioerosion (Fig. 13–1, 2). They are usually associated with a complex internal structure consisting of alternation of thin cm-scale intervals with different sorting and packing density. Internal erosional surfaces are locally present. The typical feature is a loosely/densely packed bio-fabric, poor or moderate sorting (with maximum size mostly not exceeding 10–20 mm), and concordant (both convex-up and down), nested or random orientation of bivalves, locally with sparitic shelters under convex-up valves. Other components are represented by micritic intraclasts and radial

Fig. 14 Shallow subtidal - nearshore facies types (above fair-weather wave base): *1*. Oo-grainstone (MF 13). Sample S92.3. Scale: 1 mm *2*. Bio-grainstone with micritized bioclasts (MF 12). Sample DD5.1. Scale: 5 mm *3*. Bio-packstone with micritized bioclasts (MF 20). Sample DD 13.5. Scale: 5 mm *4*. Bio-packstone with micritized bioclasts (MF 20). Sample DD17.2. Scale: 5 mm *5*. Bimodally sorted rudstone/grainstone with micritized bioclasts (MF 11). Sample B7.3. Scale: 5 mm *6*. Bimodally sorted rudstone/grainstone with micritized bioclasts (MF 11). Sample DD15.5. Scale: 5 mm *7*. Bio-rudstone with micritized bioclasts (MF 10). Sample DD26.3. Scale: 5 mm *8*. Bio-rudstone with micritized bioclasts (MF 10). Sample DD14.5. Scale: 5 mm

ooids. Ooids are frequently encrusted by sessile foraminifers.

MF 20 – Bio-wackestone/packstone with micritized bioclasts

This type is characterized by moderate or good sorting and loose/dense packing of bioclasts, mostly dominated by bivalves (Fig. 13–3, 4, 6, Fig. 14–3, 4) and by a complex internal microstratigraphy. In the fossil assemblages characterized by high degree of taphonomic alternation, fragments of recrystallized bivalves, echinoderm ossicles (sometimes with syntaxial rims), juvenile gastropods, corals, solenoporacean red algae and brachiopods are abundant. In general, micritic rims are very common. The microfauna is represented by sessile (*Tolypammina*), nodosariid or glomospirellid foraminifers, serpulids, green algae (*Acicularia*), globochaetes (*Globochaete alpina, G. tatrica*) and ostracods.

MF 21 – Crinoid wackestone/packstone

This type is characterized by the abundance of complete or fragmented crinoid ossicles, locally still articulated, with microborings and locally with micritic envelopes. The biofabric is densely/loosely packed and moderately sorted. Fragments of brachiopods, bivalves, ostracods, echinoid spines are less common.

Discussion

Facies interpretation

In the following discussion , particular microfacies types are interpreted in terms of paleoenvironment and compared with coeval facies types known from other Upper Triassic Tethyan carbonate settings. Fenestral and cryptalgal bindstones (MF 3) can be interpreted as algal or microbial mat deposits that are typical mainly of peritidal flats (Shinn 1983). In the Upper Triassic carbonate environments, they typically represent an intertidal member of the Lofer sequences (Schwarzacher 1948; Fischer 1964; Flügel 1981; Enos and Samankassou 1998). In addition, they commonly occur in shallow restricted lagoonal settings of the Kössen and Calcare di Zu Formation (Kuss 1983; Lakew 1990). Fenestral fabric is mainly formed by desiccation and shrinkage or air and gas bubble formation, and is often preserved within stromatolites due to irregular growth processes (Shinn 1968). Algal mat lamination is not limited only to supra-intertidal environment, but it is mostly not preserved due to bioturbation and gastropod grazing in subtidal environments (Garrett 1970), although it may be preserved in a hypersaline environment. The absence of bioturbation and body fossil fauna thus indicates unfavourable conditions for metazoan life. Regular, mm-scale alternation of

micritic and calcisiltic laminae in MF 3c indicates alternating bedload and suspension transport. Micritic intraclasts in breccia (MF 2) have been probably derived from disrupted stromatolitic laminae, which were exhumed and buried again in the same type of sediment.

Mudstones (MF 1) often occur in the upper part of shallowing upward, lagoonal-peritidal sequences and have comparable equivalents in the Kössen Formation (Kuss 1983; Ehses and Leinfelder 1988; Stanton and Flügel 1989). The fenestral fabric and close association with laminated types indicate a peritidal origin (Bystrý potok and Ráztoky sections). A low diverse fauna of agglutinated foraminifers (*Glomospirella*) (Gadzicki 1983) and ostracods indicates high-stress habitat in a very shallow restricted environment, where great fluctuations in salinity and temperature are probable.

Good taphonomic preservation of brachiopods in brachiopod floatstones/packstones (MF 5) and associated sedimentologic data (micritic matrix, absence of ooids or intraclasts) point to an environment below the fair-weather wave base with low-energy background conditions. Complex internal structure formed by the alternation of interbeds with different packing density, various proportions of disarticulated valves and different orientations (nested or concordant) suggests episodic high-energy influence of storm wave and currents (Aigner et al. 1978; Török 1993). The deposition of gastropod floatstones/packstones (MF 6) probably took place in a low-energy photic environment with a low net rate of sedimentation and low turbidity, with good conditions for algal growth and herbivorous gastropods. Solenoporacean framestones (MF 7) are characterized by preservation of autochthonous small-scale algal banks, deposited in a setting below the fair-weather wave base. It is interesting to note that benthic assemblages dominated by solenoporaceans in the Eastern Alps (Stanton and Flügel 1987) are characterized by a different type of matrix fabric (packstones/grainstones).

Coral framestones (MF 8) represent *in-situ* preserved coral colonies. Automicritic deposits have probably been produced by microbial processes (Kazmierczak et al. 1996). The main evidence is formed by a) gravity-defying orientation (mucus matrix allows the accumulation), b) differences in the comparison with the second type of micrite (absence of other bioclasts, colour, structure) and c) common presence in cavities. In the "Oberrhätkalk" in the Eastern and "Calcare di Zu" in the Southern Alps, dark homogenous microbial coatings similarly occur and are limited mainly to the interspaces between the branches of retiophyllid corals and sponges (Stanton and Flügel 1989; Lakew 1990). Comparable poorly diverse coral assemblages dominated by high-growing *Retiophyllia* are well known from the intra-platform Kössen basin and marginal parts of the Dachstein platform (Schäfer 1979; Piller 1981; Kuss 1983; Stanton and Flügel 1987). According to Roniewicz & Stolarski (1999), life strategy of epithecal phaceloid growth forms, to which *Retiophyllia* belongs, is comparable to the mudsticker strategy of secondary soft-bottom dwelling bivalves (Seilacher 1984). Such growth forms were well-adapted for life in an environment with a relatively high rate of sedimentation and turbidity. Growth forms of retiophyllid corals are correlatable with water energy (Stanton and Flgel 1987). In analogy to the distribution of *R. clathrata* A and B morphotypes in the Eastern Alps, recognized according to corallite diameter and robustness of colonies, branched corals in the samples are mostly robust and closely packed, although variation in morphotypes is high in some cases. This can partially point to a less protected habitat of the *Retiophyllia* assemblage in the Fatra Formation with relatively higher water energy. However, as interstices between coral branches are filled with micrite and the proportion of sparite cement and bioclastic debris is low, their habitat was probably situated below the fair-weather wave base. Low species diversity of patch-reef/biostrome assemblages, in contrast to some highly diverse assemblages with corals, sponges, hydrozoans and tabuluzoans from the Northern Calcareous Alps (Zankl 1969; Schäfer 1979; Dullo 1980; Wurm 1982; Stanton and Flügel 1987, Turnšek et al. 1999) or Western North America (Stanley 1979) can be most likely related to the short-term environmental instability of habitats in a very shallow, intra-platform setting (Stanton and Flügel 1987). An uneven patchy distribution of coral aggregations can point to a high spatial variation in environmental conditions or chance aspects of larval dispersion, first recruitment and subsequent success (e.g. competition exclusion) in survival.

Bio-floatstones with micritized corals (MF 9) are characterized by higher alteration in comparison to coral framestones, due to higher intensity of bioerosion/micritization and episodic influence of high-energy storm events (intraclasts, packing, thin well-sorted interlayers). It represents a parautochthonous fossil assemblage. Primary sparitic cement is lacking, indicating primarily a low-energy environment between the fair-weather and normal-storm wave base.

Fabric criteria of rudstones with micritized bioclasts (MF 10) indicate an environment above the fair-weather wave base, with a long-term high-energy current (concordant orientations) or wave activity (edgewise orientations). High degrees of taphonomic damage point to a prolonged exposure time on the sediment/water interface (Kidwell and Bosence 1991; Perry 1998). However, variation in preservation and the presence of grains of different origin (peloids, ooids, intraclasts) indicate a complex burial/exhumation history. In some cases, episodically storm-reworked, rapidly deposited beds can mimic fabric pattern indicative of a long-term high-energy environment. The biofabric of bimodally-sorted rudstones/grainstones (MF 11) indicates that the most important process was probably a high-energy current event which controlled the preferred orientation of bivalves. High levels of taphonomic alteration were probably mainly influenced by former long-term depositional history. Bio-grainstones (MF 12) occur in the uppermost part of the coarsening-upward cycles, or they form intercalations in the successions with low-energy de-

posits. Fabric criteria point to the deposition of small-scale skeletal banks/shoals under long-term high-energy conditions caused by fair-weather wave activity or frequent episodic storm activity (Ball 1967; Hine et al. 1981). A high proportion of abrasion indicates influence of wave activity and a high degree of micritization and encrustation indicates long residence time on the sea-floor and, therefore, reduced net rate of sedimentation (Kobluk and Risk 1977).

The sedimentary features typical of inter- or subtidal oolite shoals, beaches or bars such as large bed thickness and cross-bedding (Wilson 1975; Hine 1977; Inden and Moore 1983) are lacking in oo-grainstones (MF 13). In the recent, aragonitic radial ooids were reported from relatively lower-energy environments, while in the highest-energy conditions (the crests of bars) the crystals become flattened and are broken into a tangential orientation (Simone 1981; Gaffey 1983; Strasser 1986; Tucker and Wright 1990). Ooids with comparable microstructure from Purbeckian limestones originated in intermittently agitated water (Strasser 1986). Low-Mg calcitic radial delicate microstructure is probably primary (Kuss 1983; Mišík 1997) Although it is assumed that the "aragonite sea" was typical of the whole Triassic (Sandberg 1983; Hardie 1996; Stanley and Hardie 1998), the Late Triassic is characterized by the dominance of originally calcite ooids, in contrast to the Early and Middle Triassic (Wilkinson et al. 1985).

In pel-packstones (MF 14), restricted diversity of bioclasts and dominance of peloids indicate deposition in a low-energy, perhaps peritidal, environment with poor connection with the open basin. Intra-packstone type (MF 15) is comparable to the coated-grain facies from the Kössen Formation (Kuss 1983), which passes laterally into the coral biostrome and mound facies. The same situation is also preserved in the Fatra Formation, where this type (e.g. Dedošova, Borišov) laterally passes into the coral limestones with autochthonous coral thickets (Revúcky Mlyn section). In general, this type has been attributed to the "reef-detritus mud facies" by Flügel (1981), typical of a protected reef-slope. On the basis of the sedimentologic (well-sorted bioclastic-intraclastic matrix, local winnowing of micrite, absence of primary sedimentary structures) and high variation in taphonomic alteration, it is possible to imagine an unstable exposed shallow subtidal environment above the storm wave base with higher rates of environmental changes (with periods with higher water energy) leading to a complex burial/exhumation history of particles. The particles are predominantly derived from the patch-reef/biostrome facies. Poor sorting of ruditic shell material, variations in taxonomic composition in the horizontal direction and presence of large coral colonies indicate a local parautochthonous origin affected by storm activity, excluding extensive lateral transport.

The composition and preservation of components in oobio-packstones (MF 16) indicate a complex origin, probably related both to out-of-habitat transport and time-averaging. Ooids can be deposited in depressions adjacent to oolithic banks/bars or can represent residual *in-situ* components when local setting changes from high- to low-energy conditions. Subtypes with a high proportion of components encrusted by foraminifers are mostly typical of relatively protected back-barrier areas with moderate water energy.

A high degree of taphonomic alteration, fabric criteria and stratigraphic position immediately above peritidal deposits indicate that intrabio-packstones/grainstones (MF 17) represent a lag deposit originating under a much reduced rate of sedimentation related to long-term winnowing and particle reworking.

The relatively good taphonomic preservation of bivalves in bivalve floatstones (MF 18), low proportion of bioclastic debris and absence or scarcity of microintraclasts and ooids indicate a protected low-energy environment with poor storm reworking. Macrobenthic assemblages dominated by bivalves are preserved *in-situ* and are comparable to those from the lower part of the Kössen Formation (*Placunopsis-Bakevellia* biofacies, Golebiowski 1991).
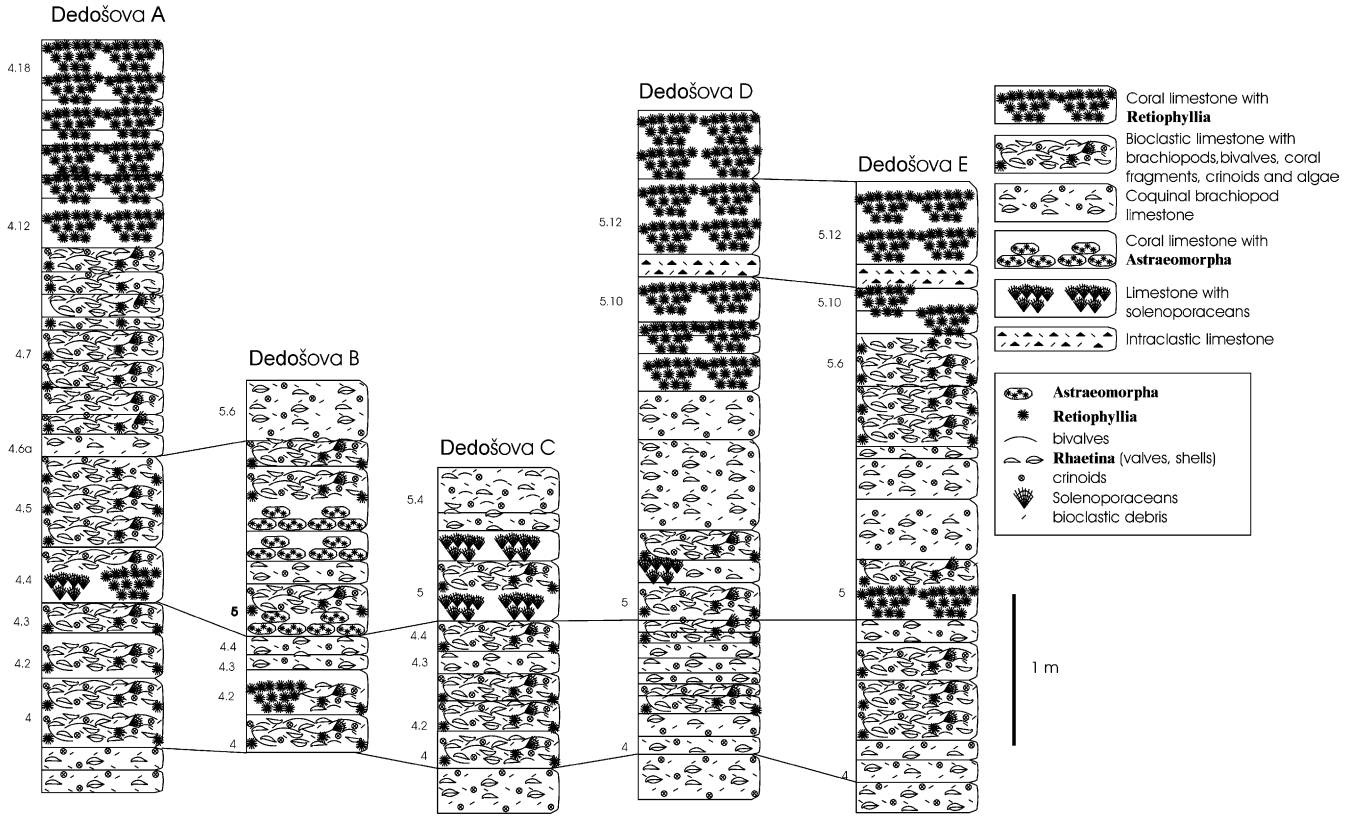
Bio-floatstones (MF 19) and bio-wackestones/packstones (MF 20) with micritized bioclasts are typically associated with an internal complex stratification, indicating high-energy episodic storm-reworking and complex taphonomic pathways. The two types differ basically in the degree of sorting and packing, suggesting different degrees of storm overprint. A high degree of micrization/bioerosion on both external and internal surfaces suggests a long post-mortem residence time on the sediment/water interface. The presence of encrusted and coated, locally also fragmented, ooids, the occurrence of similar-sized allochems without ooidic layers, and the variable preservation of co-occuring bioclasts points to their complex origin caused by transport or by environmental condensation due to rapid changes in environmental factors. Higher water energy could have been caused by episodic storm events or long-term fair-weather wave activity, which led to the accumulation and sorting of allochthonous material together with carbonate mud in an adjacent depression near the subtidal skeletal banks. Crinoid wackestones/packstones (MF 21) were deposited in the environment around the storm wave base. Crinoid ossicles are probably parautochthonous.
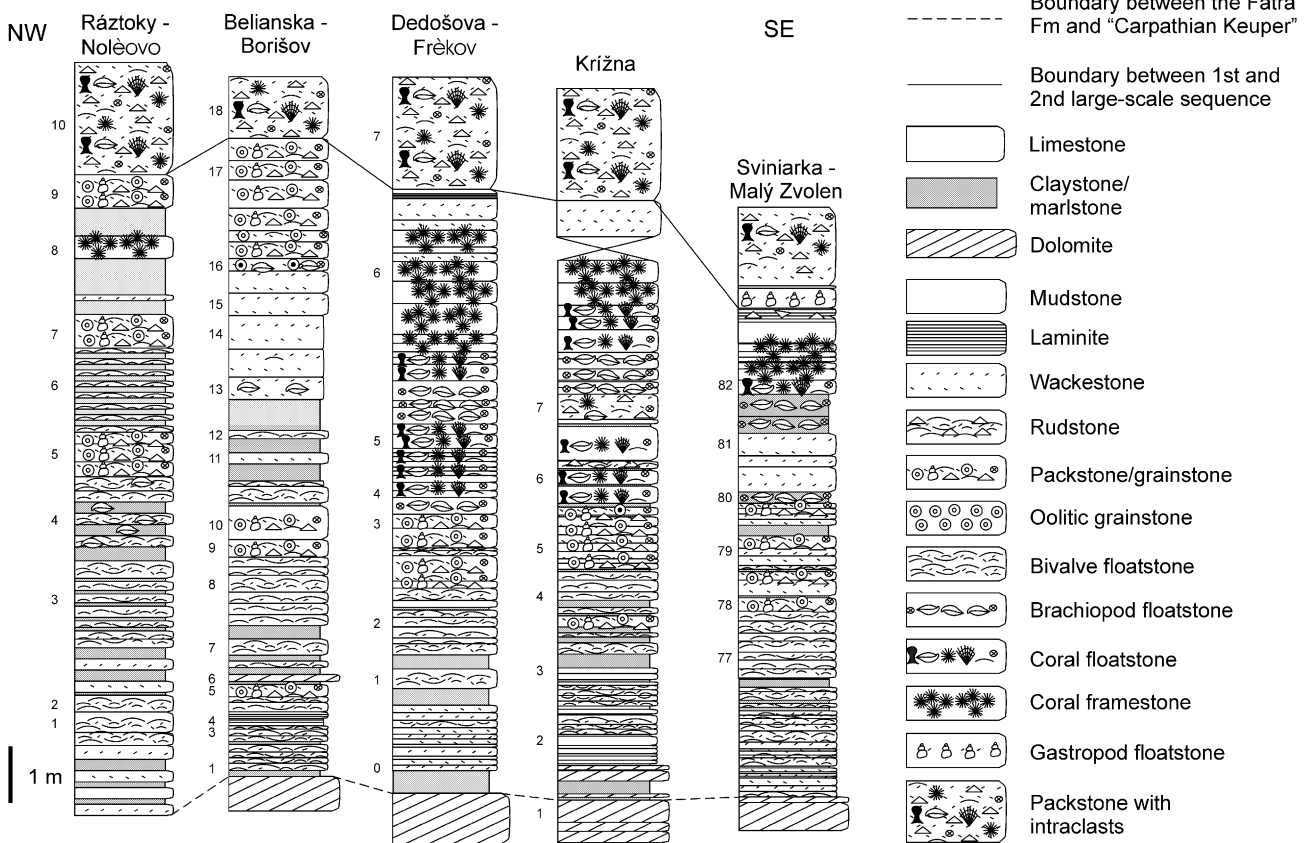
Facies associations

Facies types were subdivided according to their environmental interpretation, vertical and lateral transitions into four basic types of facies associations (facies groups deposited in the same general environment with local differences): 1. peritidal (or perimarine) environment, 2. shallow subtidal environment, above fair-weather wave base, 3. above normal storm wave base and 4. above maximum storm wave base.

The peritidal environment includes supratidal and intertidal flats, tidal islands and restricted depressions. These deposits are characterized by the presence of

A

Dedošova A

Dedošova D

Dedošova E

Dedošova B

Dedošova C

Coral limestone with **Retiophyllia**

Bioclastic limestone with brachiopods, bivalves, coral fragments, crinoids and algae

Coquinal brachiopod limestone

Coral limestone with **Astraeomorpha**

Limestone with solenoporaceans

Intraclastic limestone

Astraeomorpha
Retiophyllia
bivalves
Rhaetina (valves, shells)
crinoids
Solenoporaceans
bioclastic debris

1 m

B

NW

Ráztoky - Nolèovo

Belianska - Borišov

Dedošova - Frèkov

Krížna

SE

Sviniarka - Malý Zvolen

Boundary between the Fatra Fm and "Carpathian Keuper"

Boundary between 1st and 2nd large-scale sequence

Limestone

Claystone/ marlstone

Dolomite

Mudstone

Laminite

Wackestone

Rudstone

Packstone/grainstone

Oolitic grainstone

Bivalve floatstone

Brachiopod floatstone

Coral floatstone

Coral framestone

Gastropod floatstone

Packstone with intraclasts

1 m

biolaminites, the scarcity and poor diversity of benthic fauna, evidence of dessication or shrinkage and short-term high-energy events. This facies association comprises 4 basic microfacies types: mudstones (MF 1), breccias (MF 2), laminated bindstones (MF 3) and pel-packstones (MF 14).

The shallow subtidal environment above the fair-weather wave base is characterized by the presence of a facies association showing signs of long-term water agitation (packing, sorting, poor taphonomic preservation, ooids). They were deposited in subtidal skeletal and oolithic banks, incipient shoals and bars and adjacent back-barrier depressions. 5 microfacies types involve bio-rudstones (MF 10), bio-rudstones/grainstones (MF 11) and grainstones with micritized bioclasts (MF 12), oo-grainstones (MF 13) and oobio-packstones (MF 16).

An environment above the normal storm wave base can be compared to open lagoons with normal salinity and coral patch-reef/biostrome development, or restricted lagoons with abnormal salinity. This facies association is characterized by features pointing to low-energy background conditions (micritic matrix-supported fabric, relatively good preservation of bioclasts) and by presence of poorly or moderately diverse level-bottom and patch-reef macrobenthic assemblages with bivalves, gastropods, brachiopods, echinoderms, corals, sponges and red algae (Fig. 15A). Typically, facies types are characterized by a complex internal stratification on the bed scale and show evidence of short-term high-energy overprint, which is attributable to episodic storm events. This facies association includes floatstones/packstones with brachiopods (MF 5), gastropods (MF 6), floatstones with micritized corals (MF 9), micritized bioclasts (MF 19) and wacke-stones/packstones with micritized bioclasts (MF 20).

Below the normal storm wave base, deposits show no evidence of substantial reworking or erosion, although traces of storm-induced winnowing (pavements with skeletal concentrations) or deposition from seaward flowing storm-surge currents (thin packstone interbeds) were preserved. Benthic assemblages are typically autochthonous. Microfacies types can overlap with those from the preceding facies association, with definitive assignment based mostly on subtle taphonomic differences in the degree of storm-reworking (MF 4, 5, 6, 7, 8, 9, 18, and 21).

Environmental gradients

Although the DCA ordination of the exhaustive data set (Fig. 16A) is obviously affected by data heterogeneity

(Shi 1993), a continuous variation between microfacies types is apparent and some basic trends are visible. Along the first dimension, the samples representing shallow subtidal setting below the fair-weather wave base, represented by framestones and floatstones with corals (MF 8 and 9) on the right, pass into the mixture of samples with various degrees of high-energy overprint. However, oobio-packstones (MF 16) and oo-grainstones (MF 13) are situated on the left and are isolated from the rest. Therefore, the first dimension can be possibly correlated with the long-term wave activity gradient. Ordination of the reduced data set in the coordinate system of the first two dimensions shows relatively distinct separation of facies types (Fig. 16B). In this data set, including only microfacies types with benthic assemblages unaffected by transport or strong condensation (Fig. 15B), there is a gradational relationship among microfacies types which are well-defined and mostly non-overlapping. The first dimension can perhaps be related to a gradient in the substrate stability/water turbidity, with coral thickets living in a generally muddy environment (cf. Roniewicz and Stolarski 1999). Although the interpretation of the second axis in DCA is less clear (Kenkel and Orloci 1986), along the second dimension, there is a continuous gradation from poorly diverse bivalve- and gastropod-dominated microfacies with rare euhaline taxa in the lower part, to facies types with red algae, echinoderms, corals in the middle part, and brachiopod floatstones (MF 5) in the upper part of the plot. This dimension may reflect a salinity gradient.

Based on the correlation of the individual sections (Tomašových 2002, see above), there are three relatively well-defined unconformities, subdividing the stratigraphic column of the Fatra Formation in four large-scale depositional sequences (see description of sections above, Fig. 4, 7–10). Although an interpretation of the sequence stratigraphy is beyond the scope of this paper, in order to interpret and understand spatial facies relationships, a preliminary assessment of their temporal distribution patterns is discussed here. Within the depositional sequences that are defined according to these unconformities, vertical distribution of facies associations show a characteristic repetitive pattern. Therefore, in a simplified scheme, the distribution of microfacies types/facies associations in the lowermost large-scale sequence (Fig. 15B) of the Fatra Formation is used as the reference for reconstruction of the depositional environment (Fig. 17) here. Vertical changes in facies types enable us to interpret lateral shifts in the depositional environment (Walther's Law). It is important to note that this reconstruction does not include the complicated bottom topography, but is primarily focused on lateral relationship of facies types (Fig. 17).

Fig. 15 A Spatial variation in the facies development of coral patch-reef/biostrome facies in Dedošova – Frčkov. The distance between A and E section is 30 m. **B**. The correlation of the first large-scale sequence with coral patch-reef/biostrome facies (lower part of the Fatra Formation). The distance between Ráztoky-Nolčovo (NW part) and Sviniarka-Malý Zvolen (SE part) is about 25 km

1. In the lower part of the large-scale depositional sequence, MF types 18 (bivalve floatstones), 19 (bio-floatstones with micritized bioclasts) and 20 (bio-packstones/wackestones with micritized bioclasts) alternate with grainstones and bivalve rudstones (MF 10-

Fig. 16 A Detrended correspondence analysis of all samples showing ordination of samples and components using dimensions 1 and 2. **B**. Detrended correspondence analysis of reduced data matrix showing ordination of samples and bioclasts using dimensions 1 and 2. Numbered points represent individual samples. Explanations: Biv—bivalves, Gpd—gastropods, Bpd—brachiopods, Ech—echinoderms, Ost—ostracods, Cor—corals, Spo—calcareous sponges, For—foraminifers, Ssf—sessile foraminifers, Ral – red algae, Gal – green algae, Oo – ooids, Int – intraclasts, Pel – peloids
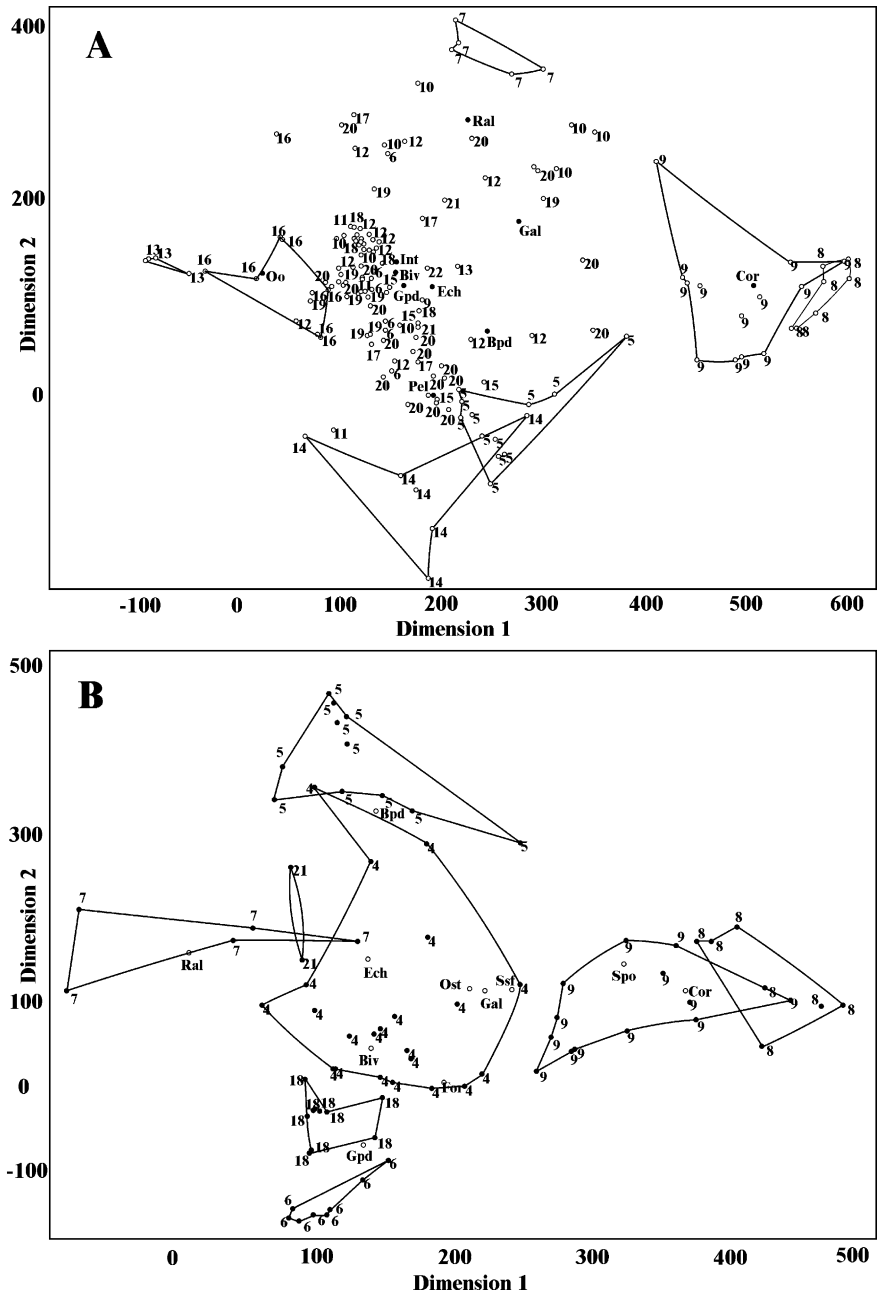

12), often forming shallowing-upward lagoonal-skeletal bank sequences. One of the most typical features is the presence of small-scale structures related to storm-reworking in MF 19 and 20, which are therefore usually characterized by a complex small-scale stratigraphic architecture. Although DCA based on component frequencies in microfacies types revealed an environmental gradient related to wave/water energy, incorporation of fabric/geometric and taphonomic criteria allows recognizing a depth-related environmental gradient with higher confidence (Fig. 17A). Areas lying above the fair-weather wave base subjected to long-term high-energy influence or multiple storm events are characterised by the presence of well-

sorted bio-grainstones, oo-grainstones and bivalve rudstones, commonly with amalgamation. Below the fair-weather wave base, simple or multiple-event storm-reworked deposits occur, with a bivalve-dominated assemblage. Variation in the degree of bioerosion/micritization points to the complex history related to the rate of burial/residence time on the sea-floor. Towards the more protected environment below normal storm wave base, intensity of storm event decreases and relatively undisturbed bivalve floatstones are preserved. In depressions lying in adjacent positions to high-energy ooid-skeletal banks, oobio-packstones were deposited. In landward direction, low-energy peritidal flats have been formed. In summary,
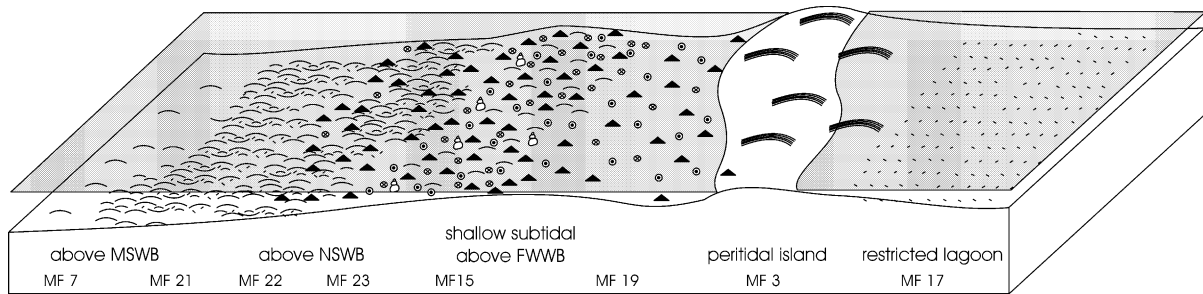
A. Shallow lagoon with flats/skeletal banks
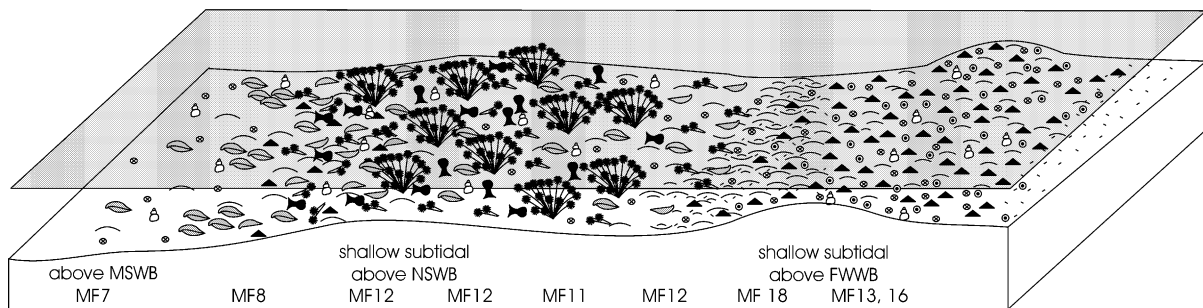
B. Deeper lagoon below FWWB with euhaline level-bottom and patch-reef benthic assemblages
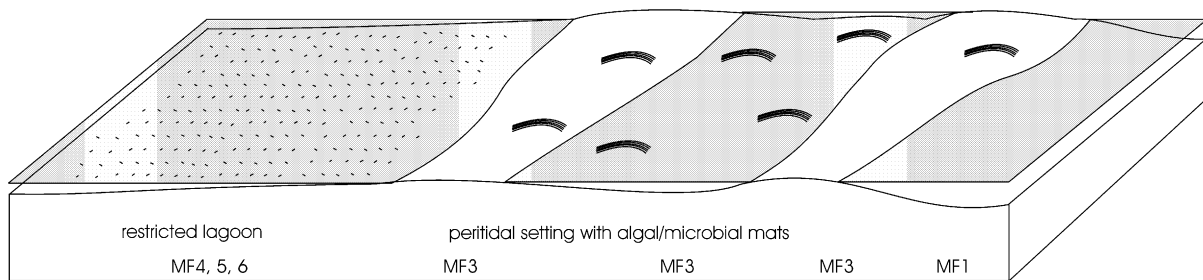
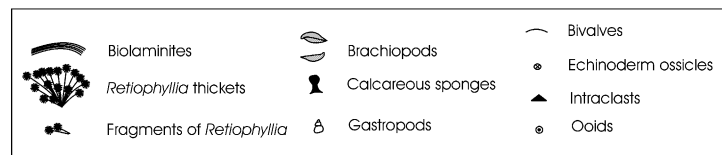C. Restricted peritidal environment

Fig. 17 Schematic reconstruction of lateral facies relationship in an environmental gradient in three different stages, developed within one large-scale sequence. **A.** Shallow lagoon with tidal flats/ skeletal banks and poorly diverse bivalve-dominated assemblages **B.** Deeper lagoon below FWWB with euhaline assemblages **C.** Restricted peritidal environment

this stage can be termed as a shallow lagoon with tidal flats and skeletal banks and poorly diverse bivalve-dominated assemblages.

2. In the middle part of the large-scale sequence, float-stones, packstones and framestones with poorly or moderately diverse macrobenthic assemblages (MF 5,

7, 8, 9) are dominant. Coral assemblages are represented by dm-scale biostromes or by small-scale, 2-m thick patch-reefs composed of several stacked coral colony aggregations (Fig. 15A, Fig. 5). The dominance of a matrix-supported fabric and the presence of stenohaline taxa indicate the deposition in an open

lagoon below the fair-weather wave base (Fig. 17B). The horizontal dimension of 1 to 2-m-thick coral patch-reef/biostrome between Dedošova-Frčkov and Malý Zvolen-Sviniarka attains about 10 km (Fig. 15B). In the marginal, NW part, high-energy skeletal banks were deposited. The evidence of storm-reworking points to a relatively shallow environment above normal storm wave base. Most exposed habitats are represented by bio-wackestones/packstones with micritized bioclasts (MF 20) and bio-floatstones with micritized corals (MF 9). In areas characterized by lower intensity of storm activity and/or lower intensity of taphonomic alteration, undisturbed brachiopod floatstones and monotypic coral aggregations (*Retiophyllia* framestones) were preserved. This stage is termed as a deeper lagoon below FWWB with benthic assemblages dominated by stenohaline taxa.

Patch-reef and biostrome-like areas played several roles in the carbonate production. They trapped and/or stabilized mostly fine-grained sediments, formed the sites of automicrite precipitation, and hosted a relatively diverse spectrum of carbonate-secreting organisms. On the one hand, taphonomic processes leading to precipitation of automicritic crusts probably stabilized and enhanced preservation potential of coral colonies. The presence of automicrite and encrustations (foraminifers) in intra-skeletal coral cavities indicates their post-mortem origin. On the other hand, corals are commonly preserved in parautochthonous deposits (MF 9) with signs of storm reworking (Fig. 175) and substantial bioerosion. It is not easy to distinguish between these two interrelated destructional factors and evaluate which was more important in destroying coral thickets. In some beds, there is evidence of extensive degradation of *in-situ* corals by bivalve macroborings (Fig. 51, Fig. 66). There is a positive correlation between the intensity of bioerosion and the degree of fragmentation of corals. In framestones (MF 8) with a low proportion of fragmented corals, the intensity of bioerosion is low in contrast to bio-floatstones with micritized corals (MF 9). It is possible that the higher activity of bioeroders related to local fluctuations in nutrient supply or turbidity made corals more susceptible to the destruction by storm activity (Hallock and Schlager 1986; Hallock 1988; Perry 1999). This can be confirmed by the fact that the regeneration potential of epithecate corals (Roniewicz and Stolarski 1999) is relatively low due to a lack of an edge-zone (tissue covering the external surface and repairing injuries).

3. In the upper part of the large-scale sequence, immediately below the terminal unconformity, mudstones and stromatolitic mudstones are dominant among various facies types (Fig. 15B). At this time, over most of the area, mudstones, laminated mudstones and mudstones with poorly diverse microfauna (ostracods, foraminifers) prevailed (Fig. 17C). However, it has been established that typical peritidal features (e.g. fenestrae, desiccation, evaporates) can also develop in non-tidally influenced environments, e.g. fluctuations in sea level may be caused by wind activity or seepages in back-barrier lagoons (Tucker and Wright 1990).

Depositional environment

The spatial arrangement of facies types along the depth-related environmental gradients points to the importance of water energy as one of the main control factors influencing their distribution patterns. Long-term wave energy and possibly tidal currents influenced sediment composition and fabric in skeletal and oolithic banks above the fair-weather wave base. However, the absence of large-scale barrier-bank complexes and small thicknesses are indicative of a relatively shallow depth level of the FWWB. During episodic storm events, in addition of substantial overprint of shoreface setting, areas below the fair-weather wave base were influenced by erosion, rapid burial and redeposition of sediment by storm waves and currents. The main biologic carbonate production took place below the fair-weather wave base, where coral patch-reef/biostrome assemblages and level-bottom benthic assemblages were living. The distribution of macro-benthic taxa can be correlated similarly with depth in a simplified scheme. This pattern is visible in the ordination of samples and taxa in the DCA, where trends related to water energy level, substrate stability and salinity can be inferred. This view about the position of coral-patch reefs differs from that in the depositional model of Michalik (1982), where coral patch-reefs are situated in the area of main wave activity. However, phaceloid growth morphology, sedimentologic (mud baffling, structures indicating storm activity) and taphonomic data (preservation state) are indicative that low-energy conditions in the vicinity of the storm wave base were their main preferred habitat.

On this spatial scale of analysis, facies patterns are therefore typical of ramp morphologies, where energy gradients are a consequence of gradual depth changes and higher production is limited to low-energy setting below FWWB in mid-ramp position (Burchette and Wright 1992). This can be a consequence of several factors related to the dominance of destructive taphonomic processes (high rate of degradation due to bioerosion and storm activity, e.g. Kuss 1983; Bernecker et al. 1999), perhaps the ecology of frame-building organisms (according to Stanton and Flügel 1987, branching retiophyllid corals mostly did not build rigid wave-resistant framework that could withstand the highest wave activity, but there are contradictory opinions, see Piller 1981; Schäfer 1984; Schäfer and Senowbari-Daryan 1981), environmental restriction/instability of Fatric intra-shelf setting leading to poor species richness (Michalík 1982), and/or slow subsidence or slow eustatic sea level rise (limited accommodation space). A comparable depositional model was developed for the lower part of the Kössen Formation (Kuss 1983). However, due to the

increase of the accommodation potential with relative sea level rise in the Upper Rhaetian, large-scale patch-reefs developed at distally-steepened ramps at the Kössen Basin margin or formed isolated structures within the Kössen Basin (Stanton and Flügel 1995). This is in contrast to the Fatric Unit, where the thickness of coral patch-reefs/biostromes attains maximally 4–5 m.

Given the abundant evidence of storm-reworking in the Fatra Formation, this intra-platform setting can be interpreted as storm-dominated. Although a typical tempestitic succession (Aigner 1982, 1985), including horizontal, hummocky-cross and ripple stratification, is mostly not preserved, several consistent features, such as erosional boundaries and grading associated with micritic fabric are indicative of storm origin. The evaluation of tidal activity is problematic and remains inconclusive at this point. Due to well-known low preservation potential of inter-supratidal deposits in modern seas, the absence of some typical tidal structures (e.g. herringbone cross-stratification) cannot be directly taken at face value. In a traditional model, the depositional setting of shallow epeiric seas is supposed to be essentially tideless due to bottom friction dampening tidal range. However, Pratt and James (1986) developed a model of a tide-dominated carbonate platform, based on assumptions that tidal height increases with increasing continental shelf area (Klein and Ryer 1978; Cram 1979); bottom friction is important only if there is substantial turbulence in the bottom layer and tidal currents themselves directly create the sea-floor topography.

In general, high variation in distribution of shallow water facies types and paleogeographic data (relatively restricted intra-shelf position) indicate that environmental conditions in respect to water energy, salinity or water turbidity were relatively unstable and ecologically restricted. This is supported by low or moderate diversity of both level-bottom and patch-reef/biostrome assemblages in comparison to those in the Eastern Alps (Golebiowski 1991) or dominance of eurytopic taxa (Michalík 1979, 1982).

Conclusions

21 microfacies types of the Rhaetian Fatra Formation supported by a cluster analysis represent a storm-dominated shallow environment. Main components are bivalves, gastropods, brachiopods, echinoderms, corals, foraminifers and red algae, ooids, intraclasts and peloids. The typical feature is the considerable lateral facies variation. Thus the depositional environment consisted of a wide spectrum of facies types, from peritidal flats/islands with algal or microbial mats, skeletal and oolitic banks and bars, open or restricted lagoons to small-scale coral biostromes and patch-reefs. Along the depth-related environmental gradient primarily linked to water energy, they form 4 facies associations corresponding to a peritidal setting, high-energy shoreface (above fair-weather wave base), shallow subtidal setting above normal storm wave base and shallow subtidal setting above maximum storm wave base.

The distribution and preservation of components were mainly influenced by the position of base level (FWWB), storm activity and differences in rate of biogenic carbonate production between individual settings. Water depths obviously remained very shallow throughout the deposition of the Fatra Formation. The main site of coral patch-reef/biostrome carbonate production was situated below the fair-weather wave base. Poorly diverse *Retiophyllia*-dominated coral assemblages form locally autochthonous several dm-thick colony aggregations or more commonly parautochthonous assemblages with evidence of the storm-reworking and substantial bioerosion by boring bivalves and microborings. Ordination methods indicate that changes in water energy, substrate stability/turbidity and salinity had substantial effects on the distribution of benthic groups.
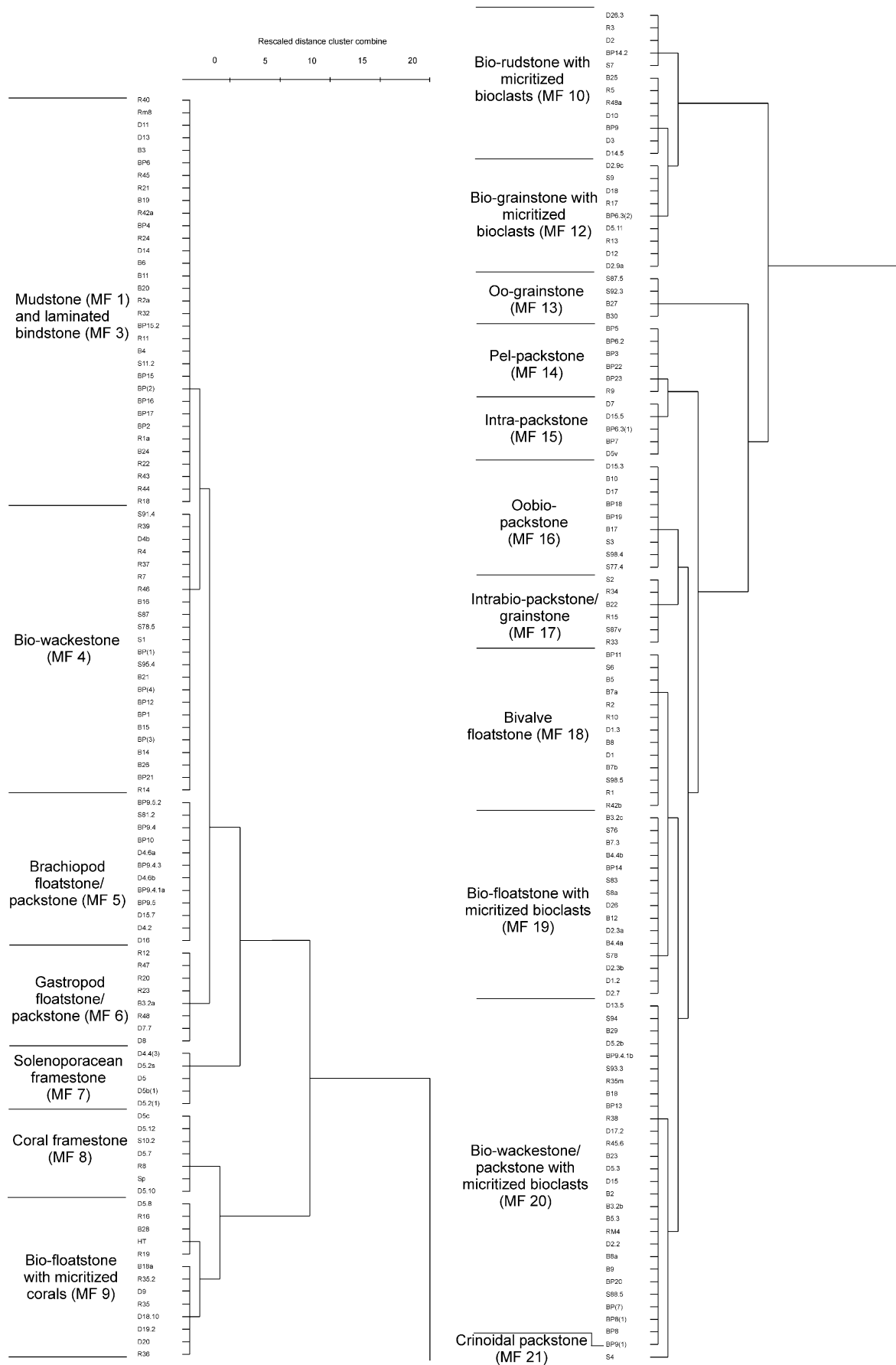
The reconstruction of the depositional environment involves three stages, differing in the position of relative sea level, namely a) shallow lagoon with tidal flats/skeletal banks and poorly diverse bivalve-dominated assemblages, b) deeper lagoon below FWWB with euhaline level-bottom and patch-reef/biostrome assemblages and c) restricted peritidal environment.

Facies types and assemblages are closely comparable to those known from the uppermost Triassic of the Eastern and Southern Alps (Hochalm Member of the Kössen Formation or Calcare di Zu Formation), pointing to similar intra-shelf depositional conditions. The absence of large-scale patch-reefs and the poor diversity of level-bottom and patch-reef/biostrome assemblages indicate the Fatric intra-platform setting was more restricted from the open ocean than intra-shelf habitats in the Eastern or Southern Alps at the end of the Triassic.

Appendix

The appendix consists of Fig. 18.

Rescaled distance cluster combine

0 5 10 15 20

Mudstone (MF 1) and laminated bindstone (MF 3)

Bio-wackestone (MF 4)

Brachiopod floatstone/ packstone (MF 5)

Gastropod floatstone/ packstone (MF 6)

Solenoporacean framestone (MF 7)

Coral framestone (MF 8)

Bio-floatstone with micritized corals (MF 9)

Bio-rudstone with micritized bioclasts (MF 10)

Bio-grainstone with micritized bioclasts (MF 12)

Oo-grainstone (MF 13)

Pel-packstone (MF 14)

Intra-packstone (MF 15)

Oobio-packstone (MF 16)

Intrabio-packstone/ grainstone (MF 17)

Bivalve floatstone (MF 18)

Bio-floatstone with micritized bioclasts (MF 19)

Bio-wackestone/ packstone with micritized bioclasts (MF 20)

Crinoidal packstone (MF 21)

References

Aigner T (1982) Calcareous tempestites: storm-dominated stratification in Upper Muschelkalk limestones (Middle Trias, SW-Germany). In: Einsele G, Seilacher A (eds) Cyclic and event stratification. Berlin-Heidelberg-New York, pp 180–198

Aigner T (1985) Storm depositional systems. Dynamic stratigraphy in modern and ancient shallow marine sequences. Lecture Notes Earth Sc 3: 1-174

Aigner T, Hagdorn H, Mundlos R (1978) Biohermal, biostromal and storm-generated coquinas in the Upper Muschelkalk. N Jahrb Geol Paläont, Abh 157:42–52

Bacelle L, Bosellini A (1965) Diagrammi per la stime visiva della composizione percentuale nelle rocce sedimentaire. Ann Univ Ferrara, Sci Geol Paleont 1:59–62

Ball MM (1967) Carbonate sand bodies of Florida and the Bahamas. J Sedim Petrol 37: 556–591

Bernecker M, Weidlich O, Flügel E (1999) Response of Triassic reef coral communities to sea-level fluctuations, storms and sedimentation: evidence from a spectacular outcrop. Facies 40:229–280

Borza K (1975) Mikroproblematika aus der oberen Trias der Westkarpaten. Geol Zb Geol Carpath 26: 199–236

Burchette TP, Wright VP (1992) Carbonate ramp depositional systems. Sedim Geol 79:3-57

Cram JM (1979) The influence of continental shelf width on tidal range: paleoceanographic implications. J Geol 87:441–447

Duffin CJ, Gadzicki A (1977) Rhaetian fish remains from the Tatra Mountains. Acta Geol Polon 27: 333–348

Dullo WC (1980) Paläontologie, Facies und Geochemie der Dachsteinkalke (Obertrias) im südwestlichen Gesäuse, Steiermark, Österreich. Facies 2:55–122

Dunham RJ (1962) Classification of carbonate rocks according to depositional texture. Mem AAPG 1:108–121

Ehses HH, Leinfelder RR (1988) Laterale und vertikale Fazies-entwicklung der Rhät/Unterlias-Sedimentation im Wallberg-Blankenstein-Gebiet (Tegernsee, Nrdliche Kalkalpen). Mainz Geowiss Mitt 17: 53–94

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

Embry AF, Klovan JE (1972) Absolute water depth limits of Late Devonian paleoecological zones. Geol Rund 61:672–686

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

Flügel E (1972) Mikroproblematika in Dünnschliffen von Trias-Kalken. Mitt Ges Geol Bergbaustud 21:957–988

Flügel E (1981) Paleoecology and facies of Upper Triassic reefs in the Northern Calcareous Alps. In: Toomey DF (ed) European fossil reef models. SEPM Spec Publ 30: 291–359

Flügel E (2002) Triassic reef patterns. In: Kiessling W, Flügel E, Golonka J (eds) Phanerozoic reef patterns. SEPM Spec Publ 72:391–463

Flügel E, Kiessling W (2002) Patterns of Phanerozoic reef crises. In: Kiessling W, Flügel E, Golonka J (eds) Phanerozoic reef patterns. SEPM Spec Publ 72:691–733

Gaffey SJ (1983) Formation and infilling of pits of marine ooid surfaces. J Sedim Petrol 53: 193–208

Garrett P (1970) Phanerozoic stromatolites – non-competitive ecologic restriction by grazing and burrowing animals. Science 169:171–173

Gawlick, HJ (2000) Paläogeographie der Ober-Trias Karbonattplatform in den Nordlichen Kalkalpen. Mitt Ges Geol Bergbaustud Österr 44: 45–95

Gadzicki A (1971) Megalodon limestones in the subtatric Rhaetian of the Tatra Mts. Acta Geol Polon 21:387–398

Gadzicki A (1974) Rhaetian microfacies, stratigraphy and facial development in the Tatra Mts. Acta Geol Polon 24: 17–96

Gadzicki A (1983) Foraminifers and biostratigraphy of Upper Triassic and Lower Jurassic of the Slovakian and Polish Carpathians. Palaeont Polon 44: 109–169

Gadzicki A, Michalík J, Planderová E, Sýkora M (1979) An Upper Triassic—Lower Jurassic sequence in the Krížna nappe (West Tatra Mountains, West Carpathians, Czechoslovakia). Záp Karp, Geol 5: 119–148

Golebiowski R (1991) Becken und Riffe der alpinen Obertrias—Lithostratigraphie und Biofazies der Kossener Formation. Exkursionen Jungpaläozoikum und Mesozoikum, Österr, Österr Paläont Gesell, pp 79–119

Haas J, Kovács S, Krystyn L, Lein R (1995) Significance of Late Permian-Triassic facies zones in terrane reconstructions in the Alpine-North Pannonian domain. Tectonophysics 242:19–40

Hallam A (1996) Recovery of the marine fauna in Europe after the end-Triassic and early Toarcian mass extinctions. In: Hart MB (ed) Biotic recovery from mass extinction events. Geol Soc Lond Spec Publ 102: 231–236

Hallam A (2002) How catastrophic was the end-Triassic mass extinction? Lethaia 35:147–157

Hallam A, Wignall PB (1997) Mass extinctions and their aftermath. Oxford Univ Press, Oxford, 320 pp

Hallock P (1988) The role of nutrient availability in bioerosion: consequences to carbonate buildups. Palaeogeogr, Palaeoclimatol, Palaeoecol 63:275–291

Hallock P, Schlager W (1986) Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios 1:389–398

Hardie LA (1996) Secular variation in seawater chemistry: an explanation for the coupled secular variation in the mineralogies of marine limestones and potash evaporites over the past 600 m.y. Geology 24:279–283

Hill MO, Gauch HG Jr (1980) Detrended correspondence analysis: an improved ordination technique. Vegetatio 42:47–58

Hine AC (1977) Lily Bank, Bahamas: history of an active oolite sand shoal. Journal Sedim Petrol 47:1-25

Hine AC, Wilber RJ, Neumann AC (1981) Carbonate sand bodies along contrasting shallow bank margins facing open seaways in Northern Bahamas. AAPG Bull 65:261–290

Inden RF, Moore CH (1983) Beaches. In: Scholle PA, Bebout DG, Moore CH (eds) Carbonate depositional environments. AAPG Memoir 33:211–265

Kazmierczak J, Colemn ML, Gruszczynski M, Kempe S (1996) Cyanobacterial key to the genesis of micritic and peloidal limestones in ancient sea. Acta Palaeont Polon 41:319–388

Kenkel NC, Orlóci L (1986) Applying metric and nonmetric multidimensional scaling to ecologic studies. Some new results. Ecology 67:919–928

Kidwell SM, Bosence DWJ (1991) Taphonomy and time-averaging of marine shelly faunas. In: Allison PA, Briggs DEG (eds) Taphonomy: Releasing the data locked in the fossil record. Plenum Press, New York, pp 115–129

Klein G De V, Ryer TA (1978) Tidal circulation patterns in Precambrian, Paleozoic, and Cretaceous epeiric and mioclinal shelf seas. Geol Soc Am Bull 89:1050–1058

Kobluk DR, Risk MJ (1977) Micritization and carbonate-grain binding by endolithic algae. AAPG Bull 61:1069–1082

Kochanová M (1967) Zur Rhaet-Hettang-Grenze in den Westkarpaten. Sb Geol Vied, Záp Karpaty 7:7-102

Kołodziej B (1997) Boring Foraminifera from exotics of the Štramberk-type limestones (Tithonian-Lower Berriasian, Polish Carpathians). Ann Soc Geol Polon 67:249–256

Kowalewski M, Gürs K, Nebelsick JH, Oschmann W, Piller WE, Hoffmeister AP (2002) Multivariate hierarchical analyses of Miocene mollusk assemblages of Europe: paleogeographic,

Fig. 18 Dendrogram of Q-mode cluster analysis including sample numbers and microfacies types. Microfacies types 2 (intraclastic breccia) and 11 (Bio-rudstones/grainstones with bimodal sorting) were recognized additionally according to fabric criteria. Explanations of the symbols: The capital letter designates the locality (D – Dedošova—Frčkov, S – Sviniarka – Malý Zvolen, B – Belianska – Borišov, BP – Bystrý potok – Ružomberok, R – Ráztoky – Nolčovo) and the number designated the bed number

paleoecological, and biostratigraphic implications. Geol Soc Am Bull 114: 239–256

Kuss J (1983) Faziesentwicklung in proximalen Intraplattform-Becken: Sedimentation, Palökologie und Geochemie der Kössener Schichten (Ober-Trias, Nördlichen Kalkalpen). Facies 9:61–172

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

Lescinsky HL (2001) Epibionts. In: Briggs DEG, Crowther PR (eds) Palaeobiology II. Blackwell Sc, Oxford, pp 460–464

Michalík J (1973) Paläogeographische Studie des Räts der Krížna-Decke des Strážov-Gebirges und einiger anliegender Gebiete. Geol Zb Geol Carpath 24: 123–140

Michalík J (1974) Zur Paläogeographie der Rhätische Stufe des weslichen Teiles der Krížna-Decke in der West-Karpaten. Geol Zb Geol Carpath 25: 257–285

Michalík J (1975) Genus *Rhaetina* Waagen, 1882 (Brachiopoda) in the Uppermost Triassic of the West Carpathians. Geol Zb Geol Carpath 26: 47–76

Michalík J (1977) Paläogeographische Untersuchungen der Fatra-Schichten (Kossen - Formation) des nordlichen Teiles des Fatrikums in der Westkarpaten. Geol Zb Geol Carpath 28:71-94

Michalík J (1979) Paleobiogeography of the Fatra-Formation of the Uppermost Triassic of the West Carpathians. Paleont Konf 77, Charles University, Prague, pp 25–39

Michalík J (1980) A paleoenvironmental and paleoecological analysis of the West Carpathian part of the Northern Tethyan nearshore region in the Latest Triassic time. Riv Ital Paleont 85: 1047–1064

Michalík J (1982) Uppermost Triassic Short-Lived Bioherm Complexes in the Fatric, Western Carpathians. Facies 6: 129–146

Michalík J (1985) Bystrý Potok. Litofaciálny vývoj rétskeho súvrstvia. In: Samuel O, Franko O (eds) Sprievodca k XXV. celoštátnej geologickej konferencii Slovenskej geologickej spoločnosti. Geol. Ústav. D. Štúra, pp 168–170

Michalík J (1994) Notes on the paleogeography and paleotectonics of the Western Carpathian area during the Mesozoic. Mitt Österr Geol Gesell 86:101–110

Michalík J, Gadzicki A (1983) Stratigraphic and environmental correlations in the Fatra- and Norovica Formation (Upper Triassic, Western Carpathians). Schrift Erdwiss Komm 5: 267–276

Michalík J, Jendrejáková O (1978) Organism communities and biofacies of the Fatra Formation (Uppermost Triassic, Fatric) in the West Carpathians. Geol Zb Geol Carpath 29: 113–137

Michalík J, Sýkora M (1979) Fatra- und Kopienec-Schichten in dem Profil Ráztoky des Nolčovo-Tales in der Grossen Fatra Gebirge (höchste Trias-untere Jura des Krížna-Decke, Westkarpaten). Kmetianum, 5:113–133

Mišík M (1997) Stratigraphical and spatial distribution of limestones with calcite, chamosite, hematite and illite ooids in the Western Carpathians. Miner Slov 29: 83–112 (in Slovak with English summary)

Perry CT (1998) Grain susceptibility to the effects of microboring: implications for the preservation of skeletal carbonates. Sedimentology 45:39–51

Perry CT (1999) Reef framework preservation in four contrasting modern reef environments, Discovery Bay, Jamaica. J Coast Res 15:796–812

Perry CT, Bertling M (2000) Spatial and temporal patterns of macroboring within Mesozoic and Cenozoic coral reef systems. In: Insalaco E, Skelton PW, Palmer TJ (eds) Carbonate platform systems: components and interactions. Geol Soc Lond Spec Publ 178:33–50

Piller W (1981) The Steinplatte reef complex, part of an Upper Triassic carbonate platform near Salzburg, Austria. In: Toomey DF (ed) European fossil reef models. SEPM Spec Publ 30: 261–290

Pratt BR, James NP (1986) The St George Group (Lower Ordovician) of western Newfoundland: tidal flat island model for carbonate sedimentation in shallow epeiric seas. Sedimentology 33: 313–343

Rakús M (1993) Lias ammonites of the West Carpathians. Zap Karpaty Paleont 17:7-40

Raup DM, Sepkoski JJ Jr (1982) Mass extinctions in the marine fossil record. Science 215:1501–1503

Raup DM, Sepkoski JJ Jr (1986) Periodic extinction of families and genera. Science 231:833–836

Reyment RA, Savazzi E (1999) Aspects of multivariate statistical analysis in geology. Elsevier, Amsterdam, 285 pp

Roniewicz E, Michalík J (1991a) A new Triassic scleractinian coral from the High Tatra Mountains (Western Carpathians, Czecho-Slovakia). Geol Carpath 42: 157–162

Roniewicz E, Michalík J (1991b) Zardinophyllum (Scleractinia) from the Upper Triassic of the Central Western Carpathians (Czecho-Slovakia). Geol Carpath 42: 361–363

Roniewicz E, Michalík J (1998) Rhaetian scleractinian corals in the Western Carpathians. Geol Carpath 49:391–399

Roniewicz E, Stolarski J (1999) Evolutionary trends in the epithecate scleractinian corals in the Western Carpathians. Acta Palaeont Polon 44:131–166

Sandberg PA (1983) An oscillating trend in Phanerozoic nonskeletal carbonate mineralogy. Nature 305:19–22

Schäfer K (1969) Vergleichs-Schaubilder zur Bestimmung des Allochemgehalts bioklastischer Karbonatgesteine. N Jahrb Geol Paläont, Monatshefte 1969: 173–184

Schäfer P (1979) Fazielle Entwicklung und palökologische Zonierung zweier obertriadischer Riffstrukturen in den Nördlichen Kalkalpen ("Oberrhät"-Riffkalke, Salzburg). Facies 1: 3–45

Schäfer P (1984) Development of ecological reefs during the latest Triassic (Rhaetian) of the Northern Limestone Alps. Palaeontogr Amer 54:210–218

Schäfer P, Senowbari-Daryan B (1981) Facies development and paleoecologic zonation of four Upper Triassic patch-reefs, Northern Calcareous Alps near Salzburg, Austria. In: Toomey DF (ed) European fossil reef models. SEPM Spec Publ 30: 241–259

Schwarzacher W (1948) Über sedimentäre Rhytmik des Dachsteinkalkes am Lofer. Verh Geol Bundes, 10–12: 176–188

Seilacher A (1984) Constructional morphology of bivalves: evolutionary pathways in primary versus secondary soft-bottom dwellers. Palaeontology 27:207–237

Shi GR (1993) Multivariate data analysis in palaeoecology and palaeobiogeography—a review. Palaeogeogr, Palaeoclimatol, Palaeoecol 105: 199–234

Shinn EA (1968) Practical significance of birdseye structures in carbonate rocks. J Sedim Petrol 38: 215–223

Shinn EA (1983) Birdseyes, fenestrae, shrinkage pores, and loferites: a reevaluation. J Sedim Petrol 53:619–628

Simone L (1981) Ooids: a review. Earth Sc Rev 16:319–355

Stanley GD (1979) Paleoecology, structure, and distribution of Triassic coral build-ups in Western North America. Univ Kansas Paleont Contr 65: 1–58

Stanley GD Jr (1988) The history of Early Mesozoic reef communities: a three-step process. Palaios 3:170–183

Stanley GD Jr, Swart PK (1995) Evolution of the coral-zooxanthellae symbiosis during the Triassic: a geochemical approach. Paleobiology 21:179–199

Stanley MS, Hardie LA (1998) Secular oscillations in the carbonate mineralogy of reef-building and sediment-producing organisms driven by tectonically forced shifts in seawater chemistry. Palaeogeogr, Palaeoclimatol, Palaeoecol 144:3-19

Stanton RJ Jr, Flügel E (1987) Paleoecology of Upper Triassic reefs in the Northern Calcareous Alps: reef communities. Facies 16: 157–186

Stanton RJ Jr, Flügel E (1989) Problems with reef models: The Late Triassic Steinplatte "reef" (Northern Alps, Salzburg/Tyrol, Austria). Facies 20: 1–138

Stanton RJ Jr, Flügel E (1995) An accretionary distally steepened ramp at an intra-shelf basin margin: an alternative explanation for the Upper Triassic Steinplatte "reef" (Northern Calcareous Alps). Sedim Geol 95: 269–286

Strasser A (1986) Ooids in Purbeck limestones (lowermost Cretaceous) of the Swiss and French Jura. Sedimentology 33: 711–727

Stur D (1859) Über die Kössener Schichten in nord-westlichen Ungarn. Sitzungsber Akad Wiss, math-nat Kl 38:1006–1024

Tomašových A (2000) Lagoonal-peritidal sequences in the Fatra Formation (Rhaetian): an example from the Veľká Fatra Mountains (Western Carpathians). Slovak Geol Mag 6:256–259

Tomašových A (2002) Benthic assemblages and depositional environment in the uppermost Triassic (Rhaetian) of the West Carpathians (Fatric Unit, Veľká Fatra Mts.). Master of Science Thesis, Comenius University, Bratislava, pp 1–136

Tomašových A, Michalík J (2000) Rhaetian/Hettangian passage beds in the carbonate development in the Krížna Nappe (central Western Carpathians). Slovak Geol Mag 6:241–249

Török A (1993) Brachiopod beds as indicators of storm events: an example from the Muschelkalk of southern Hungary. In: Pálfy J, Vrs A (eds) Mesozoic brachiopods of Alpine Europe. Budapest, pp 161–172

Tucker ME, Wright VP (1990) Carbonate sedimentology. Blackwell Sc Publ, Oxford London, 482 pp

Turnšek D, Dolenec T, Siblík M, Ogorelec B, Ebli O, Lobitzer H (1999) Contributions to the fauna (corals, brachiopods) and stable isotopes of the Late Triassic Steinplatte reef/basin complex, Northern Calcareous Alps, Austria. Abh Geol Bundesanstalt 56:121–140

Wilkinson BH, Owen RM, Carroll AR (1985) Submarine hydrothermal weathering, global eustasy, and carbonate polymorphism in Phanerozoic marine oolites. J Sedim Petrol 55:171–183

Wilson JL (1975) Carbonate facies in geologic history. Springer, Berlin, 471 pp

Wood R (1999) Reef evolution. Oxford Univ Press, 414 pp

Wurm D (1982) Mikrofazies, Paläontologie und Palökologie der Dachsteinriffkalke (Nor) des Gosaukammes, Österreich. Facies 6:203–296

Zankl H (1969) Der Hohe Göll: Aufbau und Lebensbild eines Dachsteinkalk-Riffes in der Obertrias des Nördlichen Kalkalpen. Abh Senckenberg Naturforsch Ges 519:1–123