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Biofacies evolution in the Triassic platforms of the Dolomites, Italy

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Abstract

The Triassic of the Dolomites includes many carbonate platform generations, ranging in age from the Anisian to the Norian-Rhaetian. After the Permian-Triassic biological crisis, "reef" communities reappeared during the Anisian time. These buildups were generally characterized by a limited relief, lacking any primary skeletal framework and evidence of syndepositional cementation. The microfacies are dominated by micrites, mainly allochthonous or detrital in origin. The sparse biota are generally binder and buffler organisms, such as dasycladacean algae, sphinctozoans and briozoans.

The second generation of carbonate buildups (late Anisian–early Ladinian, Sciliar Fm) are dominated by syndepositional cements (e.g. Marmolada Platform). These cements represent the main component of margin and upper slope facies. They form more or less isolated or laterally linked bodies: the "evinosponges". During the late Ladinian and Carnian p.p., the post-volcanic platforms developed (Cassian Dolomite). The microfacies of these platforms manly consist of micrites, cements and skeletons. The automicrites constitute more than 50% of the rock volume, the cements the 20%, and the skeletal organisms less than the 10%. The metazoan contribution is subordinated to that of skeletal cyanobacteria, like *Cladogirvanella cipitensis* and microproblematica, like *Tubyphites*. The primary marine cements provide evidence of a widespread early syndepositional lithification. Towards the top of Julian Substage (Carnian), at the base of the Heiligkreutz/Dürrenstein Formation (i.e. Alpe di Specie), small calcareous bioconstructions, interpreted as patch-reefs, show a much more "modern" faunal association. For the first time in the Triassic, a primary skeletal framework developed, largely formed by calcified demosponges and scleractinians. Corals were still subordinated to sponges. Taxonomic diversity increases greatly and the skeletal component exceeds the 50% of the rock volume. These biofacies anticipate the "modernization" of the reef-building communities, occurring at a global scale between the Late Carnian and the Norian-Rhaetian.

Keywords: Carbonate platforms, organisms, automicrites, Triassic, Dolomites, Italy.

Introduction

The seminal papers of Richthofen (1860) and Mojsisovics (1879) already described the "reef" nature of the Dolomite mountains and provided their first stratigraphic framework. A geometric and sequence stratigraphic synthesis was proposed by Bosellini (1984); more recently, the major role of the non coralline bioconstructors and the importance of the synsedimentary cementation were recognized by Senowbari-Daryan et al. (1993), and Russo et al. (1998b, 2000). A detailed biostratigraphic and chronological framework was settled by Brack and Rieber (1993).

The stratigraphic framework of the Dolomites includes Permian to Cretaceous units, but the area is dominated by the Triassic formations, which constitute most of Dolomite mountains.

This paper summarizes our original researches on constructor communities and sedimentary facies

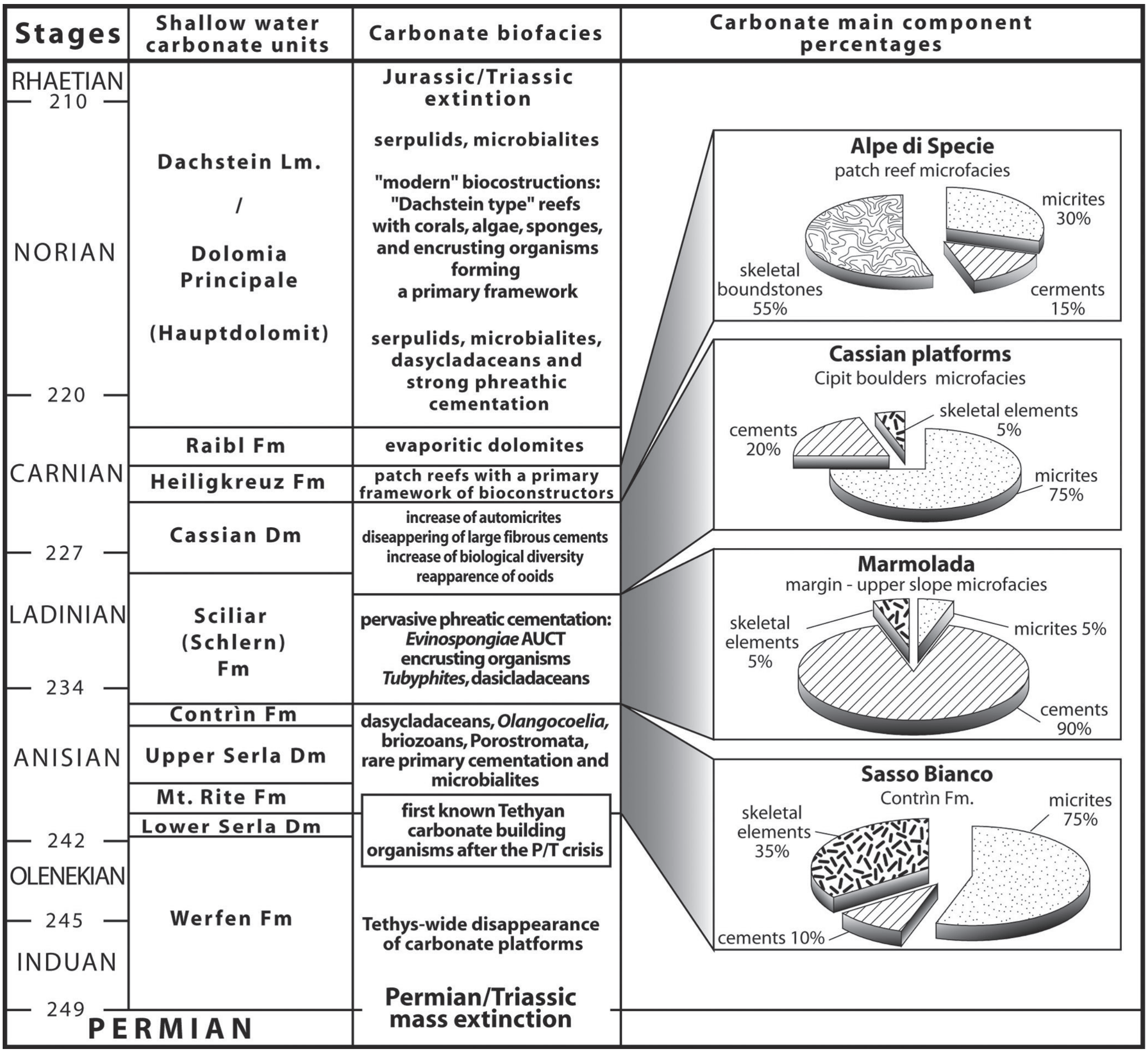


Fig. 1. A synthesis of stratigraphy, biofacies and carbonate component percentages in the Triassic carbonate platforms of the Dolomites (Italy). Modified from Stefani et al. (2004). Dating from Gradstein et al. (1995).

of the following carbonate buildups: Sasso Bianco, Marmolada, Molignon, Punta Grohmann, Sella, Sett Sass, Alpe di Specie.

The Anisian banks of Contrìn Formation: the Sasso Bianco case history

Masetti and Neri (1980) for the first time briefly described the limestone succession cropping out in the Sasso Bianco area. The Sasso Bianco is an upper Anisian buildup, belonging to the Formazione di Contrìn, which preserves the primary microfacies unaffected by the late diagenetic pervasive dolomitization. The succession is characterized by micritic layers, alternated to calcarenites and less common fine-grained calcirudites. They unit consists of bio-intraclastic packstones, rich in bioclasts of dasycladacean algae (e.g. *Teutloporella* sp.; Pl. 1, Fig. 1) and, subordinately, crinoids, gastropods, thick shelled pelecypods, brachiopods, sponges, etc. Boundstone intraclasts are relatively common and are constituted by *Tubiphytes*, *Olangocoelia otti* (Pl. 1, Fig. 2), and encrusting forams, such as *Tolypammina gregaria*. Micritic intraclasts and microbial stromatolite fragments are also present. The succession records the pro-gradation of a gently inclined slope, rich in loose carbonate mud. The carbonate mud seems to be mainly allochthonous or detrital in origin, as inferred from the absence of any non-gravitational texture, such as stromatolitic and/or thrombolitic fabric, boring, and synsedimentary fracturing structures. The widespread bioturbation confirms the loose soft nature of the primary mud. This abundance in loose calcareous mud controlled the low topographic gradients of the study slopes. Steeper clinostratifications are spatially confined to a few areas and chronologically limited to the maximum progradation phase (Neri and Stefani 1998).

The first platform generations, after the Permo/Triassic crisis, seem to be characterized by a large amount of allochthonous micrites and by a reduced syndepositional cementation (Fig. 1).

Pre-volcanic carbonate platforms (late Anisian–early Ladinian): the Marmolada buildup and its "*Evinospongiae*"

A regional drowning terminated the Contrìn carbonate system. Shallow water carbonate-producing environments survived only at small isolated highs, which experienced a rapid aggradational evolution. These buildups shared many facies similarities with the former and wider Contrìn platforms, being still rich in micritic sediments and dasycladacean algae. The western buildups (e.g. Latemar, Catinaccio, Marmolada Platforms) rapidly reached an average thickness of 800-900 m, while just a few tens of metres of cherty limestones were accumulated in the adjacent basins (Knollenkalke Mb of the Livinallongo Fm). During the early Ladinian, the subsidence slowed down considerably and a massive progradation phase began, spanning over a comparatively short early Ladinian interval. The progradational phase was characterized by pervasive phreatic marine cementation of the margin and upper slope limestones and by the development of very steep (up to 30-40°), planar breccia slopes.

Outer margin-upper slope

The Marmolada platform, which represents a well preserved pre-volcanic buildup, is characterized by an outer margin and an uppermost slope dominated by decimetre scale boundstones blocks, coated and linked each other by very large amounts of fibrous calcite cements, arranged in concentric bands. These cements represent the main component of the margin-upper slope facies (Fig. 1) and form more or less isolated or laterally linked bodies: the evinosponges (Pl. 1, Fig. 3). The syn-depositional origin of these elements is demonstrated by the fact that they are frequently reworked as clasts in mid to low slope deposits.

Samples show isopachous bands of fibrous calcite of different thickness and colors: light and dark layers alternate each others, millimetres to centimetres in size (Pl. 1, Fig. 4)

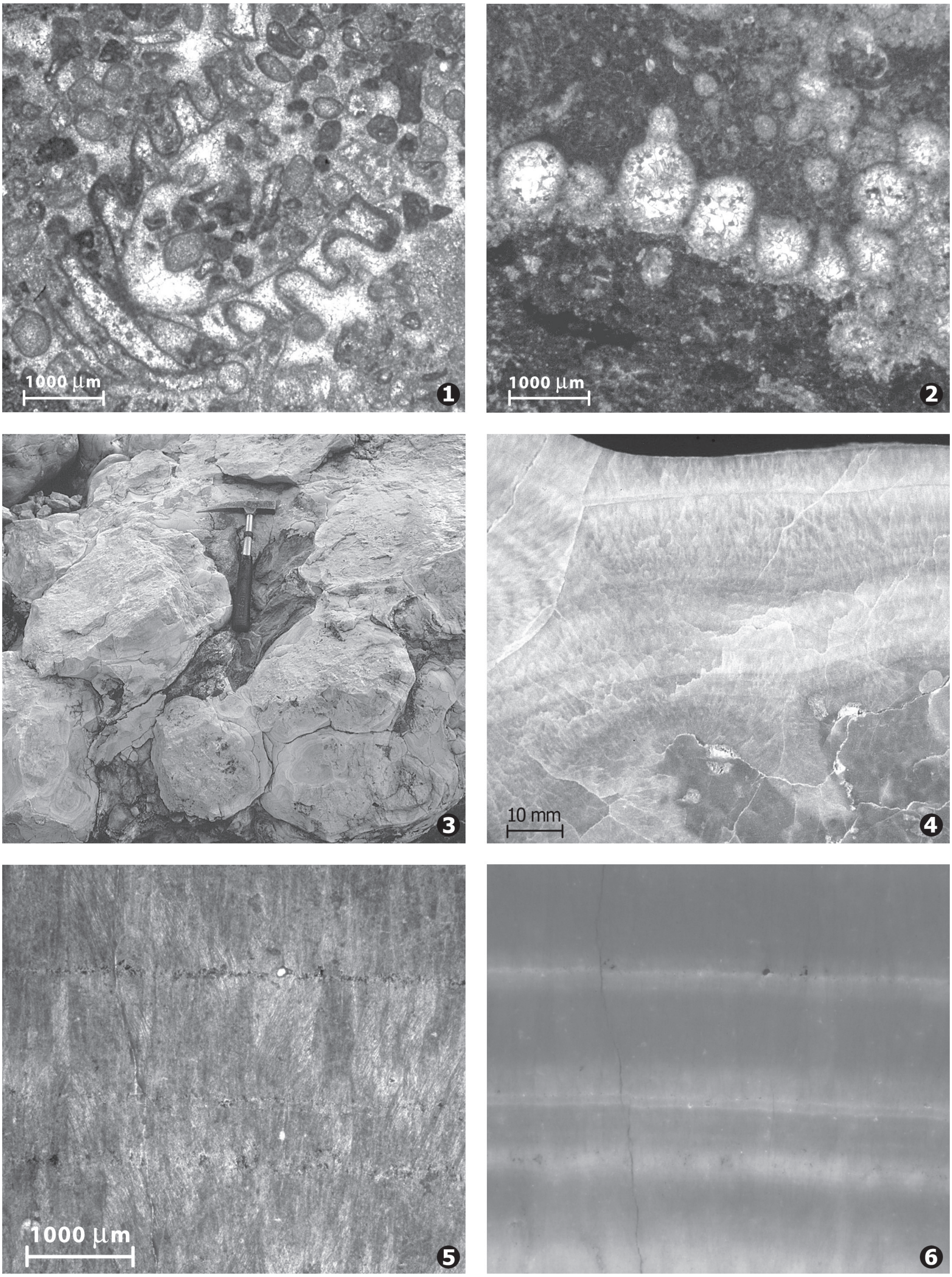
Epifluorescence observations on uncovered thin sections of evinosponges show an alternation of strongly and feebly fluorescent bands (Pl. 1, Figs 5-6) indicating the presence of residual organic matter (Cuif et al. 1990; Müller-Wille and Reitner 1993; Reitner and Neuweiler 1995; Russo et al. 1997, 2000). SEM observations on strongly fluorescent areas revealed the presence of more or less spherical bodies, ranging in size from 100 to 300 nm. These fossils could represent the relicts of nannobacterial cells. Epifluorescence data, together with micro-morphological analyses, indicate a widespread presence of organic matter remains which is likely to have played a significant role in supporting the widespread syndepositional cementation (Russo et al. 2005).

The platform top

The platform top is constituted by intra-bioclast calcarenites and calcirudites, interbedded with subordinated boundstones. The boundstones are made up by early lithified peloidal micrites, organized in thrombolitic clots or, more rarely, in thin stromatolitic laminae. These facies are very rich in primary cavities, lined with isopachous fibrous cements. The boundstones are not particularly abundant and consist of skeletal cyanobacteria (porostromata) and dasycladacean algae, with less amount of foraminifers, gastropods, echinoids, and pelecypods.

Well lithified boundstone intraclasts prevail in the grainstone facies; bioclasts are also present and derive, in decreasing order of frequency, from porostromata, dasycladacean algae, gastropods, pelecypods, foraminifers, echinoderms, micro-problematica, and sporadic sponges (Pl. 2, Fig. 1).

Most of the observed porostromata (skeletal cyanobacteria) belong to the genera *Ortonella*, *Hedstroemia*, *Bevocastria* and *Cayeuxia*. The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porostromata thalli are often found as micritized and coated ghosts. Dasycladacean algae mainly belong to the species *Macroporella alpina*, *Diplopora annulata*, *Diplopora nodosa*, *Gyroporella* sp. and *Oligoporella* sp. This association indicates an upper Anisian-lower Ladinian age, in good agreement with the more accurate ammonoid dating (Brack and Rieber 1994, 1996). The calcareous micro-problematica, so common in the post-volcanic platforms (Brandner et al. 1991a, b; Russo et al. 1997), become relatively rare and are represented by a few taxa, such as *Tubiphytes obscurus*, *Tubiphytes carinthiacus* and *Plexoramea cerebriformis*. Sponges occur only as isolated specimens.

Some forms are referable to the genus *Deningeria* and the more frequent species is *Olangocoelia otti*.

Foraminifers, pelecypods, gastropods, echinoid spines, and rare ostracods are found in both bound-stones and grainstones facies. Foraminifers are re-presented by agglutinated forms as *Endothyranella* sp. and *Earlandinita* sp.; specimens of duostominids and miliolids are less frequent.

Post-volcanic platforms (late Ladinian-early Carnian): examples from Molignon, Punta Grohmann, Sella, and Sett Sass

At the fading out of the middle Ladinian tectono-magmatic activity, an even healthier carbonate production developed, supporting the widespread progradation of several generations of post volcanic carbonate platforms (so called Cassian Dolomite, also referred to Oberer Schlern Dolomit).

The sedimentological characteristics and the margin/upper slope biofacies of the Cassian platforms (late Ladinian-early Carnian) can be studied only through the analysis of the "Calcari di Cipit" (Richthofen 1860). These are calcareous platform-derived olistoliths, exported into the basin. These boulders escaped to the dolomitization process because they were packed and sealed within impermeable basinal sediments (Russo et al. 1991). The "Calcari di Cipit" represent the unique record of upper slope/margin microfacies of the Cassian buildups, now deeply dolomitized (Fürsich and Wendt 1977; Biddle 1981; Brandner et al. 1991a; Russo et al. 1991).

The "Calcari di Cipit" crop out both as solitary blocks or as megabreccia lenses within the La Valle and San Cassiano Fms (upper Ladinian–lower Carnian) (Mastandrea 1994; Mastandrea et al. 1997). The microfacies and biofacies are relatively uniform through time (mainly bindstone type) and are dominated by three components: micrites, cements and skeletons (Fig. 1).

Micrites

The carbonate mud, in the lithified form of micrites, is the dominant component of the microfacies (Russo et al. 1997, 1998a, b). The mi crites represent more than 60% of the rock volume (Fig. 1) and are organized in stromatolitic laminae, thrombolitic clots or aphanitic (structureless) fabrics. From a genetic point of view, it is possible to distinguish two types of micrites: automicrites and allomicrites. Micromorphological and fabric characteristics allow a first distinction between the two types of micrites. The organic-induced nature of the automicrites, which developed *in situ,* may be postulated in the case of accretionary micrites, like stromatolitic micrites or clotted peloidal microfabric, usually reflecting thrombolitic fabric (Tsien 1994; Reitner and Neuweiler 1995). An inorganic origin may be inferred for the micrites containing sparse fine bioclastic debris, terrigenous grains etc., testifying a detrital nature of the carbonate mud (allomicrite).

We investigated the micrites of the Cipit boulders with epifluorescence microscopy, in

Plate 1

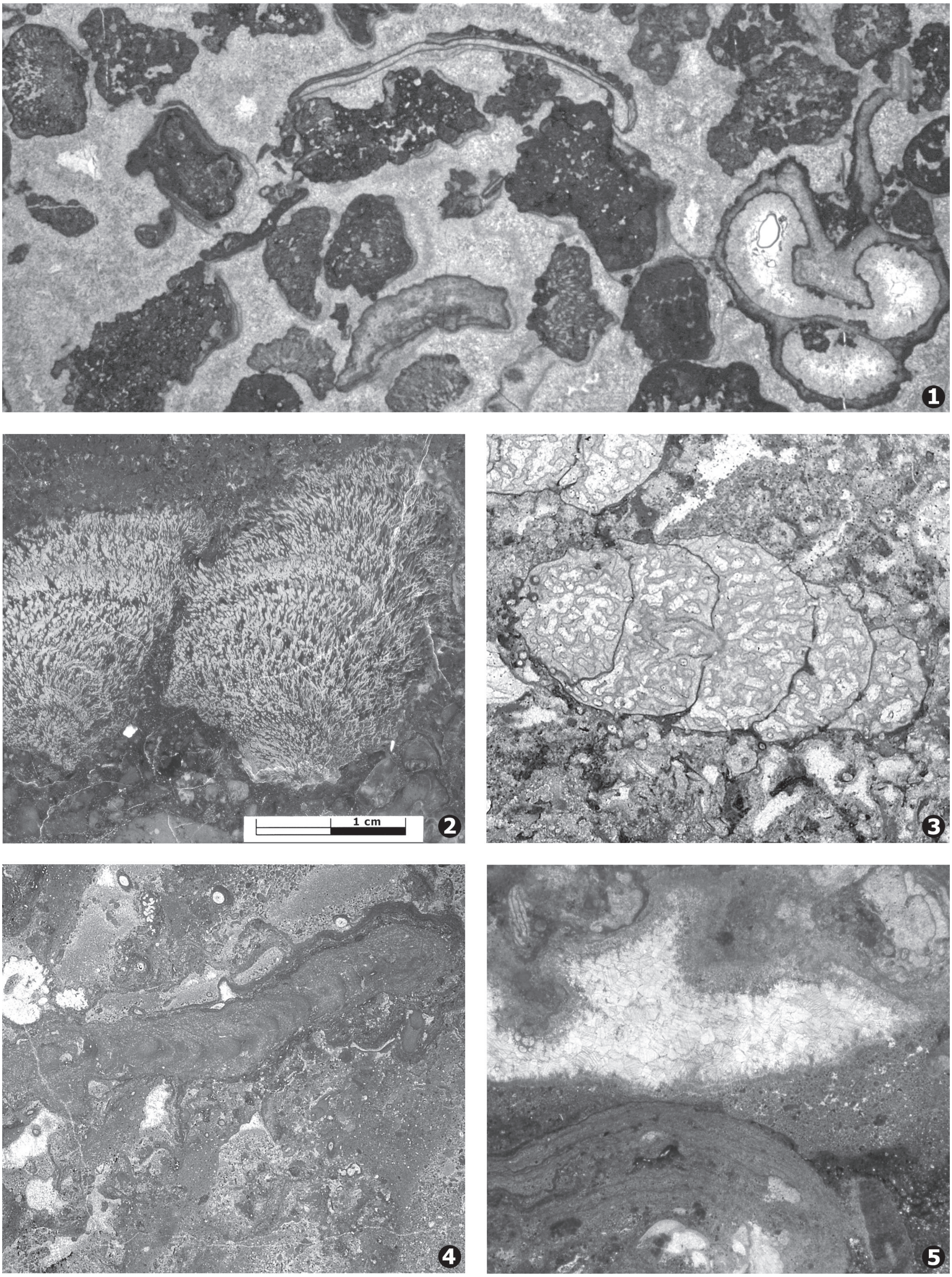
Fig. 1. Dasycladacean grainstone: sub-longitudinal section of *Teutloporella* sp. with various small bioclasts and intraclasts. Sasso Bianco.

Fig. 2. Packstone with *Olangocoelia otti* Bechstädt and Brandner. Sasso Bianco.

Fig. 3. Field views of a cement crust network ("evinospongiae"). The facies largely dominates the outer margin and the upper slope settings (Marmolada, Pian dei Fiacconi at about Q 2750 m).

Fig. 4. Polished surface of fibrous marine cement ("evinospongia") coating a boundstone nucleous (Marmolada, Pian dei Fiacconi).

Figs 5-6. Isopachous layers of fibrous calcite cements in transmitted and epifluorescent light. 5, thin section of fibrous cements showing isopachous layers, separated by very thin alignment of dark microcrystalline aggregates. 6, Epifluorescent image of Fig. 5; note the alternation of strongly and feebly fluorescent bands. The bands are extremely variable in thickness and the boundaries between isopachous layers are always marked by bright epifluorescence (yellow fluorescence BP 450-490 nm/LP 515 nm).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order to reveal the possible organic matter content. Stromatolitic laminites and thrombolites display a bright fluorescence, confirming their organic-induced mineralization; sometimes a bright fluorescence is also displayed by carbonate muds, where organic-controlled origin is not inferable from their morphologic features.

Cements

The more prominent cements observable in the Cipit boulders are directly derived from primary cements, formerly represented by botryoidal aragon ite and fibrous Mg-calcite, both typical of "reef" environments.

They now occur as botryoid and fan array calcite, with aragonite relics, and as isopachous fibrous calcite (with microdolomite inclusions).

The inference that aragonite was the precursor of botryoidal-array calcite is supported by petrographic evidence, by analogy with modern submarine aragonite botryoids, by relics of aragonite needles, and by amounts of Sr up to 5,000 ppm. Burial diagenesis is widespreadly documented by blocky ferroan calcite, with a significant Mg content, and by later and less common ferroan dolomite.

Stromatactis-like cavities lined by isopachous fibrous calcite and filled by blocky ferroan calcite and/or secondary ferroan dolomite are rather frequent (Pl. 2, Fig. 5).

Plate 2
Fig. 1. Grainstone consisting of boundstone intraclasts, skeletal cyanobacteria, bivalve and gastropod bioclasts, sometimes micritized. Note the random orientation of the clasts, the large amount of isopachous marine cements, and the conspicuous vadose cements (Marmolada, Pian dei Fiacconi). x 7.
Fig. 2. *Cladogirvanella cipitensis* Ott bafflestone (Punta Grohmann).
Fig. 3. *Solenolmia manon manon* (Münster), longitudinal/tangential section (Punta Grohmann). x 7.
Fig. 4. *Tubiphytes* embedded in a peloidal micrite boundstone (Punta Grohmann). x 3.
Fig. 5. Stromatactis-like cavity, showing geopetal infilling by peloidal micrite. The remnant cavity, with the typically indented roof, is lined by dark fibrous cement and filled by late blocky calcite. (Punta Grohmann). x 4.

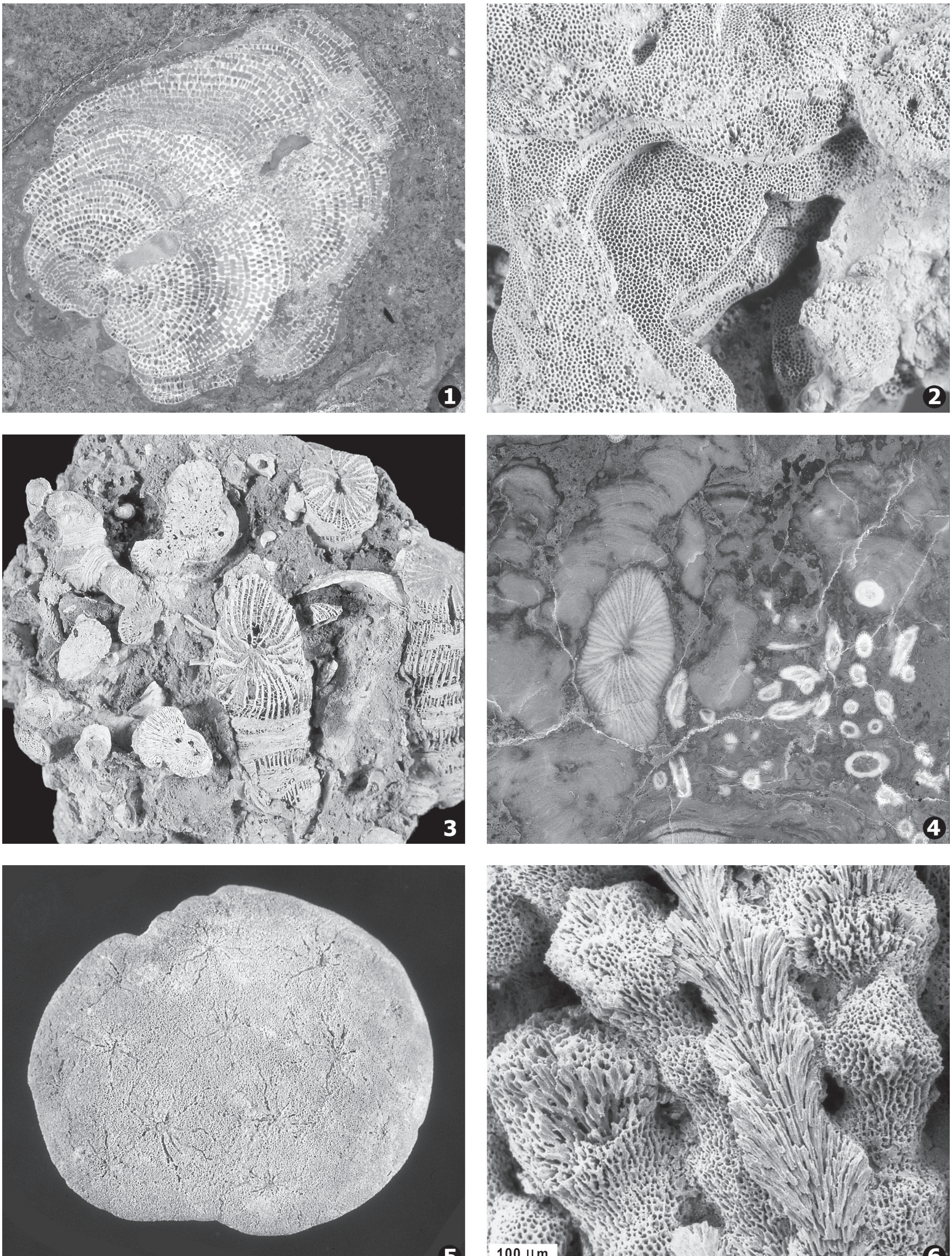
Skeletons

The more common skeletal organisms are represented by cyanobacteria (or bacteria), associated with problematic organisms such as *Tubiphytes* (Pl. 2, Fig. 4) and *Plexoramea cerebriformis*. The baffling cyanobacterium *Cladogirvanella cipitensis* (Pl. 2, Fig. 2) forms colonies up to 5 cm in height, sometimes distributed in levels with remarkable lateral continuity. Sponges and scleractinian corals occur only as isolated specimens (Pl. 2, Fig. 3). The presence of demosponges is testified by the relatively frequent occurence of calcitic pseudomorphs of formerly siliceous spiculae. Minor amount of foraminifers (*Lamelliconus*, *Paleolituonella*, *Kaeleria*, etc.), bivalves and rare echinoderms also contributed to the boundstone fabric.

The patch-reefs of Alpe di Specie

Towards the top of Julian Substage (Carnian), at the base of the Heiligkreutz/Dürrenstein Formation (i.e. Alpe di Specie), bioconstructed lens bodies (patch-reefs) crop out alternated with marls and bioclastic calcarenites (Russo et al. 1991, 1998b). The more meaningful outcrops of this succession are located in the Parola Valley, at the "Tra i Sass" locality, in the Alpe di Specie height, and at the base of the western side of the Picco di Vallandro. The patch reefs, decimetric to plurimetric in size, have preserved their original mineralogy and microstructures (Russo et al. 1991). The study of the boundstones, which constitute the main component of these patch reefs, revealed, for the first time in Triassic bioconstructions of the Dolomites, the presence of a well developed skeletal primary framework. This framework is formed by demosponges and subordinately by scleractinians (as *Thecosmilia* and *Margarosmilia*) (Pl. 3, Figs 3-4). Stromatoporoids (*Stromatowendtia*, *Burgundia*, etc.) (Pl. 3, Fig. 5) together with chetetids (*Atrochaetetes medius,* etc.) (Pl. 3, Fig. 2) represent the dominant groups among sponges. *Sestrostomella robusta* and *Peronidella loretzi* are very common inozoan species which can form colonies, up to decimetres high. Sphinctozoans (*Cassianothalamia zardinii*, *Amblysiphonella strobiliformis*, *Solenolmia manon manon*, etc.) (Pl. 3, Fig. 1), bryozoans, and calcareous algae (*Dendronella articulata*) (Pl. 3, Fig. 6) play a minor role.

In the patch-reefs of Alpe di Specie, biological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diversity increases enormously (the skeletal percentage exceeds the 50%; Fig. 1), if compared with that of the productive margins of the Cassian platforms.

The richness and the preservation state lead the Carnian fauna and flora of Alpe di Specie to be one of most important and famous Triassic fossil record in the world.

The biofacies of the Alpe di Specie forerun the turnover and modernization of constructor commu nities which happened on a global scale between the Upper Carnian and the Norian-Rhaetian (Flügel 1982, 2002).

This event is not documentable in the Dolomites, for the absence of bioconstructed facies in the Upper Carnian (Raibl Fm) and the Norian (Dolomia Principale) interval.

On the contrary, the turnover is recognizable on the Norian and Rhaetian reefs of the Northern Calcareous Alps, where it is recorded by the shift of scleractinian corals from subordinate to dominant forms in the construction of primary frameworks. This phenomenon was probably correlated to the acquisition of coral photosymbiosis capability.

Conclusions

After the great Permo/Triassic biological crisis, the first carbonate platforms in the Dolomites appeared in the Anisian time, rich in allochthonous detrital calcareous mud and dasycladacean algae. The widespread bioturbation confirms the loose soft nature of the primary mud. These buildups were generally characterized by a limited relief, lacking any wave-resistant organic framework and any evidence of syndepositional cementation.

The Marmolada platform, which represents a typical well preserved pre-volcanic buildup, is characterized by an outer margin and an uppermost slope dominated by decimetre scale boundstone blocks, coated and linked each other by very large amounts of radiaxial fibrous calcite cements, arranged in concentric bands, the so called "evinosponges". The presence of organic matter remains within these cements suggests that organic matter could have played a significant role in supporting the widespread syndepositional cementation.

The post-volcanic platforms (Cassian Dm, Late Ladinian and the Carnian *p.p.*) are constituted mainly by three components: micrites (more than 50%), cements (20%), and skeletons (less than the 10%). The fauna is dominated by skeletal cyanobacteria and microproblematica. The litho-genetic contribution of metazoans is sharply subordinated.

The patch-reefs of Alpe di Specie (Heiligkreutz/ Dürrenstein Fm) developed during the Julian Substage (Carnian) and show much more "modern" faunal association. For the first time in the Triassic, an actual building organism framework developed, dominated by calcified demosponges and scleractinians. These biofacies anticipate the "modernization" of the reef-building communities, occurring at a global scale between the Late Carnian and the Norian-Rhaetian. This change was likely related to the acquisition of symbiontic association with the scleractinian corals (Fig. 1).

Plate 3

Fig. 1. Polished longitudinal section of *Cassianothalamia zardinii* Reitner. Note the excellent preservation of the skeleton microstructure (Alpe di Specie). x 3.

Fig. 2. Detail of *Atrochaetetes medius* Cuif and Fischer, demosponge with the skeleton still preserved in aragonite (Alpe di Specie). x 2.

Fig. 3. Coral sponge boundstone with *Margarosmilia zieteni* (Klipstein) (Alpe di Specie). x 1.

Fig. 4. Coral solenoporacean boundstone. Polished section (Alpe di Specie). x 0.8.

Fig. 5. Shape and distribution of the upper surface of the stromatoporoid *Stromatowendtia triassica* Russo, Mastandrea, Baracca. The traces of the superficial aquiferous system forming a stellate structure of branched and radial grooves (astrorhiza) (Alpe di Specie). x 1.5.

Fig. 6. SEM micrograph of the red alga *Dendronella articulata* Moussavian and Senowbari –Daryan. The broken branches exhibit the general arrangement of filaments. The thallus is still preserved in aragonite (Alpe di Specie).

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Riassunto

[Evoluzione delle biofacies nelle piattaforme delle Dolomiti, Italia]

La successione stratigrafica del Trias delle Dolomiti comprende numerose generazioni di piattaforme carbonatiche, di età compresa tra l'Anisico ed il Norico-Retico.

Dopo la grande crisi permo-triassica, le prime costruzioni carbonatiche compaiono nell'Anisico. Si tratta di strutture a basso rilievo, ricche di fango, prive di impalcatura scheletrica primaria e di cementazione sinsedimentaria. Le microfacies sono dominate da micrite, principalmente alloctona e di origine detritica. I pochi e dispersi organismi scheletrici sono spesso binders o bufflers come alghe dasicladali, sfinctozoi (*Olangocoelia otti*, *Celiphia zoldana*) e briozoi.

La seconda generazione di rilievi carbonatici (Anisico superiore–Ladinico inferiore) è dominata da cementi sindeposizionali (per es. Marmolada), gli organismi scheletrici giocano ancora un ruolo minoritario, anche se sono più abbondanti e caratterizzati da una maggior diversità tassonomica. Nonostante ciò, vicino al limite Anisico-Ladinico, la massiccia produttività carbonatica teneva il passo con una forte subsidenza e permetteva la formazione di grandi corpi carbonatici, dello spessore di parecchie centinaia di metri (Sciliar/Schlern Fm). Durante il Ladinico superiore e parte del Carnico si svilupparono le piattaforme post-vulcaniche (Dolomia Cassiana). Lo studio delle microfacies di tali corpi dolomitici è possibile soltanto per mezzo dei "Calcari di Cipit", olistoliti calcarei risedimentati nelle unità bacinali impermeabili e pertanto scampati alla dolomitizzazione. Le microfacies delle piattaforme postvulcaniche sono costituite principalmente da tre componenti: micriti, cementi ed organismi scheletrici; questi ultimi costituiti sopratutto da leganti ed intrappolatori. La componenente maggioritaria è l'automicrite (più del 50%), seguita dai cementi (20%) e dagli organismi scheletrici (meno del 10%). Il contributo dei metazoi è certamente subordinato rispetto a quello dei cianobatteri scheletrici, come *Cladogirvanella cipitensis*, e dei microrganismi problematici. Le demosponge a scheletro calcareo supplementare sono tuttavia relativamente frequenti. I cementi marini primari testimoniano una cementazione sinsedimentaria ampia e diffusa. Verso la fine dello Julico (Carnico), alla base della Formazione di Heilgkreutz/Dürrenstein (Alpe di Specie), piccole biocostruzioni carbonatiche (interpretate come patch-reefs) mostrano un'associazione faunistica molto più moderna. Per la prima volta nel Triassico, si sviluppa una vera e propria impalcatura scheletrica primaria, costituita principalmente da demospongie calcificate e scleractinie. I coralli rimangono comunque ancora subordinati alle spugne. La diversità tassonomica cresce gran-demente e la componente scheletrica supera il 50%. Tali biofacies preludono al ricambio e alla "modernizzazione" delle comunità recifali, evento che si realizza a scala globale fra la fine del Carnico ed il Norico-Retico.

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