The Geological Society of America Bulletin

The role of autochthonous versus detrital micrite in depositional geometries of Middle Triassic carbonate platform systems

--Manuscript Draft--

Manuscript Number:	B31318R1
Full Title:	The role of autochthonous versus detrital micrite in depositional geometries of Middle Triassic carbonate platform systems
Short Title:	Autochthonous micrite and carbonate depositional geometries
Article Type:	Article
Keywords:	autochthonous micrite, detrital micrite, carbonate platform, depositional geometries, Triassic, Dolomites, Italy
Corresponding Author:	Adriano Guido, Ph.D. University of Calabria Rende, Cosenza ITALY
Corresponding Author's Institution:	University of Calabria
First Author:	Adriano Guido, Ph.D.
Order of Authors:	Adriano Guido, Ph.D.
	Adelaide MAstandrea, Prof.
	Marco Stefani, Prof.
	Franco Russo, Prof.
Abstract:	Middle Triassic platforms (Formazione di Contrin, upper Anisian) in the Italian Dolomites, Southern Alps, record large changes in carbonate production and depositional geometry. The changes include variation in the abundance of the detrital micrite, i.e. allochthonous calcareous mud, relative to the autochthonous micrite, which formed in situ and was syndepositionally lithified. Carbonate factory dynamics controlled the geometry of the clinostratified slope units and were probably associated with changes in oxygenation. Early Anisian low relief platforms were followed by late Anisian, high relief buildups, associated with basinal dysoxic-anoxic environments. The geometric evolution of the platform slopes records a progressive increase in the dip angle of clinostratifications, matched by a deepening evolution of the basinal environments. At the same time, the slope sediments recorded a gradual change from loose detrital micrite, characterizing the lower portion, to autochthonous micrite, dominating the upper part and recording massive syndepositional lithification. The development of the autochthonous micrite was associated with the preservation of significant amounts of organic matter. This sharp increase in automicrite formation was probably induced by a rapid change from oxic to suboxic conditions in the carbonate slope and margin environments, while anoxic conditions developed in the adjacent organic rich basin (Moena Fm). The low oxygen level promoted the preservation of organic matter and the activity of sulphate reducing bacteria, which in turn induced in situ deposition of autochthonous micrite, through biomediated processes. This pervasive early cementation and lithification induced the development of steep platform slopes. The conceptual model distilled from this Middle Triassic case can support the interpretation of analogous buildups, where the skeletal framework is subordinated to the micrite component.
Suggested Reviewers:	Stephen Kershaw, Professor Brunel University London stephen.kershaw@brunel.ac.uk Expert in carbonate sedimentation and environmental change on Earth
	Brian Pratt, Professor University of Saskatchewan brian.pratt@usask.ca Expert in carbonate sedimentology and microbial sedimentation

Daniele Masetti , Professor
Universita degli Studi di Ferrara
daniele.masetti@unife.it
Deep knowledge of the Dolomites and depositional architectures of Triassic platforms

Opposed Reviewers:

Response to Reviewers:

ANSWERS TO REVIEWERS AND ASSOCIATE EDITOR COMMENTS

Reviewer #1

GENERAL COMMENTS
This very interesting paper describes Middle Triassic carbonate platforms from the Dolomites in Italy, yet the title suggests a more broad approach in carbonate platforms generally. The only general reference in the abstract is the last sentence that indicates that the ideas presented in the paper may be applicable to other Phanerozoic carbonate platforms, but does NOT specify any examples that would help the reader. Thus there seems to be a mismatch between the title and the abstract. Furthermore, the only reference to other Phanerozoic platforms in the text is the last sentence of the conclusions, on lines 367-369.

RECOMMENDATIONS
1. I suggest that the authors change the title so that it matches the content better. I suggest: "The role of autochthonous versus detrital micrite in depositional geometries of Middle Triassic carbonate platform systems"; then remove from the abstract the last sentence, and also remove the last sentence from the conclusions.

We changed the title as suggested by the Reviewer#1, considering that the research is focused on Middle Triassic carbonate platforms from the Dolomites.
However, other buildups may present, in time and space, analogous depositional geometries attributable to the change in the micrite type. Therefore we modified the last sentence of the abstract in the following way: “The conceptual model distilled from this Middle Triassic case can support the interpretation of analogous buildups, where the skeletal framework is subordinated to the micrite component”
The last sentence of the conclusions has been changed in the following way:
“A clear correlation between the change of carbonate production style and the evolution of the carbonate platform dynamics is therefore observable. This correlation, between the syndepositional cemented micrite fraction and the steepness of slopes, can be recognized in other carbonate successions of different age and location. The study of this relationship can provide a new tool for an improved understanding of the depositional geometry of carbonate platform slopes, lacking a primary skeletal framework”

2. Fig. 5 would benefit from additional photos to show the material in fluorescence, in order to demonstrate whether they fluoresce or not, and therefore show the reader the evidence of their detrital nature, comparable with Fig. 8.

Done. We added a new figure (Figure 6) with the epifluorescence of the detrital micrite.

SPECIFIC COMMENTS
1. Section on Triassic platforms of the Dolomites: This is a useful summary of the major features of the area.

Yes, we think this paragraph could be useful for readers not familiar with the Triassic stratigraphy of the Dolomites. In agreement with the suggestion of the reviewer#2 and Associate Editor, we synthetized the paragraph and deleted the subparagraph titles.

2. Lines 214-215: 10 and 6 samples for microfacies; Line 224: 40 thin sections. However, Fig. 4 shows 21 samples collected through nearly 40 m of rock. Also I wonder is 21 samples enough for 40 m of rock; does it show sufficient resolution of vertical change?

The samples for microfacies are 21 because there are also 5 samples collected from the lower part of the section. To avoid misunderstanding, we specified in the text that the microfacies have been analyzed also in the samples from this portion. Unfortunately, the sampling collection was limited by the steep slope condition of the outcrop. Anyway we maintain that the collected samples are exhaustive of the depositional geometry changes and thus sufficiently significant.

3. Lines 284-320:
Lines 284-301: here the authors present an argument that detrital micrites are in fully oxygenated waters.

The paleoecological setting during the deposition of the detrital micrite, mainly characterizing the bank facies, was inferred by the biota association (green algae, echinoids, crinoids, etc…) that suggests euphotic and well-oxygenated seawater conditions.

Lines 302-320: here the authors present an argument that the peloidal and automicrites are necessarily formed in suboxic conditions, and thus the microbial development of the limestone developed in low oxygen environments. This is in contrast to the detrital micrites.

Differently from the depositional conditions of the detrital micrite, that characterize mainly the bank facies, we assume that autochthonous micrite, of the slope facies, deposited in sub-anoxic setting because of the sudden decrease in the abundance of crinoids, echinoderms and the disappearance of dasycladacean algae.
Peloidal/clotted peloidal micrite has commonly been linked to anaerobic bacteria activity (Reitner, 1993; Kazmierczak et al., 1996; Riding et al., 2014; etc..).
The paleoenvironmental evolution from oxic (the bank facies) to sub-anoxic (the slope facies) conditions is in line with the interpretation of the anoxic settings documented in the coeval organic-rich basinal counterparts (Moena Formation) of the late Anisian platforms (Contrin Formation) (Masetti & Neri, 1980).

This argument is in line with modern thinking about micritic microfacies features, but does make an assumption that automicrites are in low oxygen conditions and detrital micrites are in well-oxygenated conditions. I have worked on Silurian patch reefs in carbonate platforms in UK and Sweden, where the reef is composed of automicrites. Directly lateral (and therefore approximately age-equivalent) to the reef is bedded sediment containing detrital carbonate, some of which is micrite (Kershaw et al. 2007 Geological Society of London Special Publication 275, p87-94). This suggests that the arguments presented in this manuscript are not necessarily applicable elsewhere in the Phanerozoic, and emphasises my suggestion that the title of this paper should show it is focused on Middle Triassic carbonates, and therefore delete the mention of other Phanerozoic occurrences.

In agreement with the suggestions, we changed the title and deleted “Phanerozoic occurrence” from the abstract and conclusions. We simply indicate that the proposed model can be tested to other buildups showing analogous depositional geometries. Obviously the depositional conditions interpreted here for the detrital micrite and automicrite are not necessarily valid in other cases. The main concept we would like to emphasize is the link between the depositional geometries of the carbonate bodies and their micrite types, whose depositional conditions must be investigated case by case.

4. FIGURES
Fig. 5 is used to indicate detrital micrites, while Fig 7 and 8 are interpreted as microbially formed. From the textural and fluorescence character of Fig 7 and 8 images, this is a standard interpretation. However, the authors should present photos of fluorescence of the detrital micrites in Fig. 5, to show the reader that these micrites are low in organic matter and are detrital. If the authors don't add the additional images for Fig.5 the readers will always wonder if the micrites are fluorescent or not, and raise the question about the extent to which the detrital facies are organically created.

We added a new figure showing the fluorescence of the detrital micrite.

Reviewer#2
The overall message of this paper, that authochthonous micrite is important in shaping the geometry of carbonate slopes, is of broad interest. The introduction section on the Triassic platforms of the Dolomites seems long in comparison to the new data that are presented, but may be necessary background (possibly could be shortened?). In addition, I have some issues with the organization of results and interpretations.

In agreement with the suggestion we synthetized the introduction paragraph deleting the redundant and repetitive parts, and the subparagraph titles. However we believe that a short paragraph on the Triassic platforms of the Dolomites could represent a good introduction for the reader not familiar with the stratigraphy of the Dolomites.

These and some other minor editorial points are listed below.
1. Lines 80-82- these lines echo lines 87-89….. reword so does not sound repetitive.

We deleted the repetition.

2. Line 206: SB1 to SB 5- this is five samples, not 6. Sample collection should perhaps be in methods??
Yes, we analyzed five samples. The mistake was corrected.

We moved the sample collection and the description of the study succession into a new paragraph entitled "STUDY SUCCESSION AND SAMPLE COLLECTION".

3. Line 224- 40 thin sections from 21 samples. Indicate what thin sections from which samples.

We collected 21 samples, for each we performed and analyzed one thin section parallel and one orthogonal to the stratigraphic surfaces, except for the samples SB14 and 15 of which we made only one thin section parallel to the stratigraphic surface. This statement has been introduced also in the text.

4. The authors do not clearly separate results and interpretation, as discussed below.
Facies Composition.
I was expecting a presentation of results in this section, but it seems to be a combination of results and interpretation.

We reorganized the paragraph and changed the title into FACIES ANALYSES.

It would seem more logical to first present the results of the point counting- referring to Figures 4, 5 and 6, including basis for differentiating detrital from allochthonous micrite- and then lead up to the statement regarding the evolution of the section from resedimented beds to clinostratiform bodies- ie lines 238-240. Ie end with this rather than open with lines 238-240.
Figure 4 needs to be referenced in this section as the authors guide the reader thru the stratigraphic section.

We restructured the paragraphs and referenced the figure 4 in the "FACIES ANALYSES".

Role of Authochthonous vs detrital micrite.
Here we finally get some evidence for detrial vs authoch., but the section above already described and graphed proportions of one vs the other. This order is confuing.

Need to present first simple observation, ie micrite, then the evidence to interpret if detrital or allochthonous.

As suggested we reorganized the paragraphs.

5. The authors imply that authochthonous micrite forms under anerobic bacterial processes (line 300-301).
Lines 304-306- Authors state that an increase in authoch micrite matches disappearance of dasyclad algae, crinoid and echinoderm- This supports formation of in situ micrite thru bacterially induced pathways,linked to changes in environmental framework.
They suggest this change is related to low oxygen, leading to increase in sulphate reduction and peloidal precipitation, citing studies linking clotted peloidal micrite to anaerobic bacterial activity- lines 331-332.
Clotted peloidal micrite is commonly a product of EPS degradation by heterotrophs, but does not need to take place under anoxic conditions (See Baumgartner et al 2006 for review). Thus oxygen is not the only explanation for the change from detrital to precipitated micrite. Introduction of hypersaline conditions for example could have excluded the algae and criniods, and allowed microbial mats to flourish, with resultant microbial precipitation.
Baumgartner, L.K., Reid, R.P., Dupraz, C., Decho, A.W., Buckley, D.H., Spear, J.R., Przekop, K.M., Visscher, P.T. (2006), Sulfate reducing bacteria in microbial mats: changing paradigms, new discoveries, Sedimentary Geology, v. 185, p. 131-145.

The peloidal micrite is not necessarily a product of anaerobic bacterial activity, but, in the study case, the evidence of the change in biotic assemblage and the anoxic settings documented by the organic-rich basinal counterparts (Masetti & Neri, 1980) seem to point out to a precipitation into a sub-anoxic environment. Moreover peloidal/clotted peloidal micrite has commonly been linked to anaerobic bacteria activity (Reitner, 1993; Kazmierczak et al., 1996; Riding et al., 2014; etc..).
There isn't evidence of hypersaline setting.
In agreement with the Reviewer we introduced in the text Baumgartner et al (2006) paper to provide the reader the possibility to consider other processes, not discussed in the manuscript.
In any case, regardless paleoenvironmental causes that produced autochthonous micrite, the detected relationship between the syndepositional cemented micrite fraction and steepness of the slope still remain valid and can be recognized in other carbonate successions of different ages and locations.

Associate Editor
B31318- Guido et al. AE Rasbury comments.
The observations of the relationships between internal fabric and field observations of changing platform geometry are of fundamental importance to sedimentary geology. The recognition of contemporary changing of basinal facies, representing transition from oxic to anoxic conditions, is certainly consistent with the interpretation that this is creating the environment for autothonous micrite precipitation and that this in turn is responsible for allowing steeper slopes to form. As reviewer two point out, it does not really require that this is a result of anaerobic bacteria.

The evidence of the microfacies and the correlation of the platform with the coeval basinal facies, described by Masetti and Neri (1980), suggest that the main factor, controlling the peloidal micrite precipitation and the depositional geometry evolution, is the transition from oxic to anoxic conditions. Anyway to furnish to the readers the possibility to take into consideration other processes we cited the paper of Baumgartner et al (2006) as suggested by the reviewer 2.

So, the topic is of interest, the data seem sound, the interpretations are reasonable, but one might consider more than one possible explanation, but the manuscript is too long. It is hard to read. The Introduction is probably twice as long as it needs to be. It is repetitive and this is not the place to develop logic- simply summarize. The geologic section is random. Most of it does not appear to be necessary to develop the

	contribution. The methods could be better developed. There needs to be a clear distinction between observations/results and interpretations. I suggest that the authors should go through this manuscript with the comments and criticisms of the two reviews in mind, and consider each sentence. Is it necessary? Does it follow the previous sentence? Particularly with the Introduction and Geologic Settings parts, this may help to get rid of unnecessary and redundant parts. The paragraphs have been revised and synthetized accordingly to the reviewers and Associate Editor suggestions.

The role of autochthonous *versus* detrital micrite in depositional geometries of Middle Triassic carbonate platform systems

Adriano Guido[1], A. Mastandrea[1], M. Stefani[2], and F. Russo[1]

[1]*Department of Biology, Ecology and Earth Sciences, University of Calabria, Via Bucci, cubo 15b, 87036 Rende, Cosenza, Italy (aguido@unical.it; a.mast@unical.it; francorusso44@gmail.com)*

[2]*Department of Architecture, University of Ferrara, Via della Ghiara 36, 44121 Ferrara, Italy (stm@unife.it)*

Corresponding Author:
Dr. Adriano Guido
Department of Biology, Ecology and Earth Sciences, University of Calabria
Via Bucci, Cubo 15b, 87036 Rende (CS), Italy
aguido@unical.it

Running title: Autochthonous micrite and carbonate depositional geometries

ABSTRACT

Middle Triassic platforms (Formazione di Contrin, upper Anisian) in the Italian Dolomites, Southern Alps, record large changes in carbonate production and depositional geometry. The changes include variation in the abundance of the detrital micrite, i.e. allochthonous calcareous mud, relative to the autochthonous micrite, which formed *in situ* and was syndepositionally lithified. Carbonate factory dynamics controlled the geometry of the clinostratified slope units and were probably associated with changes in oxygenation. Early Anisian low relief platforms were followed by late Anisian, high relief buildups, associated with basinal dysoxic-anoxic environments. The geometric evolution of the platform slopes records a progressive increase in the dip angle of clinostratifications, matched by a deepening evolution of the basinal environments. At the same time, the slope sediments recorded a gradual change from loose detrital micrite, characterizing the lower portion, to autochthonous micrite, dominating the upper part and recording massive syndepositional lithification. The development of the autochthonous micrite was associated with the preservation of significant amounts of organic matter. This sharp increase in automicrite formation was probably induced by a rapid change from oxic to suboxic conditions in the carbonate slope and margin environments, while anoxic conditions developed in the adjacent organic rich basin (Moena Fm). The low oxygen level promoted the preservation of organic matter and the activity of sulphate reducing bacteria, which in turn induced *in situ* deposition of autochthonous micrite, through biomediated processes. This pervasive early cementation and lithification induced the development of steep platform slopes. The conceptual model distilled from this Middle Triassic case can support the interpretation of analogous buildups, where the skeletal framework is subordinated to the micrite component.

Keywords: autochthonous micrite, detrital micrite, carbonate platform, depositional geometries, Triassic, Dolomites, Italy.

INTRODUCTION

The importance of microbes in the calcification processes that generate micrites and other non-skeletal components of carbonates has been progressively clarified through the last decades of research (Monty 1965, 1976, 1995; Reitner 1993; Reitner & Neuweiller 1995; Riding, 2000). Wolf (1965) introduced the term autochthonous micrite, or automicrite, to describe fine-grained carbonates generated *in situ* and subject to early lithification, together with its antonym allomicrite, depicting transported carbonate mud and very fine-grained biodetritus, lithified at a later post-depositional stage. Subsequently, various authors adopted the term automicrite, to describe micrites formed *in situ*, as authigenic minerals precipitation (Flügel, 1982; Neuweiler & Reitner, 1995; Bosence & Bridges, 1995; Monty, 1995; Reitner & Neuweiler, 1995; Russo et al., 1997; Riding, 2000, 2002; Guido et al., 2011, 2012a,b,c, 2013; Tosti et al., 2014). Autochthonous micrite typically occurs as very fine-grained laminated, clotted peloidal, or aphanitic (structureless) textures (Braga et al., 1995; Russo et al., 1997; Riding, 2000). Several authors have demonstrated the widespread occurrence of autochthonous micrite in recent aphotic environments (Reitner, 1993; Zankl, 1993; Reitner & Neuweiler, 1995; Riding et al., 2014). Automicrite has played an important role in controlling the depositional geometry of high relief platforms, through the large sediment production and the stabilization of steep slope angles.

Through geological time, carbonate production has been significantly affected by environmental fluctuations and biological evolution. Following the mass extinction marking the Permo-Triassic boundary, reef building communities were lacking through the majority of the

Early Triassic. However, carbonate platforms and reefs recovered, and proceeded to dominate much of the Mid-Late Triassic.

In the Southern Alps Dolomites, the primary relationships among platform-top, slope and basinal bodies can be often reconstructed in detail (Gaetani et al., 1981; Wendt, 1982; Bosellini, 1984; Hardie et al., 1986; Russo et al., 1997, 2000; Bosellini et al., 2003; Russo, 2005; Schlager & Keim, 2009; Stefani et al., 2010; Tosti et al., 2011, 2014). The interpretation of the depositional microfacies and early diagenetic evolution in the vast majority of the Triassic platforms of the region is however severely limited by the pervasive late dolomitization. The scattered limestone bodies preserving the primary calcareous facies are therefore particularly valuable for understanding the sedimentary dynamics of these Triassic carbonates. Our research is therefore focused on an Anisian outcrop, belonging to the Contrìn Formation, well preserving the calcareous platform slope facies at a comparatively pristine state. The calcareous succession records the increase of autochthonous over detrital micrite fraction, associated with a sharp change in the depositional geometry, from a low-relief bank to steeper carbonate slopes.

THE TRIASSIC PLATFORMS OF THE DOLOMITES

The development of the carbonate platforms in the Dolomites, from Anisian through Carnian times, records the evolution from low relief terrigenous-carbonate ramps, rich in loose micritic mud, to isolated high relief carbonate pinnacles, dominated by automicrite and syndepositional cements, and back to low relief mixed ramps (Stefani et al., 2004, 2010).

The Anisian of the region records at least five main phases of platform growth, framed within the same number of depositional sequences, developed within an active tectonic framework (De Zanche *et al.*, 1993; Neri & Stefani 1998). During the late Anisian, in the western Dolomites, the sedimentation of the forth depositional sequence, encompassing the study platforms, started with the accumulation of continental conglomerates (Richthofen Conglomerate) onto a subaerial erosive surface, deeply cut into Lower Triassic or even Permian units (Bosellini, 1968). The continental deposits gave way to transgressive terrigenous-carbonate beds (Morbiac Formation), which record a deepening evolution, associated with the transition from silts and clay sediments to bioturbated micrites, often rich in mollusc and crinoid bioclasts. The following basinal successions generally evolved into dark colored, laminated alternations of detrital micrites and marls, lacking bioturbation, and preserving layers rich in organic carbon (Formazione di Moena; Masetti & Neri, 1980; Masetti & Trombetta, 1998). While the basinal areas were experiencing the deepening evolution, carbonate platforms nucleated on small topographic highs, as low relief carbonate banks. The banks then aggraded into extensive shallow water carbonate bodies (Contrin Formation). The platforms often prograded over the surrounding depressions, creating large shallow water areas. At several sites, low angle ramps evolved into steeper planar slopes (Bosellini *et al.*, 1996).

During the latest Anisian, the deepening evolution of basins climaxed into a widespread drowning event, associated to the top of the Contrin and Moena Formations. Shallow water carbonate production was terminated over large areas, remaining active only at a few isolated spots, which were soon to become the cores of fast-aggrading pinnacles (Sciliar Formation, e.g. Latemar). During early Ladinian times, the nuclei expanded into large prograding platforms, about 800-1000 m thick. The margin and slope units of these platforms are dominated by large amounts of syndepositional cements and autochthonous micrites (e.g., Latemar Platform, Harris, 1993; Marmolada Platform, Russo *et al.*, 2000). Due to cementation, the Sciliar Formation platforms show impressive relief and steep clinostratifications, generally planar in shape and inclined by up to more than 40° (Bosellini, 1984; Bosellini *et al.*, 2003). During the middle Ladinian, the platform growth was disrupted by a volcanic phase. The microfacies of the post-volcanic platforms (Cassian Dolomite; upper Ladinian and Carnian p.p.) consist mainly of micrites, syndepositional cements and subordinate skeletal components (Russo, 2005). Clinostratification surfaces became generally less steep than the pre-volcanic ones.

During the Carnian, a primary skeletal framework developed for the first time (Russo *et al.*, 1991), but the coral rich biostromes were short-lived, since low angle terrigenous carbonate ramps soon developed, rich in loose micritic muds, bioclastic material and ooids. During the following Late Triassic, terrigenous input stopped, and regional low relief peritidal successions accumulated to a great thickness (Dolomia Principale) (Bosellini, 1984; Bosellini *et al*., 2003).

GEOGRAPHIC LOCATION AND GEOLOGICAL FRAMEWORK

The study area of Sasso Bianco is located in the western Dolomites, in the north-eastern part of the Trento Province, between the highest portions of the Fassa and San Nicolò valleys (Fig. 1). The carbonate unit outcrops on the steep slope north of Ciampiè, 1 km at the north-west of Passo San Nicolò. The base of the stratigraphic section is at 2,425 m of elevation, latitude 46°25'42.86"N; longitude 11°46'45.97" E Greenwich. In the area, the white Anisian limestones sharply contrast with the adjacent dark coloured Ladinian volcanics.

Below the Anisian carbonates, the Lower Triassic Werfen Formation is truncated by a disconformity, overlain by thin, discontinuous lenses of upper Anisian fluvial conglomerates and sands (Richthofen Conglomerate), and by a thin succession of transgressive silts, claystones and marls, grading into marine, dark colored marls and micrites, with sparse mollusc and crinoid bioclasts (Morbiac Formation) (Fig. 2). The following Contrin Formation preserves its stratigraphic base, but it is truncated at its top by an unconformity, related to the Ladinian tectono-magmatic event and it is directly covered by hyaloclistites and basaltic submarine lavas (Fig. 2). The calcareous unit was buried beneath thick volcanic and volcaniclastic successions, suturing the submarine erosion topography (Fig. 2). The low permeability volcanogenic units surrounding the lithologies facies hindered the circulation of the diagenetic fluids, thus preserving the primary features of this limestone unit at a more pristine state than in the vast majority of the Triassic carbonates of the Dolomites.

STUDY SUCCESSION AND SAMPLE COLLECTION

The analysed section of the Contrin Formation consists of about 38 m of thickening upward carbonate strata, showing thin horizontal beds, in the lower portion, and clinostratified surfaces, in the middle to upper part (Fig. 3).

In the lower part of the section we collected five samples for microfacies analyses (SB1 to SB5; Fig. 4). Both packstone and grainstone textures are here common. The calcarenites form planar beds, often showing a sharp base and direct gradation, sometimes associated with horizontal or inclined tractionary cross lamination. Other beds are amalgamated by bioturbation, associated with some nodularity. Metric-scale thickening and coarsening upward cycles are visible. The minor bed-parallel fault marking the top of the member does not disrupt the primary stratigraphic succession. In the central-upper portion of the section, the amalgamated calcarenite and fine calcirudite beds are characterized by a rather massive appearance, with a primary clinostratification dip angle around 15°. To investigate the microfacies of this portion of the section, we analysed ten samples (SB6 to SB15, Fig. 4). The dominant lithology is here micrite, enveloping mollusc remains. Six samples (SB16 to SB21, Fig. 4) were collected from the upper portion of the section, despite the access difficulty. This portion is poor in sedimentary structures recording transportation and resedimentation mechanisms, and has a rather massive appearance, with traces of slope dipping at around 25°.

MATERIAL AND METHODOLOGY

We collected 21 samples, for each we performed and analysed one thin section parallel and one orthogonal to the stratigraphic surfaces, except for the samples SB14 and SB15 of which we made only one thin section parallel to the stratigraphic surface. The uncovered thin sections (48mm × 28mm) were studied using an optical microscope (Zeiss Axioplan II), under plane and cross-polarized light, at a magnification of 2.5, 5, 10, 20 and 40**x**. In order to evaluate the percentage of carbonate components, all thin sections were analysed, using a point counting apparatus, linked to a microscope. The observations were carried out with a count step of 0.5 mm and 400 points were recorded for each thin section. Fluorescence microscopy was applied to reveal the organic matter distribution (Neuweiler & Reitner, 1995; Russo *et al.*, 1997). Fluorescence was induced by a mercury vapour lamp linked to Axioplan II imaging microscope, equipped with high performance, wide bandpass filters (BP 436/10 nm/LP 470 nm for green light; BP 450 to 490 nm/LP 520 nm for yellow light). Chemical composition of micrite was determined using a Genesis 4000 energy dispersive X-ray spectrometer linked to a FEI-Philips ESEM-FEG Quanta 200F scanning electron microscope. The analysed samples were polished with 0.25 μm diamond-impregnated surfaces, then etched and carbon coated (about 250 Å coating thickness). Working conditions and detector constants were as follows: voltage 15 kV, tilt angle 0°, and take-off angle 36.01°.

FACIES ANALYSES

The lower part of the section, samples SB1-5, is dominated by bio-intraclastic packstone/wackestone (Fig. 4 and 5). The microfacies are rich in calcareous intraclasts and in crinoid, echinoid, gastropod, and bivalve bioclasts (Fig. 4 and 5). Brachiopods, foraminifers, skeletal (*Spirorbis*) and agglutinated (terebellid) polychaetes provide minor components. Fragments of dasycladacean algae (*Teutloporella*) are visible in two samples. Grains are commonly engulfed by micrite (Fig. 5). The micritic fraction is characterized by a dense texture of very fine carbonate grains, engulfing bioclasts, and by a low organic matter content, as indicated by the weak epifluorescence (Fig. 5 and 6). The slight epifluorescence is due to the residual sedimentary organic matter trapped among the fine carbonate grains (Fig. 6). Silt sized siliciclastic grains and clay minerals (1 to 2 wt%) are dispersed within a bioturbated carbonate matrix. Non-gravitational textures, such as stromatolitic and/or thrombolitic fabric, are absent. The micrite fraction shows soft mud bioturbation structures, whereas the granular intercalations show direct gradation and tractionary structures. The quantitative analyses confirm the dominance of the detrital micrite, which constitutes the 47% of the sampled rock volume. Next in abundance are bioclasts and intraclasts, representing the 45%, while peloidal micrite and cements provide minor components, respectively 5% and 3% of the rock volume (Fig. 7).

In the middle portion of the section, samples SB6-15, intraclasts provide the main component, and skeletal grains become less common (Fig. 4). Among the bioclasts, echinoderms fragments are less abundant, and dasicladacean algae disappear altogether, whereas sponges (e.g. *Olangocoelia otti*) are often present. In this portion of the section, micrite shows peloidal to clotted peloidal fabrics and lacks grain-supported textures, with large interclot areas showing fabric incompatible with a gravitational genesis. Two samples (SB14 and 15) consist of grainstones and therefore do not show any significant micritic content. The peloidal micrite component increases in abundance and alternates in dominance with the loose detrital calcareous mud fraction. Quantitative data on the average composition of these samples show that the rock consists of 40% peloidal micrite, 35% grains, 15% detrital micrite, and 10% early marine phreatic cements (Fig. 7).

The upper portion of the section consists mainly of boundstones, rich in peloidal and clotted peloidal micrite. In this portion, samples SB16-21, an important change in skeletal grain composition occurs (Fig. 4). *Tubiphytes* and encrusting foraminifers (e.g. *Tolypammina gregaria*) provide the main biogenic components, with minor amounts of sponges (Fig. 8). Gastropods, bivalves, brachiopods and benthic foraminifers are also here less common than in lower portions of the section. Crinoids are rare and dasycladacean algae are absent. In this facies, agglutinated worm tubes are on the contrary common (Fig. 8D). The compact to flocculent walls of these worms are often peloidal in nature and sometime contains small siliciclastic grains. Bright fluorescence, under UV light, indicates a higher content of organic matter in the peloidal micrite, clotted peloidal micrite, and agglutinated skeletons than in the associated detrital micrites and calcite spar cements (Fig. 9). In the upper portion of the section, the autochthonous micritic facies becomes dominant, representing 50% of the rock volume, while grains constitute 30%, cements 15%, and detrital micrite only the 5% (Fig. 7).

MICRITE ORIGIN

The lower portion of the study unit is rich in detrital micrite that originally consisted of loose carbonate mud. The detrital micrite mainly derived from skeleton disintegration of micro- and macro-organisms, transported from source areas (Stockman *et al.*, 1967; Tucker & Wright, 1990). The richness and diversity of the biota, dominated by crinoids, echinoids, and green algae, suggest shallow, euphotic and well oxygenated seawater (Fig. 10A). The lack of autochthonous micrites seems to suggest the lack of bacterial calcification activities, during the early depositional phase of the bank. We suggest that the well oxygenated conditions fostered aerobic biological processes, degrading and removing organic matter from the depositional system. This environmental framework disabled dysaerobic/anaerobic bacterial processes, limiting the formation of *in situ* micrite.

The increase in autochthonous micrite, in the middle and upper part of the section, matches the decrease in abundance and eventual disappearance of dasycladacean algae, crinoid and echinoderm remains (Fig. 10B). The available evidence strongly supports an *in situ* origin of this type of micrite, through bacterially induced mineralization processes, including autotrophic and heterotrophic biochemical pathways (Monty, 1976; Chafetz, 1986; Buczynski & Chafetz, 1991; Reitner, 1993; Kazmierczak *et al*., 1996; Castanier *et al*., 1999, 2000; Folk & Chafetz, 2000; Reitner *et al*., 2000; Riding & Tomás, 2006; Camoin *et al*., 2007; Westphal *et al*., 2010; Guido *et al*., 2011, 2013, 2014; Riding *et al*., 2014). The change in micrite nature and biological association is likely to be linked to modification of the environmental framework of the depositional system. The oxic-sub/anoxic boundary is inferred to have been fluctuating at relatively deep water, during the early depositional phase of the bank. The boundary then probably moved upward through the water column, during the deposition of the middle and upper portion of the section (Fig. 10C). Therefore the carbonate bank gradually experienced suboxic conditions, producing ecological changes affecting the dweller communities and the microbial activities (Fig. 10B, C). Anoxic conditions are well documented in the organic-rich basinal counterparts (Moena Formation) of the late Anisian platforms (Contrin Formation)

(Masetti & Neri, 1980). Low oxygen levels supported the accumulation of organic matter, which could have triggered the increase in bacterial sulphate reduction, which in turn favoured *in situ* carbonate precipitation, and the development of peloidal and clotted peloidal micrites (Fig. 7). The high organic content, associated with the bright fluorescence of the peloidal micrite, supports autochthonous deposition *via* bacterial metabolism, as suggested for similar facies by Cuif *et al*. (1990), Müller-Wille & Reitner (1993), and Russo *et al*. (1997).

Clotted peloidal micrite has commonly been linked to anaerobic bacteria activity (Monty, 1976; Chafetz, 1986; Buczynski & Chafetz, 1991; Reitner, 1993; Kazmierczak *et al*., 1996; Folk & Chafetz, 2000; Riding, 2002; Riding & Tomás, 2006; Riding *et al*., 2014). Comparable clotted peloidal micrite was reported from the Pleistocene to Holocene reef microbialites at Tahiti, where lipid biomarkers indicate a microbial community dominated by sulphate reducing bacteria (SRB), degrading the organic matter (Heindel *et al*., 2010, 2012). The involvement of SRB in micrite precipitation within Holocene biostalactites in submerged caves of Sicily has also been suggested (Guido *et al*., 2012a, 2013, 2014). Similar mechanisms can be inferred also in the study Middle Triassic platform. Even if SRB are commonly thought to lack any oxygen tolerance and therefore to exist only in anoxic environments, investigations of Baumgartner *et al.* (2006), on microbial mat systems, demonstrated that SRB are also abundant and active in oxic zones. Furthermore, it has been shown that SRB are highly active in lithified zones of microbial mats, suggesting that they may be directly involved into lithification processes (Visscher *et al.*, 2000; Dupraz *et al.*, 2004).

DEPOSITIONAL GEOMETRY EVOLUTION

Previous research clarified the relationship between carbonate sediment composition and platform slope geometries. Kirkby (1987) proposed a quantitative model for the depositional geometry of slopes, according to their composition and depositional frameworks. Kenter (1990), Adams *et al*. (1998) and Adams & Schlager (2000) suggested that muddy, cohesive sediments, and piles of non-cohesive sand and rubble represent the two-end members of the carbonate slope spectrum, and introduced quantitative relationships between slope curvature, dip angle, and sediment composition. Schlager & Reijmer (2009) demonstrated the role that different types of micrite can play in the control of the depositional geometry of slopes. They found that, in Neogene platforms, fine-grained carbonate precipitated as loose mud and therefore it can readily be re-suspended during storms and exported into the basins. On the contrary, in the Triassic platforms the precipitation of micrite occurred on the sea floor, as crusts and pellets, induced by microbial mat activity. These differences in micrite origins explain the divergence between mud-shedding Neogene and debris-shedding Triassic platforms and slopes (Schlager & Reijmer, 2009).

In the Sasso Bianco section, we observed a gradual change from resedimented carbonates, rich in bioclasts and loose detrital micrite, to clinostratified bodies, rich in autochthonous syndepositional cemented micrite, providing stability to the carbonate slopes. The abundance of originally loose calcareous mud and the reduced syndepositional cementation were matched with the development of a low-relief carbonate bank, during the first stage of the buildup growth (Fig. 7 and 10A). In the middle part of the section, the autochthonous micrite fraction increases, initially alternating in dominance with the loose calcareous mud, and becoming dominant in the upper portion of the succession (Fig. 7). The autochthonous micrite records massive syndepositional lithification, matched with a progressive increase in the dip angle of clinostratification (Fig. 10B, C). This steepening of the slope surfaces, associated with a change in micrite type, is in good agreement with the previous studies on the depositional controls on the slope geometry (Kenter, 1990; Schlager & Reijmer 2009).

CONCLUSIONS

The Sasso Bianco area provides a good example of correlation between depositional geometries and the amount of syndepositional cemented autochthonous micrite. The Anisian succession records a change of micrite type, from the loose detrital fraction, that dominates the lower carbonate bank portion, to the syndepositional lithified fraction ruling the upper buildup portion. The variation is associated with a gradual change in the depositional geometry, i.e. the steepening up of the slope. The carbonate bank, initially developed in shallow water, gradually evolved into a high relief isolated platform, with steep slopes prograding onto the adjacent basins. During sea level rise, suboxic/anoxic conditions affected the slope environment and supported the proliferation of sulphate reducing bacteria. These communities developed on organic matter remains and induced the *in situ* precipitation of micrite that stabilized the bioconstruction. A clear correlation between the change of carbonate production style and the evolution of the carbonate platform dynamics is therefore observable. This correlation, between the syndepositional cemented micrite fraction and the steepness of slopes, can be recognized in other carbonate successions of different age and location. The study of this relationship can provide a new tool for an improved understanding of the depositional geometry of carbonate platform slopes, lacking a primary skeletal framework.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the reviewers and to the editors for comments and suggestions. We are grateful to Robert Riding for revising the text. This research was supported by Regional Operative Program (ROP) Calabria ESF 2007/2013 - IV Axis Human Capital - Operative Objective M2-Action d.5 (Post-Doctoral Fellowship, Adriano Guido).

REFERENCES

Arias, O., and Denyer, P., 1991, Estructura geológica de la región comprendida en las hojas topográficas Abras, Caraigres, Candelaria y Río Grande, Costa Rica: Revista Geológica de América Central, no. 12, p. 61–74.

Adams, E.W., Schlager, W., and Wattel, E., 1998, Submarine slopes with an exponential curvature: Sedimentary Geology, v. 117, p. 135–141.

Adams, E.W., and Schlager, W., 2000, Basic types of submarine slope curvature: Journal of Sedimentary Research, v. 70, p. 814–828.

Baumgartner, L.K., Reid, R.P., Dupraz, C., Decho, A.W., Buckley, D.H., Spear, J.R., Przekop, K.M., and Visscher, P.T., 2006, Sulfate reducing bacteria in microbial mats: changing paradigms, new discoveries: Sedimentary Geology, v. 185, p. 131–145.

Bosellini, A., 1968, Paleogeologia pre-anisica delle Dolomiti centro-settentrionali: Atti Accademia Nazionale Lincei, v. 9, p. 3–33.

Bosellini, A., 1984, Progradation geometries of carbonate platforms: example from the Triassic of the Dolomites, Northern Italy: Sedimentology, v. 31, p. 1–24.

Bosellini, A., Neri, C., and Stefani M., 1996, Geologia delle Dolomiti: Società Geologica Italiana, 78a Riunione Estiva, Introduzione Geologica e guida all’escursione, p. 120.

Bosellini, A., Gianolla, P., and Stefani, M., 2003, Geology of the Dolomites: Episodes, v. 26, p. 181–185.

Bosence, D.W.J., and Bridges, P.H., 1995, A review of the origin and evolution of carbonate mudmounds, *in* Monty, C.L.V., Bosence, D.W.J., Bridges, P.H., and Pratt, B.R., eds., Carbonate Mud Mounds: Their Origin and Evolution: International Association of Sedimentologist, Special Publication, 23, pp. 3–9.

Braga, J.C., Martìn, J.M., and Riding, R., 1995, Controls on microbial dome development along a carbonate-siliciclastic shelf-basin transect, Miocene, S.E. Spain: Palaios, v. 10, p. 347–361.

Buczynski, C., and Chafetz, H.S., 1991, Habit of bacterially induced precipitates of calcium carbonate and the influence of medium viscosity on mineralogy: Journal of Sedimentary Petrology, v. 61, p. 226–233.

Camoin, G.F., Gautret, P., Montaggioni, L.F., and Cabioch, G., 1999, Nature and environmental significance of microbialites in Quaternary reefs: the Tahiti paradox: Sedimentary Geology, v. 126, p. 271–304.

Castanier, S., Le Métayer-Levrel, G., and Perthuisot, J.-P., 1999, Ca-carbonates precipitation and limestone genesis-the microbiogeologist point of view: Sedimentary Geology, v. 126, p. 9–23.

Castanier, S., Le Métayer-Levrel, G., and Perthuisot, J.-P., 2000, Bacterial roles in the precipitation of carbonate minerals, *in* Riding, R.E., and Awramik, S.M., eds., Microbial sediments: Springer Verlag, Berlin, pp. 32–39.

Chafetz, H.S., 1986, Marine peloids: a product of bacterially induced precipitation of calcite: Journal of Sedimentary Petrology, v. 56, p. 812–817.

Cuif, J.P., Gautret, P., Laghi, G.F., Mastandrea, A., Pradier, B., and Russo, F., 1990, Recherche sur la fluorescence UV du squelette aspiculaire chez les Démosponges calcitiques triasiques: Geobios, v. 23, p. 21–31.

De Zanche, V., Gianolla, P., Mietto, P., Siorpaes, C., and Vail, P.R., 1993, Triassic sequence stratigraphy in the Dolomites (Italy): Memorie di Scienze Geologiche, v. 45, p. 1–27.

Dupraz, C.D., Visscher, P.T., Baumgartner, L.K., and Reid, R.P., 2004, Microbe–mineral interactions: early carbonate precipitation in a hypersaline lake (Eleuthera Island, Bahamas): Sedimentology, v. 51, p. 745–765.

Flügel, E., 1982, Microfacies analysis of limestones: Berlin (Springer), pp.633.

Folk, R.L., and Chafetz, H.S., 2000, Bacterially induced microscale and nanoscale carbonate precipitates, *in* Riding, R.E., and Awramik, S.M., eds., Microbial sediments: Springer Verlag, Berlin, pp. 44–49.

Gaetani, M., Fois, E., Jaoul, F., and Nicora, A., 1981, Nature and evolution of middle Triassic carbonate buildups in the Dolomites (Italy): Marine Geology, v. 44, p. 25–57.

Guido, A., Papazzoni, C.A., Mastandrea, A., Morsilli, M., La Russa, M.F., Tosti, F., and Russo, F., 2011, Automicrite in a 'nummulite bank' from the Monte Saraceno (Southern Italy): evidence for synsedimentary cementation: Sedimentology, v. 58, p. 878–889.

Guido, A., Mastandrea, A., Rosso, A., Sanfilippo, R., and Russo, F., 2012a, Micrite precipitation induced by sulphate reducing bacteria in serpulid bioconstructions from submarine caves (Syracuse, Sicily): Rendiconto Online della Società Geologica Italiana, v. 21, p. 933–934.

Guido A., Mastandrea A., Demasi F., Tosti F., and Russo F (2012b, Organic matter remains in the laminated microfabrics of the Kess-Kess mounds (Hamar Laghdad, Lower Devonian, Morocco): Sedimentary Geology, v. 263–264, p. 194–201.

Guido A., Vescogni A., Mastandrea A., Demasi F., Tosti F., Naccarato A., Tagarelli A., and Russo F, 2012c, Characterization of the micrites in the Late Miocene vermetid carbonate bioconstructions, Salento Peninsula, Italy: record of a microbial/metazoan association: Sedimentary Geology, v. 263–264, p. 133–143.

Guido, A., Heindel, K., Birgel, D., Rosso, A., Mastandrea, A., Sanfilippo, R., Russo, F., and Peckmann, J., 2013, Pendant bioconstructions cemented by microbial carbonate in submerged marine caves (Holocene, SE Sicily). Palaeogeography Palaeoclimatology Palaeoecology, v. 388, p. 166–180.

Guido, A., Mastandrea, A., Rosso, A., Sanfilippo, R., Tosti, F., Riding, R., and Russo, F., 2014, Commensal symbiosis between agglutinated polychaetes and sulfate-reducing bacteria: Geobiology, v. 12, p. 265–275.

Hardie, L.A., Bosellini, A., and Goldhammer, R.K., 1986, Repeated subaerial exposure of subtidal carbonate platforms, Triassic, northern Italy: evidence for high frequency sea-level oscillations on a 104 year scale: Paleoceanography, v. 1, p. 447–457.

Harris, M.T., 1993, Reef fabric, biotic crusts and syndepositional cements of the Latemar reef margin (Middle Triassic), northern Italy: Sedimentology, v. 40, p. 383–401.

Heindel, K., Birgel, D., Peckmann, J., Kuhnert, H., and Westphal, H., 2010. Formation of deglacial microbialites in coral reefs off Tahiti (IODP 310) involving sulfatereducing bacteria: Palaios, v. 25, p. 618–635.

Heindel, K., Birgel, D., Brunner, B., Thiel, V., Westphal, H., Gischler, E., Ziegenbalg, S.B., Cabioch, G., Sjövall, P., and Peckmann, J., 2012. Post-glacial microbialite formation in coral reefs of the Pacific, Atlantic, and Indian Oceans: Chemical Geology, v. 304–305, p. 117–130.

Kazmierczak, J., Coleman, M.L., Gruszczynski, M., and Kempe, S., 1996, Cyanobacterial key to the genesis of micritic and peloidal limestones in ancient seas. Acta Palaeontologica Polonica, v. 41, p. 319–338.

Kenter, J.A.M., 1990, Carbonate platform flanks: slope angle and sediment fabric: Sedimentology, v. 37, p. 777–794.

Kirkby, M.J., 1987, General models of long-term slope evolution through mass movement, *in* Anderson, M.G., and, Richards, K.S., eds., Slope Stability: Wiley, Chichester, pp. 359–380.

Masetti, D., and Neri C., 1980, L'Anisico della Val di Fassa (Dolomiti Occidentali): sedimentologia e paleogeografia: Annali dell'Università di Ferrara, no. 7, p. 1–19.

Masetti, D., and Trombetta, G.L., 1998, L'eredità anisica nella nascita ed evoluzione delle piattaforme medio-triassiche delle Dolomiti Occidentali: Memorie di Scienze Geologicha Sci. Geol. Mem., v. 50, p. 213–237.

Monty, C.L.V., 1965, Recent algal stromatolites in the Windward lagoon, Andros Island, Bahamas: Annales de la Société Géologique de Belgique, v. 88, p. 269–276.

Monty, C.L.V., 1976, The origin and development of cryptalgal fabrics. In: Stromatolites (Ed. Walter, M.R.): Development in Sedimentology, v. 20, p. 193–249.

Monty, C.L.V., Bosence, D.W.J., Bridges, P.H., and Pratt, B.R., 1995, Carbonate Mud Mounds: Their Origin and Evolution. International Association of Sedimentologist, Special Publication, v. 23.

Müller-Wille, S., and Reitner, J., 1993, Palaeobiological reconstruction of selected sphinctozoan sponges from the Cassian Beds (Lower Carnian) of the Dolomites (Northern Italy): Berliner Geowissenschaftliche Abhandlungen, v. 9, p. 253–281.

Neri, C., and Stefani M., 1998, Sintesi cronostratigrafica e sequenziale dell'evoluzione permiana superiore e triassica delle Dolomiti: Memorie della Società Geologica Italiana, v. 53, p. 417–463.

Neuweiler, F., and Reitner, J., 1995, Epifluorescence-microscopy of selected automicrites from lower Carnian Cipit-boulders of the Cassian formation (Seeland Alpe, Dolomites): Facies, v. 32, p. 26–28.

Reitner, J., 1993, Modern cryptic microbialite/metazoan facies from Lizard Island (Great Barrier Reef, Australia): formation and concepts: Facies, v. 29, p. 3–39.

Reitner, J., and Neuweiler, F., 1995, Mud Mounds : a polygenetic spectrumof fine-grainedcarbonate buildups: Facies, v. 32, p. 1–70.

Riding, R., 2000, Microbial carbonates: the geological record of calcified bacterial-algal mats and biofilms: Sedimentology, v. 47, p. 179–214.

Riding, R., 2002, Structure and composition of organic reefs and carbonate mud mounds: concepts and categories: Earth-Science Reviews, v. 58, p. 163–231.

Riding, R., Liang, L., and Braga J.C., 2014, Millennial-scale ocean acidification and late Quaternary decline of cryptic bacterial crusts in tropical reefs: Geobiology, v. 12, p. 387–405.

Riding, R., and Tomás, S., 2006, Stromatolite reef crusts, Early Cretaceous, Spain: bacterial origin of in situ precipitated peloid microspar?: Sedimentology, v. 53, p. 23–34.

Russo, F., Neri, C., Mastandrea, A., and Laghi, G., 1991, Depositional and diagenetic history of the Alpe di Specie (Seelandalpe) fauna (Carnian, Northeastern Dolomites): Facies, v. 25, p. 187–210.

Russo, F., Neri, C., Mastandrea, A., and Baracca, A., 1997, The mud-mound nature of the Cassian platform margins of the Dolomites. A case history: the Cipit boulders from Punta Grohmann (Sasso Piatto Massif, northem Italy): Facies, v. 36, p. 25–36.

Russo, F., Mastandrea, A., Stefani, M., and Neri, C., 2000, Carbonate facies dominated by syndepositional cements: a key component of Middle Triassic platforms. The Marmolada case history (Dolomites, Italy): Facies, v. 42, p. 211–226.

Russo, F., 2005, Biofacies evolution in the Triassic platforms of the Dolomites, Italy, in Fugagnoli, A., Bassi, D., eds., Giornate di Studi Paleontologici “Prof. Carmen Loriga Broglio”: Annali dell'Università degli Studi di Ferrara, Museologia Scientifica e Naturalistica, Rastignano, Bologna, p. 33–43.

Schlager, W., and Reijmer, J.J.G., 2009, Carbonate platform slopes of the Alpine Triassic and the Neogene – a comparison: Austrian Journal of Earth Sciences, v. 102, p. 4–14.

Schlager, W., and Keim, L., 2009, Carbonate platforms in the Dolomites area of the Southern Alps — historic perspectives on progress in sedimentology. Sedimentology, 56, 191–204.

Stefani, M., Brack, P., Gianolla, P., Keim, L.,Mastandrea, A., Maurer, F., Neri, C., Preto, N., Ragazzi, E., Riva, A., Roghi,G., and Russo, F., 2004, Triassic carbonate platforms of the Dolomites. Carbonate production, relative sea-level fluctuations and the shaping of the depositional architecture: 32nd International Geological Congress, Florence - Italy, Post-Congress field trip, p. 44–64.

Stefani, M., Furin, S., and Gianolla, P., 2010, The changing climate framework and depositional dynamics of Triassic carbonate platforms from the Dolomites: Palaeogeography Palaeoclimatology Palaeoecology, v. 290, p. 43–57.

Stockman, K.W., Ginsburg R.N., and Shinn, E.A., 1967, The production of lime mud by algae in South Florida: Journal of Sedimentary Petrology, v. 37, p. 633–648.

Tosti, F., Guido, A., Demasi, F., Mastandrea, A., and Russo, F., 2011, Biogeochemical characterization of automicrites building the Cipit Boulders of the Ladinian–Carnian platforms in the Dolomites (northeastern Italy): Rendiconti Online della Società Geologica Italiana, v. 17, p. 179–183.

Tosti, F., Mastandrea, A., Guido, A., Demasi, F., Russo, F., and Riding, R., 2014, Biogeochemical and redox record of mid-late Triassic reef evolution in the Italian Dolomites: Palaeogeography Palaeoclimatology Palaeoecology, v. 399, p. 52-66.

Tucker, M.E., and Wright, V.P., 1990, Carbonate Sedimentology: Blackwell Scientific Publications, London, 488 pp.

Visscher, P.T., Reid, R.P., and Bebout, B.M., 2000, Microscale observations of sulfate reduction: correlation of microbial activity with lithified micritic laminae in modern marine stromatolites: Geology, v. 28, p. 919–922.

Wendt, J., 1982, The Cassian patch reefs (Lower Carnian, Southern Alps). Facies, 6, 185–202.

Westphal, H., Heindel, K., Brandano, M., and Peckmann J., 2010, Genesis of microbialites as contemporaneous framework components of deglacial coral reefs, Tahiti (IODP 310): Facies, v. 56, p. 337–352.

Wolf, K.H., 1965, Gradational sedimentary products of calcareous algae: Sedimentology, v. 5, p. 1–37.

Zankl H., 1993, The origin of high-Mg-calcite microbialites in cryptic habitats of Caribbean coral reefs - their dependence on light and turbulence: Facies, v. 29, p. 55–60.

FIGURE CAPTIONS

Figure 1. Paleogeographic scheme of the western Dolomites region during the late Anisian, showing the location of the Sasso Bianco section.

Figure 2. Geometric stratigraphic scheme of the Lower and Middle Triassic of the western Dolomites.

Figure 3. The Sasso Bianco area. Based on stratification geometry, the carbonate body has been subdivided into a lower bank unit and an upper platform slope unit. The black dotted line represents the sampled transect.

Figure 4. Stratigraphic column with the location of the studied samples.

Figure 5. Packstone/wackestone microfacies from the lower bank unit. The compact texture of the detrital micrite engulfs fragments of dasycladacean thalli (A-B; samples SB1, SB3), gastropods, bivalves, echinoderms, foraminifers (C-E; samples SB1, SB3, SB5), and *Olangocoelia otti* sponge fragments (F; sample SB5). Scale bar = 1mm. Arrows indicate stratigraphic top.

Figure 6. Detrital micrite observed in transmitted (left) and ultraviolet (right) light. The weak epifluorescence of the intergrains areas, due to residual sedimentary organic matter, is much lower than that generated by the small dasycladacean fragments. Arrows indicate stratigraphic top. Note the wide difference of epifluorescence between the detrital micrite and the autochthonous micrite of Figure 9.

Figure 7. Percentage of the main microfacies components in the lower, middle and upper portions of the Sasso Bianco section, shown on a schematic outline of the depositional geometry. Note the good correlation between slope angle increases and the

augmentation of the syndepositional cemented autochthonous micrite. The dotted line indicates the location of the studied succession.

Figure 8. Microfacies from the platform slope unit. Note the clotted peloidal texture of the autochthonous micrites. The non-gravitational fabric suggests *in situ* deposition and syndepositional cementation. (A-B) Algal/microbial encrustation of skeletal grains (samples SB8, SB10); (C-D) *Tubiphytes* (samples SB13, SB17); (E) Agglutinated tube worms (terebellids) engulfed in peloidal micrite (SB18); (F) Clotted peloidal micrite (SB19). Scale bar: a,d,e = 500 μm; b = 1mm; c,f = 200 μm. Arrows indicate stratigraphic top.

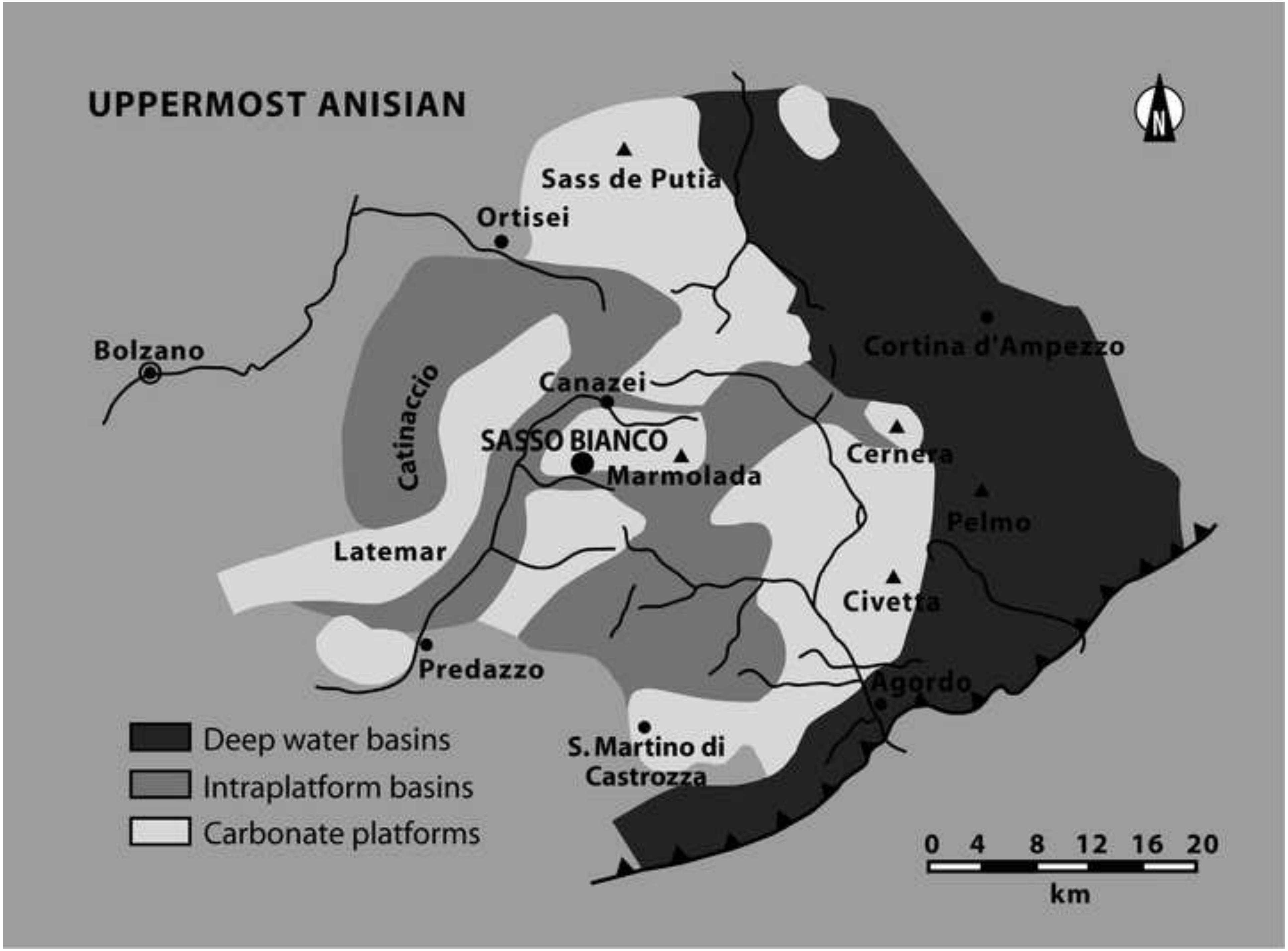
Figure 9. Micrite components observed in transmitted (left) and ultraviolet (right) light. The bright epifluorescence of the autochthonous clotted peloidal micrite denotes high organic matter content. Sparite and detrital micrite, in the right part of photo (A), appear dark in color under ultraviolet light. Arrows indicate stratigraphic top.

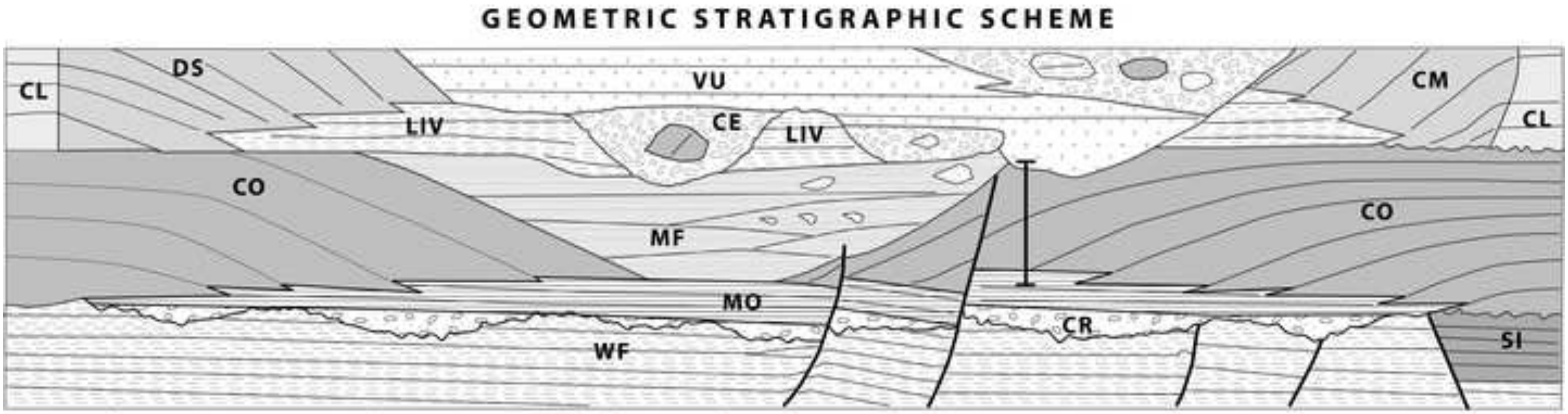
Figure 10. Schematic reconstruction of the environmental evolution during the deposition of the Sasso Bianco succession. (A) Development of carbonate bank, during the first stage of buildup grow. The loose nature of the carbonate mud created a low relief, low angle morphology, while the richness and diversity of the biota, dominated by crinoids, echinoids and green algae, suggest shallow and well-oxygenated seawater. (B) Increase in the syndepositional cementation and autochthonous micrite deposition produced a steepening of the slope surfaces. Suboxic/anoxic conditions started to affect the carbonate platform, inducing a major change in the faunal assemblages. (C) The climax of autochthonous micrite production induced high angle platform slopes. Deposition of peloidal to clotted peloidal micrites was influenced by the activity of

sulphate reducing bacteria, inducing *in situ* cementation of the sediments, under suboxic-anoxic conditions.

Figure 1

Click here to download Figure Fig. 1.tif





WF=Werfen Fm.;SI=Lower Serla Fm.; CR=Richthofen Conglomerate; MO=Morbiàc Fm.; Co=Contrin Fm.;MF=Moena Fm.; LIV=Livinallongo Fm.; CL=Latemar Fm.; CM=Marmolada Limestone; DS=Sciliar Dolmite; CE=Caotico Eterogeneo; VU=Vulcanite.
I—I Stratigraphic position of the Sasso Bianco section.

Figure 3

Click here to download Figure Fig. 3.tif

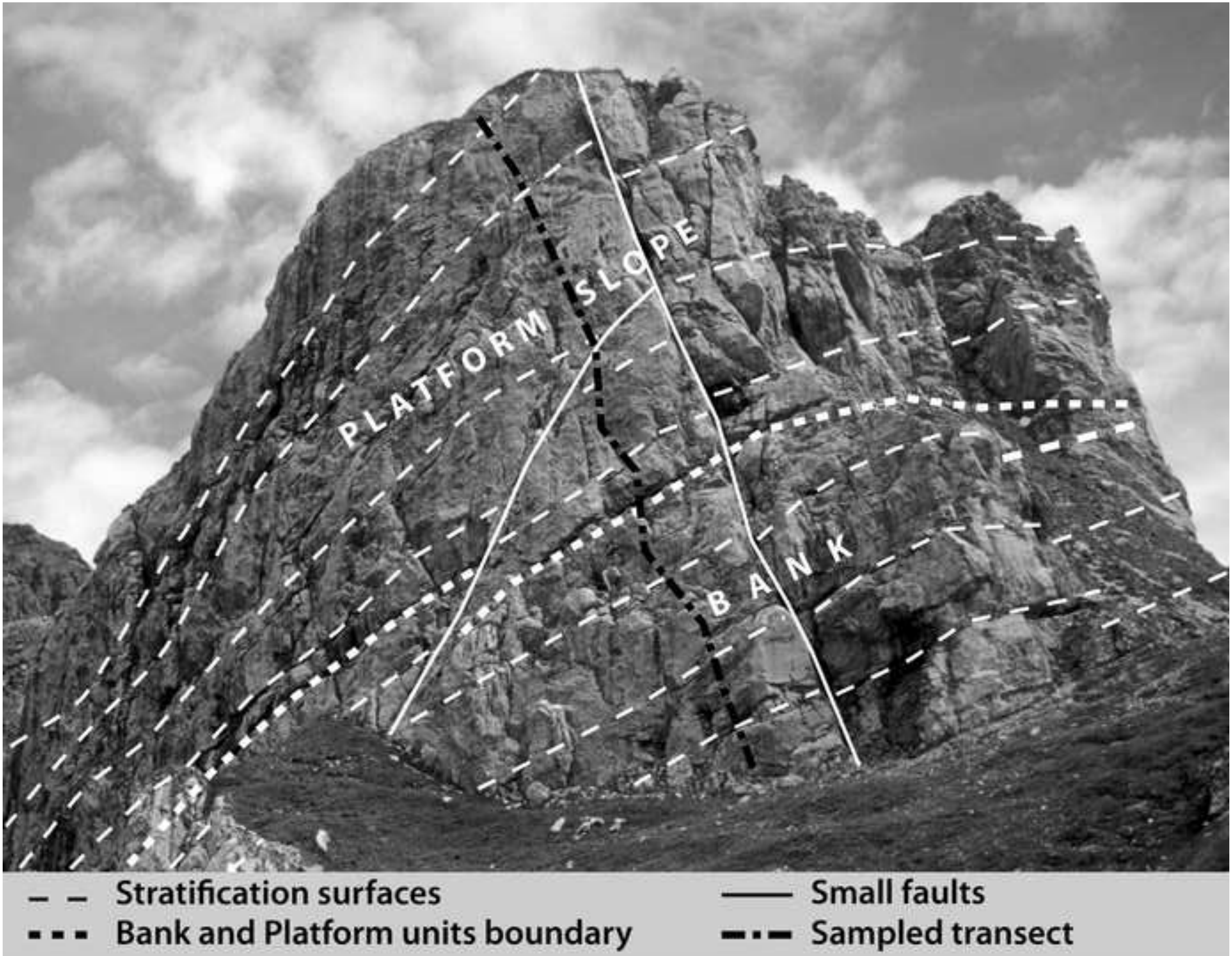


Figure 4

Click here to download Figure Fig. 4.tif

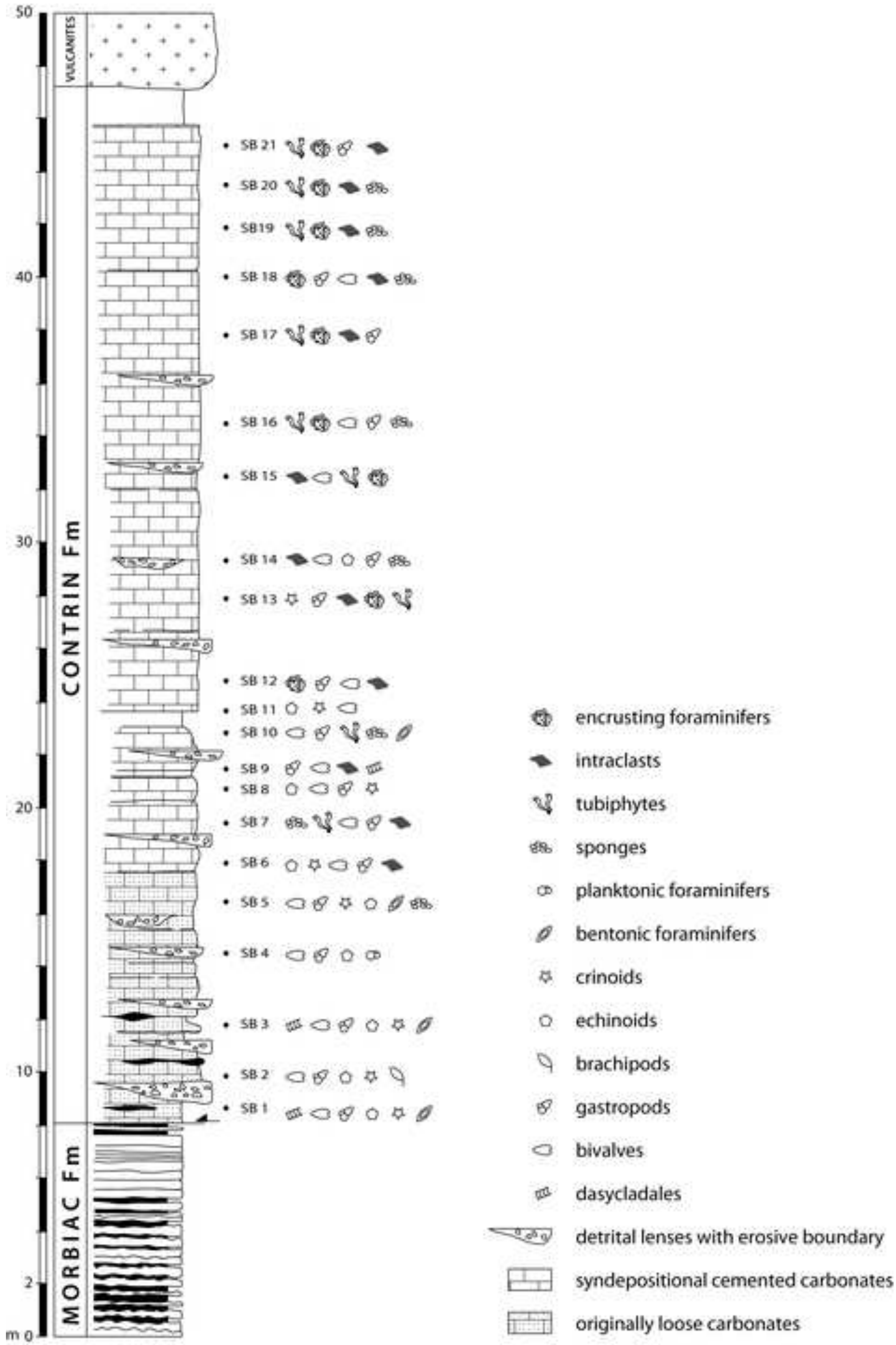


Figure 5

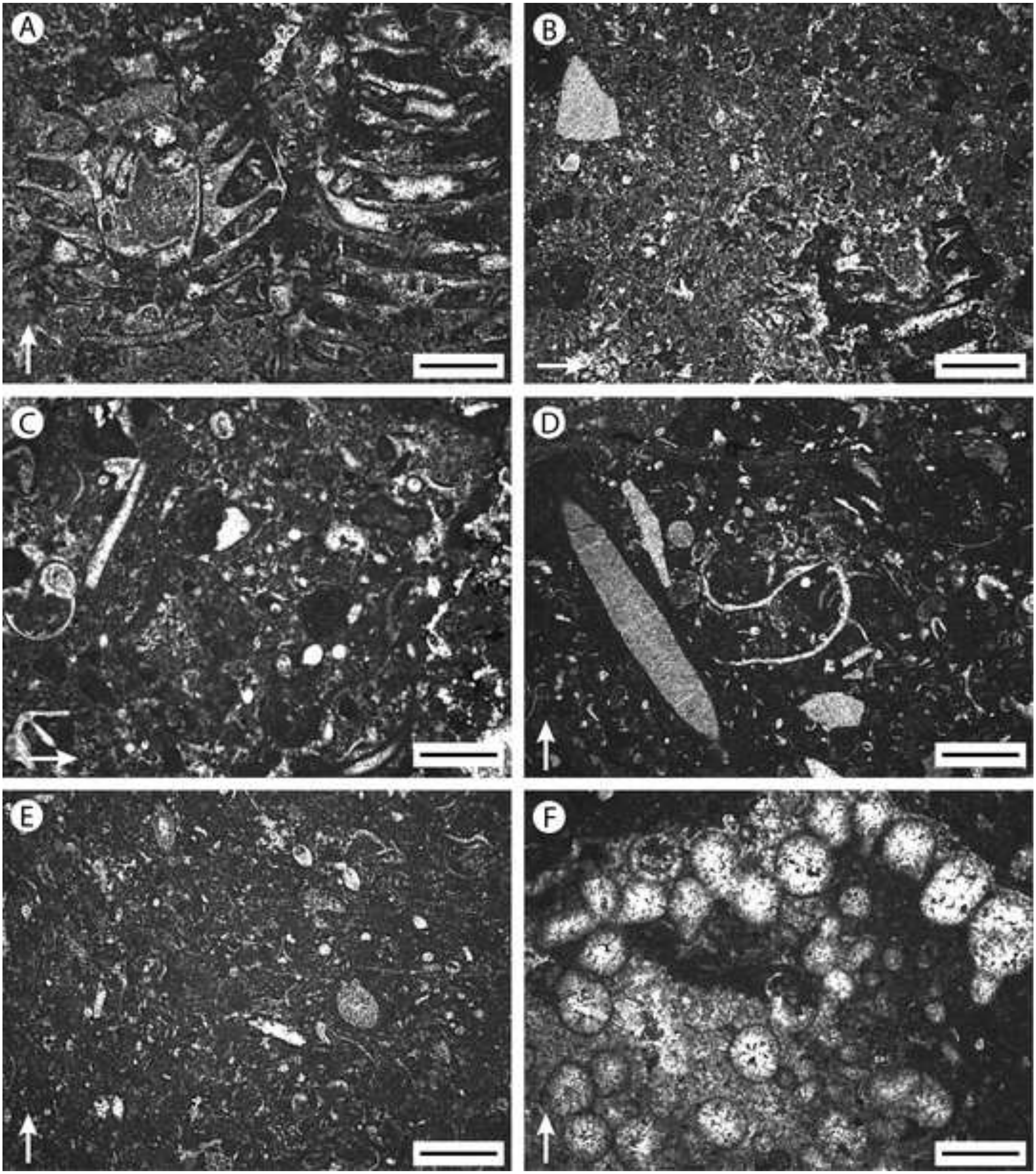


Figure 6

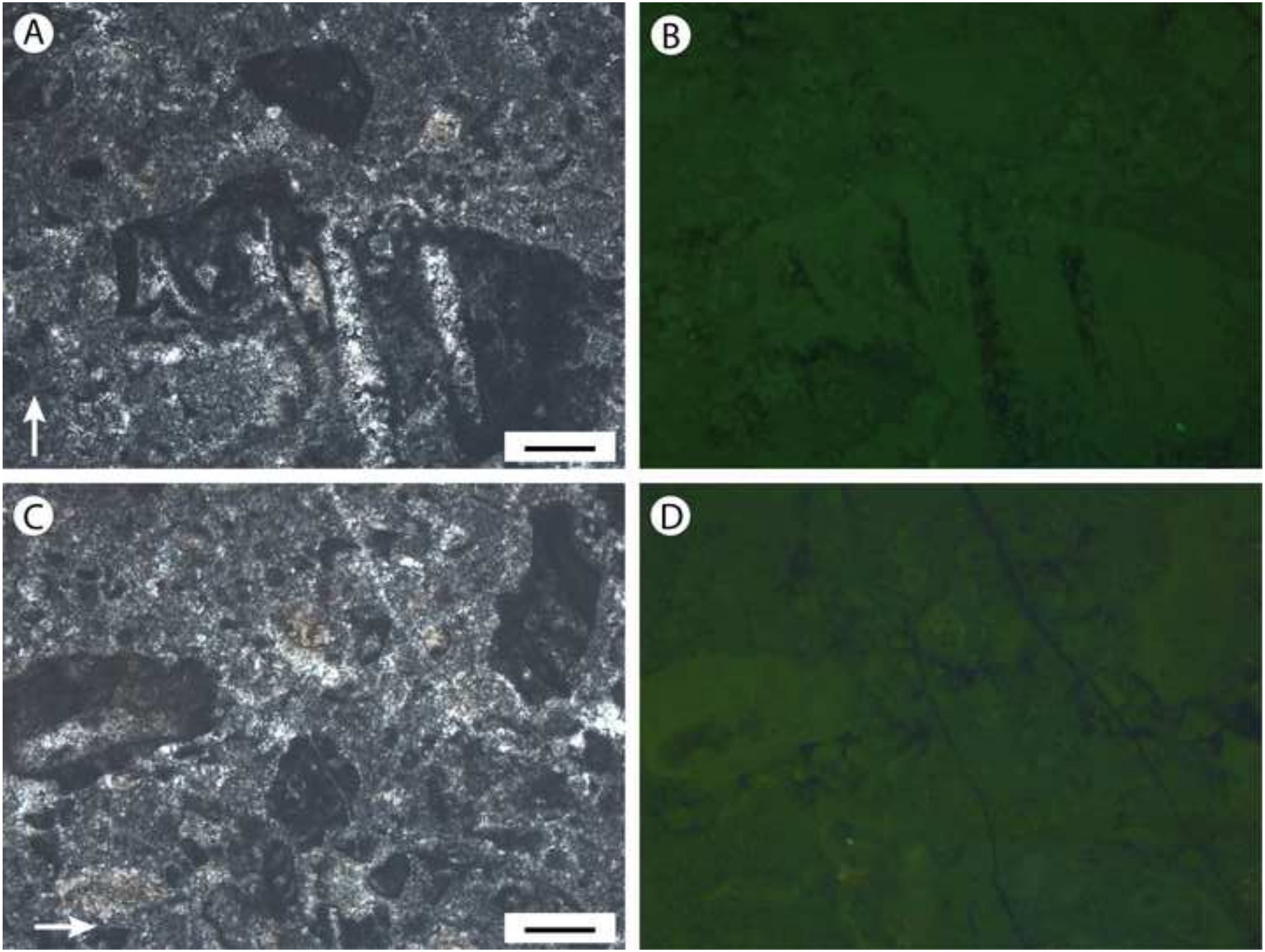


Figure 7

Click here to download Figure Fig. 7.tif

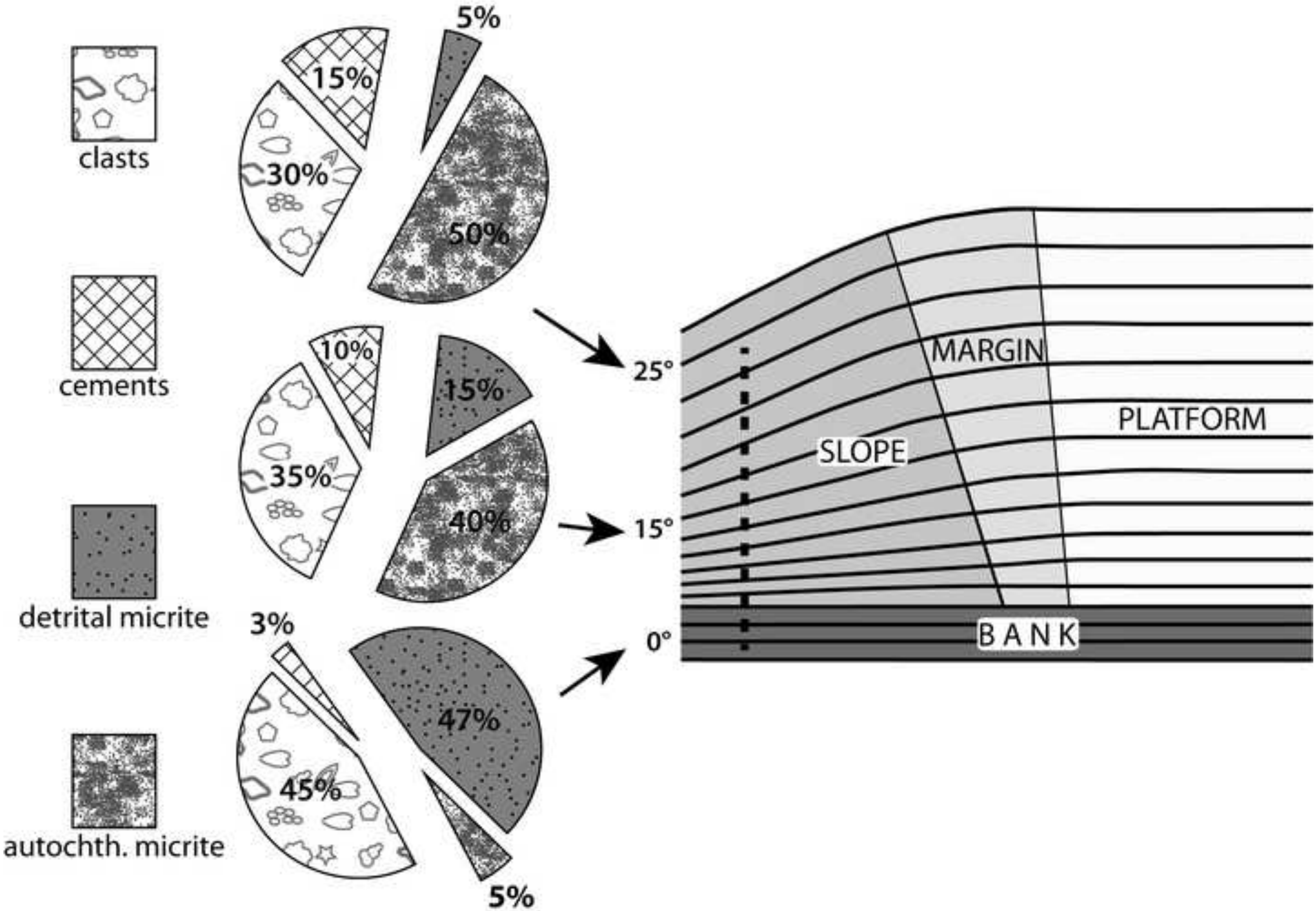


Figure 8 Click here to download Figure Fig. 8.tif

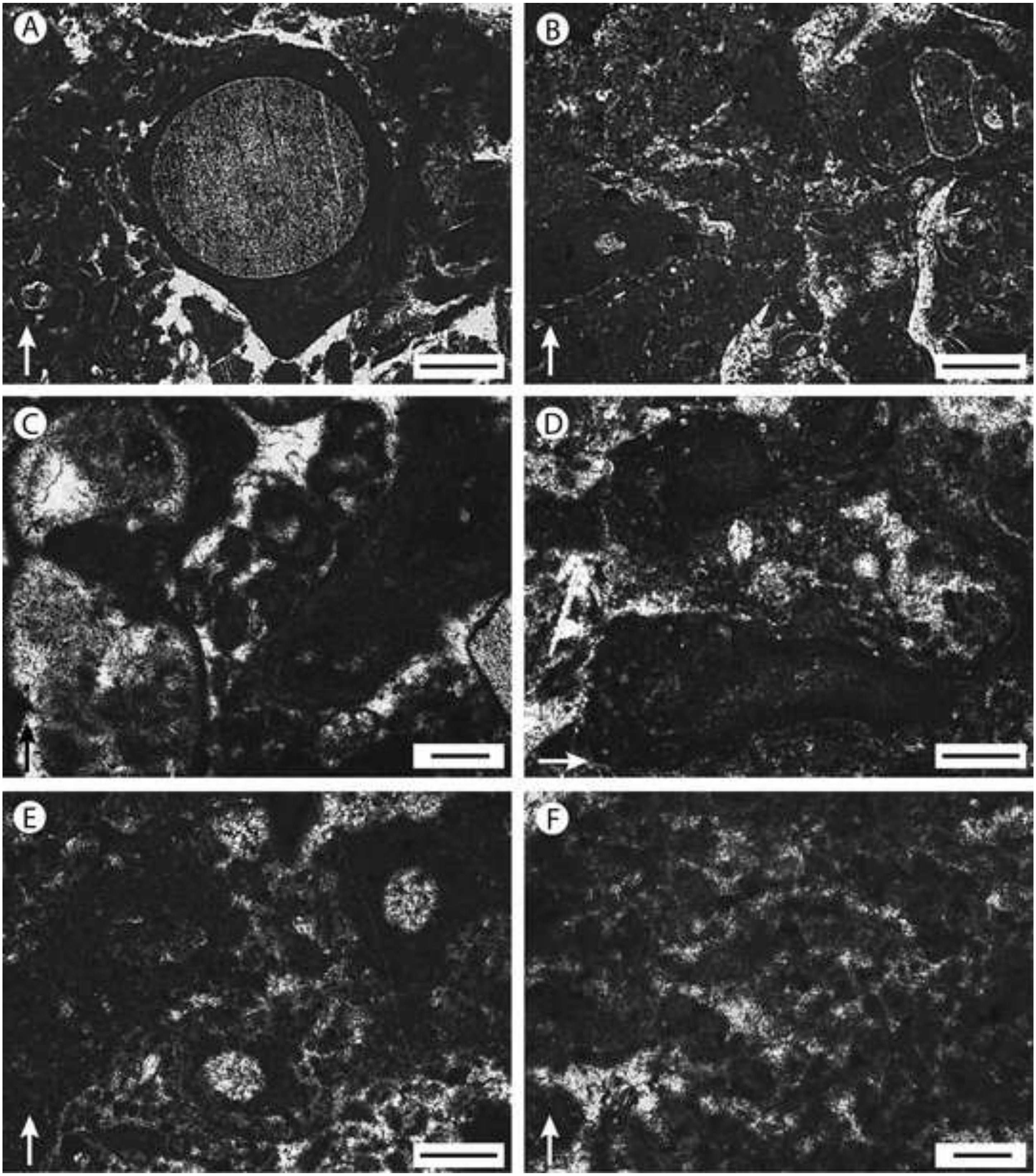


Figure 9

Click here to download Figure Fig. 9.tif

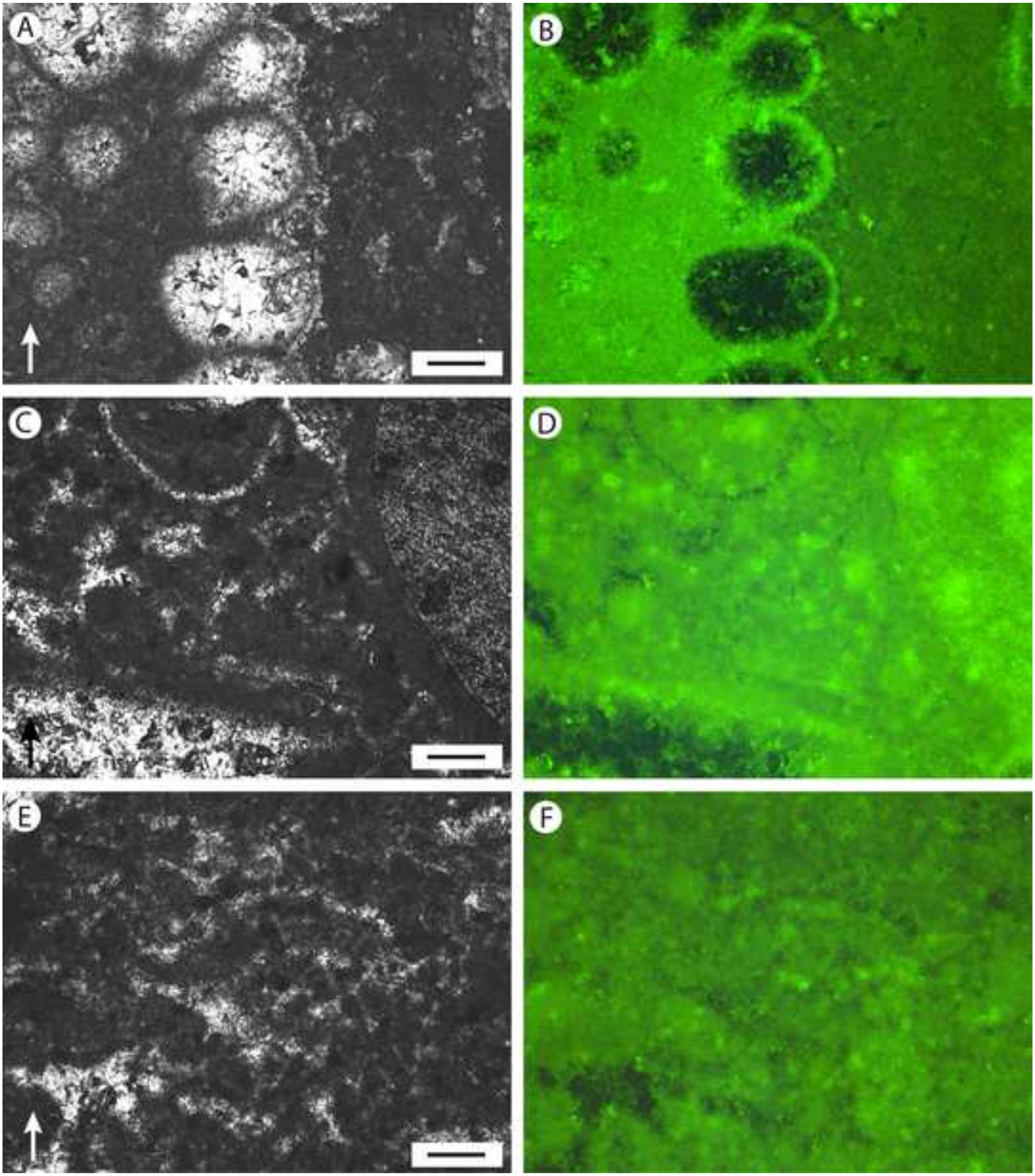


Figure 10

Click here to download Figure Fig. 10.tif