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Abstract: In this contribution sedimentary facies analysis and geological 3D modeling are applied to constrain the sequence stratigraphy of a complex stratigraphic interval in the Late Triassic of the Dolomites and allow to highlight the interaction of sea level and climate changes. This multidisciplinary approach was key to disentangle the timing of climatic change vs. sea level fluctuation and their effects on a shallow water carbonate depositional system. The "Carnian Pluvial Event", a global episode of climate change worldwide documented at low latitudes, involved increased rainfall and possibly global warming. This climatic event, predates a drop of sea-level and caused the demise of microbial-dominated high-relief carbonate platforms that dominated the Dolomites region and was followed by a period characterized by the coexistence of small microbial carbonate mounds and loose arenaceous carbonates. A subsequent sea level fall brought to the definitive disappearance of microbialites and shallow water carbonates switched to ramps dominated by loose carbonate sediment. The climate-induced crisis of Early Carnian shallow water carbonate systems of the Dolomites generated a geological surface similar to a drowning unconformity, although no transgression occurred. The sudden infilling of basins at the end of the Early Carnian was the result of the climatic-induced switch from high-relief carbonate systems characterized by steep slopes to a gently inclined ramp, rather than by the continuous progradation of a high-relief microbial platform. Results show that the evolution of carbonate systems of the Dolomites at the end of the Early Carnian cannot be interpreted in the light of sea level changes only, pointing out that ecological changes can induce significant modifications in depositional geometries. This case study may serve as a conceptual model for the sedimentary evolution of carbonate systems subject to ecological crisis that do not evolve in platform drowning because of a lack of accommodation.

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Padova, February 24th, 2014

Prof. David J. Bottjer
Palaeogeography, Palaeoclimatology, Palaeoecology
Editor

I submit for your kind attention the manuscript entitled "Sequence stratigraphy after the demise of a high-relief carbonate platform (Carnian of the Dolomites): sea-level and climate disentangled", with the hope that it can be published in Palaeogeography, Plaeoclimatology, Palaeoecology.

I believe that this contribution is of interest for the broad community of earth scientists, as it brings new data useful to constrains the sequence stratigraphy of a complex stratigraphic interval in the Late Triassic of the Dolomites allowing to further detail the the effects of the interaction of sea level and climate changes on carbonate platform systems.
The study has been carried out coupling facies analysis and 3D geological modeling techniques. This multidisciplinary approach was key to disentangle the timing and interaction of climatic change vs. sea level fluctuation.

The evolution of the sedimentary system described in this paper can be summarized as follows:
A worldwide documented Late Triassic climatic event increased rainfall and possibly led to global warming triggering the demise of the microbial-dominated high-relief carbonate platforms of the Dolomites. After this event, a period of coexistence of small microbial carbonate mounds and loose arenaceous carbonates is documented. A subsequent sea level fall brought to the complete disappearance of microbialites and shallow water carbonates switched to ramps dominated by associations typical of a cool-water factory mixed with siliciclastic sediment.

The climate-induced crisis of microbial-dominated high-relief carbonate platforms generated a geological surface similar to a drowning unconformity, although no transgression was involved. This observation highlights a known caveat of the sequence stratigraphy of carbonates: ecological changes determine significant changes in depositional geometries, and so the evolution of carbonate systems cannot be interpreted or predicted on the basis of the observations of sea level change only. This case study may serve as conceptual model for the interpretation of the evolution of carbonate system in times of ecological crisis.

Sincerely,

Giovanni Gattolin
(on behalf of all authors)

Facies analysis and geological 3D modeling applied to constrain sequence stratigraphy

A multidisciplinary approach to disentangle climatic vs. sea level change effects

The switch from microbial to cool-water factory results triggered by climate change

A carbonate system subject to ecological crisis that does not evolve in a drowning

Generation of a surface similar to a drowning unconformity without a transgression

Sequence stratigraphy after the demise of a high-relief carbonate platform (Carnian of the Dolomites): sea-level and climate disentangled.

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Abstract

In this contribution sedimentary facies analysis and geological 3D modeling are applied to constrain the sequence stratigraphy of a complex stratigraphic interval in the Late Triassic of the Dolomites and allow to highlight the interaction of sea level and climate changes. This multidisciplinary approach was key to disentangle the timing of climatic change vs. sea level fluctuation and their effects on a shallow water carbonate depositional system. The “Carnian Pluvial Event”, a global episode of climate change worldwide documented at low latitudes, involved increased rainfall and possibly global warming. This climatic event, predates a drop of sea-level and caused the demise of microbial-dominated high-relief carbonate platforms that dominated the Dolomites region and was followed by a period characterized by the coexistence of small microbial carbonate mounds and loose arenaceous carbonates. A subsequent sea level fall brought to the definitive disappearance of microbialites and shallow water carbonates switched to ramps dominated by loose carbonate sediment. The climate-induced crisis of Early Carnian shallow water carbonate systems of the Dolomites generated a geological surface similar to a drowning unconformity, although no transgression occurred. The sudden infilling of basins at the end of the Early Carnian was the result of the climatic-induced switch from high-relief carbonate systems characterized by steep slopes to a gently inclined ramp, rather than by the continuous progradation of a high-relief microbial platform. Results show that the evolution of carbonate systems of the Dolomites at the end of the Early Carnian cannot be interpreted in the light of sea level changes only, pointing out that ecological changes can induce significant modifications in depositional geometries. This case study may serve as a conceptual model for the sedimentary evolution of carbonate systems subject to ecological crisis that do not evolve in platform drowning because of a lack of accommodation.

Key Words

Sequence stratigraphy, carbonate platform demise, climate change, Dolomites, Triassic.

1. Introduction

Sequence stratigraphy is a powerful tool to understand the history and the evolution of depositional systems and sedimentary basins (e.g., Vail et al., 1991; Catuneanu, 2006; Catuneanu et al., 2011). It has been successfully applied in a variety of geodynamic settings to both siliciclastic (Galloway and Williams 1991; Helland-Hansen 1992; Mellere and Steel 1995; Miall and Arush 2001; Catuneanu et al., 2002; Cantalamessa et al., 2005; Breda et al., 2009a; Galloway 2008; Miall et al., 2008; among others) and carbonate systems (De Zanche et al. 1993; Pasquier and Strasser 1997; Gianolla et al. 1998; Gianolla and Jacquin 1998; Pomar and Tropeano 2001; Mateu-Vicens et al., 2008; among others). However, the sequence stratigraphic interpretation of carbonate systems still has significant limitations, related to the capability of some carbonate platforms to produce sediment in situ, at a rate that is influenced by oceanographic and climatic parameters more than by sea level change (Schlager, 1991; 1993; Schlager et al., 1994; Pomar, 2001). One singularity of carbonate platforms is that they can drown, that is, the platform top can be submerged below the photic zone; in that case, the platform cannot catch up to sea level and the carbonate production is irreversibly shut down (Schlager 1981; 1999a, b; Hallock and Schlager 1986). The geometry and facies of drowned carbonate platforms mime a rise of the sea level even during periods of sea level stability. In the specific case of carbonate platforms drowning, the special behavior of carbonate systems has been often related to a change in the ecology or biology of carbonate producers, in turn commonly linked to climate and/or environmental changes (Schlager 1981; Hallock and Schlager 1986; Jenkyns 1991; Mutti et al. 1997, 2005; Weissert et al. 1998; Wilson et al. 1998; Mutti and Hallock 2003; Schlager 2003; Pomar et al., 2004; Föllmi and Godet 2013; Godet et al. 2013; among others). In the Triassic of the Dolomites (North-eastern Italy, Fig. 1a), sedimentary sequences are dominated by carbonates. During the last decades, several sequence stratigraphic interpretations of these successions were proposed (Brandner, 1984; De Zanche et al., 1992; De Zanche et al., 1993; Rüffer and Zühlke,1995; Neri and Stefani, 1998; Gianolla et al. 1998; Neri et al., 2007) that had to face the paradox of drowning platforms, at times of prolonged and intense subsidence as the Middle Triassic (De Zanche et al., 1995; Blendinger et al., 2004; Preto et al., 2005; Brack et al., 2007).

At the end of the early Carnian, a major event of carbonate platform demise is recorded in the Dolomites: carbonate production in high-relief platforms suddenly shuts off and is replaced by the deposition of mixed carbonate-siliciclastic sediments deposited on a low-relief ramp depositional profile (Heiligkreuz Formation in Neri et al 2007, ex Dürrenstein Formation of De Zanche et al., 1993; Preto and Hinnov, 2003; Bosellini et al., 2003; Stefani et al., 2010; Fig. 2). This crisis of high-relief carbonate platforms is not confined to the Dolomites. In fact, it was initially identified in the Northern Calcareous Alps of Austria (Schlager and Schöllenberger, 1974) and then recognized at the scale of the Tethys ocean (e.g., Simms et al., 1995; Hornung et al., 2007a; Preto et al., 2010). This crisis is now considered as one of the many effects of a global episode of climate change, the "Carnian Pluvial Event" (CPE) of Simms and Ruffell (1989). The CPE corresponds to an increase in rainfall and runoff at low latitutes, reflected in sedimentological, geochemical and palynological proxies (e.g., Simms and Ruffel, 1989, 1990; Simms et al., 1995; Roghi, 2004; Prochnow et al., 2006; Preto et al., 2010; Nakada et al., 2014), triggered by a major perturbation of the global carbon cycle (Dal Corso et al., 2012). Oxygen isotopes of conodont apatite also suggest that the CPE corresponds to an episode of global warming (Hornung et al., 2007b; Rigo and Joachinski, 2010). The onset of the CPE is tightly constrained in the area of Rifugio Dibona (Dal Corso et al., 2012), where the outcrops considered in this study are located.

In the Dolomites, the interpretation of the stratigraphic interval around the CPE, in terms of sequence stratigraphy, is challenging. In literature the ramp deposits formed after the demise of high-relief early Carnian platforms are interpreted as a complete 3rd order depositional sequence. The sea level fall at the base of this interval is considered the cause of the demise of these carbonate platforms (De Zanche et al. 1993; Gianolla et al. 1998; Bosellini et al., 2003). However, this interpretation does not explain the change in the type of carbonate sediments and is incongruous with most episodes of carbonate platform drowning of the Mesozoic (Schlager, 1981; 1999a, b; 2005; Weissert et al., 1998). The suite of climatic and geochemical changes recorded at the CPE, and its global rather than regional distribution, are in fact remarkably similar to those of major Mesozoic Oceanic Anoxic Events (Preto et al., 2010). These events are associated to ecological crises of carbonate platforms, including commonly their drowning (e.g, Jenkyns, 1985; 1991; Weissert et al., 1998; Léonide et al., 2012).

In this work, a reappraisal of the sequence stratigraphy of the Heiligkreuz Formation (youngest early Carnian) is endeavored in the light of the analogy between the CPE and other Mesozoic perturbations of the carbon cycle, and their effects on carbonate platforms. The focus is put on the sequence boundary at the base of the Heiligkreuz Formation, with the aim of disentangling the roles of sea level change and environmental factors on the demise of the underlying high-relief carbonate platforms. To this end we applied 3D modeling techniques coupled with facies analysis to assess the relative timing of the platform demise with respect to the sedimentary record of sea level fall and subaerial exposure. Our data suggest that the demise of high-relief carbonate platforms occurred before sea level fall and the consequent subaerial exposure; depositional geometries mimicking a sequence boundary were thus generated and are unrelated to an actual decrease in accommodation, in analogy to typical drowning unconformities (type 3 SB of Schlager, 1999b). Differently from episodes of drowning of the Middle Triassic, however, the CPE and the related demise of high-relief carbonate platforms occurred at a time of tectonic quiescence, at the end of a long-term depositional cycle (Gianolla and Jacquin, 1998), when accommodation in the area was created at a slow rate. The case study of the Carnian of the Dolomites thus shows that climate-induced crises of carbonate systems can generate surfaces similar to drowning unconformities not related to times of prolonged transgression.

2. Geological setting

During the Middle-Late Triassic, the Dolomites (North-eastern Italy, Fig. 1a) were located in the western portion of the Tethys Ocean (Ziegler, 1988; Dercourt et al., 1993) at northern tropical latitudes (Fig. 1b; Muttoni et al., 1996; Broglio Loriga et al., 1999; Flügel, 2002). The area was characterized by a “chess-board-like” paleotopography featuring domains with different subsidence rates (horsts and grabens) and bounded by roughly North-South and East-West faults (Masetti and Neri, 1980; Blendinger, 1986; De Zanche 1993; Gianolla et al., 1998; Preto et al., 2011). Often, horsts hosted the onset of isolated high-relief carbonate platforms dominated by Microbial to Tropical carbonate factories (*sensu* Schlager 2003), while in grabens a carbonate to siliciclastic basinal sedimentation took place (Masetti e Neri 1980; Gaetani et al., 1981; Bosellini 1984; Bosellini et al. 2003; Neri et al. 2007; Preto el al. 2011; among others). Toward the end of the early Carnian, a progressive slowdown of the high subsidence rates along with a strong siliciclastic input to marginal basins resulted in the flattening of this complex paleotopography. Contemporaneously, an important turnover in carbonate factories and carbonate platform geometries occurred and

Microbial to Tropical factories were replaced by Cool-water to Tropical factories (*sensu* Schlager, 2003) which originated ramp geometries (Bosellini et al., 2003; Preto and Hinnov, 2003; Stefani et al., 2010). The demise of the last generation of high-relief Carnian carbonate platforms (Fig. 2; Cassian 2 platforms in De Zanche et al. 1993) is attributed to two main factors: (1) the subaerial exposure they suffered following an important sea level drop and (2) the considerable siliciclastic input (in turn triggered by the sea level drop) which can be detrimental to the carbonate production (Russo et al., 1991; Keim et al., 2001; Bosellini et al., 2003). This sea level drop constitutes the lower sequence boundary of a third order depositional sequence (Fig. 2; Car 3 in De Zanche et al. 1993; Gianolla et al., 1998), object of this study.

3. Methods

A three-dimensional model of the southern walls of Tofana di Rozes (see Fig. 1a for location; Fig 3a) was created with the photogrammetric software Agisoft™ Photoscan. Forty-six highly overlapping photographs were taken from a working distance of ~ 4 km using a Sony α200 DSLR camera (resolution = 10.2 megapixel) coupled with a Minolta AF 100-200 f4.5 zoom lens (selected focal length = 100mm, f = 9). To scale and georeference the model 20 GPS points, well recognizable both on the field and on the photographs, were taken with the aid of a Royaltek RBT-2200 bluetooth GPS (average uncertainty in the specific conditions ~ 1 – 5 m) coupled with a HP iPAQ 214 handheld pc running Esri® ArcPAD™ 7.0. A three-dimensional model of the Dibona Hut outcrop (Fig. 1a for location; Fig. 4a) was acquired through an Optech Ilris 3D terrestrial laser scanner (wavelength 1500 nm, acquisition speed 2500 points per second). The working distance was ~ 60 m and the resolution of the point clouds is ~ 1 point every 4 cm. To georeference the model, the GPS position of 6 targets was taken using a high precision Base-Rover Topcon HiPer® Pro system (uncertainty ~ 3 cm).

Sedimentary facies were defined in the field and through petrographic analysis, using standard sedimentology methods (e.g., Tucker and Wright, 1990; Flügel, 2004).

4. Lithozones

The sedimentary succession was divided into six lithozones. Each of these lithozones is characterized by a different facies association, stratal patterns and depositional geometries. A brief description of lithozones is provided below; for a more detailed description the reader is referred to Preto and Hinnov (2003) and Gattolin et al. (2013).

Lithozone 1 (L-1)

This lithozone was observed only at Tofana di Rozes, where it constitutes a wedge pinching out toward the East. Its maximum thickness is ~ 200 m on the western side of the outcrop (Figs. 3b, c). It is mainly constituted by m thick clinoforms of pervasively dolomitized limestone. Locally megabreccias, with m to tens of m large boulders, were identified. Dolomitization hampers the observation of original facies. L-1 pertains to the platform slope of one of the Carnian high-relief carbonate platforms (Cassian 2 of De Zanche et al. 1993; Gianolla et al 1998). The correspondent margin and platform top facies are not observable in the Dibona and Tofane area, but have been described in neighboring outcrops at Falzarego Pass (Fig. 1a; Breda et al., 2009b). The microbial character of these platforms is known, however, from allocthonous boulders and carbonate grains in the adjacent basins (Russo et al., 1997; Keim and Schlager, 1999; 2001; Preto, 2012). Except for the toe of slope portion, which is often characterized by megabreccias, they are dominated by microbial boundstones.

Lithozone 2 (L-2)

The boundary between the first and the second lithozone was observed at Tofana di Rozes. It is constituted by a sharp, ~ E dipping by-pass surface on top of the last slope clinoform of L-1. L-2 is constituted by lenticular-shaped carbonate bodies (mounds) mainly made up of microbial boundstone (Figs. 3b, c; 5), interlayered and laterally onlapped by dm thick beds of arenaceous grainstones with bivalves, gastropods, peloids, plant remains (Fig. 6). Mounds are the dominant facies at Tofana di Rozes, where they present maximum size (10-100 m), while arenaceous grainstones prevail at Dibona Hut (Fig. 5; 6). Cm- dm thick beds of calcsiltite and shale are rare at both localities (Fig. 7).

At Dibona Hut, the last part of this lithozone is constituted by a ~ 3 m thick sequence of m-scale beds with a highly erosive base, made up of arenaceous-conglomeratic grainstones (main components are volcanic rock fragments, quartz, molluscs, echinoderms, plant debris and rare amber droplets; Breda et al., 2009b) which testifies the onset of mass flows. These coarse grained beds are overlaid by a 30 m thick clinostratified body (L-2-CLINO in Fig. 4c) which dm-scale beds are essentially made up of arenaceous grainstone (main components are bivalves, gastropods, peloids, plant remains and echinoderms), with plane parallel bed joints. Beds are grouped in bedsets which present foresets dipping ~ 25° toward the E (after correction of tectonic tilt) and topsets progressively lowered toward the E (Fig. 4c). These clinostratified bedsets represent the two-dimensional along-dip cut of a sedimentary body which along-strike geometry is not visible due to exposure bias. As the three dimensional geometry of clinoforms is not observable, it is not possible to actually interpret the sedimentary body. The high dip-angle of the beds and the amplitude of the bedsets constrain the shortlist to two possibilities: a delta (implying an along-strike lobate shape of clinoforms) or a coastal prograding wedge (implying an along-strike rectilinear shape of clinoforms), but a further distinction between them is not possible. The clinostratified body is onlapped by tabular dm to m beds of often dolomitized arenaceous grainstone (L-2-ONLAP in Fig. 4c).

Lithozone 3 (L-3)

This lithozone consists of an alternation of dm to m thick dolostone beds, with peloids, often capped by stromatolitic lamination, sheet cracks and planar fenestrae, and dm-scale calcarenite beds. Both facies are characterized by burrows and by a rooted or karstic horizon at the top of the beds. Over the karstified top of some beds, thin layers of dark clays and shales are present and display roots, plant fragments, amber, pyrite and coal. Rare dm beds of massive arenites were observed and among them the most evident are located in the lower portion of this lithozone. This stacking of facies suggests a peritidal/paralic environment (see interval D of Preto et al. 2003 and interval 1 of Gattolin et al. 2013). Dolostones and grainstones represent the normal peritidal cycles, clays and shales the development of littoral swamps (paralic). Massive arenites are rare episodes of high continental sediment discharge into the basin while some of them represent lags. At Tofana di Rozes, the boundary between L-2 and L-3 is marked by a well developed karstic surface that toward the West interests also L-1 (Fig. 8). At Dibona Hut, L-3 directly overlies L-2-ONLAP and no evidences of karstification have been observed between them.

Lithozone 4 (L-4)

The limit between the third and the fourth lithozone is gradational. Due to the absence of a sharp boundary between them it has been arbitrary placed at the first occurrence of well developed planar cross stratification within the succession. Those sedimentary structures are common in L-4 and were observed in dm thick beds, mainly made up of oolitic-bioclastic calcarenites. Sets of laminae alternately migrating in two opposing directions can be found. Dm-scale beds of fine to medium grained arenite, mainly made up of quartz, chert, feldspar and lithic grains are also observed, with local presence of cm to dm-scale cross stratification, at times migrating in two opposing directions.

Levels of imbricated bivalve shells (Coquina) can be found at the base of calcarenites and arenites. Dm thick beds of calcsiltites to calcarenites with mud interbeds, characterized by the presence of ripples, are common. The most represented grains in this facies are peloids. The general structure of this facies is flaser-bedding to wavy-bedding as a function of variable mud content. Cm- dm thick beds of dark shales and siltites rich in plant remains are locally characterized by the presence of isolated ripples made up of calcarenites, producing lenticular bedding. White wackestone to grey marly wackestone, not showing sedimentary structures, and massive dm beds of mixed carbonate-siliciclastic to pure siliciclastic arenites, were rarely observed. The whole L-4 is often interested by burrows. The facies stacking pattern suggests that L-4 deposited in a subtidal environment. Calcarenites and arenites with planar cross bedding and foresets alternatively migrating in opposing directions, as well as flaser to wavy to lenticular bedding, indicate that the dominant mechanism of sediment transport was reversing tidal currents. Episodes of subaerial exposure are almost absent (see interval 2 of Gattolin et al., 2013 for details).

Lithozone 5 (L-5)

The boundary between L-4 and L-5 is gradational, it has been placed at the complete disappearance of tractional sedimentary structures. L-5 consists of dm to m thick nodular beds of often dolomitized limestones and marly limestones. Ammonoids and conodonts were found at Dibona. Some ammonoids were collected also in the Col dei Bos area, ~ 500 m West of Tofana di Rozes (Preto and Hinnov, 2003; Breda et al., 2009b). Cm to dm beds of gray marls with *Chondrites* and locally with pyrite nodules were locally observed. The absence of tractional sedimentary structures and of evidences of subaerial exposure, together with the nodular bed joints and the fossils content (ammonoids), suggest a completely subtidal origin for this lithozone, deeper than L-4, and a temporary partial starvation of the system (see interval 3 of Gattolin et al., 2013 for details).

Lithozone 6 (L-6)

The sixth lithozone (L-6, Figs. 3c and 4c) consists of ~ 30 m of massive dolostone. Sedimentary structures are obliterated by dolomitization, only ooids are locally recognizable. Observations on the same interval carried out by Gattolin et al. (2013, see their interval 4) on outcrops neighboring the Dibona and Tofane area, reveal the presence of dm to m thick beds of dolostones (Lastoni di Formin; Fig. 1a) and mixed oolitic-siliciclastic arenites (Falzarego Pass, Valparola Pass, Lastoni di Formin; Fig. 1a) with planar cross bedding and herringbone cross bedding. The absence of subaerial exposure surfaces and the presence of planar and herringbone cross bedding suggest that L-6 deposited in a subtidal environment, dominated by tidal currents. The top of L-6 is marked in the whole area by a well developed karstic surface (Fig. 9).

Lithozone 7 (L-7)

This lithozone (L-7; Figs. 3c and 4c) consists of dm thick beds of aphanitic, mottled dolostones alternated to dark clays and represents a marginal marine/paralic environment. L-7 constitutes the basal part of the Travenanzes Formation, a mixed siliciclastic/carbonate succession of alluvial plain to floodbasin to tidal flat environments that deposited during Upper Carnian on a wide, low-relief coastal area (Breda and Preto, 2011).

5. Sequence stratigraphy

The described succession, together with observations made on stratal patterns, depositional geometries and erosional surfaces led to disentangle the sequence stratigraphy of the studied interval. The sequence stratigraphic interpretation of the succession is provided below using the standard terminology of Catuneanu et al. (2009; 2011). As in the previous sequence stratigraphic interpretations of this interval (De Zanche et al., 1993; Gianolla et al., 1998) and according to Vail et al. (1991), the sequence boundary is placed at the base of the falling stage systems tract .

5.1 1st depositional sequence

Highstand systems tract

The pervasively dolomitized clinostratified sedimentary body outcropping at the base of the Tofana di Rozes (L-1; Fig. 3) represents the slope of the last Carnian high-relief carbonate platforms in the Dolomites area (Cassian 2 of De Zanche et al. 1993; Gianolla et al. 1998). In terms of geometry, the toe of slope rapidly advances basinward. The shoreline trajectory, which is marked by the trajectory of the platform margin, is not observable in this outcrop, but it is known that this generation of carbonate platforms always presents a downward-concave prograding shoreline trajectory, suggesting a gradual decrease of the accommodation rate (e.g., Bosellini, 1984; Biddle et al., 1992). This observation enables to interpret the L-1 as an highstand systems tract (Fig. 10; Car 2 HST of De Zanche et al. 1993; Gianolla et al. 1998).

The upper bed joint of the youngest clinoform of L-1 paleoslope is characterized by the presence of a by-pass surface without evident erosion features (e.g., karst). At Tofana di Rozes, L-2 is dominated by carbonate mounds directly overlaying this surface (Fig. 5) which occur along the whole slope length. Here mounds and arenaceous grainstones of facies L-2 fill the accommodation space up the shelf break of the underlying high-relief platform, from which the clinoforms of facies L-1 originate (Fig. 3). This testifies that, during the deposition of L-2, the sea level was still as high as during the deposition of L-1, so that L-2 is still part of the highstand systems tract of the first depositional sequence (Fig. 10). The difference in the abundance of carbonate mounds vs. arenaceous grainstones observed in L-2 between Tofana di Rozes and Dibona Hut outcrops (Figs. 5;

6) is due to their different paleotopographic location. Tofana lies on the high paleo-slope of the Cassian platform, while Dibona was closer to the basin depocenter (Gattolin et al. 2013).

5.2 2nd depositional sequence

Falling stage systems tract

The ~ 3 m thick coarse grained interval found at the top of L-2 and representing the onset of mass flow deposits, is interpreted as the beginning of the sea level fall and consequent increase of sediment discharge in the basin. A sharp increase in sediment grain size is testified also at the coeval outcrop of Borca di Cadore and in the whole Cadore area (Neri et al., 2007; Breda et al., 2009b). The basal surface of forced regression (Hunt and Tucker, 1992) can be placed at the base of this coarse grained interval (Fig. 10). At Tofana di Rozes, this surface coincides with a well developed subaerial exposure surface, showing karst (Fig. 8). The clinostratified bedsets, made up of arenaceous grainstones, which constitute the lower portion of the cliff observed at Dibona Hut (L-2-CLINO; Fig. 4), irrespective of their interpretation as a delta body or a coastal prograding wedge, record a fall of the sea level (e.g., Massari et al., 1999; Hernández-Molina et al., 2000; Tropeano and Sabato 2000; Pomar and Tropeano 2001; Massari and D'Alessandro 2010). The offlapping geometry evidences an overall progradation of the shoreline along a descending, low angle trajectory. Consequently, together with the last coarse grained portion of the L-2, the L-2-CLINO represents the falling stage system tract of the second depositional sequence (Fig. 10; Car 3 of De Zanche et al. 1993; Gianolla et al. 1998).The stair-stepping surface at the top of the clinostratified sedimentary body (L-2-CLINO; Fig. 4) represents the correlative conformity (*sensu* Hunt and Tucker, 1992, Fig. 10). Being in a paleotopographical higher position with respect to Dibona (Gattolin et al. 2013), the falling stage system tract is not recorded at Tofana di Rozes. Instead, a well developed karst surface is produced by subaerial exposure on top of L-2 (Figs. 8, 10). More to the West, e.g., at Falzarego Pass (Fig. 1a), this karstified surface merges with the sequence boundary and lies on top of the platform interior facies of the older Cassian platform, a time equivalent of facies L-1 (Fig. 10).

Lowstand systems tract

At Dibona Hut, above the correlative conformity (*sensu* Hunt and Tucker, 1992), the dolomitized arenaceous grainstones beds (L-2-ONLAP; Fig. 4) onlapping the clinoforms represent the base of the lowstand system tract (Fig. 10). This interval, coherently with the paleotopography of the area, deposited only at Dibona Hut which was in a more basinal setting than Tofana di Rozes.

Transgressive systems tract

At Dibona Hut, the basal portion of L-3 often displays massive arenites with basal lags, which lie on the kastified top of the underlying peritidal cycles and evolve into the subtidal portion of the following cycle. These are thus interpreted as transgressive lags formed on a formerly emerged coastal area and are evidence of a transgressive ravinement surface (Cattaneo and Steel, 2003). The L-3 marks a sharp change in lithology with respect to the pervasively dolomitized L-2 ONLAP (see Fig. 4c) and is characterized by shallow water peritidal-paralic deposits of tidal-flat/lagoon, cyclically subjected to subaerial exposure and soil development (interval D of Preto and Hinnov, 2003; interval 1 of Gattolin et al., 2013). At Tofana di Rozes, L-3 directly overlies in disconformity the karstic surface on top of L-2 and L-1 (i.e. the sequence boundary; Figs. 3; 10). The facies association observed in L-4 is typical of a mainly subtidal environment dominated by tidal currents and therefore identifies a marked deepening of the depositional environment with respect to L-3 (interval E-F of Preto and Hinnov 2003; interval 2 of Gattolin et al. 2013). Deepening takes on in L-5, which finer grain-size and nodular bed joints testify the deepest environment of the entire depositional sequence (interval 3 of Gattolin et al. 2013). In this work, L-3 is attributed to the transgrassive systems tract because the lag deposits at the base of peritidal cycles are interpreted as minor ravinement surfaces at the beginning of a slow transgression. Thus, Lithozones L-3, L-4 and L-5 represent the transgressive system tract of the second depositional sequence (Fig. 10; Car 3 of De Zanche et al. 1993; Gianolla et al. 1998). Alternatively, these peritidal cycles may be seen as representing tidal-flat and lagoon environments protected by a prograding shoal barrier. In this alternative interpretation, L-3 belongs to the lowstand systems tract and the transgressive systems tract is made up of L-4 and L-5. The maximum flooding surface (Frazier, 1974; Posamentier et al., 1988) is likely placed within L-5 as confirmed by the occurrence of open marine fossils (ammonoids and conodonts; Preto and Hinnov, 2003) and the absence of indicators of high hydraulic energy, implying sedimentation below the wave base.

Highstand systems tract

Above, L-6 is coarser grained and characterized by well developed planar to herringbone cross bedding, thus recording a return to shallower conditions with respect to L-5. The observed facies association suggests a subtidal, tide dominated sedimentary environment similar to that of facies association L-4. L-6 is observed in the whole Dolomites area (interval H of Preto and Hinnov, 2003; Neri et al., 2007) and testifies for an important shift of the coast line toward the basins (interval 4 of Gattolin et al. 2013). This lithozone constitutes the HST of the second depositional sequence (Fig. 10; Car 3 of De Zanche et al. 1993; Gianolla et al. 1998).

The well developed karstic surface on top of L-6 in the study area is observed at a regional scale in the Dolomites and beyond, and is the subaerial unconformity that marks the boundary with the subsequent depositional sequence (Fig. 9; Car 4 of De Zanche et al. 1993; Gianolla et al. 1998).

Above it, an abrupt landward shift in facies is observed, with the deposition of the coastal sediments of the Travenanzes Formation, here represented by dm thick beds of aphanitic and mottled dolostones alternated with dark clays (L-7) and suggesting marginal/paralic environments (Breda and Preto, 2011).

6. Discussion

6.1 Role of 3D modeling in the study of depositional geometries

During the last three decades, several interpretations were proposed for the stratigraphic succession outcropping at Dibona Hut, and in particular for the clinostratified body of L-2-CLINO (Fig. 4). Bosellini et al. (1982) and later Doglioni and Carminati (2008) interpreted this body as a tectonically tilted block, bounded by an angular unconformity at its top. Preto and Hinnov (2003) instead interpreted this sedimentary body as a prograding shoal barrier with a tabular geometry. The inaccessibility of this outcrop is the main cause for the lack of an unambiguous interpretation which was carried out on the basis of local observations of sedimentary facies coupled to panoramic views (in the field or on photographs), which are essentially bi-dimensional, and thus affected by perspective distortion. Only the use of three dimensional acquisition and modeling techniques allowed to retrieve quantitative information and observe the true geometry of the outcrop (see in particular L-2-CLINO and L-2-ONLAP in § 4; Fig. 4). The stair stepping surface at the top of L-2-CLINO, which was a key feature to identify and define the falling stage system tract of the second depositional sequence, could only be recognized and traced on the remote-sensed 3D geological model of the outcrop (Fig. 4). Differently from the previous sequence stratigraphic interpretation (De Zanche et al., 1993; Gianolla et al., 1998), the lower portion of the Heiligkreuz Formation is now interpreted to be the last part of the highstand system tract (L-2) of the first depositional sequence (Fig. 10; Car 2 in De Zanche et al., 1993; Gianolla et al., 1998) and not as the lowstand system tract of the second depositional sequence (Car 3 in De Zanche et al., 1993; Gianolla et al., 1998). This is confirmed by the observations carried out from the 3D model of the Tofana di Rozes outcrop. Here, the maximum altitude reached by the mounds of facies L-2, recorded by gps-aided mapping, is the same of the shelf break of the underlying high-relief platform once the original depositional geometry is restored in the 3D environment of the geological model. This implies that during the growth of mounds the sea level was still as high as during the development of the underlying high-relief platform, and so the L-2 s.s. is part of the highstand of the first depositional sequence.

Photogrammetry and terrestrial laser scanning are methods which allow the rapid acquisition of field data on a variety of scales, from a metre-scale outcrop to the km scale of a mountain slope. These data can be used as the base for accurate three-dimensional models of sedimentary bodies. Here we have shown that not only 3D acquisition techniques can speed-up the field work and increase accuracy, but also provide the means for interpretations that would be otherwise impossible on inaccessible or exceedingly wide outcrops. In this case, the definition of an accurate sequence stratigraphy across the Carnian Pluvial Event in the Dolomites was only possible using the 3D reconstruction of the outcrops.

6.2 What triggered the platform demise?

The demise of the Carnian high-relief carbonate platforms (L-1; the Cassian 2 of De Zanche et al. 1993; Gianolla et al. 1998) was attributed by the previous authors (De Zanche et al., 1993; Gianolla et al., 1998) to a subaerial exposure, and a sequence boundary (*sensu* Vail et al., 1991) was placed just above the demised platform and its slopes (base of Car 3 sequence in De Zanche et al., 1993; Gianolla et al., 1998). This work highlighted that the sea level fall occurred at a later stage with respect to the high-relief platform demise. After the Cassian platform demise, small, mainly microbial mounds nucleated all along the abandoned slopes (cf. also Keim et al., 2006). The nucleation of mounds was probably possible because of the shut-down of the underlying high-relief platform (Fig. 5) and interrupted the slope-shedding (Kenter, 1990; Keim et al. 2006). Boulders and other platform-derived sediments, typical of the Cassian platforms (e.g., Reijmer, 1998; Preto, 2012), are in fact not found associated with mounds of lithozone L-2. Mounds are rather interfingered with arenaceous grainstones made up of prevailing skeletal grains (Figs. 6; 7), which are only a minor component in the high-relief Cassian platforms (Kenter 1990, Russo et al. 1997, Reijmer 1998; Keim and Schlager 1999, 2001). These observations are confirmed at Lavarella by Keim et al. (2001, 2006; see Fig. 1a for location). Microbial carbonate mounds (Fig. 5) can be interpreted as relics of the Cassian Microbial factory (*sensu* Schlager 2003) that try to hold up the crisis. They are tightly interfingered with arenaceous grainstones that highlight the onset of a important siliciclastic input and of a different carbonate factory producing mostly loose skeletal grains (Figs. 6, 7). At Tofana di Rozes, this unit onlaps the Cassian platform slope up to the shelf break (Fig. 3) and is capped by the same karstic surface found at the top of the Cassian platform (Fig. 8), thus, the main episode of sea level fall is subsequent to the high-relief carbonate platform demise and to the establishment of mounds on the abandoned slope. Sea level fall thus did not trigger the crisis of the high-relief microbial platform.

In Late Triassic high-relief carbonate platforms of the Dolomites (Cassian *sensu* De Zanche et al. 1993), the carbonate production was dominated by microbialites (Russo et al., 1997; Keim and Schlager 1999, 2001). Being independent from light availability, microbialites are less influenced by sea level variations with respect to metazoan reefs. Microbial platforms are usually characterized by a carbonate production zone spread from shallow to deep waters (down to 200-300 m depth; Kenter 1990; Della Porta et al. 2003, 2004; Kenter et al. 2005; Marangon et al. 2011). Data from the geological record demonstrate that carbonate production rates of healthy Tropical and Microbial carbonate factories are high enough to keep the pace of eustatic variations (Schlager 1981; 1999a,b; 2003), and in fact the demise of a carbonate platform is generally caused by pulses of tectonic subsidence or by climatic events (Schlager 1981). In the Dolomites, a slow-down of subsidence is observed during the development of the last generations of Carnian high-relief platforms (Bosellini 1984; Gianolla and Jacquin, 1998; Bosellini et al. 2003; Stefani et al., 2010). The following depositional sequence (second depositional sequence of this work) testifies the complete filling of sedimentary basins and a flattening of the paleotopography (Fig. 2), so that important subsidence pulses can be excluded. The most probable trigger for the demise of Cassian platforms is thus an episode of climatic change, and specifically the onset of the Carnian Pluvial Event (CPE of Simms and Ruffell 1989; Preto et al. 2010; Dal Corso et al. 2012). The negative carbon isotope excursion that defines the CPE was identified in the Milieres section (Dal Corso et al., 2012), near Rifugio Dibona, and can be traced in the demise surface at the top of the high-relief microbial platform of Tofane. Being a humid period, the CPE determined an increase of hinterland weathering and rivers runoff, reflected in an important input of siliciclastics to the basins. This should have been coupled with an increase in available nutrients which triggered the change of carbonate factory (e.g., Hallock and Schlager 1986; Mutti and Hallock, 2003; Pomar et al., 2004; Schlager, 2005; Keim et al., 2006).

At Dibona Hut, mounds were found only under the mass flow deposits and the clinostratified body representing the falling stage systems tract. Above the falling stage systems tract, microbial mounds disappear completely. The demise of the lower Carnian Cassian platforms of the Dolomites was thus a two-step process, in which a first climate and/or oceanographic event (the CPE) killed the km-scale microbial platforms, and then a sea level drop led to the definitive efface of the microbial carbonates. Apart from exposing the shelf, sea level fall may have further stressed the microbial carbonate systems by increasing the siliciclastic and nutrient input.

6.3 Comparison with Picco di Vallandro and the ecological control on platform geometry

The change in depositional geometry described in the previous paragraphs is documented also in a few more outcrops of the Dolomites, as the Lavarella slope (Keim et al., 2001; 2006), the eastern flanks of the Sella massif at Passo Campolongo (Keim et al., 2001), and Picco di Vallandro

(Rudolph et al., 1989; Biddle et al., 1992). At la Varella and Passo Campolongo unfavourable outcrop conditions prevent a complete reconstruction of this interval, while at Picco di Vallandro, depositional geometries of the early Carnian carbonate platform were carefully reconstructed by Rudolph et al. (1989) and Biddle et al. (1992) (Fig. 11A, B) that recognized repeated episodes of progradation and retrogradation of the platform. They interpreted a sedimentary body of massive dolomite capping the basinal sediments of the San Cassiano Formation as the last episode of strong progradation of the clinostratified high-relief early Carnian platform. An alternative interpretation can be proposed on the basis of the work of Russo et al. (1991) and our own observations. In that view the massive dolomite body lies above a facies association made up of small microbial mounds, skeletal and oolitic grainstones and dark marls (Member A of Russo et al., 1991) which is perfectly comparable to the here described L-2 (§ 4). Since clinoforms are not visible in the field we suggest that the last phase of progradation identified by Rudolph et al. (1989) and Biddle et al. (1992) at Picco di Vallandro is not the last progradation phase of the high-relief platform, but rather represents a low-angle carbonate system bearing small microbial mounds that follows its demise, in analogy to L-2 (§ 4). This unit filled the residual basin initially onlapping the slopes of the high-relief platform at Picco di Vallandro after its demise (Member A of Russo et al., 1991). In the impossibility of identifying internal bedding surfaces, it was interpreted as a strong progradation phase (Rudolph et al., 1989; Biddle et al., 1992). This evolution can be also interpreted in terms of ecological vs. hydrodynamic accommodation (Pomar, 2001; Pomar et al., 2004).The early Carnian high-relief microbial platform built up to sea level, and its steep slopes determined the formation of a well defined basin. During this phase, accommodation can be interpreted as "ecological" on the platform top. After the demise of this platform, however, a mixed sedimentation of shale-sand and loose carbonate grains took place. Being not early cemented, these sediments settled below the wave base, in accordance with a deeper, hydrodynamic equilibrium profile (Pomar, 2001) and thus infilled the residual basins from their bottom. The carbonate body that immediately followed the demise sit on this infilling sequence and extended basinward much more rapidly, and with much less inclined internal bedding, than the underlying platform clinoforms.

In sum, sedimentological evidences coupled with changes in the geometry of carbonate bodies recognized in the Cortina area and their comparison to Picco di Vallandro enable to reinterpret the patterns of progradation, basin infilling and ramp development (Fig. 12) at the end of the early Carnian of the Dolomites (Figs. 11; 12) and link them to climatic forcing rather than to changes in sea-level.

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References

Biddle, K.T., Schlager, W., Rudolph, K.W., Bush, T.L., 1992. Seismic model of a progradational carbonate platform, Picco di Vallandro, the Dolomites, Northern Italy. AAPG bulletin 76, 14 -30.

Blendinger, W., 1986. Isolated stationary carbonate platforms: the Middle Triassic (Ladinian) of the Marmolada area, Dolomites, Italy. Sedimentology 33, 159–183.

Blendinger, W., Brack, P., Norborg, A.K., Wulff-Pedersen, E., 2004. Three-dimensional modelling of an isolated carbonate buildup (Triassic, Dolomites, Italy). Sedimentology 51, 297–314.

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

Bosellini, A., dal Cin, R., Gradenigo, A., 1978. Depositi litorali raibliani nella zona di Passo Falzarego (Dolomiti Centrali). Annali dell'Università di Ferrara 5, 223-238.

Bosellini, A., Gianolla, P., Stefani, M., 2003. Geology of the Dolomites. Episodes 26, 181-185.

Bosellini, A., Masetti, D., Neri, C., 1982. La geologia del Passo del Falzarego. In: Castellarin, A., Vai, G.B. (Eds.), Guida alla Geologia del Sudalpino Centro-Orientale. Guide geologiche regionali della Società Geologica Italiana, Bologna, pp. 273-278.

Brack, P., Rieber, H., Mundil, R., Blendinger, W., Maurer, F., 2007. Geometry and chronology of growth and drowning of Middle triassic carbonate platforms (Cernera and Bivera/Clapsavon) in the southern Alps (northern Italy). Swiss Journal of Geosciences 100, 327–347.

Brandner, R., 1984. Meeresspiegelschwankungen und Tektonik in der Trias der NW-Tethys. Jahrbuch der Geologischen Bundesanstalt 126, 435–475.

Breda, A., Mellere, D., Massari, F., Asioli, A., 2009a. Vertically stacked Gilbert-type deltas of Ventimiglia (NW Italy): the Pliocene record of an overfilled incised valley. Sedimentary Geology 219, 58-76.

Breda, A., Preto, N., 2011. Anatomy of an Upper Triassic continental to marginal-marine system: the mixed siliciclastic–carbonate Travenanzes Formation (Dolomites, Northern Italy). Sedimentology 58, 1613-1647.

Breda, A., Preto, N., Roghi, G., Furin, S., Meneguolo, R., Ragazzi, E., Gianolla, P., 2009b. The Carnian Pluvial Event in the Tofane area (Cortina d'Ampezzo, Dolomites, Italy). Geo. Alp 6, 80-115.

Broglio Loriga, C., Cirilli, S., De Zanche, V., Di Bari, D., Gianolla, P., Laghi, G.F., Lowrie, W., Manfrin, S., Mastandrea, A., Mietto, P., Muttoni, G., Neri, C., Posenato, R., Reichichi, M., Rettori, R., Roghi, G., 1999. The Prati di Stuores/Stuore Wiesen Section (Dolomites, Italy): . global stratotype section and point for the base of the Carnian stage. Rivista Italiana di Paleontologia e Stratigrafia 105, 37–78.

Cantalamessa, G., Di Celma, C., Ragaini, L. 2005. Sequence stratigraphy of the Punta Ballena Member of the Jama Formation (Early Pleistocene, Ecuador): insights from integrated sedimentologic, taphonomic and paleoecologic analysis of molluscan shell concentrations. Palaeogeography, Palaeoclimatology, Palaeoecology 216, 1-25.

Cattaneo, A., Steel, R.J., 2003. Transgressive deposits: a review of their variability. Earth-Science Reviews 62, 187-228.

Catuneanu, O., 2006. Principles of Sequence Stratigraphy. Elsevier, Amsterdam. 375 pp.

Catuneanu, O., Abreu, V., Bhattacharya, J.P., Blum, M.D., Dalrymple, R.W., Eriksson, P.G., Fielding, C.R., Fisher, W.L., Galloway, W.E., Gibling, M.R., Giles, K.A., Holbrook, J.M., Jordan, R., Kendall, C.G.St.C, Macurda, B., Martinsen, O.J., Miall, A.D., Neal, J.E., Nummedal, D., Pomar, L., Posamentier, H.W., Pratt, B.R., Sarg, J.F., Shanley, K.W., Steel, R.J., Strasser, A., Tucker, M.E, Winker, C., (2009). Towards the standardization of sequence stratigraphy. Earth-Science Reviews, 92, 1-33.

Catuneanu, O., Galloway, W. E., Kendall, C. G., Miall, A. D., Posamentier, H. W., Strasser, A., Tucker, M. E., 2011. Sequence stratigraphy: methodology and nomenclature. Newsletters on Stratigraphy 44, 173-245.

Catuneanu, O., Hancox, P.J., Cairncross, B., Rubidge, B.S., 2002. Foredeep submarine fans and forebulge deltas: orogenic off-loading in the underfilled Karoo Basin. Journal of African Earth Sciences 35, 489-502.

Dal Corso, J., Mietto, P., Newton, R.J., Pancost, R.D., Preto, N., Roghi, G., Wignall, P.B., 2012. Discovery of a major negative $\delta^{13}C$ spike in the Carnian (Late Triassic) linked to the eruption of Wrangellia flood basalts. Geology 40, 79-82.

Della Porta, G., Kenter, J.A.M., Bahamonde, J.R., 2004. Depositional facies and stratal geometry of an Upper Carboniferous prograding and aggrading high-relief carbonate platform (Cantabrian Mountains, N Spain). Sedimentology 51, 267–295.

Della Porta, G., Kenter, J.A.M., Bahamonde, J.R., Immenhauser, A., Villa, E., 2003. Microbial boundstone dominated carbonate slope (Upper Carboniferous, N Spain):microfacies, lithofacies distribution and stratal geometry. Facies 49, 175–207.

Dercourt, J., Ricou, L.E., Vrielynck, B., 1993. Atlas Tethys Palaeoenvironmental Maps. Explanatory Notes. Gauthier-Villars, Paris, 307 pp.

De Zanche, V., Franzin, A., Gianolla, P., Mietto, P., Siorpaes, C., 1992. The Piz da Peres Section (Valdaora-Olang, Pusteria Valley, Italy): a reappraisal of the Anisian stratigraphy in the Dolomites. Eclogae Geologicae Helvetiae 85, 127-143.

De Zanche, V., Gianolla, P., Manfrin, S., Mietto, P., Roghi, G., 1995. A Middle Triassic backstepping carbonate platform in the Dolomites (Italy): sequence stratigraphy and biochronostratigraphy. Memorie di Scienze Geologiche 47, 135– 155.

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

Doglioni, C., Carminati, E., 2008. Structural style & Dolomites field trip. Memorie descrittive della carta geologica d'Italia volume LXXXII. APAT, Roma, 295 pp.

Flügel, E., 2002. Triassic reef patterns. In: Kiessling, W., Flugel, E., Golonka, J. (Eds.), Phanerozoic Reef Patterns. SEPM Special Publication 72, pp. 391–463.

Flügel, E., 2004. Microfacies of carbonate rocks. Springer-Verlag, Berlin-Heidelberg (Germany), 976 pp.

Föllmi, K.B., Godet, A., 2013. Paleoceanography of Lower Cretaceous Alpine platform carbonates. Sedimentology 60, 131–151.

Frazier, D.E., 1974. Depositional episodes: their relationship to the Quaternary stra-tigraphic framework in the northwestern portion of the Gulf Basin. University of Texas at Austin, Bureau of Economic Geology. Geological Circular, vol. 4, 1. 28 pp.

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

Galloway, W.E., 2008. Depositional evolution of the Gulf of Mexico Sedimentary Basin. In: Miall, A.D. (Ed.), The Sedimentary Basins of the United States and Canada: Sedimentary Basins of the World, v. 5, K. J. Hsu, Series Editor, Elsevier Science Amsterdam, pp. 505–550.

Galloway, W.E., Williams, T.A., 1991. Sediment accumulation rates in time and space: Paleogene genetic stratigraphic sequences of the northwestern Gulf of Mexico basin. Geology 19, 986-989.

Gattolin, G., Breda, A., Preto. N., 2013. Demise of Late Triassic carbonate platforms triggered the onset of a tide-dominated depositional system in the Dolomites, Northern Italy. Sedimentary Geology 297, 38-49.

Gianolla, P., De Zanche, V., Mietto, P., 1998. Triassic sequence stratigraphy in the Southern Alps (northern Italy): definition of sequences and basin evolution. In: De Graciansky, P.C., Hardenbol, J., Jacquin, T., and Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM Special Publication 60, pp. 719-748.

Gianolla, P., Jacquin, T., 1998. Triassic sequence stratigraphic framework of western European basins. In: De Graciansky, P.C., Hardenbol, J., Jacquin, T., and Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM Special Publication

60, pp. 643–650.

Godet, A., Föllmi, K.B., Spangenberg, J.E., Bodin. S., Vermeulen, J., Adatte, T., Bonvallet, L., Arnaud, H., 2013. Deciphering the message of Early Cretaceous drowning surfaces from the Helvetic Alps: What can be learnt from platform to basin correlations? Sedimentology 60, 152–173.

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

Helland-Hansen, W., 1992. Geometry and facies of Tertiary clinothems, Spitsbergen. Sedimentology 39, 1013-1029.

Hernández-Molina, F. J., Fernández-Salas, L. M., Lobo, F., Somoza, L., Díaz-del-Río, V., Dias, J. A., 2000. The infralittoral prograding wedge: a new large-scale progradational sedimentary body in shallow marine environments. Geo-Marine Letters 20, 109-117.

Hornung, T., Krystyn, L., Brandner, R., 2007a. A Tethys-wide mid-Carnian (Upper Triassic) carbonate productivity decline: evidence for the Alpine Reingraben Event from Spiti (Indian Himalaya)? Journal of Asian Earth Sciences 30, 285–302.

Hornung, T., Brandner, R., Krystyn, L., Joachimski, M., Keim, L., 2007b. Multistratigraphic constraints on the NW Tethyan “Carnian crisis”. In: Lucas, S.G., Spielmann, J.A. (Eds.), The Global Triassic: New Mexico Museum of Natural History and Science Bulletin 41, pp. 59–67.

Jenkyns, H.C., 1985. The Early Toarcian and Cenomanian-Turonian anoxic events in Europe: comparisons and contrasts. Geologische Rundschau 74, 505–518.

Jenkyns, H.C., 1991. Impact of Cretaceous sea level rise and anoxic events on the Mesozoic carbonate platform of Yougoslavia. AAPG Bulletin 75, 1007–1017.

Keim, L., Brandner, R., Krystyn, L., Mette, W., 2001. Termination of carbonate slope progradation: an example from the Carnian of the Dolomites, Northern Italy. Sedimentary Geology 143, 303–323.

Keim, L., Schlager, W., 1999. Automicrite facies on steep slopes (Triassic, Dolomites, Italy). Facies 41, 15–25.

Keim, L., Schlager, W., 2001. Quantitative compositional analysis of a Triassic carbonate platform (Southern Alps, Italy). Sedimentary Geology 139, 261–283.

Keim, L., Spötl, C., Brandner, R., 2006. The aftermath of the Carnian carbonate platform demise: a basinal perspective (Dolomites, Southern Alps). Sedimentology 53, 361–386.

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

Kenter, J.A.M., Harris, P.M., Della Porta, G., 2005. Steep microbial boundstonedominated platform margins - examples and implications. Sedimentary Geology 178, 5-30.

Léonide, P., Floquet, M., Durlet, C., Baudin, F., Pittet, B., Lécuyer, C., 2012. Drowning of a carbonate platform as a precursor stage of the Early Toarcian global anoxic event (Southern Provence sub-Basin, South-east France). Sedimentology 59, 156–184.

Marangon, A., Gattolin, G., Della Porta, G., Preto, N., 2011. The Latemar: A flat-topped, steep fronted platform dominated by microbialites and synsedimentary cements. Sedimentary Geology 240, 97–114.

Masetti, D., Neri, C., 1980. L'Anisico della Val di Fassa (Dolomiti occidentali): sedimentologia e paleogeografia. Annali Università Ferrara 9, 1–19.

Massari, F., D'Alessandro, A., 2010. Icehouse, cool-water carbonate ramps: the case of the Upper Pliocene Capodarso Fm (Sicily): role of trace fossils in the reconstruction of growth stages of prograding wedges. Facies 56, 47-58.

Massari, F., Sgavetti, M., Rio, D., D'alessandro, A., Prosser, G., 1999. Composite sedimentary record of falling stages of Pleistocene glacio-eustatic cycles in a shelf setting (Crotone basin, south Italy). Sedimentary Geology 127, 85-110.

Mateu-Vicens, G., Pomar, L., Tropeano, M., 2008. Architectural complexity of a carbonate transgressive systems tract induced by basement physiography. Sedimentology 55, 1815-1848.

Mellere, D., Steel, R., 1995. Variability of lowstand wedges and their distinction from forced-regressive wedges in the Mesaverde Group, southeast Wyoming. Geology 23, 803-806.

Miall, A. D., Arush, M., 2001. The Castlegate Sandstone of the Book Cliffs, Utah: sequence stratigraphy, paleogeography, and tectonic controls. Journal of Sedimentary Research 71, 537-548.

Miall, A. D., Catuneanu, O., Vakarelov, B., Post, R., 2008. The Western Interior Basin. In: Miall, A.D. (Eds.), The Sedimentary Basins of the United States and Canada: Sedimentary basins of the World, v. 5, K. J. Hsü, Series Editor, Elsevier Science, Amsterdam, pp. 329–362.

Mutti, M., Bernouilli, D., Stille, P., 1997. Temperate carbonate platform drowning linked to Miocene oceanographic events: Maiella platform margin, Italy. Terra Nova 9, 122–125.

Mutti, M., Droxler, A.W., Cunningham, A.D., 2005. Evolution of the Northern Nicaragua Rise during the Oligocene-Miocene: drowning by environmental factors. Sedimentary Geology 175, 237–258.

Mutti, M., Hallock, P., 2003. Carbonate systems along nutrients and temperature gradients: some sedimentological and geochemical constraints. International Journal of Earth Sciences (Geologische Rundschau) 92, 465–475.

Muttoni, G., Kent, D.V., Channell, J.E., 1996. Evolution of Pangea: paleomagnetic constraints from the Southern Alps, Italy. Earth and Planetary Science Letters 140, 97-112.

Nakada, R., Ogawa, K., Suzuki, N., Takahashi, S., Takahashi, Y., 2014. Late Triassic compositional changes of aeolian dusts in the pelagic Panthalassa: Response to the continental climatic change, Palaeogeography, Palaeoclimatology, Palaeoecology 393, 61-75.

Neri, C., Gianolla, P., Furlanis, S., Caputo, R., Bosellini, A., 2007. Note illustrative della Carta Geologica d'Italia alla scala 1:50000, foglio 029 Cortina d'Ampezzo. APAT, Roma, 200 pp.

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

Pasquier, J.B., Strasser, A., 1997. Platform-to-basin correlation by high-resolution sequence stratigraphy and cyclostratigraphy (Berriasian, Switzerland and France). Sedimentology 44, 1071-1092.

Pomar, L., 2001. Ecological control of sedimentary accommodation: evolution from a carbonate ramp to rimmed shelf, Upper Miocene, Balearic Islands. Palaeogeography, Palaeoclimatology, Palaeoecology 175, 249-272.

Pomar, L., Brandano, M., Westphal, H., 2004. Environmental factors influencing skeletal-grain sediment associations: a critical review of Miocene examples from the Western-Mediterranean. Sedimentology 51, 627–651

Pomar, L., Tropeano, M., 2001. The Calcarenite di Gravina Formation in Matera (southern Italy): new insights for coarse-grained, large-scale, cross-bedded bodies encased in offshore deposits. AAPG bulletin 85, 661-689.

Posamentier, H.W., Jervey, M.T., Vail, P.R., 1988. Eustatic controls on clastic deposition I —conceptual framework. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.), Sea Level Changes—An Integrated Approach. Special Publication, vol. 42. Society of Economic Paleon-tologists and Mineralogists (SEPM), pp. 110–124.

Preto, N., 2012. Petrology of carbonate beds from the stratotype of the Carnian (Stuores Wisen section, Dolomites, Italy): the contribution of platform-derived microbialites. Geo. Alp 9, 12-29.

Preto, N., Franceschi, M., Gattolin, G., Massironi, M., Riva, A., Gramigna, P., Bertoldi, L., Nardon, S., 2011. The Latemar: a Middle Triassic polygonal fault-block platform controlled by synsedimentary tectonics. Sedimentary Geology 234, 1–18.

Preto, N., Hinnov, L.A., 2003. Unraveling the origin of carbonate platform cyclothems in the Upper Triassic Durrenstein Formation (Dolomites, Italy). Journal of Sedimentary Research 73, 774-789.

Preto, N., Kustatscher, E., Wignall, P.B., 2010. Triassic climates - State of the art and perspectives. Palaeogeography, Palaeoclimatology, Palaeoecology 290, 1-10.

Preto, N., Spötl, C., Mietto, P., Gianolla, P., Riva, A., Manfrin, S., 2005. Aragonite dissolution, sedimentation rates and carbon isotopes in deep-water hemipelagites (Livinallongo Formation, Middle Triassic, northern Italy). Sedimentary Geology 181, 173-194.

Prochnow, S.J., Nordt, L.C., Atchley, S.C., Hudec, M.R., 2006. Multi-proxy paleosol evidence for Middle and Late Triassic climate trends in eastern Utah. Palaeogeography, Palaeoclimatology, Palaeoecology 232, 53–72.

Reijmer, J.J.G., 1998. Compositional variations during phases of progradation and retrogradation of a Triassic carbonate platform (Picco di Vallandro/Durrenstein, dolomites, Italy). Geologische Rundschau 87, 436–448.

Rigo, M., Joachimski, M.M., 2010. Palaeoecology of Late Triassic conodonts: Constraints from oxygen isotopes in biogenic apatite. Acta Palaeontologica Polonica 55, 471-478.

Roghi, G., 2004. Palynological investigations in the Carnian of the Cave del Predil area (Julian Alps, NE Italy). Review of Palaeobotany and Palynology 132, 1–35.

Rudolph, K.W., Schlager, W., Biddle, K.T., 1989. Seismic models of a carbonate foreslope-to-basin transition, Picco di Vallandro, Dolomite Alps, northern Italy. Geology 17, 453-456.

Rüffer, T., Zühlke, R., 1995. Sequence stratigraphy and sea-level changes in the Early to Middle Triassic of the Alps: a global comparison. In: Haq, B.U. (Ed.), Sequence Stratigraphy and Depositional Response to Eustatic, Tectonic and Climatic Forcing. Kluwer, Amsterdam, pp. 161–207.

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

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

Schlager, W., 1981. The paradox of drowned reefs and carbonate platforms. Geological Society of America Bulletin 92, 197-211.

Schlager, W., 1991. Depositional bias and environmental change - important factors in sequence stratigraphy. Sedimentary Geology 70, 109-130.

Schlager, W., 1993. Accommodation and supply - a dual control on stratigraphic sequences. Sedimentary Geology 86, 111-136.

Schlager, W., 1999a. Scaling of sedimentation rates and drowning of reefs and carbonate platforms. Geology 27, 183–6.

Schlager, W., 1999b. Type 3 sequence boundarbies. In: Harris, P.M., Sallet, A.H., Simo, T. (Eds.), Advances in Carbonate Sequence Stratigraphy: Application to Reservoirs, Outcrops and Models. SEPM Special Publication 63, 35–45.

Schlager, W., 2003. Benthic carbonate factories of the Phanerozoic. International Journal of Earth Sciences 92, 445-464.

Schlager, W., 2005. Carbonate sedimentology and sequence stratigraphy. SEPM concept in sedimentology and paleontology 8, 200 pp.

Schlager, W., Reijmer, J.J.G., Droxler, A., 1994. Highstand shedding of carbonate platforms. Journal of Sedimentary Research 64, 270-281.

Schlager, W., Schöllnberger, W., 1974. Das Prinzip stratigraphischer Wenden in der Schichtfolge der Nördlichen Kalkalpen. Mitteilungen. Österreichische Geologische Gesellschaft 66–67, 165–193.

Simms, M.J., Ruffell, A.H., 1989. Synchroneity of climatic change and extinctions in the Late Triassic. Geology 17, 265-268.

Simms, M.J., Ruffell, A.H., 1990. Climatic and biotic change in the late Triassic. Journal of the Geological Society of London 147, 321–327.

Simms, M.J., Ruffel, A.H., Johnson, L.A., 1995. Biotic and climatic changes in the Carnian (Triassic) of Europe and adjacent areas. In: Fraser, N.C., Sues, H.D. (Eds.), In the Shadow of the Dinosaurs: Early Mesozoic Tetrapods. Cambridge University Press, pp. 352–365.

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

Tropeano, M., Sabato, L., 2000. Response of Plio-Pleistocene mixed bioclastic-lithoclastic temperate-water carbonate systems to forced regressions: the Calcarenite di Gravina Formation, Puglia, SE Italy. In: Hunt, D., Gawthorpe, R.L. (Eds.), Sedimentary responses to forced regressions, Geological Society, London, Special Publications 172, 217-243.

Tucker, ME., Wright, VP., 1990. Carbonate sedimentology. Blackwell, Oxford, 492 pp.

Vail P.R., Audemard, F., Bowman, S.A, Eisner, P.N., Perez Cruz, C., 1991. The stratigraphic signatures of tectonics, eustasy and sedimentology-an overview. In: G. Einsele, G., Ricken, W., Seilacher, A. (Eds.), Cycles and events in stratigraphy, Springer-Verlag, Berlin-Heidelberg, pp. 617-659.

Weissert, H., Lini, A., Föllmi, K.B., Kuhn, O., 1998. Correlation of Early Cretaceous carbon isotope stratigraphy and platform drowning events: a possible link? Palaeogeography, Palaeoclimatology, Palaeoecology 137, 189–203.

Wilson, P.A., Jenkyns, H.C., Elderfield, H., Larson, R.L., 1998. The paradox of drowned carbonate platforms and the origin of Cretaceous Pacific guyots. Nature 392, 889–94.

Ziegler, P.A., 1988. Evolution of the Arctic-North Atlantic and Western Tethys. AAPG Memoir 43, Tulsa, pp. 164- 196.

Captions

Fig. 1. (A) Location and map of the study area. Stars indicate the studied outcrops (see Fig. 3A, 4A), triangles the major mountain tops (elevations in meters) and dots the main towns. (B) Position of the Dolomites during Middle-Late Triassic.

Fig. 2. Lithostratigraphic scheme (modified from Preto and Hinnov, 2003) of the studied interval in the Cortina-Tofane area. The Heiligkreuz Formation, is highlighted in grey. The platform (to the left) corresponds to Tofana di Rozes area, the basin (to the right) corresponds to Dibona Hut area. Ammonoid symbols indicate ammonoid occurrences in the area. (A) Names of lithostratigraphic units (from Neri et al., 2007). (B) Ammonoid biostratigraphy (from Mietto and Manfrin, 1995). (C-D) Chronostratigraphy stages and substages. The clinostratified body of Dibona Hut was represented with tabular progradation in Preto and Hinnov (2003) but is here reinterpreted as a clinostratified prograding body with descending trajectory of the shelf edge (see L-2 clino in § 4 and Fig. 4C, and § 5).

Fig. 3. (A) The outcrop on the southern wall of the Tofana di Rozes. The white rectangle indicates the area of interest i.e. the stratigraphic interval object of this study. (B) Photogrammetric three dimensional model of the outcrop (only the area of interest was modeled). (C) Line drawing of the

outcrop. Black dashed lines indicate the lithozones limits (see the § 4for a description of facies and stratal relationships). F7 indicates the location of Fig. 7.

Fig. 4. (A) The Dibona Hut outcrop. (B) Three dimensional model of the outcrop. This model is a three dimensional point cloud obtained by a terrestrial laser scanner. (C) Line drawing of the outcrop. Black dashed lines indicate the lithozones limits, grey continuous lines the bedding in the second lithozone (see § 4 for a description of facies and stratal relationships).

Fig. 5. Outcrops at the boundary between L-1 and L-2 at Tofana di Rozes and their interpretation. The boundary between L-1 and L-2 is constituted by a E dipping by-pass surface which developed on the top of the youngest L-1 clinoform. This surface is onset by lenticular-shaped carbonate bodies (mounds) mainly made up of microbial boundstone.

Fig. 6. (A) Outcrop of L-2 at Dibona Hut and (B) its interpretation. Lenticular-shaped carbonate bodies (mounds) mainly made up of microbial boundstone are interlayered and laterally onlapped by dm thick beds of arenaceous grainstones.

Fig. 7. (A) Stratigraphic log of a loose sediment intercalation in the L-2 at Tofana di Rozes and (B) a detail of it. This intercalation lies between two carbonate mounds and is mainly made up of cm-dm thick beds of grainstone (and its dolomitized counterpart), arenaceous grainstones, calcsiltite and shales. The location of this stratigraphic log is highlighted in Fig. 3C.

Fig. 8. (A) Western portion of Tofana di Rozes outcrop and (B) its interpretation. Here the L-1 is directly overlaid by the L-3. The boundary between L-1 and L-3 is constituted by a karstic surface.

Fig. 9. Karst at the top of the L-6 at Lastoni di Formin (see Fig. 1A for location).

Fig. 10. Sequence stratigraphic correlation of three schematic stratigraphic logs representing the sequences outcropping at Tofana di Rozes, Dibona Hut and Lastoni di Formin/Falzarego Pass/Valparola Pass (see Fig. 1a for locations). The Lastoni di Formin/Falzarego Pass/Valparola Pass log has been summarized according to Bosellini et al (1978), Preto and Hinnov (2003); Gattolin et al. (2013). The figure not in scale, the thickness of lithozones is only indicative. HST = highstand system tract, FSST = falling stage system tract, LST= lowstand system tract, TST = trasgressive system tract. SU = subaerial unconformity, BSFR = basal surface of forced regression (Hunt and Tucker, 1992), CC = correlative conformity (*sensu* Hunt and Tucker 1992), TRS = trasgressive ravinement surface (Cattaneo and Steel, 2003); MFS = maximum flooding surface (Frazier, 1974; Posamentier et al., 1988). In this scheme the L-2 has been comprised in the TST but it can be alternatively considered as part of the LST (see § 5).

Fig. 11. (A) Interpretation of the Picco di Vallandro area modified from Rudoolph et al. (1989) and Biddle et al., (1992). The Cassian 2 (*sensu* De Zanche et al., 1993) is the last generation of Carnian high-relief carbonate platforms (L-1 in this paper), its basinal equivalent is the San Cassiano Fm. (De Zanche et al., 1993); Heiligkreuz Fm. is used *sensu* Neri et al. (2007) and corresponds to the lithozones from L-2 to L-6 described in this paper (see Fig. 2 for details on stratigraphy). (B) Detail of the South-western sector modifed from the Fig. 5 of Biddle et al. 1992 displaying the closure of the basin and the consequent end of the high-relief platform progradation. (C) New interpretation of the Picco di Vallandro area according to Russo et al., (1991) and our own data. Member A of Russo et al., (1991) corresponds to the interval between the surface of demise of high-relief platforms and the base of the falling stage systems tract, in turn correspondent to the L-2 of this paper. Thus the infilling of the basin is subsequent to the high-relief platform demise and the change in depositional geometry is related to the climate change triggering the carbonate factory turnover.

Fig. 12. Schematic reconstruction of the key depositional phases observed in the studied stratigraphic interval.

Figure1

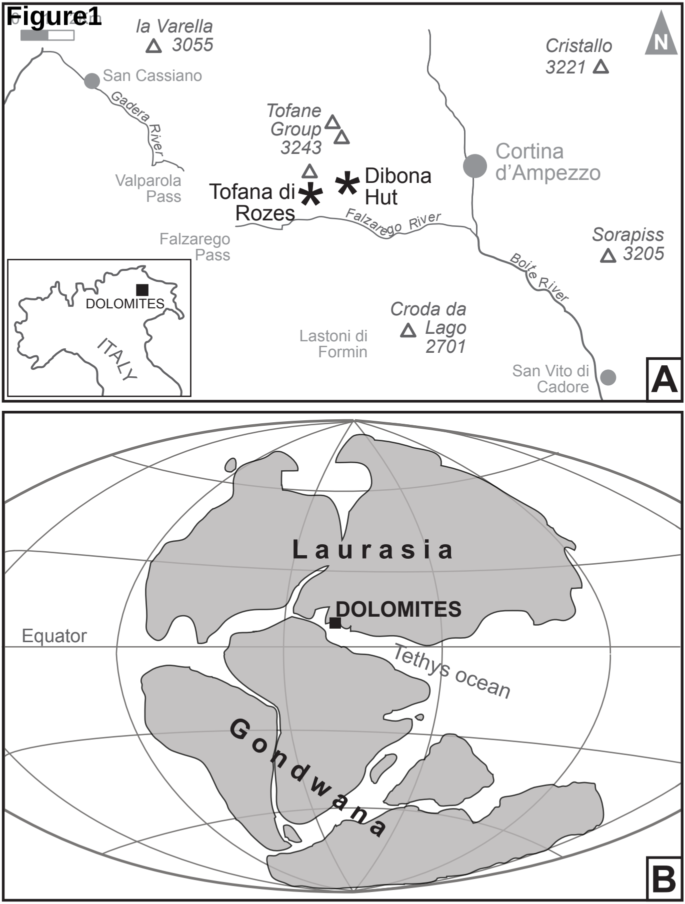

la Varella
3055
San Cassiano
Gadera River
Cristallo
3221
N
Tofane
Group
3243
Cortina
d'Ampezzo
Valparola
Pass
Dibona
Hut
Tofana di
Rozes
Falzarego River
Falzarego
Pass
Sorapiss
3205
Boite River
DOLOMITES
ITALY
Croda da
Lago
2701
Lastoni di
Formin
San Vito di
Cadore
A
Laurasia
DOLOMITES
Equator
Tethys ocean
Gondwana
B

Figure2

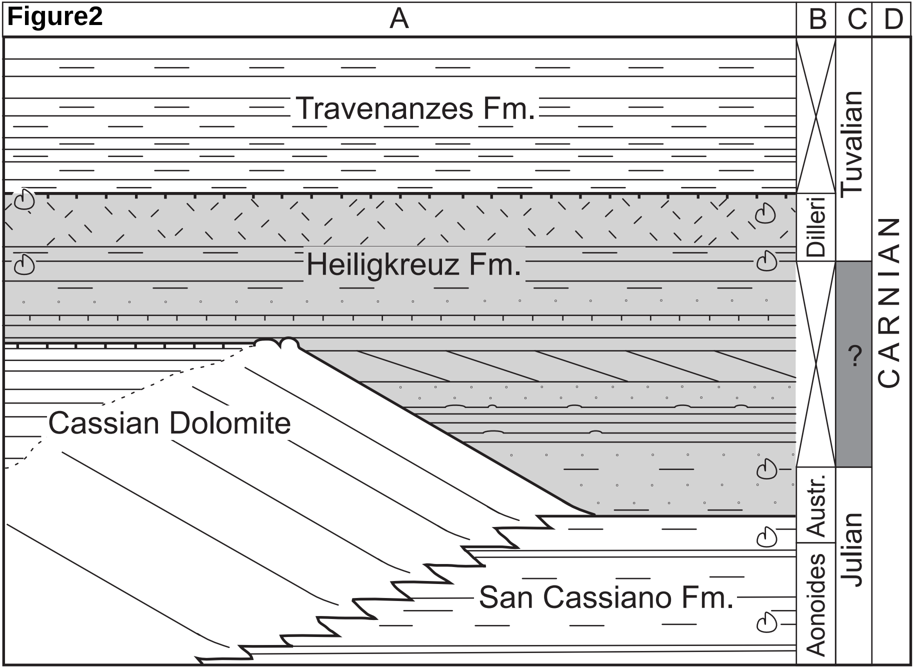

A
B
C
D
Travenanzes Fm.
Heiligkreuz Fm.
Cassian Dolomite
San Cassiano Fm.
Dilleri
Austr.
Aonoides
Tuvalian
?
Julian
CARNIAN

Figure3

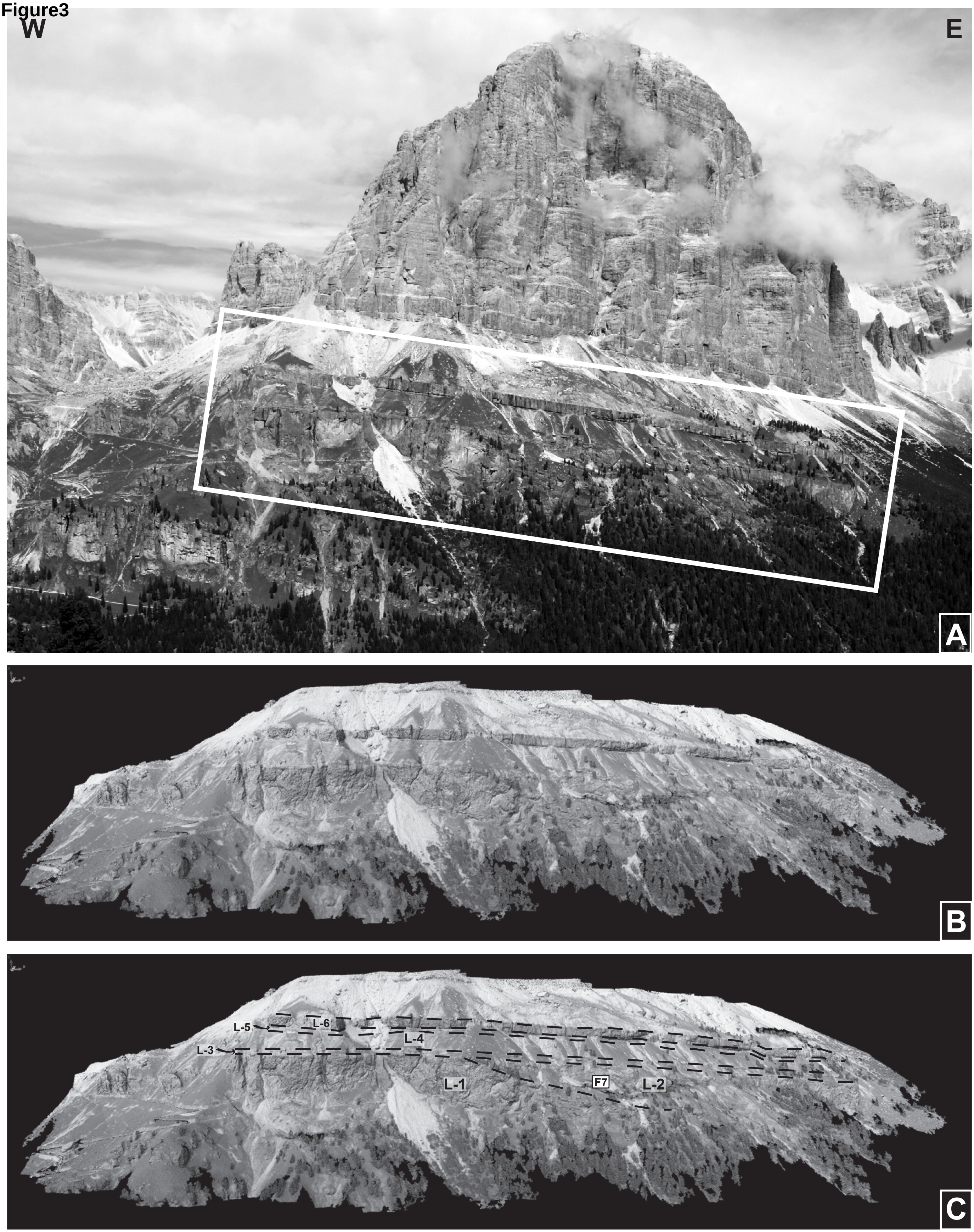


Figure4

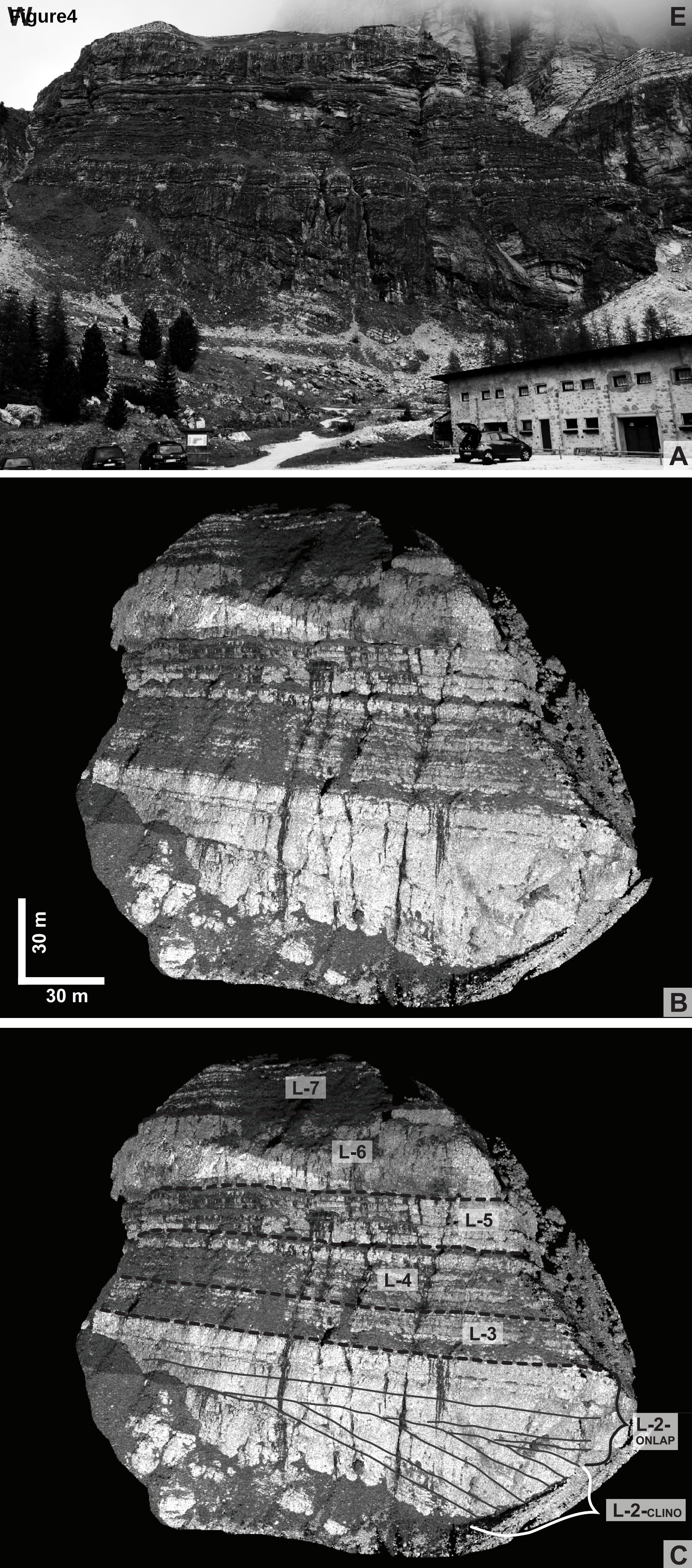


Figure5

Figure6

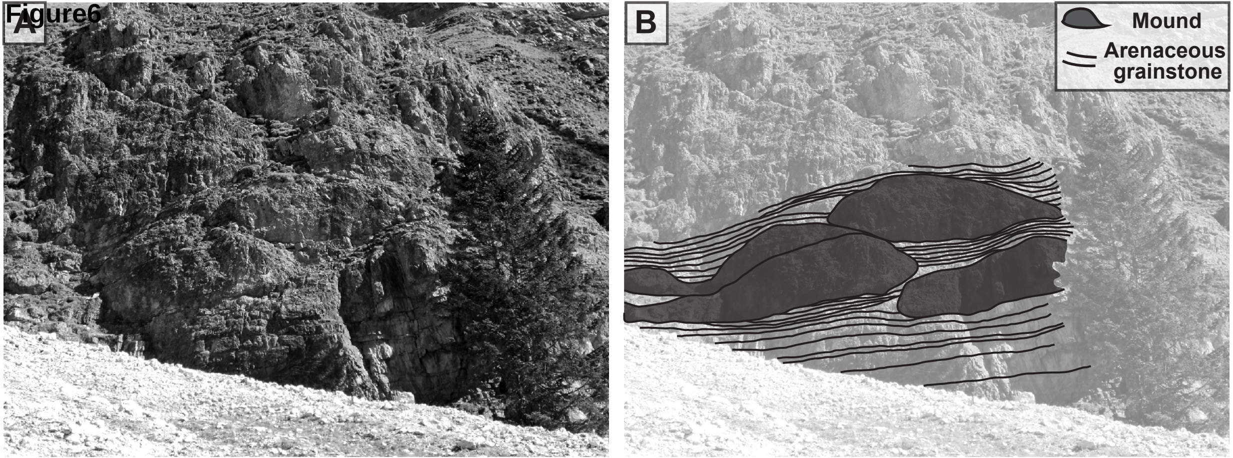
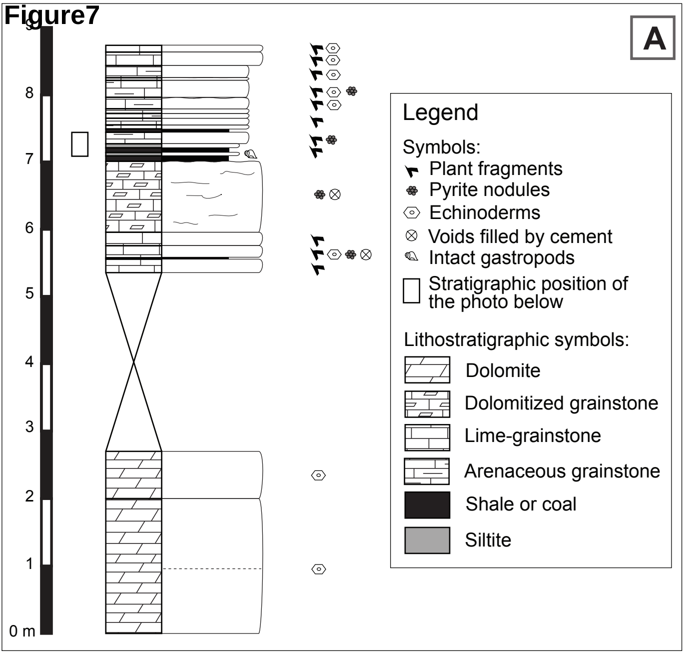


Figure7


A
0 m
1
2
3
4
5
6
7
8
9
Legend
Symbols:
Plant fragments
Pyrite nodules
Echinoderms
Voids filled by cement
Intact gastropods
Stratigraphic position of the photo below
Lithostratigraphic symbols:
Dolomite
Dolomitized grainstone
Lime-grainstone
Arenaceous grainstone
Shale or coal
Siltite


B

Figure8

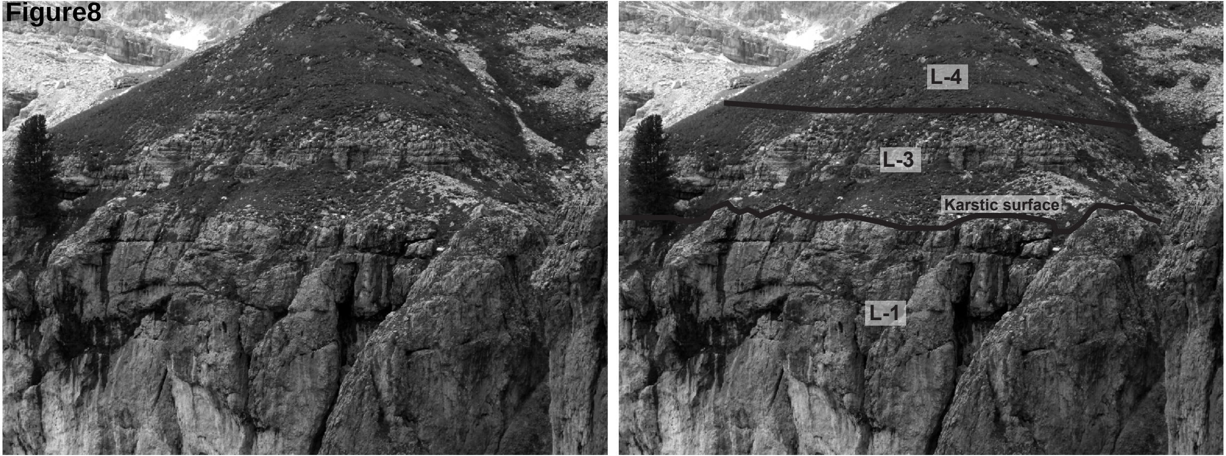


Figure9

Figure 10

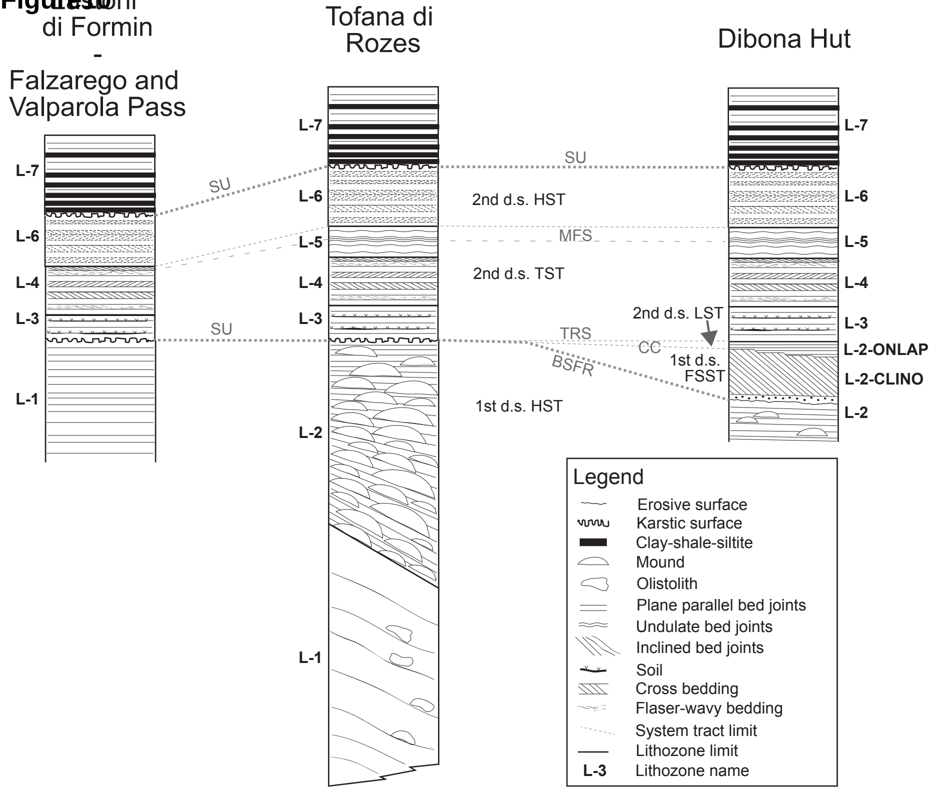
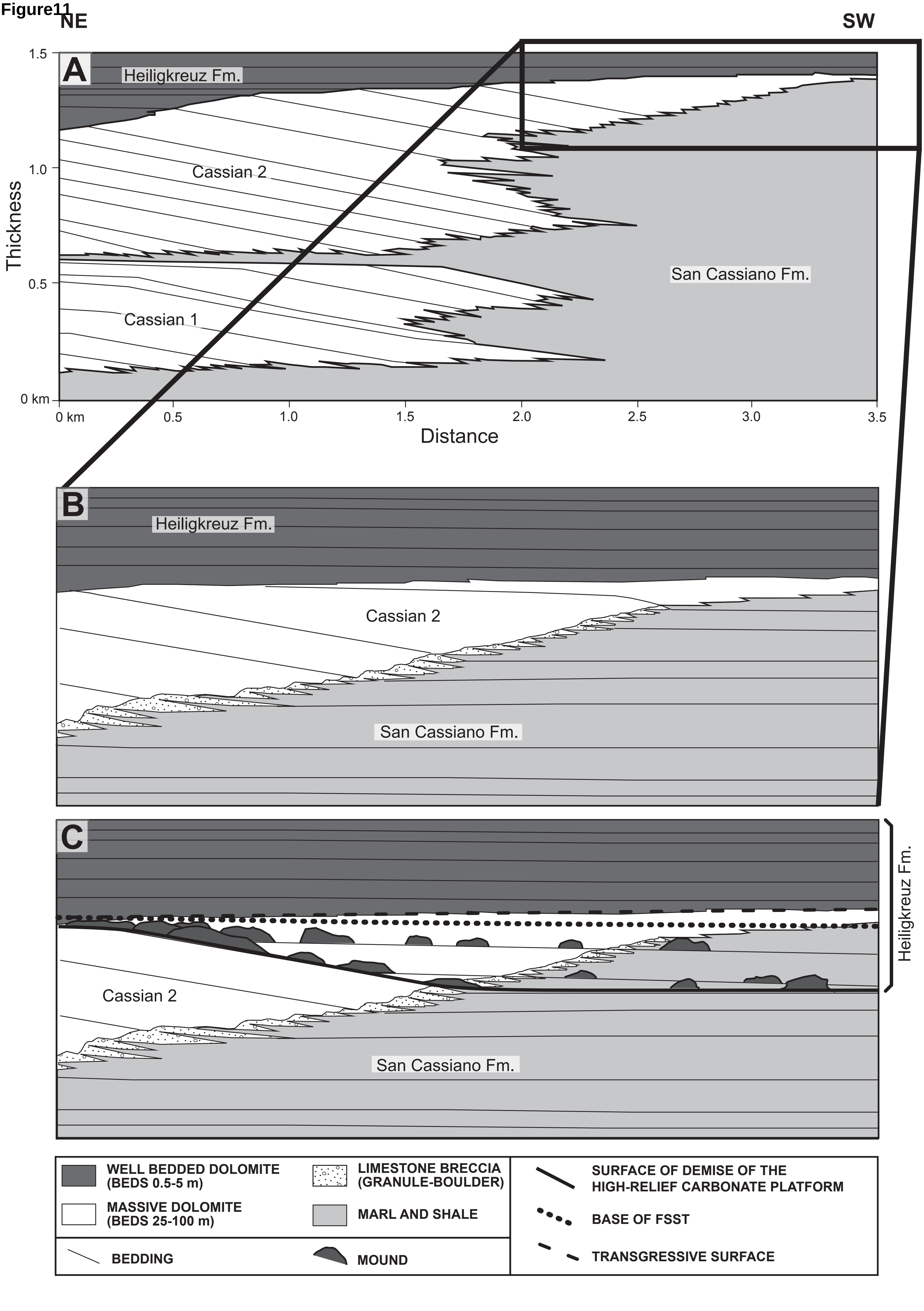
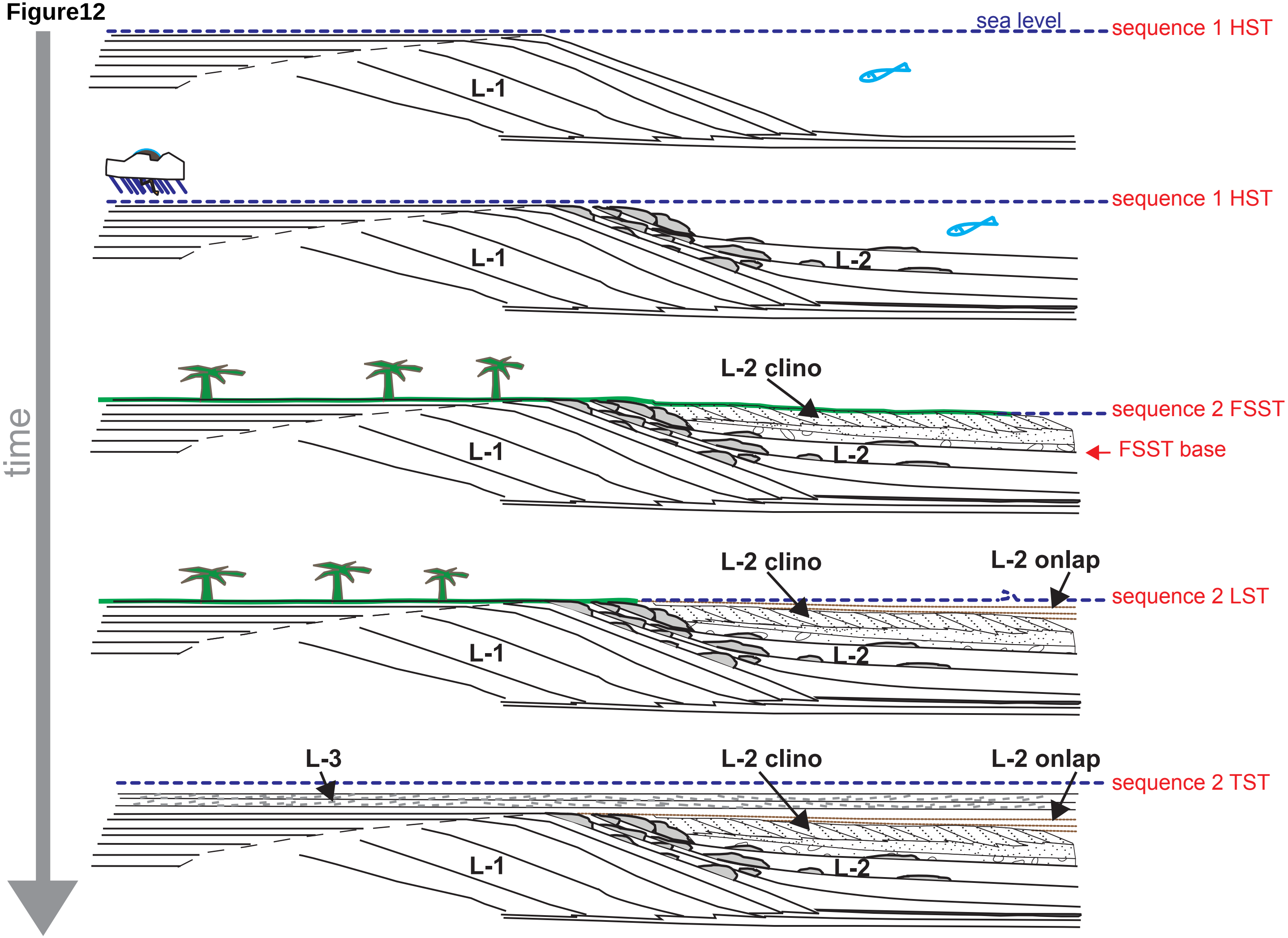

Lastoni di Formin - Falzarego and Valparola Pass
Tofana di Rozes
Dibona Hut
L-7
L-6
L-5
L-4
L-3
L-2
L-1
L-2-ONLAP
L-2-CLINO
SU
MFS
TRS
CC
BSFR
2nd d.s. HST
2nd d.s. TST
2nd d.s. LST
1st d.s. FSST
1st d.s. HST
Legend
Erosive surface
Karstic surface
Clay-shale-siltite
Mound
Olistolith
Plane parallel bed joints
Undulate bed joints
Inclined bed joints
Soil
Cross bedding
Flaser-wavy bedding
System tract limit
Lithozone limit
L-3
Lithozone name

Figure11



NE
SW
A
Heiligkreuz Fm.
Cassian 2
Cassian 1
San Cassiano Fm.
Thickness
1.5
1.0
0.5
0 km
0 km
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance
B
Heiligkreuz Fm.
Cassian 2
San Cassiano Fm.
C
Heiligkreuz Fm.
Cassian 2
San Cassiano Fm.
WELL BEDDED DOLOMITE (BEDS 0.5-5 m)
LIMESTONE BRECCIA (GRANULE-BOULDER)
MASSIVE DOLOMITE (BEDS 25-100 m)
MARL AND SHALE
BEDDING
MOUND
SURFACE OF DEMISE OF THE HIGH-RELIEF CARBONATE PLATFORM
BASE OF FSST
TRANSGRESSIVE SURFACE

Figure12



Legend

Mound
Clinostratified grainstones
Coarse grained facies
Cross stratification
Platform margin
Subaerial exposure
L-1 Lithozone name
Climate change (rainfall increase)