Q:1 *Geometry and evolution of Triassic high-relief, isolated microbial platforms in the Dolomites, Italy: The Anisian Latemar and Carnian Sella platforms compared*

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ABSTRACT

Exceptional outcrop conditions in the Dolomites of north Italy allow appreciation of facies variability, depositional geometries, and platform-to-basin relationships at seismic scale that developed during a complex sedimentary evolution. This itinerary focuses on two Triassic microbial carbonate platforms, the Latemar and Sella, providing examples of key concepts that are fundamental for the interpretation of subsurface geologic bodies. By comparing these two microbial platforms, a variability of facies architectures is highlighted. The relatively easy access, the exceptional exposure conditions, and the variety of carbonate platform types that grew in the Triassic of the Dolomites make this region an ideal field geology laboratory for training geologists working in exploration and in addition provide potential outcrop analogs of subsurface carbonate reservoirs.

INTRODUCTION

Carbonate platforms of the Dolomites serve as important analogs to hydrocarbon reservoirs (e.g., Central Asia, Central America, northern Russia, and North America), and microbial carbonate platforms such as those of the Dolomites are widespread in marine successions from the Precambrian to the Mesozoic. They commonly constitute carbonate reservoirs, but because they are distinct from modern carbonate platforms, a standardized facies model has yet to be developed. Prediction of shapes and

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stratigraphic architectures of similar platforms in the subsurface commonly relies on comparison with outcrop analogs.

The Triassic of the Dolomites (northeastern Italy) recorded the recovery of carbonate platforms after a major crisis of shallow water carbonate systems—the end-Permian mass extinction—and thus offers the opportunity to examine not only one but a full spectrum of microbial carbonate platforms. Outcrop conditions in the Dolomites are commonly exceptionally good, featuring entire, seismic-scale isolated carbonate platforms with well-preserved depositional geometries and facies relationships. Because of their several-kilometer–scale outcrops, the Dolomites have been historically important for the development of fundamental concepts in sedimentary geology. More recently, the petroleum industry found in the Dolomites an ideal field location for teaching geological interpretation of seismic data and sequence stratigraphic principles.

The exposures at Latemar highlight some important, recent advancements in the understanding of carbonate systems. First, many Phanerozoic carbonate platforms are microbial, i.e., built by microbial communities. Second, microbial platforms evolve in specific ways; that is, they respond differently from modern tropical platforms to sea level change (e.g., the slope shedding of Kenter et al., 2005). Third, synsedimentary tectonics exerted a strong and direct control on platform geometries and ultimately on the petrophysical properties (e.g., Blendinger, 1986; Bigi et al., 2015). The itinerary also includes the Sella, another microbial platform that is significantly different from the Latemar, not only because the tectonic context was different but also in terms of facies belts and carbonate producers. This highlights that not all microbial platforms are the same, or in other words, a standard and unique depositional model for microbial platforms cannot exist.

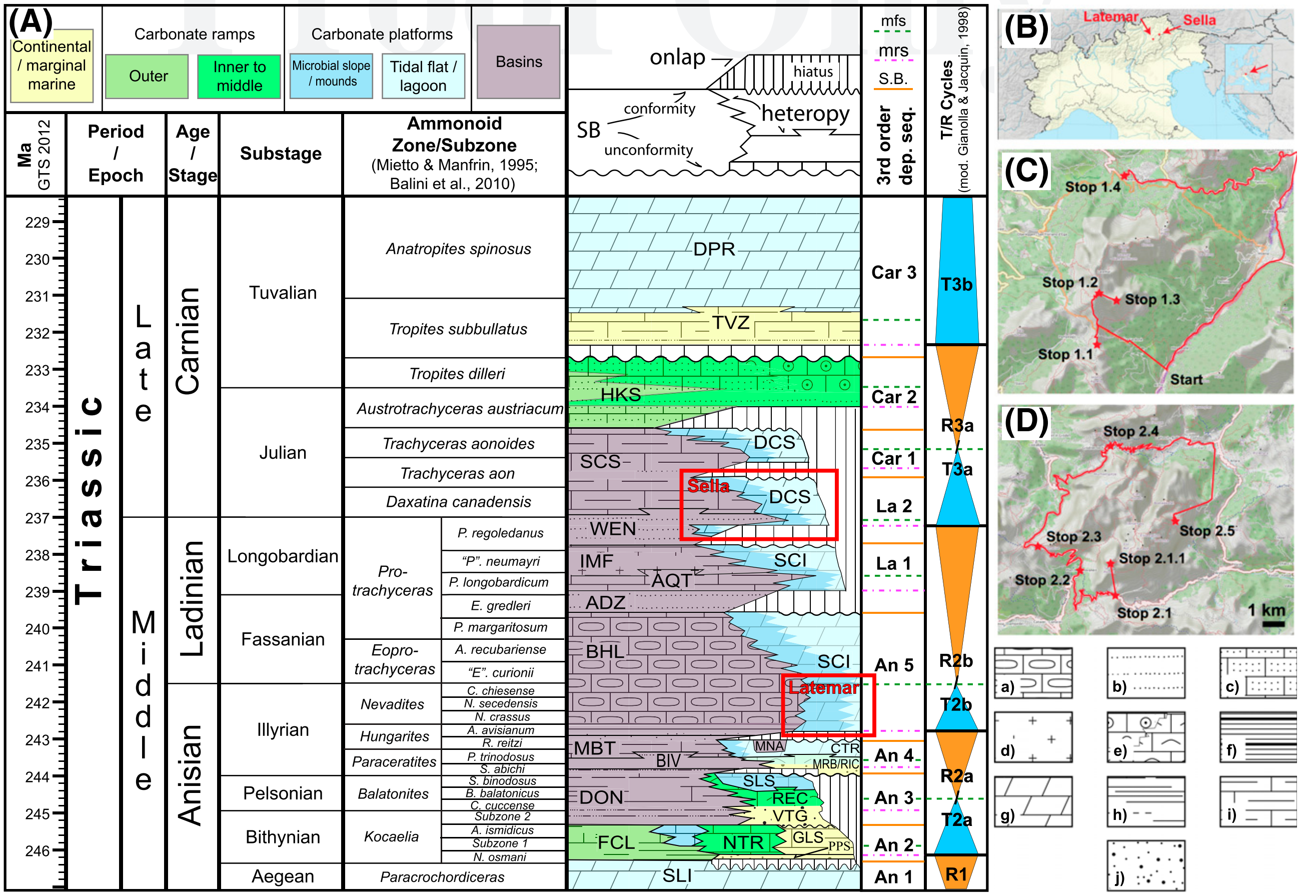
GEOLOGICAL BACKGROUND

The superb exposures of the Dolomites allowed early geologists to understand some basic principles of sedimentary geology; thus, the Dolomites were a pivotal factor in the history of geology (Gianolla et al., 2008; Schlager and Keim, 2009). Here the dolomite mineral and rock were discovered, and lateral facies transitions (heteropies) within sedimentary bodies were first observed and understood. More recently, geometrical models of carbonate platforms were developed, using the kilometer-scale outcrops of the Dolomites as templates (e.g., Bosellini, 1984; Kenter, 1990).

During the Triassic, the Dolomites were located in tropical latitudes in western Tethys. From Late Permian to Early Triassic, the area was occupied by a wide shallow sea, but deepening started in the early–middle Anisian (Middle Triassic), when the first high-relief carbonate buildups developed. Subsidence rates climaxed in the late Anisian, when the paleogeography of the Dolomites featured isolated carbonate platforms that rose up to 1000 m above the surrounding deep basins. This paleotopography was eventually filled by the progradation of carbonate platforms and siliciclastic sediments at the end of the early Carnian. The migration of the shorelines or of the carbonate platform shelf breaks defines numerous depositional sequences in the Late Permian to Carnian interval (cf. Stefani et al., 2010). The late Anisian Latemar isolated carbonate platform represents the transgressive systems tract (TST) of the An5 depositional sequence (the HST part having been eroded on most of the massif), and the early Carnian Sella platform represents the TST and HST of the La2 depositional sequence (Figure 1).

The Latemar platform belongs to the Sciliar Formation (Figure 1). Its depositional profile lacks a distinct barrier or reef so that the outer platform dips gently toward the basin, similarly to other high-relief microbial platforms during the Phanerozoic (Marangon et al., 2011).

The basic architecture of the Latemar platform is of a flat, cyclic platform interior with common subaerial exposure horizons, an outer platform of poorly layered microbialite, and steep slopes, which, in the upper few hundred meters, are composed of microbial boundstone (Marangon et al., 2011). It nucleated on a fault-bounded block, which dissected an earlier Late Anisian carbonate bank, the Contrin Formation (Figure 2), and then vertically aggraded to form a pinnacle. The shape of the platform interior, somewhat polygonal, reflects the presence of active extensional faults underneath and shows that facies belts did not migrate laterally through time (Preto et al., 2011). As the relief of the platform increased with time, so did the instability of its slopes (Preto



Q:7 **Figure 1.** (A) Stratigraphic framework of the Middle and Upper Triassic of the Dolomites. The stratigraphic intervals corresponding to the
Q:8 Latemar and Sella are highlighted with red rectangles. (B–D) Proposed field trip on the Latemar and Sella platforms. (B) Position of the Latemar and Sella in northern Italy. (C) Itinerary around the Latemar platform (day 1). (D) Itinerary around the Sella platform (day 2). Lithostratigraphic abbreviations: ADZ = Zoppè Sandstone; AQT = Acquatona Formation; BHL = Livinallongo/Buchenstein Formation; BIV = Bivera Formation; CTR = Contrin Formation; DCS = Cassian Dolomite; DON = Dont Formation; DPR = Dolomia Principale/Hauptdolomit; FCL = Coll'Alto dark limestones; GLS = *Gracilis* Formation; HKS = Heiligkreuz Formation; IMF = Fernazza Formation and volcanites; MBT = Ambata Formation; MNA = Moena Formation; MRB/RIC = Richthofen Conglomerate and Morbiac dark limestone; NTR = Monte Rite Formation; PPS = Piz da Peres Conglomerate; REC = Recoaro Limestone; SCI = Sciliar Dolomite/Limestone; SCS = San Cassiano Formation; SLI = Lower Serla Dolomite; SLS = Upper Serla Formation; TVZ = Travenanzes Formation; VTG = Voltago Conglomerate; WEN = Wengen
Q:9 Formation. Lithologies: a = cherty limestone; b = sandstone; c = sandy limestone; d = volcanics; e = oolitic–bioclastic limestone; f = black platy limestone or dolostone, black shale; g = dolostone; h = marlstone, claystone, and shale; i = marly limestone; j = conglomerate. From
Q:10 OpenStreetMap. Map of Italy by Eric Gaba – Wikimedia Commons user: Sting, regions boundaries by User: NordNordWest.

et al., 2011). The depositional profile of the Latemar thus changed through time, while always comprising the same facies belts: an inner platform, an outermost platform, a shelf break and upper slope, a lower slope, and a periplatform basin (Marangon et al., 2011).

The Sella massif shows two superimposed cliffs, separated by a distinct ledge (Figure 3). The base of the massif consists of a lower Carnian isolated carbonate buildup, the Sella platform sensu stricto, approximately 600 m thick, mainly clinostratified and dipping radially. Climbing progradation and oblique-tangential patterns occur to the southwest (Passo Sella and Passo Pordoi), whereas horizontal progradation and oblique-parallel patterns occur to the north (Bosellini, 1984). This unit belongs to the Cassian Dolomite (Figure 1). The middle interval, forming the ledge, includes the carbonate–siliciclastic Heiligkreuz and Travenanzes Formations (formerly Raibl beds), still Carnian in age, whereas the upper section of the cliff is formed by the cyclic peritidal facies of a large-scale epeiric platform, the Carnian–Norian Dolomia Principale. The middle interval is variable in thickness, reaching its maximum (40–50 m) in the external part in the Piz Ciavaces and Piccolo

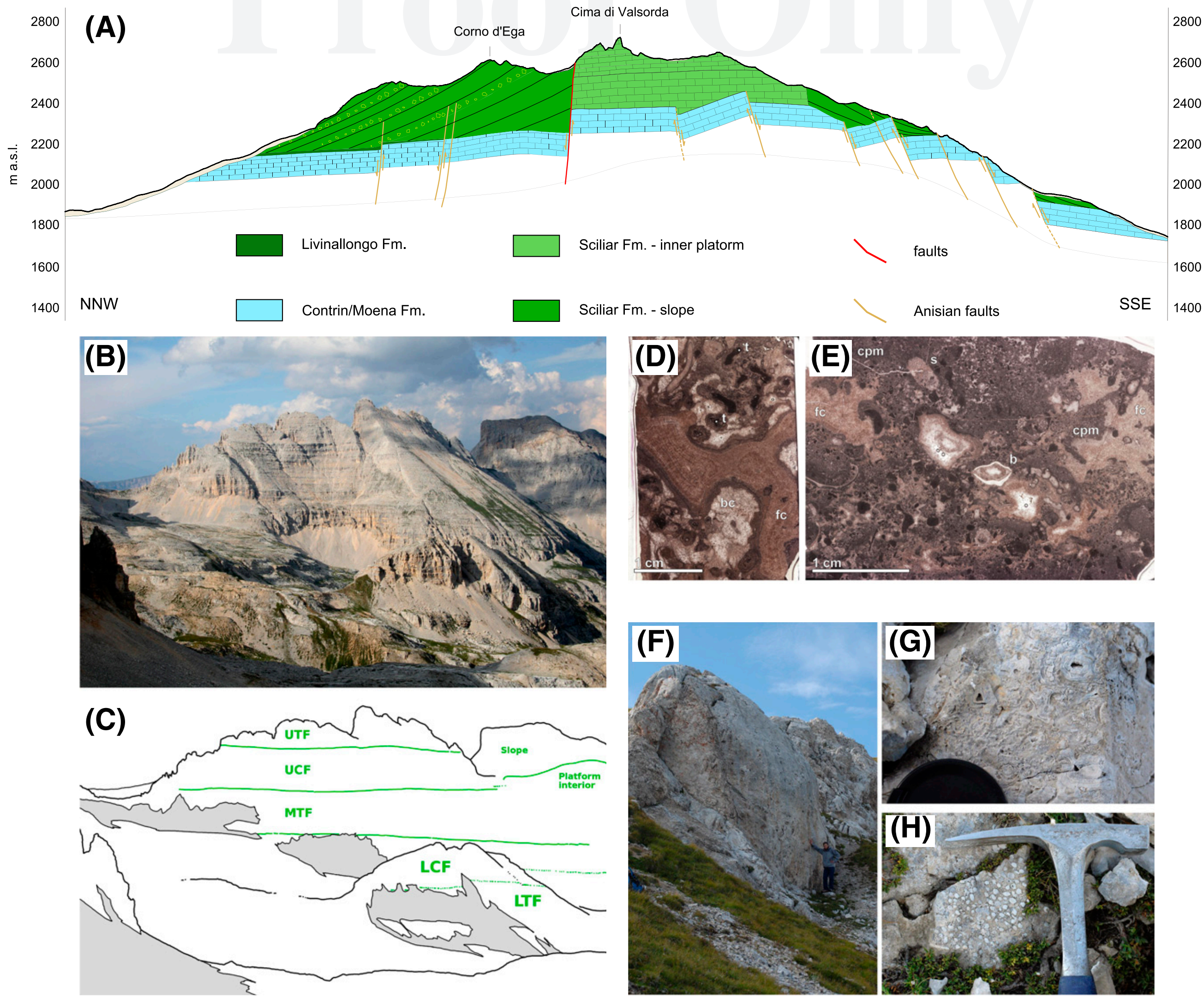


Figure 2. Overview of the Latemar platform. (A) A geological cross section of the Latemar platform in the area visited with this excursion. This cross section clearly shows the control of syndepositional tectonics on the evolution of the platform; in particular, the margin on the left (north–northwest) is controlled by a syndepositional (Anisian) normal fault, reactivated afterward by Alpine tectonics. (B) The core of the Latemar platform, as seen from Rifugio Torre di Pisa. Platform interior facies are easily identified because of their regular layering, whereas the massive facies of the peak on the right (Mount Cornon) are typical of the upper slopes. (C) The names refer to the lithostratigraphic subdivision of the inner platform. (D) Cementstone from the shelf break of Cima Feudo, northern Latemar. Botryoidal, formerly aragonitic cements (bc) and fibrous cements (fc) are the main types. *Tubyphites* (t) are also present but subordinate. (E) Microbial boundstone from Forcella dei Toac, with brachiopods (b), sponge (s), other fossils, and large primary cavities filled with fc. The fossils dispersed in a framework of clotted peloidal micrite (cpm). (F) Massive microbial boundstones as seen in the field. This is the typical facies of the shelf break and upper slopes at Latemar. (G) Microbial boundstone with large intraframework–fenestral pores, partially or totally filled by crusts of radiaxial fc. Metazoans represented by calcareous sponges (e.g., upper right corner) are common accessory components. (H) Colonial corals may also be present, though rare. Fm. = Q:11 formation; LCF = lower cyclic facies; LTF = lower tepee facies; MTF = middle tepee facies; UCF = upper cyclic facies; UTF = upper tepee facies.

Pordoi. It disappears moving toward the center of the platform. This is because of differential compaction of the basinal deposits beneath the platform (Doglioni and Goldhammer, 1988).

The Lower Carnian Sella platform interfingers with mixed siliciclastic–carbonate sediments of the San Cassiano Formation (Figure 3). The northern side of the Sella Massif is characterized by a prominent megabreccia body, the Gardena Megabreccia, up to 200 m thick, which is intercalated between the volcaniclastic Wengen Formation and the San Cassiano Formation.

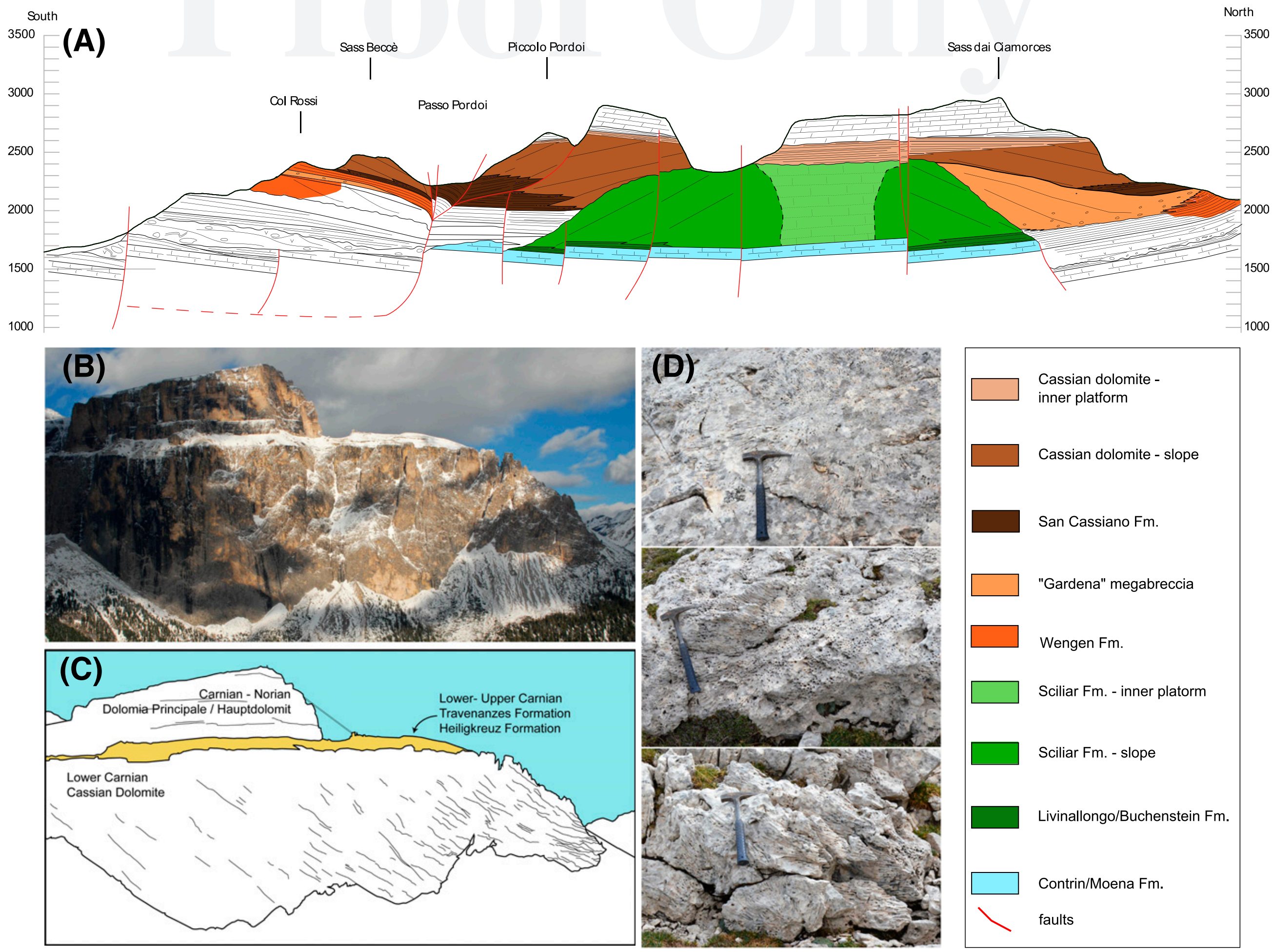


Figure 3. (A) A south–north geological cross section of the Sella platform from Passo Pordoi to Passo Gardena, showing the superposition of different generations of carbonate platforms. (B) The wall of the Sella massif at Sass Pordoi, as seen from near Passo Sella, with a lower massive clinostratified vertical wall corresponding to the Lower Carnian isolated platform (Sella platform). A prominent ledge and an upper well-stratified wall are immediately evident in the field. (C) Line drawing of the picture in (B), with trace of most visible clinoforms. Note that clinoforms do not originate at the shelf break and are not present in the upper 100–200 m of the slope, which is massive. In this picture, the Heiligkreuz and Q:12 Travenanzes Formations (Fms.) are thinning toward the platform interior because of differential compaction of basinal areas, where the platform prograded, with respect to inner platform core. (D) Coral framestones at Col de Stagn. Corals are found as molds of colonies up to few meters in size, commonly in life position, demonstrating the existence of a coral reef at the margin of the Sella platform in the early Carnian.

Both the Latemar and Sella platforms exhibit a flat-bedded cyclic inner platform and highly inclined (~35°) slopes, which, in their upper part, are chiefly made of microbial boundstones. However, there are also major differences (Figure 4), and two should be highlighted here. (1) Differently from Sella, at Latemar, microbial boundstones did not form a topographic barrier, and there was thus no lagoon; and (2) the tight microbial framework and early marine cements at Latemar occluded primary porosity at the time of deposition, which was probably not the case at Sella.

At Latemar, the inner platform passes into flattish microbial boundstones seaward, and the shelf break is made by tight microbial boundstone and marine cements (Marangon et al., 2011). Facies of the shelf break are nearly indistinguishable from those of the upper slope. Therefore, there was no elevated, rigid barrier bordering the inner platform area at Latemar. In contrast, the shelf break facies of the Sella platform are coral–algal framestones. These must have formed a rigid barrier, which enclosed a lagoon. However, the existence of a metazoan-dominated margin in the Carnian platforms implies that a facies belt of reefs and ooid shoals was forming, differently from what could be observed in older platforms such as the Latemar. In analogy with modern coral reefs, such

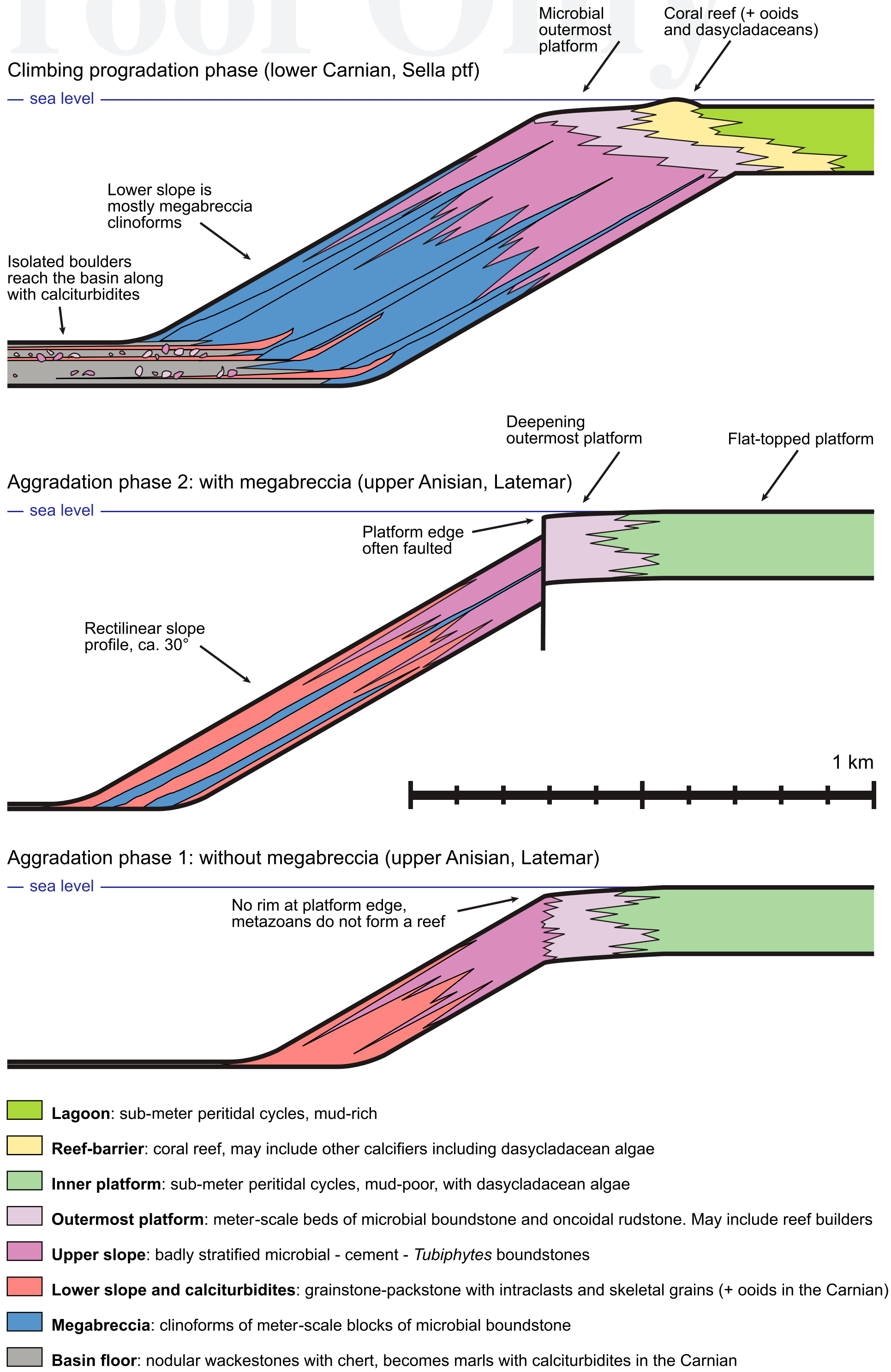


Figure 4. Comparison of the depositional profiles of the Latemar and Sella. Note how different tectonic settings and type and distribution of calcifying organisms determined changes in the depositional geometry. Carbonate boulders are not shown within the slopes, but most of the slope profile at Sella and, in a late phase, at Latemar is made of megabreccia (blue). Q:13 ptf = platform.

facies belt may, under favorable conditions, form deposits with high primary porosity, which may survive or develop moldic porosity during burial (e.g., Figure 3). Still, the upper slopes were made of microbial boundstones and have a massive appearance without clear clinoforms (Kenter, 1990) (Figure 3).

Other key differences are related to contrasting tectonic regimes. The vertically aggrading margins at Latemar had underlying normal faults that were probably active (Figure 2). This, along with strong subsidence, fixed the positions of the margins during the platform growth (Blendinger, 1986; Preto et al.,

2011) (see also Figure 4). The platform margins were also affected by enhanced fracturing (Bigi et al., 2015), because of either Anisian tectonics or later reactivation, and this potentially improves the local petrophysical properties. In contrast, the Sella platform prograded strongly, and there is no clear relationship between syndepositional tectonics and platform geometry (Figure 3).

GENERAL ACCESS AND SAFETY

The Dolomites can be easily reached from Venice, Verona, and Innsbruck airports, either by car or by public transport. The Dolomites offer an extensive variety of accommodation, e.g., in the Fiemme, Fassa, Badia, Gardena, or Cordevole valleys. Panoramic views of the platforms are reached both by public transport and by car. Closer examination of the rocks requires some hiking, commonly at high elevations. However, all the main localities can be reached via easy trails. The basic rules for safe hiking in a mountain environment should be observed. Many of the stops on the excursions are accessed via cable cars.

FIELD ITINERARY

This 2-day itinerary involves two excursions allowing a comparison of the depositional features of the late Anisian (Middle Triassic) Latemar and the early Carnian (Late Triassic) Sella platforms. Excursion to the Sella includes mostly car transfers and short walks (except for two optional stops) and could be reserved for a day of less fair weather, although reasonably good visibility is necessary at all locations.

Excursion 1: Latemar Platform

The itinerary starts from a viewpoint at Dos Capel, south of the Latemar (stop 1.1). The Latemar skyline seen here coincides well with the Middle Triassic depositional geometry that features a flat platform top, a gentle shelf break, and a steep slope plunging in the adjacent deep basin. From Rifugio Torre di Pisa (stop 1.2), the platform interior succession is visible from the back of Rifugio on the Cimon del Latemar (Figure 2B, C). A trace on the mountain crest then leads to the cross at Cima Feudo. This walk is along one of the best preserved inner platform–margin–slope transects of the Latemar platform. This is the platform-to-slope outcrop visible from stop 1.1, and this excursion provides the opportunity of looking at this depositional profile both in terms of depositional geometry (stop 1.1) and in terms of facies (from stop 1.2 to stop 1.3). Figure 2 illustrates some of the facies visible at stop 1.3. The last stop is optional. Lago di Carezza–Karersee can be reached by car with an approximately 40 min drive from Predazzo. From Lago di Carezza, the view of the Latemar platform is opposite to that from Rifugio Torre di Pisa and shows the other side of Cimon del Latemar.

Excursion 2: Sella Platform

The proposed itinerary is a clockwise journey around the Triassic isolated carbonate platform. At Passo Pordoi (stop 2.1), the progradations of the Sella platform and of a minor platform, the Sass Becé, are visible. From Pian Schiavaneis (stop 2.2), an outstanding view of the southern face of the Sella platform is clearly seen. The climbing progradation of the clinoforms on the underlying basinal deposits is the key feature. The following stop is in Passo Sella (stop 2.3), where it is possible to appreciate the interfingering of the basinal volcaniclastics of the Wengen Formation and the San Cassiano Formation (marls and calciturbidites) with the toe of slope of the prograding platform. At Passo Gardena (stop 2.4), a still not well understood megabreccia body can be seen, the so-called Gardena Megabreccia, which lies against (or cuts into) basinal deposits of the San Cassiano and Wengen formations. Above, the steep clinoforms of the Sella slopes are again visible. The last stop, which is optional, is at Col de Stagn, where the margin of the platform can be observed in detail: it could be reached with a lift from Corvara, a 15-min drive from Gardena Pass.

Key Learnings

In contrast to the late Cenozoic platform model, the Latemar and Sella are both isolated, high-relief carbonate platforms in which carbonate production was mostly achieved by microbial consortia. Despite some superficial similarities in geometry with modern carbonate platforms, they are fundamentally different from those of the present oceans, which are mostly built by metazoans. Yet, not all microbial platforms are the same, as highlighted for example by the two platforms of this field trip. Probably as a consequence of this variability, a comprehensive depositional model of microbial carbonate platforms does not exist yet. The Triassic microbial carbonate platforms of the Dolomites capture a relevant part of this variability, which is one of the reasons why a field trip to the Dolomites may be helpful to all carbonate sedimentologists and especially those working in the field of hydrocarbon exploration.

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Q:14

AUTHOR QUERIES

AUTHOR PLEASE ANSWER ALL QUERIES

Q:1 Please provide a short title for your article; it must be no more than 80 characters long, including spaces.

Q:2 Please provide a short (two- to three-sentence) biography for each author, including education and work history and research interests.

Q:3 Please provide e-mail addresses for all authors.

Q:4 Please include English unit equivalents in parentheses after all metric measurements in the text and figures.

Q:5 In the sentence "The late Anisian Latemar isolated carbonate platform represents…," please spell out "An5" and "La2" and define "HST."

Q:6 In the sentence "From Lago di Carezza, the view of the Latemar platform…," "that opposed to" was changed to "opposite to." Please confirm that this change conveys your intended meaning.

Q:7 In Figure 1, please provide complete reference information for Mietto and Manfrin (1995) and Balini et al. (2010).

Q:8 Please include latitude and longitude for all maps in Figure 1.

Q:9 In the caption of Figure 1, please define all abbreviated genus names (e.g., *P. regoledanus*), all abbreviations in the dep. seq. column (Car 3, etc.), all abbreviations in the T/R cycles column (T3b, etc.), SB, GTS, T/R, dep. seq., mod., mfs, and mrs.

Q:10 Please clarify the meaning of the sentences beginning "From 'OpenStreetMap'….." Is your intended meaning that the panels B–D were created from the map of Italy created Eric Gaba using OpenStreetMap.com? If so, please provide full bibliographic details for the map and the manufacturer name and location for OpenStreetMaps.

Q:11 In the caption of Figure 2, please confirm that "Fm." has been defined correctly.

Q:12 In the caption of Figure 3, please confirm that "Fm." has been defined correctly.

Q:13 In the caption of Figure 4, please confirm that "ptf" has been defined correctly.

Q:14 The reference Gianolla and Jacquin (1998) is not cited in the text. Please indicated where it should be cited or remove the reference.

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The superb exposures of the Dolomites allowed early geologists to understand some basic principles of sedimentary geology; thus, the Dolomites were a pivotal factor in the history of geology (Gianolla et al., 2008; Schlager and Keim, 2009). Here the dolomite mineral and rock were discovered, and lateral facies transitions (heteropies) within sedimentary bodies were first observed and understood. More recently, geometrical models of carbonate platforms were developed, using the kilometer-scale outcrops of the Dolomites as templates (e.g., Bosellini, 1984; Kenter, 1990).

During the Triassic, the Dolomites were located in tropical latitudes in western Tethys. From Late Permian to Early Triassic, the area was occupied by a wide shallow sea, but deepening started in the early–middle Anisian (Middle Triassic), when the first high-relief carbonate buildups developed. Subsidence rates climaxed in the late Anisian, when the paleogeography of the Dolomites featured isolated carbonate platforms that rose up to 1000 m above the surrounding deep basins. This paleotopography was eventually filled by the progradation of carbonate platforms and siliciclastic sediments at the end of the early Carnian. The migration of the shorelines or of the carbonate platform shelf breaks defines numerous depositional sequences in the Late Permian to Carnian interval (cf. Stefani et al., 2010). The late Anisian Latemar isolated carbonate platform represents the transgressive systems tract (TST) of the An5 depositional sequence (the HST part having been eroded on most of the massif), and the early Carnian Sella platform represents the TST and HST of the La2 depositional sequence (Figure 1).

The Latemar platform belongs to the Sciliar Formation (Figure 1). Its depositional profile lacks a distinct barrier or reef so that the outer platform dips gently toward the basin, similarly to other high-relief microbial platforms during the Phanerozoic (Marangon et al., 2011).

The basic architecture of the Latemar platform is of a flat, cyclic platform interior with common subaerial exposure horizons, an outer platform of poorly layered microbialite, and steep slopes, which, in the upper few hundred meters, are composed of microbial boundstone (Marangon et al., 2011). It nucleated on a fault-bounded block, which dissected an earlier Late Anisian carbonate bank, the Contrin Formation (Figure 2), and then vertically aggraded to form a pinnacle. The shape of the platform interior, somewhat polygonal, reflects the presence of active extensional faults underneath and shows that facies belts did not migrate laterally through time (Preto et al., 2011). As the relief of the platform increased with time, so did the instability of its slopes (Preto

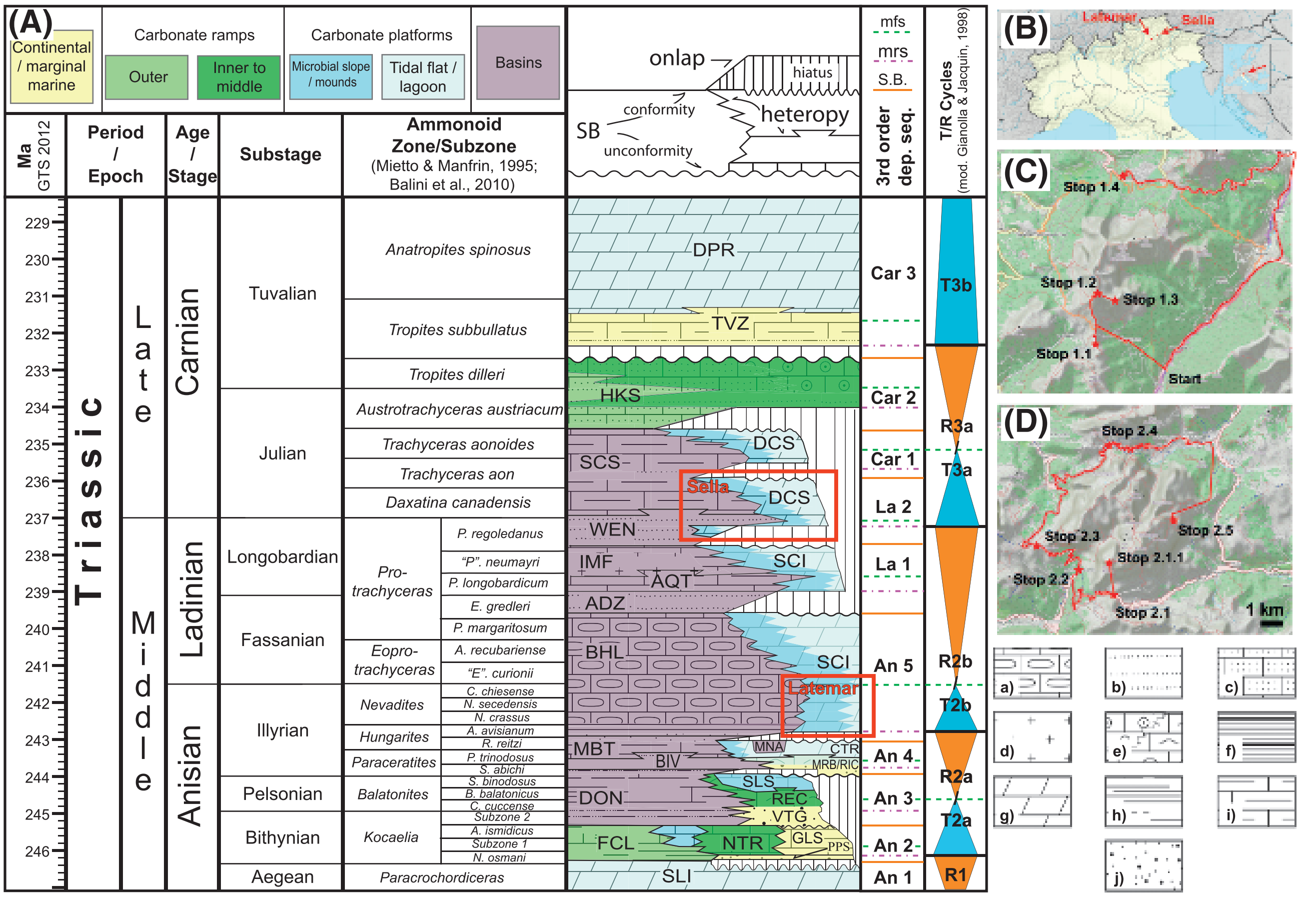


Figure 1. (A) Stratigraphic framework of the Middle and Upper Triassic of the Dolomites. The stratigraphic intervals corresponding to the Latemar and Sella are highlighted with red rectangles. (B–D) Proposed field trip on the Latemar and Sella platforms. (B) Position of the Latemar and Sella in northern Italy. (C) Itinerary around the Latemar platform (day 1). (D) Itinerary around the Sella platform (day 2). Lithostratigraphic abbreviations: ADZ = Zoppè Sandstone; AQT = Acquatona Formation; BHL = Livinallongo/Buchenstein Formation; BIV = Bivera Formation; CTR = Contrin Formation; DCS = Cassian Dolomite; DON = Dont Formation; DPR = Dolomia Principale/Hauptdolomit; FCL = Coll'Alto dark limestones; GLS = *Gracilis* Formation; HKS = Heiligkreuz Formation; IMF = Fernazza Formation and volcanites; MBT = Ambata Formation; MNA = Moena Formation; MRB/RIC = Richthofen Conglomerate and Morbiac dark limestone; NTR = Monte Rite Formation; PPS = Piz da Peres Conglomerate; REC = Recoaro Limestone; SCI = Sciliar Dolomite/Limestone; SCS = San Cassiano Formation; SLI = Lower Serla Dolomite; SLS = Upper Serla Formation; TVZ = Travenanzes Formation; VTG = Voltago Conglomerate; WEN = Wengen Formation. Lithologies: a = cherty limestone; b = sandstone; c = sandy limestone; d = volcanics; e = oolitic–bioclastic limestone; f = black platy limestone or dolostone, black shale; g = dolostone; h = marlstone, claystone, and shale; i = marly limestone; j = conglomerate. From OpenStreetMap. Map of Italy by Eric Gaba – Wikimedia Commons user: Sting, regions boundaries by User: NordNordWest.

et al., 2011). The depositional profile of the Latemar thus changed through time, while always comprising the same facies belts: an inner platform, an outermost platform, a shelf break and upper slope, a lower slope, and a periplatform basin (Marangon et al., 2011).

The Sella massif shows two superimposed cliffs, separated by a distinct ledge (Figure 3). The base of the massif consists of a lower Carnian isolated carbonate buildup, the Sella platform sensu stricto, approximately 600 m thick, mainly clinostratified and dipping radially. Climbing progradation and oblique-tangential patterns occur to the southwest (Passo Sella and Passo Pordoi), whereas horizontal progradation and oblique-parallel patterns occur to the north (Bosellini, 1984). This unit belongs to the Cassian Dolomite (Figure 1). The middle interval, forming the ledge, includes the carbonate–siliciclastic Heiligkreuz and Travenanzes Formations (formerly Raibl beds), still Carnian in age, whereas the upper section of the cliff is formed by the cyclic peritidal facies of a large-scale epeiric platform, the Carnian–Norian Dolomia Principale. The middle interval is variable in thickness, reaching its maximum (40–50 m) in the external part in the Piz Ciavaces and Piccolo

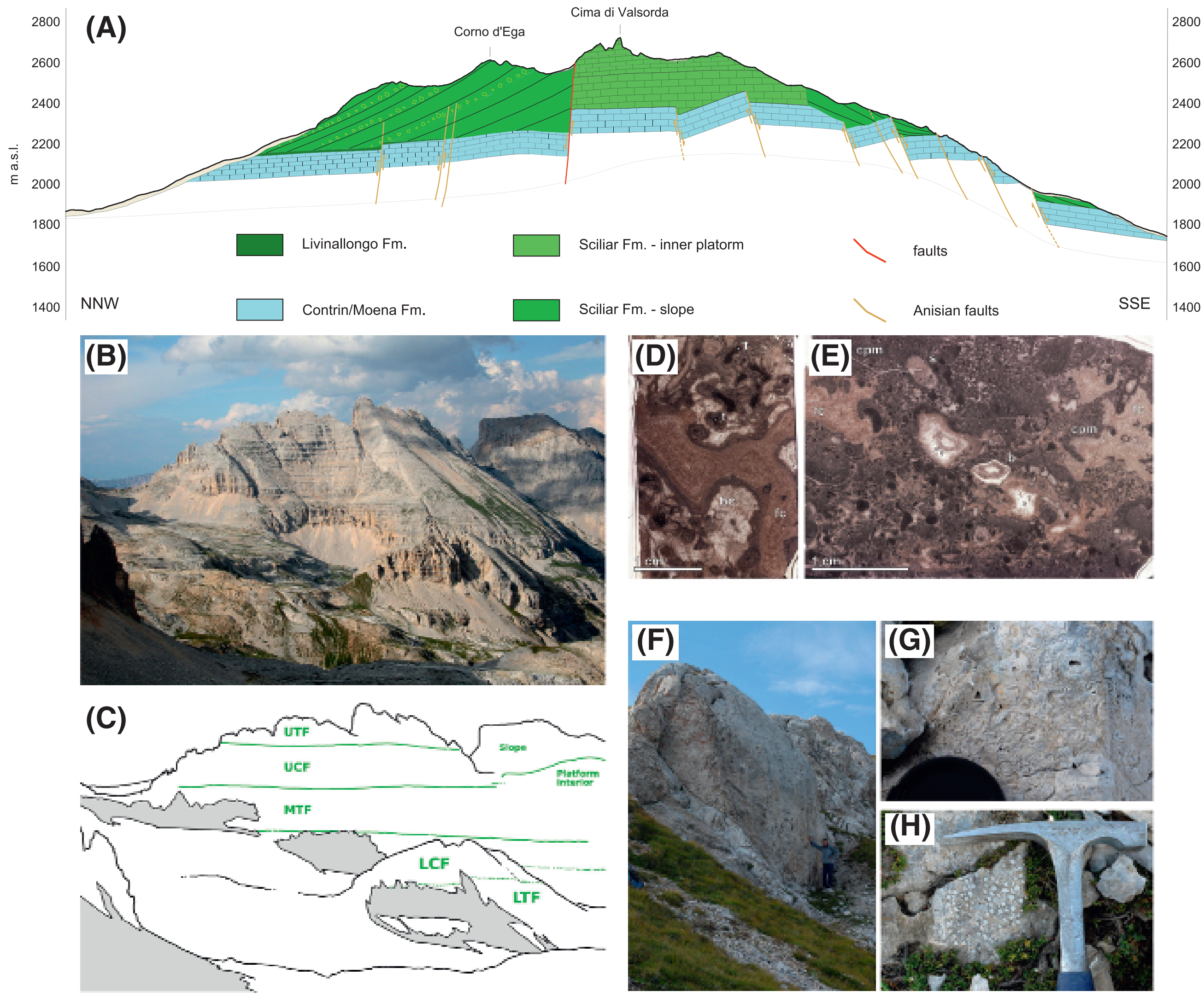


Figure 2. Overview of the Latemar platform. (A) A geological cross section of the Latemar platform in the area visited with this excursion. This cross section clearly shows the control of syndepositional tectonics on the evolution of the platform; in particular, the margin on the left (north–northwest) is controlled by a syndepositional (Anisian) normal fault, reactivated afterward by Alpine tectonics. (B) The core of the Latemar platform, as seen from Rifugio Torre di Pisa. Platform interior facies are easily identified because of their regular layering, whereas the massive facies of the peak on the right (Mount Cornon) are typical of the upper slopes. (C) The names refer to the lithostratigraphic subdivision of the inner platform. (D) Cementstone from the shelf break of Cima Feudo, northern Latemar. Botryoidal, formerly aragonitic cements (bc) and fibrous cements (fc) are the main types. *Tubyphites* (t) are also present but subordinate. (E) Microbial boundstone from Forcella dei Toac, with brachiopods (b), sponge (s), other fossils, and large primary cavities filled with fc. The fossils dispersed in a framework of clotted peloidal micrite (cpm). (F) Massive microbial boundstones as seen in the field. This is the typical facies of the shelf break and upper slopes at Latemar. (G) Microbial boundstone with large intraframework–fenestral pores, partially or totally filled by crusts of radiaxial fc. Metazoans represented by calcareous sponges (e.g., upper right corner) are common accessory components. (H) Colonial corals may also be present, though rare. Fm. = formation; LCF = lower cyclic facies; LTF = lower tepee facies; MTF = middle tepee facies; UCF = upper cyclic facies; UTF = upper tepee facies.

Pordoi. It disappears moving toward the center of the platform. This is because of differential compaction of the basinal deposits beneath the platform (Doglioni and Goldhammer, 1988).

The Lower Carnian Sella platform interfingers with mixed siliciclastic–carbonate sediments of the San Cassiano Formation (Figure 3). The northern side of the Sella Massif is characterized by a prominent megabreccia body, the Gardena Megabreccia, up to 200 m thick, which is intercalated between the volcaniclastic Wengen Formation and the San Cassiano Formation.

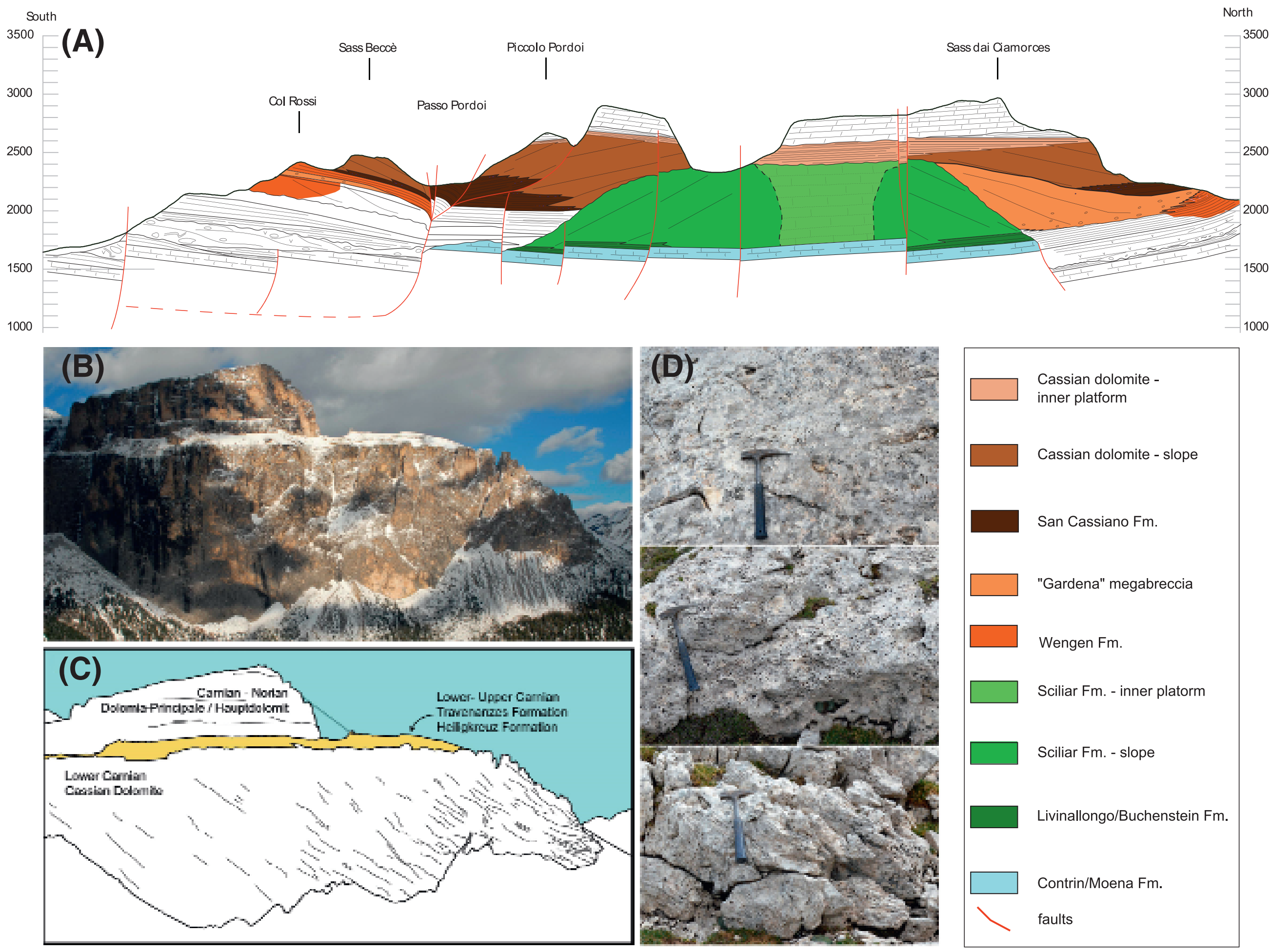
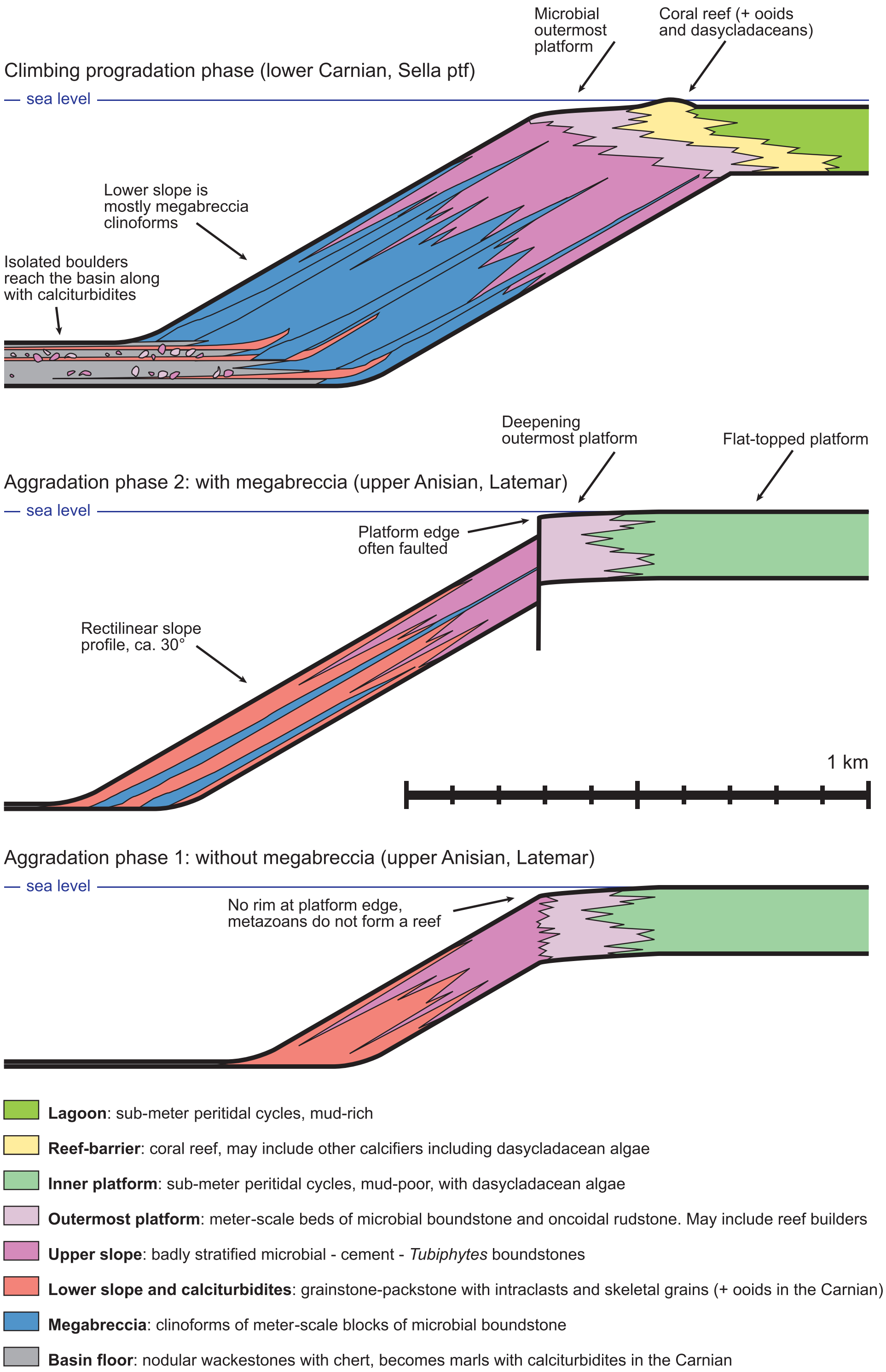


Figure 3. (A) A south–north geological cross section of the Sella platform from Passo Pordoi to Passo Gardena, showing the superposition of different generations of carbonate platforms. (B) The wall of the Sella massif at Sass Pordoi, as seen from near Passo Sella, with a lower massive clinostratified vertical wall corresponding to the Lower Carnian isolated platform (Sella platform). A prominent ledge and an upper well-stratified wall are immediately evident in the field. (C) Line drawing of the picture in (B), with trace of most visible clinoforms. Note that clinoforms do not originate at the shelf break and are not present in the upper 100–200 m of the slope, which is massive. In this picture, the Heiligkreuz and Travenanzes Formations (Fms.) are thinning toward the platform interior because of differential compaction of basinal areas, where the platform prograded, with respect to inner platform core. (D) Coral framestones at Col de Stagn. Corals are found as molds of colonies up to few meters in size, commonly in life position, demonstrating the existence of a coral reef at the margin of the Sella platform in the early Carnian.

Both the Latemar and Sella platforms exhibit a flat-bedded cyclic inner platform and highly inclined (~35°) slopes, which, in their upper part, are chiefly made of microbial boundstones. However, there are also major differences (Figure 4), and two should be highlighted here. (1) Differently from Sella, at Latemar, microbial boundstones did not form a topographic barrier, and there was thus no lagoon; and (2) the tight microbial framework and early marine cements at Latemar occluded primary porosity at the time of deposition, which was probably not the case at Sella.

At Latemar, the inner platform passes into flattish microbial boundstones seaward, and the shelf break is made by tight microbial boundstone and marine cements (Marangon et al., 2011). Facies of the shelf break are nearly indistinguishable from those of the upper slope. Therefore, there was no elevated, rigid barrier bordering the inner platform area at Latemar. In contrast, the shelf break facies of the Sella platform are coral–algal framestones. These must have formed a rigid barrier, which enclosed a lagoon. However, the existence of a metazoan-dominated margin in the Carnian platforms implies that a facies belt of reefs and ooid shoals was forming, differently from what could be observed in older platforms such as the Latemar. In analogy with modern coral reefs, such

Figure 4. Comparison of the depositional profiles of the Latemar and Sella. Note how different tectonic settings and type and distribution of calcifying organisms determined changes in the depositional geometry. Carbonate boulders are not shown within the slopes, but most of the slope profile at Sella and, in a late phase, at Latemar is made of megabreccia (blue). ptf = platform.



facies belt may, under favorable conditions, form deposits with high primary porosity, which may survive or develop moldic porosity during burial (e.g., Figure 3). Still, the upper slopes were made of microbial boundstones and have a massive appearance without clear clinoforms (Kenter, 1990) (Figure 3).

Other key differences are related to contrasting tectonic regimes. The vertically aggrading margins at Latemar had underlying normal faults that were probably active (Figure 2). This, along with strong subsidence, fixed the positions of the margins during the platform growth (Blendinger, 1986; Preto et al.,

2011) (see also Figure 4). The platform margins were also affected by enhanced fracturing (Bigi et al., 2015), because of either Anisian tectonics or later reactivation, and this potentially improves the local petrophysical properties. In contrast, the Sella platform prograded strongly, and there is no clear relationship between syndepositional tectonics and platform geometry (Figure 3).

GENERAL ACCESS AND SAFETY

The Dolomites can be easily reached from Venice, Verona, and Innsbruck airports, either by car or by public transport. The Dolomites offer an extensive variety of accommodation, e.g., in the Fiemme, Fassa, Badia, Gardena, or Cordevole valleys. Panoramic views of the platforms are reached both by public transport and by car. Closer examination of the rocks requires some hiking, commonly at high elevations. However, all the main localities can be reached via easy trails. The basic rules for safe hiking in a mountain environment should be observed. Many of the stops on the excursions are accessed via cable cars.

FIELD ITINERARY

This 2-day itinerary involves two excursions allowing a comparison of the depositional features of the late Anisian (Middle Triassic) Latemar and the early Carnian (Late Triassic) Sella platforms. Excursion to the Sella includes mostly car transfers and short walks (except for two optional stops) and could be reserved for a day of less fair weather, although reasonably good visibility is necessary at all locations.

Excursion 1: Latemar Platform

The itinerary starts from a viewpoint at Dos Capel, south of the Latemar (stop 1.1). The Latemar skyline seen here coincides well with the Middle Triassic depositional geometry that features a flat platform top, a gentle shelf break, and a steep slope plunging in the adjacent deep basin. From Rifugio Torre di Pisa (stop 1.2), the platform interior succession is visible from the back of Rifugio on the Cimon del Latemar (Figure 2B, C). A trace on the mountain crest then leads to the cross at Cima Feudo. This walk is along one of the best preserved inner platform–margin–slope transects of the Latemar platform. This is the platform-to-slope outcrop visible from stop 1.1, and this excursion provides the opportunity of looking at this depositional profile both in terms of depositional geometry (stop 1.1) and in terms of facies (from stop 1.2 to stop 1.3). Figure 2 illustrates some of the facies visible at stop 1.3. The last stop is optional. Lago di Carezza–Karersee can be reached by car with an approximately 40 min drive from Predazzo. From Lago di Carezza, the view of the Latemar platform is opposite to that from Rifugio Torre di Pisa and shows the other side of Cimon del Latemar.

Excursion 2: Sella Platform

The proposed itinerary is a clockwise journey around the Triassic isolated carbonate platform. At Passo Pordoi (stop 2.1), the progradations of the Sella platform and of a minor platform, the Sass Becé, are visible. From Pian Schiavaneis (stop 2.2), an outstanding view of the southern face of the Sella platform is clearly seen. The climbing progradation of the clinoforms on the underlying basinal deposits is the key feature. The following stop is in Passo Sella (stop 2.3), where it is possible to appreciate the interfingering of the basinal volcaniclastics of the Wengen Formation and the San Cassiano Formation (marls and calciturbidites) with the toe of slope of the prograding platform. At Passo Gardena (stop 2.4), a still not well understood megabreccia body can be seen, the so-called Gardena Megabreccia, which lies against (or cuts into) basinal deposits of the San Cassiano and Wengen formations. Above, the steep clinoforms of the Sella slopes are again visible. The last stop, which is optional, is at Col de Stagn, where the margin of the platform can be observed in detail: it could be reached with a lift from Corvara, a 15-min drive from Gardena Pass.

Key Learnings

In contrast to the late Cenozoic platform model, the Latemar and Sella are both isolated, high-relief carbonate platforms in which carbonate production was mostly achieved by microbial consortia. Despite some superficial similarities in geometry with modern carbonate platforms, they are fundamentally different from those of the present oceans, which are mostly built by metazoans. Yet, not all microbial platforms are the same, as highlighted for example by the two platforms of this field trip. Probably as a consequence of this variability, a comprehensive depositional model of microbial carbonate platforms does not exist yet. The Triassic microbial carbonate platforms of the Dolomites capture a relevant part of this variability, which is one of the reasons why a field trip to the Dolomites may be helpful to all carbonate sedimentologists and especially those working in the field of hydrocarbon exploration.

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