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TRIASSIC CARBONATE PLATFORMS OF THE DOLOMITES:
CARBONATE PRODUCTION, RELATIVE SEA-LEVEL FLUCTUATIONS AND THE SHAPING OF THE DEPOSITIONAL ARCHITECTURE

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Front Cover:

Middle Triassic, clinostratified slope breccias forming the southern portion of the Catinaccio-Rosengarten Massif, here visible in a spectacular summer sunset light.

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Introduction

Gianolla P. and Stefani M.

The spectacular Triassic outcrops of the Dolomites have been playing a major role in the understanding of the carbonate platforms since the XIX Century, as witnessed by a the huge number of publications, mainly written by German, English, French and Italian speaking geologists. The seminal studies by Richthofen (1860) and Mojsisovics (1879) already recognized the "reef" nature of the Dolomite platforms, described their steep slope clinostratifications (Ueberguss-Schichtung), and provided a first bio-chrono-stratigraphic framework (Figure 1.1). After a somewhat extenuate research period during the first half of the XX century, great attention was refocused on the Dolomites successions through the last 40 years. During this time interval, a first geometric and sequence stratigraphic synthesis was achieved (Bosellini, 1984), the major role of the non coralline bioconstructors and the importance of the synsedimentary cementation were recognized (Gaetani et al. 1981, Senowbari-Daryan et al., 1993; Russo et al., 1998b, 2000), the biostratigraphic and chronological framework was substantially refined (Brack & Rieber, 1993; Mietto and Manfrin, 1995a), the sequence stratigraphic understanding was enhanced through basin-platform correlation and refined dating (Gianolla et al., 1998a and references herein). During the last 20 yr, the origin of the platform-top sedimentary cyclicity (Figure 1.2) has triggered a hot debate, particularly on the interpretation of the Latemar Platform (Goldhammer et al., 1990; Brack et al., 1996; Egenhoff et al., 1999; Preto et al., 2001), without, for the time being, reaching any eventual conclusion.

The Dolomites Region is placed at the junction between German, Italian and Ladin speaking areas and each individual place is therefore often described by three quite different names (e.g. Rosengarten = Catinaccio = Cadenàc, second c pronounced as in child), the use of which is still triggering sensitive socio-political emotions. The intrinsic stratigraphic

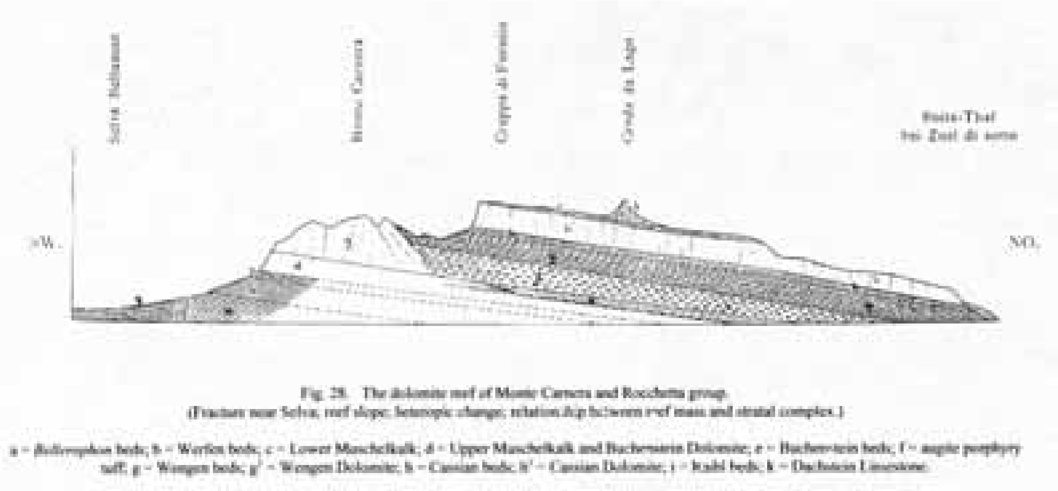


Fig. 28. The dolomite reef of Monte Cernera and Rocchetta group.
(Fracture near Selva; reef slope; heteropic change; relationship between reef mass and stratal complex.)

a = Bellerophon beds; b = Werfen beds; c = Lower Muschelkalk; d = Upper Muschelkalk and Buchenstein Dolomite; e = Buchenstein beds; f = augite porphyry tuff; g = Wengen beds; g' = Wengen Dolomite; h = Cassian beds; h' = Cassian Dolomite; i = Raibl beds; k = Dachstein Limestone.

Figure 1.1 - The Mojsisovics' (1879) "prophetic" geological profile of the visited Cernera – Crepa de Formìn carbonate platforms. The geometric relationships between the depositional bodies are essentially depicted as in the modern interpretation, even if some minor brittle tectonic structures are missing and the chonological interpretation provided by the original German text is somewhat different form the modern one. Moving from SW to NE, observe the fault, presently considered as an overthrusting of Permian evaporites (a Bellerophon Schichten) onto Middle Triassic volcanogenic units (g Augitporphyrtuffe), the Anisian Upper Serla Plafrorm (Unterer Mushelkalk), the low relief Contrìn Platform (d Oberer Mushelkalk) interfingering with Dont Fm basinal beds (e Buchensteiner Schichten), the aggradational-retrogradational uppermost Anisian Cernera Platform (g Wengener Dolomit), which was terminated by an early drowning and onlapped by terrigenous and volcanoclastic beds (f Augitporphyrtuffe and g Wengener Schichten), followed by basinal argillaceous-calcareous beds (Cassianer Schichten), shallowing up into a Cassian platform (h Cassianer Dolomit). For further explanation see introduction and Day 4 texts.

Figure 1.2 - A spectacular view of the cyclic Latemar platform-top succession, punctuated by high frequency emersion surfaces, the interpretation of which has triggered a hod debate, through the last 20 years. Coeval platform and basinal units will be visited during the trip.

variety, the long lasting geological research history and the glottological complexity of the area combine to make the stratigraphic terminology of the Dolomites quite a complex one indeed. We have made some effort to simplify the intricate litho-bio-chrono-sequence stratigraphic terminology, but we nevertheless felt compelled to still give an articulate stratigraphic picture of the Dolomites. The guide authors themselves enjoy different linguistic and scientific backgrounds and have sometime expressed diverging geological views; the guide editor (M. Stefani), while thoroughly reviewing the paper, has chosen not to impose his personal opinions, preserving this significant diversity as a scientific richness and as a way to illustrate the geological research in its making, at the risk to expose the reader to some degree of complexity; we hope that the actual view of the spectacular outcrops of the region will clarify any discussion.

The excursion will be aimed at illustrating both basin, slope and platform facies, always framed within their large depositional geometry. The carbonate platforms of the Dolomites grew in quite an active structural framework and were severely affected by a Middle Triassic magmatic event. The trip will move from west to east, starting with Anisian-Ladinian pre-volcanic platform and basin carbonates (Schlern Day 1; Seceda, Odle, Day 2), to move then on other pre- (Cernera, Day 4; Marmolada, Day 6) and post-volcanic (Sella, Day 3) isolated high relief platforms. The younger visited units consist of Carnian low relief, terrigenous-carbonate units (Falzarego area, Day 5).

Regional tectonic setting

The Dolomite Mountains form the central-northern portion of the Southern Alps (Figure1.3, Doglioni, 1987; Castellarin et al., 1998; Castellarin & Cantelli, 2000), a non metamorphic south-vergent thrust belt belonging to the much larger Alpine Chain and deriving form the comparatively gently deformation of a passive continental margin of the Mesozoic Tethys Ocean. The region records several tectonic and magmatic events including: (i) Permian rifting and massive magmatism, inducing a lithospheric anisotropy that was to significantly influence the

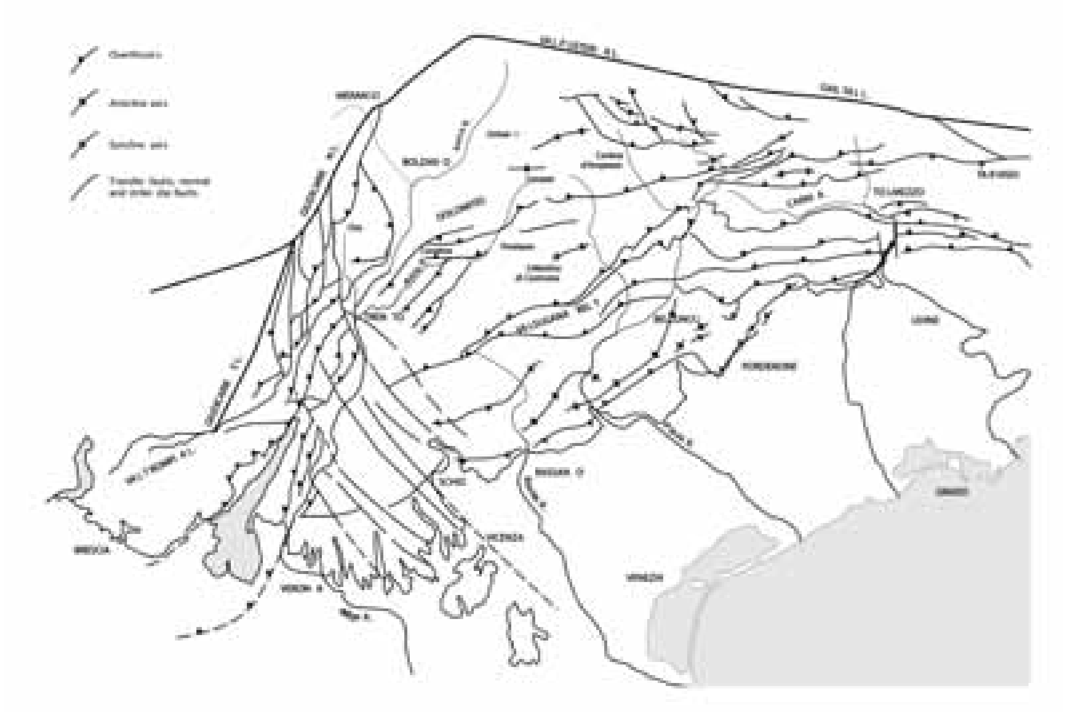


Figure 1.3 - Structural scheme of the Dolomites and of the surrounding Southernalpine region. (After Castellarin et al. (1981) – modified).

Triassic and Alpine evolution. (ii) Middle Triassic (trans-) tensional tectonics, associated with differential subsidence and uplifting and climaxing into a magmatic event. The short-lived Ladinian event induced epicrustal intrusions (Monzoni, Predazzo, Cima Pape) and a significant shoshonitic volcanism (Sloman, 1989). A late Ladinian slowing down of the deformation followed. This Middle Triassic dynamics played a major role in the shaping of the visited carbonate platforms. (iii) Continental margin rifting, starting in the Upper Triassic and climaxing into the western Tethys opening, during Jurassic times, without producing any known magmatism in the visited area. (iv) Several superimposed phases of compressional Alpine deformation, mainly brittle in nature, affecting the region during Tertiary times and generating large overthrusting and strike slip deformation. The significant tectonic shortening and the structural telescoping combine to make the detailed palaeogeographic reconstruction of the area difficult, as for instance visible in the visited Marmolada area (Day 6). The "palaeogeographic" sketches hereafter illustrated (Figure 1.6) are therefore just non-palinspastic representation of the present-day distribution of the stratigraphic units. Only minor Tertiary basaltic diking is known from the Dolomites region. A large portion of the present elevation was generated during the last 5 million years, even during the Quaternary times, which saw the development of several massive glacial episodes, the imprinting of which is visible in the spectacular regional landscape, which is largely influenced by the strong stratigraphic variability (carbonate versus basinal units).

Regional Stratigraphy

The stratigraphic framework of the Dolomites includes Permian to Cretaceous units (Figure 1.4), but the area is sharply dominated by the impressive Triassic formations, making the region a classical one for the study of this period. Following the Carboniferous Variscan orogeny, deformed and metamorphosed Palaeozoic rocks were uplifted and eroded, to form the regional basement. The Permian (trans-) tensional rifting resulted in the accumulation of a thick volcanic package, the Bozener Quartz Porphirit, mainly riodacitic in nature, with thickness locally exceeding 2000 m; these volcanites are however lacking in the eastern Dolomites. The

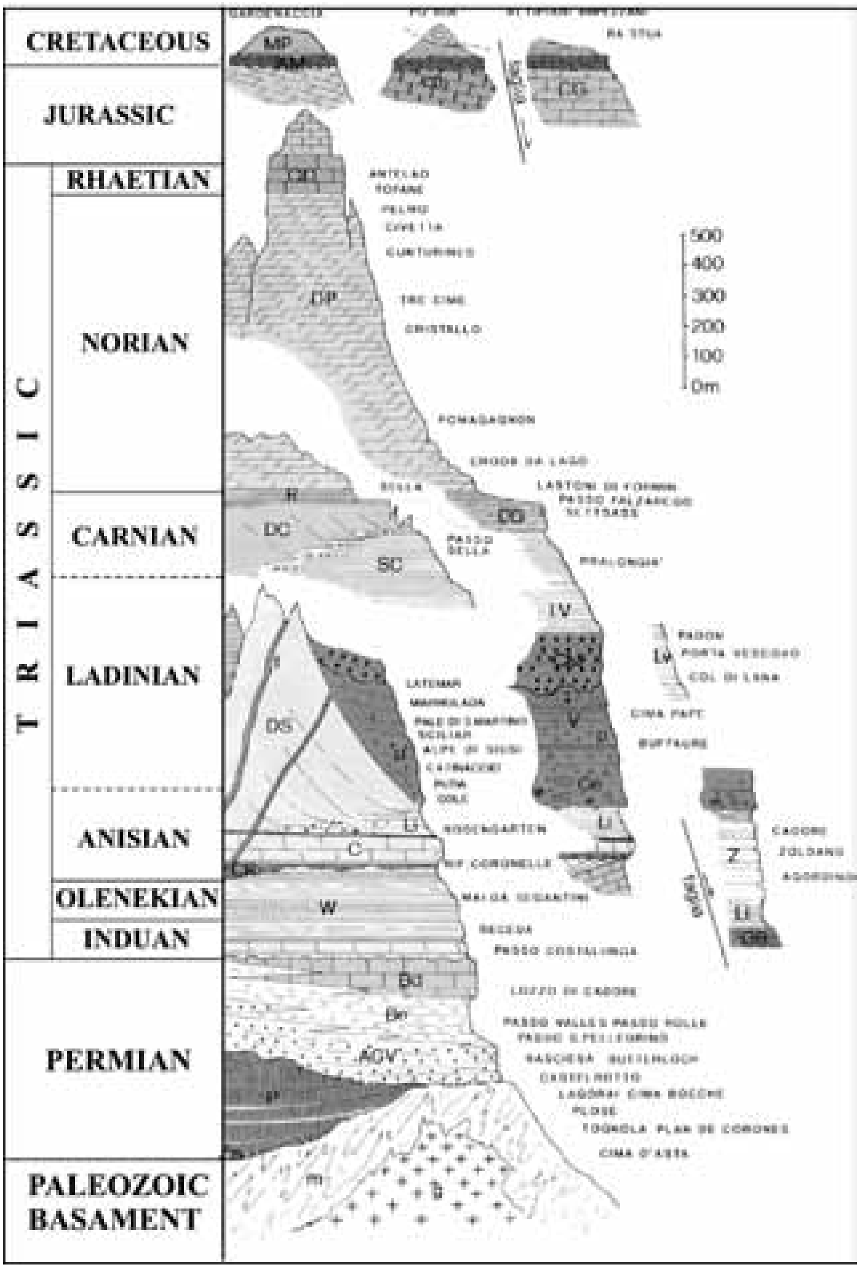


Figure 1.4 - Schematic sketch of the central-western Dolomites stratigraphic succession. Metamorphics (m); Granite (g); Basal Conglomerate (BC); Acidic Volcanites (P); Gardena Sandstone (GS); Bellerophon Fm: Black limestone (Bl), Evaporites (Be); Werfen Fm. (W); Braies Group (GB); Richthofen Conglomerate (CR); Contrin Fm. (C); Livinallongo/ Buchenstein Fm. (B); Zoppè Sandstone (Z); Sciliar/Schlern Fm (SD); Volcanics (V): pillow lava (p), hyaloclastites (h), Chaotic megabrecciae (Ch), dykes (d); La Valle/Wengen Fm. (FM, LV), Marmolada Conglomerate (MC); San Cassiano Fm. (SC); Cassian Dolomite (DC); Heiligkreuz/Dürrenstein Fm. (DD); Raibl Fm. (R); Dolomia Principale/ Haupdolomite (DP); Dachstein Limestone (CD); Calcari Grigi (CG); Rosso Ammonitico (RA); Puez Marl (MP) - (Modified after Bosellini et al. 1996).

sedimentary accumulation throughout the Dolomites started with Late Permian fluvial red beds (Arenarie di Val Gardena – Groedner Sandstein, Massari & Neri, 1997). Transgression from the Palaeothethys then triggered the accumulation of shallow marine evaporites and carbonates (Bellerophon Fm), providing the major tectonic detachment level of the region. The Lower Triassic (Werfen Fm) consists of a complex storm-dominated succession of shallow-marine carbonate and terrigenous deposits, showing an average thickness of 300-400 m. Repeated emersion episodes enable these successions to be subdivided into several depositional sequences (cf. chronostratigraphic scheme at the end of the volume). These rather laterally uniform successions witness a period of spatially uniform, comparatively moderate subsidence, but their uppermost portion starts to record differential subsidence. The Lower Triassic generally record arid climatic condition, as witnessed by evaporitic mineral occurrence.

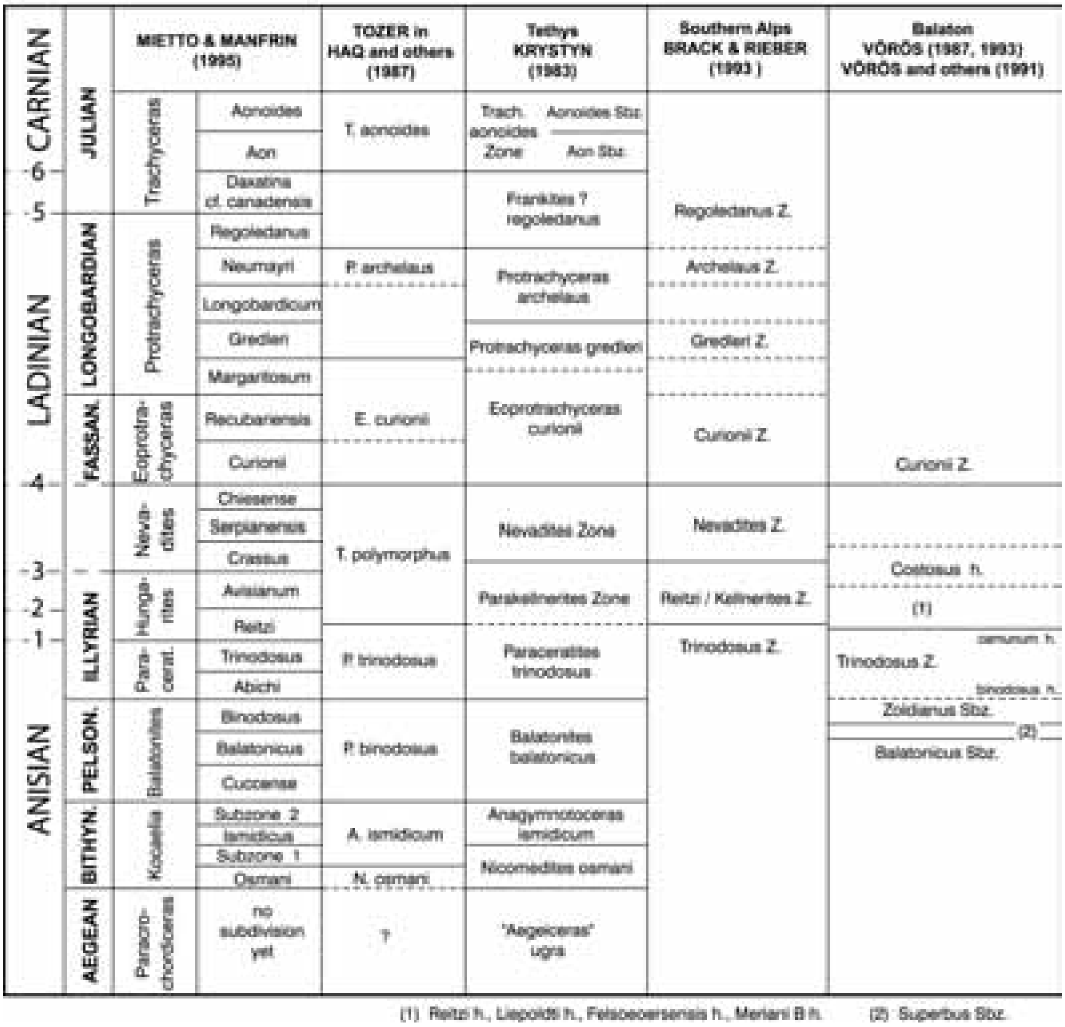
Anisian platforms

In the early Middle Triassic, a first widespread tidal flat unit (Lower Serla Dolomite), laterally grading into evaporitic environments, gave way to three generations of carbonate platforms, known as Monte Rite Fm, Upper Serla Dolomite and Contrìn Fm, grown within an increasingly active tectonic framework and belonging to different depositional sequences, punctuated by emersion unconformities, associated with continental conglomerates. During the middle-upper Anisian, while subsidence was active throughout the eastern Dolomites, the western areas experienced a significant uplifting and subaerial erosion phase, locally reaching down the Permian (Bosellini, 1968, Day 3). The two older generations are therefore mainly recorded only in the eastern portion of the Dolomites. In these oriental areas, the platform systems eventually drowned, because of a general sea-level rising trend, and basinal environments, recorded by terrigenous-carbonate successions (Dont, Bivera and Ambata Fms), developed. Long lasting basinal conditions then dominated the eastern portion of the Dolomites (Figure 1.6a-e), up to the eventual Carnian infilling of the accommodation space.

During a later Anisian phase, renewed transgression brought back marine environments to the western areas, where shallow water carbonate platforms (Contrìn Fm) developed (Figure 1.6a). These platforms, rich in dasycladacean algae, associated with encrusting and problematica organisms (*Tubiphytes*), widely prograded over basin terrigenous-carbonate deposits (Morbiàc Fm), but then dis-anoxic intraplatform basins developed (Moena Fm), conquering former shallow water platform areas. During the Anisian, sporomorph and plant associations, dominated by Volzia florae, record comparatively moister conditions.

Pre-volcanic carbonate platforms (late Anisian – early Ladinian*)*

A regional drowning terminated the Contrìn carbonate system, while organic rich anoxic sediments marked the base of deepening up basinal successions (Livinallongo Fm = Buchensteiner Schichten p.p.), visited during the second day of excursion (Seceda). This organic rich level often represents a potential source-rock horizon, coeval to actual subsurface source rocks. Shallow water carbonate-producing environments survived only at small isolated highs, which were soon to experience a rapid aggradational evolution, forced by fast regional subsidence, which created a large accommodation space. The aggrading pinnacles initially shared many facies similarities with the former and wider Contrìn platforms, being still rich in dasycladacean and *Tubiphytes* micritic sediments. The upward growth of several buildups was terminated by an early drowning, especially in the eastern more subsiding portion of the region (Cernera Platform, Day 4) and was covered by condensed ammonoid-bearing limestones. The western buildups (referred to as Sciliar-Schlern Dolomite or Marmolada Limestone, according to their composition) were on the contrary able to survive and catch up the relative sea level rise (e.g. Latemar, Catinaccio, Marmolada Platform, Days 1, 2, 6). These platforms rapidly reached an average thickness of 800-900 m, while just a few tens of metres of cherty limestones were accumulated in the adjacent basins (Knollenkalke Mb of the Livinallongo Fm, cf. Day 2). The aggradation rate of these late Anisian - early Ladinian buildups was in the order of 200-400 Bubnoffs (m/Myr), but significant lateral variations did exist, being largely controlled by differences in the subsidence speed. In the eastern Dolomites, both the basinal and the platform successions are indeed somewhat thicker than their western counterparts. During the early Ladinian, the subsidence slowed down considerably and a massive progradation phase began, spanning over a comparatively short early Ladinian interval (cf. Figure Rosengarten). Through this progradation, the isolated pinnacles



					MIETTO & MANFRIN (1995)	TOZER in HAQ and others (1987)	Tethys KRYSTYN (1983)	Southern Alps BRACK & RIEBER (1993)	Balaton VÖRÖS (1987, 1993) VÖRÖS and others (1991)
	CARNIAN	JULIAN	Trachyceras	Aonoides		T. aonoides	Trach. aonoides Zone — Aonoides Sbz.		
				Aon			Aon Sbz.		
6				Daxatina cf. canadensis			Frankites ? regoledanus	Regoledanus Z.	
5	LADINIAN	LONGOBARDIAN	Protrachyceras	Regoledanus					
				Neumayri		P. archelaus	Protrachyceras archelaus	Archelaus Z.	
				Longobardicum					
				Gredleri			Protrachyceras gredleri	Gredleri Z.	
				Margaritosum		E. curionii	Eoprotrachyceras curionii		
		FASSAN.	Eoprotra-chyceras	Recubariensis				Curionii Z.	
				Curionii					Curionii Z.
4			Neva-dites	Chiesense		T. polymorphus	Nevadites Zona	Nevadites Z.	
				Serpianensis					
				Crassus					Costosus h.
3	ANISIAN	ILLYRIAN	Hunga-rites	Avisianum			Parakellnerites Zone	Reitzi / Kellnerites Z.	(1)
2				Reitzi					
1			Para-cerat.	Trinodosus		P. trinodosus	Paraceratites trinodosus	Trinodosus Z.	camunum h. Trinodosus Z. binodosus h.
				Abichi					
		PELSON.	Balatonites	Binodosus		P. binodosus	Balatonites balatonicus		Zoldianus Sbz. (2)
				Balatonicus					Balatonicus Sbz.
				Cuccense					
		BITHYN.	Kocaelia	Subzone 2		A. ismidicum	Anagymnotoceras ismidicum		
				Ismidicus					
				Subzone 1			Nicomedites osmani		
				Osmani		N. osmani			
		AEGEAN	Paracro-chordiceras	no subdivision yet		?	'Aegeiceras' ugra		

(1) Reitzi h., Liepoldti h., Felsoeoersensis h., Meriani B h.   (2) Superbus Sbz.

Figure 1.5 - A comparison of various modern ammonoid biozonation schemes for the Triassic, according to Mietto and Manfrin, 1995. Many of these biostratigraphic units, as well as the chronostratigraphic-geochronological subdivisions are still poorly defined and somewhat controversial in nature, especially at the substage level, and will be probably redefined in the near future. (1-6: candidate boundaries).

expanded into 5-10 km wide platforms. In the western Dolomites, the average migration rate of the base of slope was probably between 1,400 and 2,700 m/Ma. Since the progradation rate largely exceeded the basinal accumulation rates, the contact surface between base of slope and basinal units is normally sharp and sub-horizontal in geometry, simulating a pseudo-downlap relationship. The progradational phase was characterized by pervasive phreatic marine cementation of the margin and upper slope limestones (e.g. Marmolada, Day 6) and by the development of very steep (up to 30-40°), planar breccia slopes (Figure 2.2, Day 1). In the northeastern Dolomites, where subsidence was still quite active, the rate of the base of slope migration was considerably smaller.

During the same time interval, acidic volcanogenic layers ("Pietra Verde") were deposited in the entire Southern Alps, providing large scale physical correlations (Brack & Rieber 1993, cf. Day 2), whereas the eastern Dolomites were the site of massive accumulation of turbiditic sands (Arenarie di Zoppè), generated by the erosion of a metamorphic basement outcropping in southern areas. The terrigenous and volcanic deposits witness an active tectonic scenario, which was soon to develop an important magmatic phase, within the Dolomites themselves.

The volcanic event

The carbonate platforms were involved into the middle Ladinian tectono-magmatic event; they were cut by a great number of shoshonitic basaltic dykes and carved by large collapsing episodes, while huge heterogeneous megabreccia bodies (Caotico Eterogeneo Auct.) accumulated into the adjacent basins. The volcanic products (pillow lavas, hyaloclastites) partially infilled the depressions, "freezing" the former platform morphology by onlapping their slopes (Figure 5.4B, Day 4, Pale di San Lucano). A few platforms of the western Dolomites, placed in close proximity to the volcanic centres, were buried beneath the volcanic and volcanoclastic products and partially involved into calderic collapses and thermometamorphism. However some kind of carbonate production was still active at any time, even close to the major magmatic centres (e.g. Sciliar/Schlern). In areas far away from the volcanoes (e.g. eastern Dolomites) the carbonate production was able to keep on at any time and the lack of any depositional break makes the distinction between pre- and post-volcanic succession locally difficult.

Post-volcanic platforms (late Ladinian-early Carnian)

At the fading out of the magmatic activity, an even healthier carbonate production developed, supporting the widespread progradation of several generations of post volcanic carbonate platforms (so called Cassian Dolomite, sometimes referred to also as Oberer Schlern Dolomit). The early post-volcanic platforms record the colonization of the margin environments by *Thecosmilia*-like branching corals, which were however always subordinated to smaller sediment-producing organisms. Ooid grains reappeared during the earliest phases of the volcanic activity (Acquatona Fm), after being lacking since the Early Triassic.

In the western Dolomites, the available accommodation space was mainly inherited from the pre-volcanic fast subsidence phase; in the eastern Dolomites the subsidence was still ongoing and considerable. The high basinal sedimentation rates, supported by the huge volcanoclastic input, induced a shallowing evolution of the basins and often forced a climbing base-of-slope migration, visible in areas facing major sediment sources (e.g. western Sella Massif, Day 3). Clinostratifications were now often concave in shape and generally less steep than the pre-volcanic ones, being richer in micrite and characterized by some argillaceous content.

Early post-volcanic aggrading platform-top successions are relatively thick in the subsiding eastern Dolomites (e.g. Picco di Vallandro-Dürrenstein), whereas in the western Dolomites they were thinner and associated with some terrigenous influx ("Schlern Plateau Beds"). In the central-eastern Dolomites, two platform generations (Cassian Dolomite I and II Auct.) are separated by a temporary stillstand of the progradation, matched with a renewed transgression and with the onlap of the basinal beds onto former carbonate slopes.

The Carnian crisis of the rimmed carbonate platforms

During the early Carnian, the amount of loose carbonate mud fed onto to the prograding slopes increased, while some clay was still available and the shallowing of the basin reduced the platform elevation; these factors combined together to reduce the slope angles, as visible in the latest Cassian Platforms (e.g. Lastoi di Formìn, Day 3, and Picco di Vallandro/Dürrenstein). The very late evolution of these platforms was matched with the appearance of patch reefs, for the first time rich in "modern" colonial corals (Alpe di Specie, Russo et al., 1991), while true buildup systems disappeared. This evolution probably corresponds to a worldwide crisis of the rimmed carbonate platforms.

The basin eventually shallowed up into the photic zone, probably also because of a relative sea-level drop, starting an in situ active carbonate production, even in the deeper depocentre areas. This evolution triggered the deposition of the low gradient Heiligkreutz Fm/Dürrenstein Fm, which records a complex palaeoenvironmental evolution. Purely carbonate sub- to peri- tidal successions laterally and vertically graded into mixed and terrigenous systems (e.g. Heiligkreutz Fm/Dürrenstein Fm, Day 5). In the western Dolomites, this Carnian interval is however poorly recorded, mainly because of the lack of available accommodation space (cf. Sella Massif, Day 3). These complex interval witness important climatic fluctuations, marked by the development of moist phases, and it is also noteworthy for its harbouring some of the oldest known amber.

Upper Triassic carbonate platform: a regional peritidal succession

During the middle-late Carnian, a variety of shallow-water terrigenous, evaporite and carbonate environments developed (Raibl Fm/Travenanzes Fm, Day 5), witnessing a sharp return to aridity. During the following phase, a large carbonate platform developed through wide Southern-Alpine areas. In the central-western Dolomites, this carbonate system (Dolomia Principale = Hauptdolomit), normally started with bioturbated subtidal facies, grading upward into rapidly aggrading peritidal successions (Bosellini and Hardie, 1988). During the Norian, dis-anoxic intraplatform depressions, rich in carbonate mud and organic matter, developed in different areas of the wide Dolomia Principale platform, to the east (Friuli and Carnia), south (Bellunese) and west (Lombardia) of the Dolomites. Differential subsidence controlled the evolution of this Upper Triassic platform, heralding the rifting stage of the Jurassic passive continental margin of Adria. Within the Dolomites, a striking thickness variation will show up at the sides of the Val Badia, while comparing the visited Sella (about 250 m, Day 3) and Tofane successions (about 1,000 m Day 5); in other southern-alpine (central Lombardy) areas the Norian-Rhaetian interval can exceed 4,000 m in thickness.

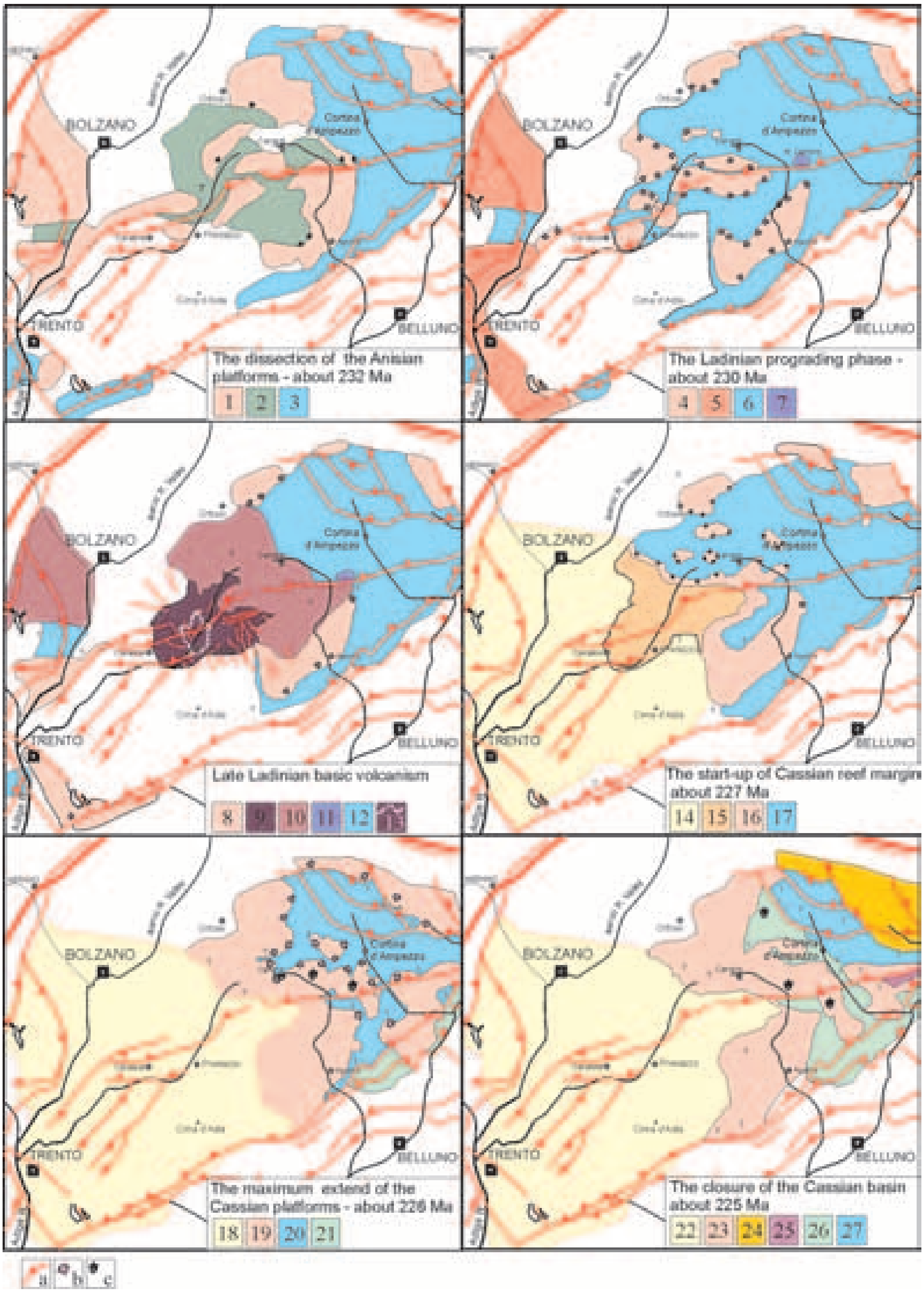
During the Jurassic passive margin evolution, the region experienced a generalized drowning, and then remained under pelagic condition up to at least until the uppermost Cretaceous.

Evolution of frame-building organisms in the triassic platforms of the dolomites

F. Russo, A. Mastandrea. M. Stefani & C. Neri

Following the biological crisis marking the Permian-Triassic boundary, “reef” communities virtually disappeared for a 7-10 Myr interval (Flügel 2002). As previously discussed, the Triassic of the Dolomites includes many carbonate platform generations, ranging from Anisian to Norian-Rhaetian in age (Fig 1.7). The older carbonate platforms occurred during the Anisian Time (Mt Rite, Upper Serla and Contrìn Fms). These buildups were generally characterised by a limited relief and lacked any wave-resistant organic framework, being dominated by binder and buffler biota, as microbial communities (microbialites), sphinctozoans (*Olangocoelia otti*, *Celiphia zoldana*, ecc.) and briozoans. (Gaetani et al., 1981; Fois & Gaetani, 1984; Senowbari-Daryan et al., 1993). Crinoidal calcarenites were locally abundant (e.g. Cernera, Day 4). The Ladinian buildup biofacies were still dominated by microbialites and/or organic-induced syndepositional cements (e.g. Marmolada, Day 6), whereas the skeletal organisms played a reduced lithogenitic role, even if they were now characterised by a much greater taxonomic diversity and abundance (Biddle, 1981; Fois & Gaetani, 1981; Brandner et al., 1991; Russo et al., 1997; 1998; Keim & Schlager, 1999). Despite the minor role of the skeletal faunae, near the Anisian-Ladinian boundary the carbonate productivity was so large to be able

Figure 1.6 - Schematic, non palinspastic sketches of the palaeogeographic elements distribution during Middle and Upper Triassic times in the Dolomites region. Alpine deformation has structurally telescoped the region (cf. Figure 1.3) producing a significant shortening, particularly so within the basinal units. The depositional evolution of the area saw the development of several generations of isolated carbonate platforms, until the eventual Carnian filling up of the accommodation space. a) Late Anisian. Low relief carbonate platforms (Contrìn Fm, 1), interspaced with anoxic depressions (Moena Fm, 2) and flanked by the wider, terrigenous influenced eastern Dolomites basin (Ambata Fm, 3). b) Early Ladinian. The maximum progradation phase of platforms (Sciliar/Schlern Fm, 4), about 800 m thick, immediately predating the volcanism onset; 5: inner platform, 6: basinal areas, 7: drowned platform. c) Middle Ladinian. At the climax of the magmatic activity, a large volcano develloped in the Predazzo area, eventually evolving into a caldera depression. The surrounding platforms were killed and buried by volcanic and volcanoclastic, whereas other carbonate systems survived in more distal areas; 8: stressed carbonate platfoms; 9: main volcanic area, 10: buried platforms, 11: drowned platform, 12: volcanoclastic basinal areas, 13: inferred extension of the Predazzo caldera. d) Late Ladinian. The volcanogenic materials filled up the inter-platform basins in the south-western Dolomites. At the fading out of the volcanisms, a new generation of platforms (Cassian D., 15, 16) started to rapidly prograde over the shallowing volcanoclastic basins (La Valle/Wengen Fm, 17); 14: while emerging main land development. e) Early Carnian. The expanding platforms (Cassian Dm, 19) had conquered the majority of the area, leaving a few shallowed terrigenous-carbonate depressions (upper S. Cassiano Fm: 20: coarse terrigenous facies, 21). This depositional system was eventually terminated by a relative sea-level drop; 18: while emerging main land development. f) Carnian Time. A complex system of shallow water carbonate and terrigenous environments developed across the eastern Dolomites (Heiligkreuz-Dürrenstein Fm, 23: emerged carbonate areas, 24: carbonate tidal flat, 25: restricted circulation lagoon, 26: coastal alluvial plain and mixed carbonate and siliciclastic areas, 27: basins. a: overthrusts, b: clinostratification, c: tetrapods footprints.


BOLZANO
Cortina d'Ampezzo
TRENTO
BELLUNO
The dissection of the Anisian platforms - about 232 Ma
1
2
3
The Ladinian prograding phase - about 230 Ma
4
5
6
7
Late Ladinian basic volcanism
8
9
10
11
12
The start-up of Cassian reef margin about 227 Ma
14
15
16
17
The maximum extend of the Cassian platforms - about 226 Ma
18
19
20
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The closure of the Cassian basin about 225 Ma
22
23
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a
b
c

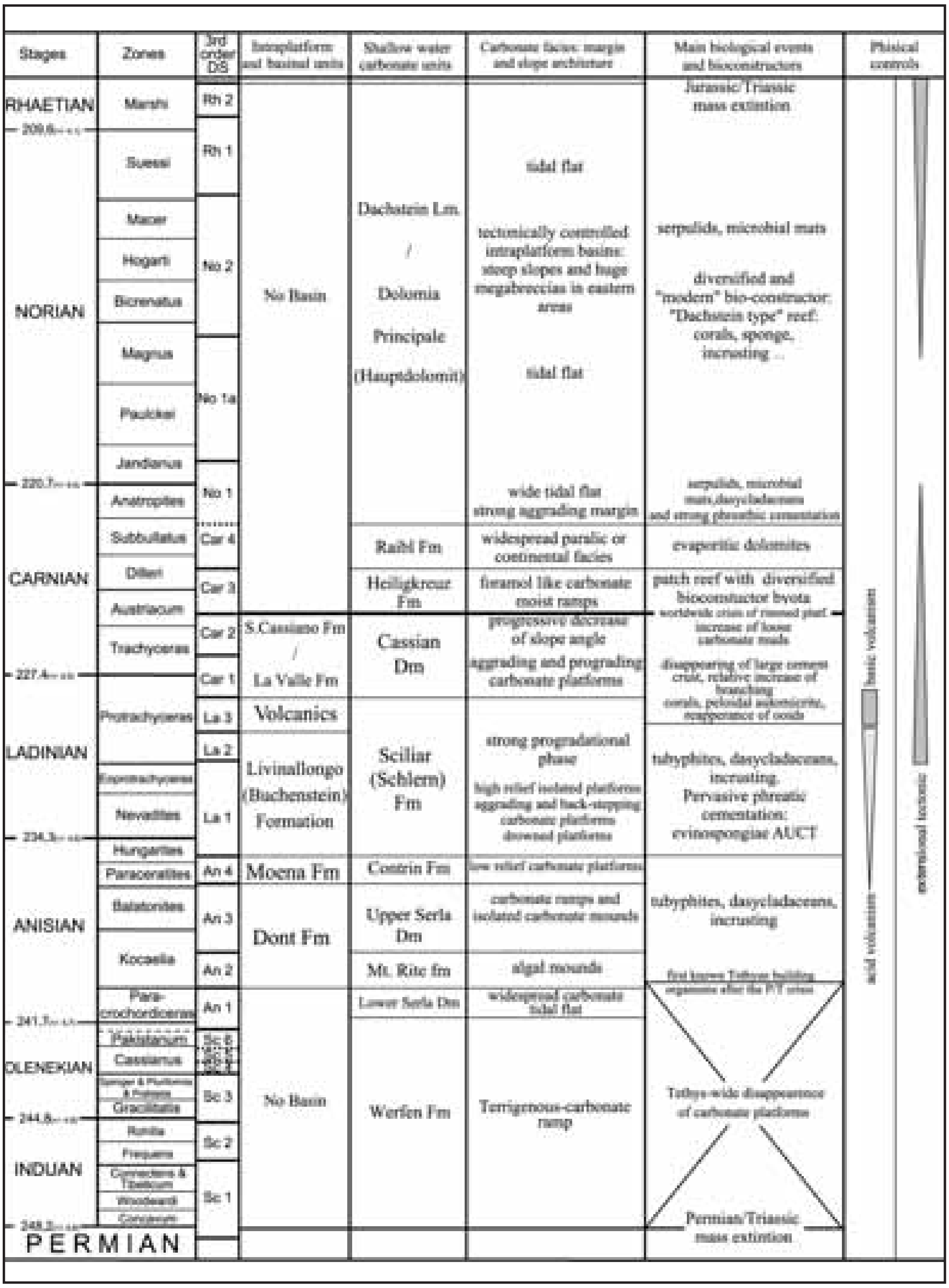


Figure 1.7 - A synthesis of the Triassic carbonate platform stratigraphy of the Dolomites. For further explanation of this complex scheme, see the guide-book text. Modified from Bosellini et al. (2003b); ages from Gradstein et al. (1995).

to take pace with the strong subsidence, supporting the growth of impressive carbonate buildups, many hundred of metres thick (Sciliar/Schlern Fm).

During the Late Ladinian and the Carnian p.p., the post-volcanic platforms were developed (Cassian Dm, e.g. Sella, Day 3). The original fabric, texture and microfacies of these carbonate buildups can be studied in detail only on the so called “Cipit Boulders”, platform-derived olistoliths resedimented into low-permeability argillaceous basinal units, which prevented the dolomitising fluid from circulating, thus preserving the block facies in a comparatively pristine state (Russo et al., 1991). The “Cipit” facies are preserved as isolated blocks or megabreccia lenses within the S. Cassian and La Valle/Wengen Formations, their age spanning from the Upper Ladinian to Lower Carnian (from the Archelaus to the Austriacum p.p. Zones, Mastandrea, 1994; Mastandrea et al., 1997). Some less well preserved facies are locally found also within dolomitised platforms, such as in the Sella (Keim & Schlager, 2001, cf. Day 3). The post-volcanic platform microfacies manly consist of bindstones and subordinated bafflestones, dominated by three main components: micrites, cements and skeletons. The micrites may show disorganized, thrombolitic or stromatolitic microfabric, with an aphanitic or peloidal texture (Figure 1.8-10) (Russo et al., 1998a ;1998b). Micromorphological and fabric features allow a first distinction between the automicrite (microbialite) and allomicrite components to be proposed. In the Cassian Platforms, the dominant component consists of automicrite (more than 50%).

The detrital micrites (allomicrites) are by far the minor constituent of these facies. The cements quantitatively represent the second component of the microfacies (25-30% of primary marine cements were recognised (isopachous high magnesium calcite, botryoidal aragonite), and secondary blocky ferroan calcite, filling up the residual cavity space.

Fossilised skeletal organisms normally represent less than the 10% of the entire rock volume of the Cassian Platforms. The faunae are dominated by skeletal cyanobacteria, like *Cladogirvanella cipitensis* (Figure 1.12a) as well as by microproblematica, like *Tubyphites* (Figure 1.12b). The lithogenetic contribution of metazoans is sharply subordinated, but calcified demosponges are often visible and locally comparatively abundant.

These microfacies suggest to view the Cassian buildups as large mud mounds (*sensu* Bosence & Bridge, 1995), with productive margins mainly made up by microbialites, with subordinate amount of skeletal remains. The primary marine cements provide evidence of a widespread early syndepositional lithification, but in the syn-post-volcanic platforms they were far from playing the sharply dominating role recorded in the pre-volcanic ones (e.g. Marmolada, Day 6).

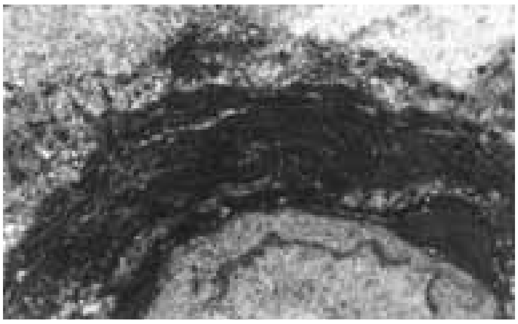


Figure 1.8 - Stromatolitic microbialite. Passo Gardena. X 30.

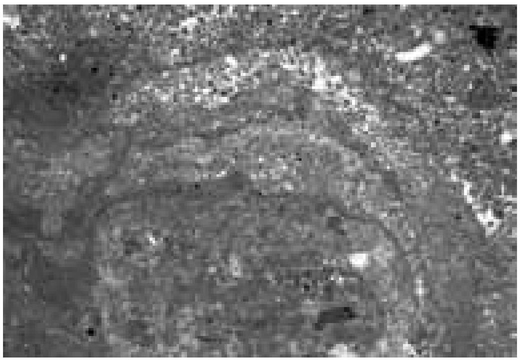


Figure 1.9 - Stromatolitic peloidal microbialite. Punta Grohmann. X 7.5.

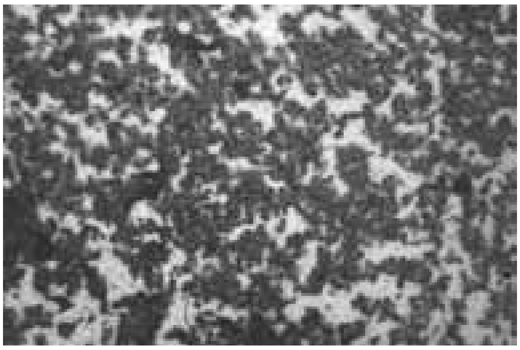


Figure 1.10 - Thrombolitic microbialite. Punta Grohmann. X 6.

Towards the top of Julian Substage (Carnian), at

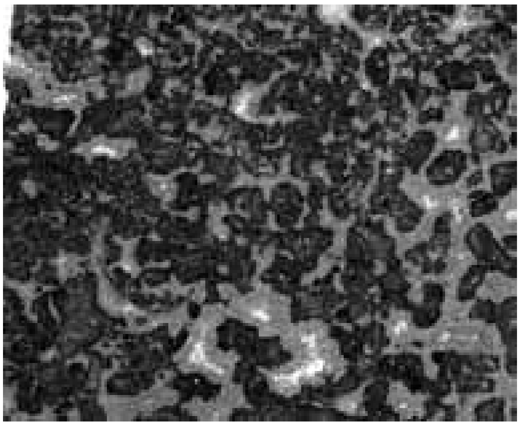


Figure 1.11 - Bioconstructed and strongly cemented margin facies from the Latemar paltform (lower cyclic facies, Valle del Fontanel).

the base of the Heiligkreutz/Dürrestein Formation (i.e. Alpe di Specie) patch-reefs show much more "modern" faunal association, very well preserved in limestones bodies embedded within impermeable marly matrix, allowing the perfect preservation of both skeletal microstructure and cements mineralogy and texture (Mastandrea and Russo, 1995; Russo et al., 1991). For the first time in the Triassic, a real primary building organism framework developed, dominated by calcified demosponges (stromatoporoids, sphinctozoans, chaetetids, inozoans) (Fig 1.12c,d,f) and scleractinians (Figure1.12e). Taxonomic diversity increases greatly and the skeletal component exceeds the 50% of the rock volume. Corals were however still subordinated to sponges, in these faunal associations. These biofacies anticipate the "modernization" of the reef-building communities, occuring at a global scale between the Late Carnian and the Norian-Rhaetian, a biological radiation and most likely related to the acquisition of symbiontic association in the scleractinian corals.

DAY 1

Transfer trip from Florence to the Dolomites and general introduction to the regional geology

p. brack, f. maurer and m. stefani

Most of the first day will be spent through a bus drive from Florence to the Dolomites. This transfer trip will provide us with a fast overlook on the Tertiary terrigenous deposits of the Northern Apennines, the flat Quaternary landscape of the Po Plain Basin, and the thick Mesozoic carbonate platforms and Permian volcanites of the Southern Alps. If the afternoon weather conditions are appropriate, two stops will be then made to get an overview of the Permian and Triassic successions of the Dolomites. These stops will offer a spectacular view of the large-scale geometry of Triassic carbonate platforms and basins, in an appropriate afternoon light. Leaving the motorway, we will rapidly reach the Ritten/Renòn Plateau, through a winding road on a thick succession of Permian acidic volcanites, dominating the Bozen area.

Stop 1.1:

Gasthof Himmelreich, Ritten/Renòn: general introduction

This stop offers an outstanding view of the western Dolomites, from 20 km to the west (Figure 2.1). The landscape morphology reveals the stratigraphic and structural framework of the area. Spectacular mountain-scale outcrops of Middle Triassic carbonate platforms (Geisler/Odle, Schlern/Sciliar, Rosengarten/Catinaccio, Latemar) give quite good an idea of the platform and basin size. The peculiar stratigraphic architecture of the Western Dolomites prevented the region from developing elongated mountain ridges, each present-day massif corresponding to an isolated Middle Triassic platform, grew between deep water basin, often corresponding to the present-day valleys. However, the Alpine tectonic telescoping of the area brought the platforms to a much greater mutual proximity than the palaeogeographic one.

Stop 1.2:

Unterinn, Ritten/Renon: geometry of the Schlern/Rosengarten Platform

The Schlern/Rosengarten Platform in the western Dolomites is a well preserved example of a prevolcanic platform evolution (Schlern/Sciliar Fm). Its southern portion, outcropping in the Rosengarten/Catinaccio range, is a textbook case for progradation geometries of carbonate platforms and will be discussed in detail. The Rosengarten section records the aggradational and progradational history of the platform and the interfingering of slope and basinal sediments (Buchenstein/Livinallongo Fm) over a distance of 5 Km and within a time framework encompassing 4 ammonoid zones (Figure 2.2). The aggrading portion of the platform is preserved in a small platform nucleus, at the Vajolet towers. The corresponding foreslope is exposed at Laurinswand/Torri di Re Laurino, where it is characterised by continuously steepening upward clinoforms, and the equivalent

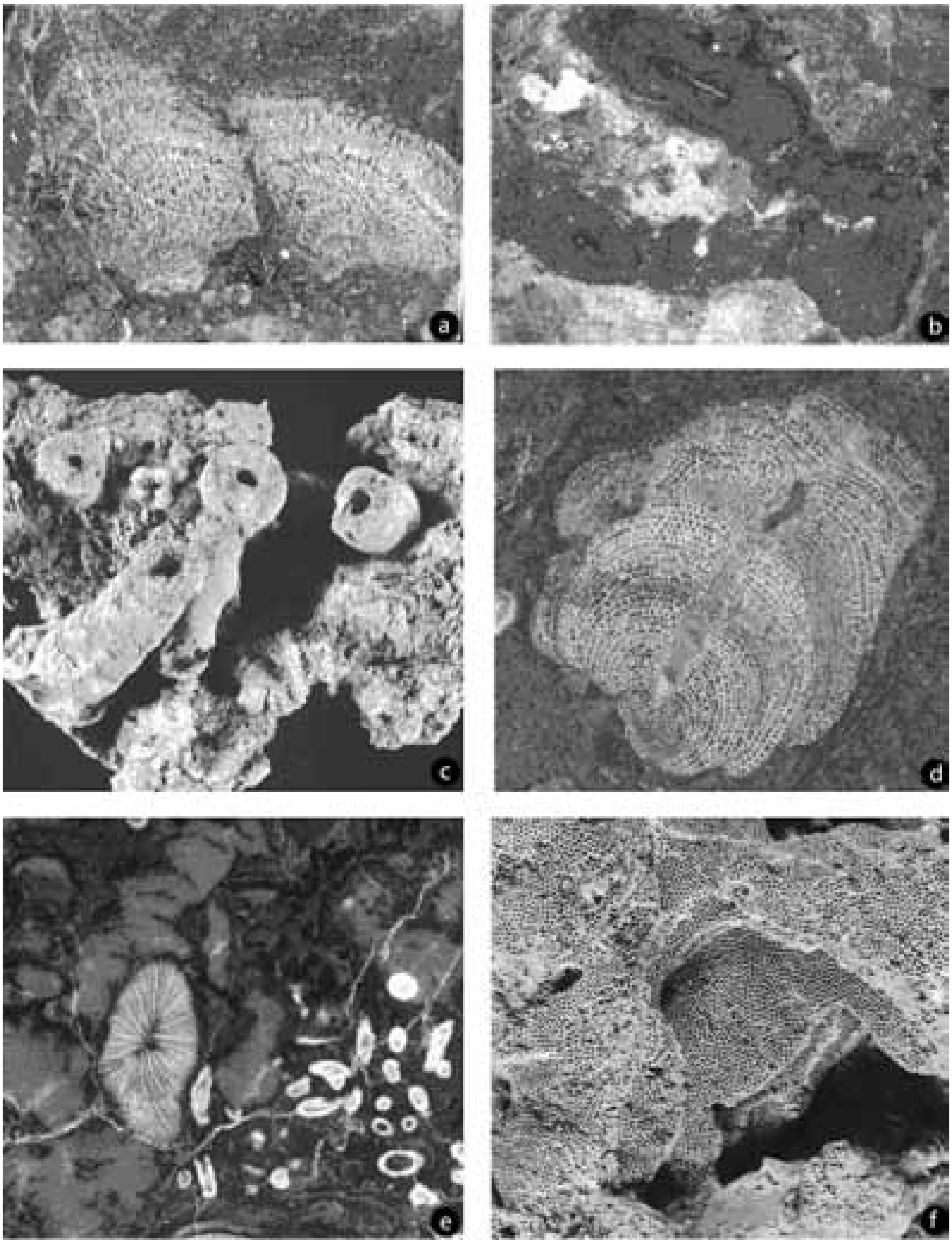


Figure 1.12 - Well preserved bioconstructor facies from post-volcanic Cassian platform (a, b) and Carnian patch reefs at the base of the Heiligkreuz (c-f). a- Cladogirvanella cipitensis bafflestone. Polished section, Punta Grohmann. X 0.7; b- Peloidal boundstone with Tubiphytes. Passo Gardena. X 2.8; c- Colony of Peronidella loretzi. Alpe di Specie. X 1.2; d- Coralsolenoporacean boundstone. Polished section, Alpe di Specie. X 0.8; f- Detail of Atrochaetetes medius with the skeleton preserved still in aragonite. Alpe di Specie.X 2.

basinal sediments show a marked lateral increase in the stratigraphic range (Figure 2.2, sections 1-4). The progradational phase of the platform is characterised by 30-35° steep clinostratifications, dipping towards SE, and by basinal sediments that increases in thickness but barely in their stratigraphic range, because of the fast base of slope migration (Figure 2.2, sections 5-10). The platform top is eroded at the Rosengarten, but is preserved at the north in the Schlern massif, where the 900m thick platform is directly overlain by Ladinian volcanics.

The day trip will end with a bus transfer to the nearby Groeden Tal-Val Gardaina-Val Gardena, western Dolomites, where we will stay overnight.

DAY 2

Prevolcanic platform and basin sediments at Seceda

P. Brack, F. Maurer and M. Stefani

Introduction

The second day will be spent in the field on the Seceda Massif, where the prevolcanic Geisler Platform (Schlern/Sciliar Fm) and the corresponding basinal sediments (Buchenstein/Livinallongo Fm) will be observed. After a close examination of the Buchenstein Fm and of the toe-of-slope brecciae, the results of an international-interdisciplinary research on a core drilled in the basinal succession will be discussed. The trip will also briefly examine the timing and emplacement/extrusion mode of Ladinian magmas and their relationship with the coeval sedimentary dynamics.

The discussed basinal succession accumulated into a growing proximity to the prograding slope of the Geisler/Odle Platform. A small remnant of the eroded aggrading platform nucleus is visible at the NE of the visited area, in the Sas Rigais northern sub-vertical wall. After an early progradational phase, the platform expanded through progradation, as recorded by the clinostratified slope deposits forming the Odle elongated picks (“odla” meaning needle in Ladin). The base of slope resedimented belt reached the visited area before the eventual onset of the magmatism, topping a basinal succession, which records, with outstanding accuracy, the whole growth period of the prevolcanic platforms.

As discussed in the introduction, considerable attention was focused through the last 20 years on the high frequency sedimentary cyclicity recorded in the Latemar platform-top succession (Figure 1.2). In the meanwhile, the coeval basinal Buchenstein beds were studied from sedimentologic, petrographic and stratigraphic points of view (Cros & Houel, 1983; Brack & Rieber, 1993), to eventually establish a plattform-basin correlation. When isotopic age results from zircons in volcanoclastic layers (Mundil et al., 1996) and magnetostratigraphic data were added to this detailed framework, the discrepancy with current Triassic time scales and with the orbital interpretation of the Latemar succession became immediately obvious and led to different interpretations of Middle-Triassic stratigraphy (Brack et al., 1996; Hardie & Hinnov, 1997). The debate carries added weight because the data are from the type area of the Ladinian Stage and are tied to the standard ammonoid zones, thus directly affecting the chronological framework of the Triassic.

The Buchenstein/Livinallongo Fm: general outline and geology around the drill site

Successions of basinal Buchenstein Fm (Livinallongo Fm; Viel, 1979) are found in a wide area throughout the Dolomites (Figure 3.1) and in adjacent areas. The Buchenstein beds were made complex by the interference of multiple sediments sources, at least three of them being active: (a) planktic material, consisting of organic matter, siliceous and possibly also calcareous tests of micro-organisms; (b) carbonate detritus and fine grained mud, exported from surrounding carbonate platforms; (c) volcanic detritus and ash falls, providing key correlation datum levels. In the upper portion of complete Buchenstein successions, reworked debris from adjacent carbonate platforms are abundant, such as in the visited area. At some distance from the coeval platforms, the Buchenstein successions are however remarkably laterally uniform (e.g. Brack & Rieber, 1993), since sets of pelagic strata can be traced over long distances (Brack & Muttoni, 2000). Layers in the Buchenstein Beds of the Dolomites have been indeed traced over 30 - 40 km and there is no evidence for significant erosion by turbidity currents or contour currents (Maurer & Schlager, 2003).

A full section of Buchenstein Formation is exposed in a steep east cliff of the Seceda peak (caution has to be pay while visiting the dangerous outcrops, hanging over a vertical Contrin Fm cliff). In this area, this formation has so far yielded the most significant succession of macrofossils (ammonoids, pelagic pelecypods such as *Daonella*) of uppermost

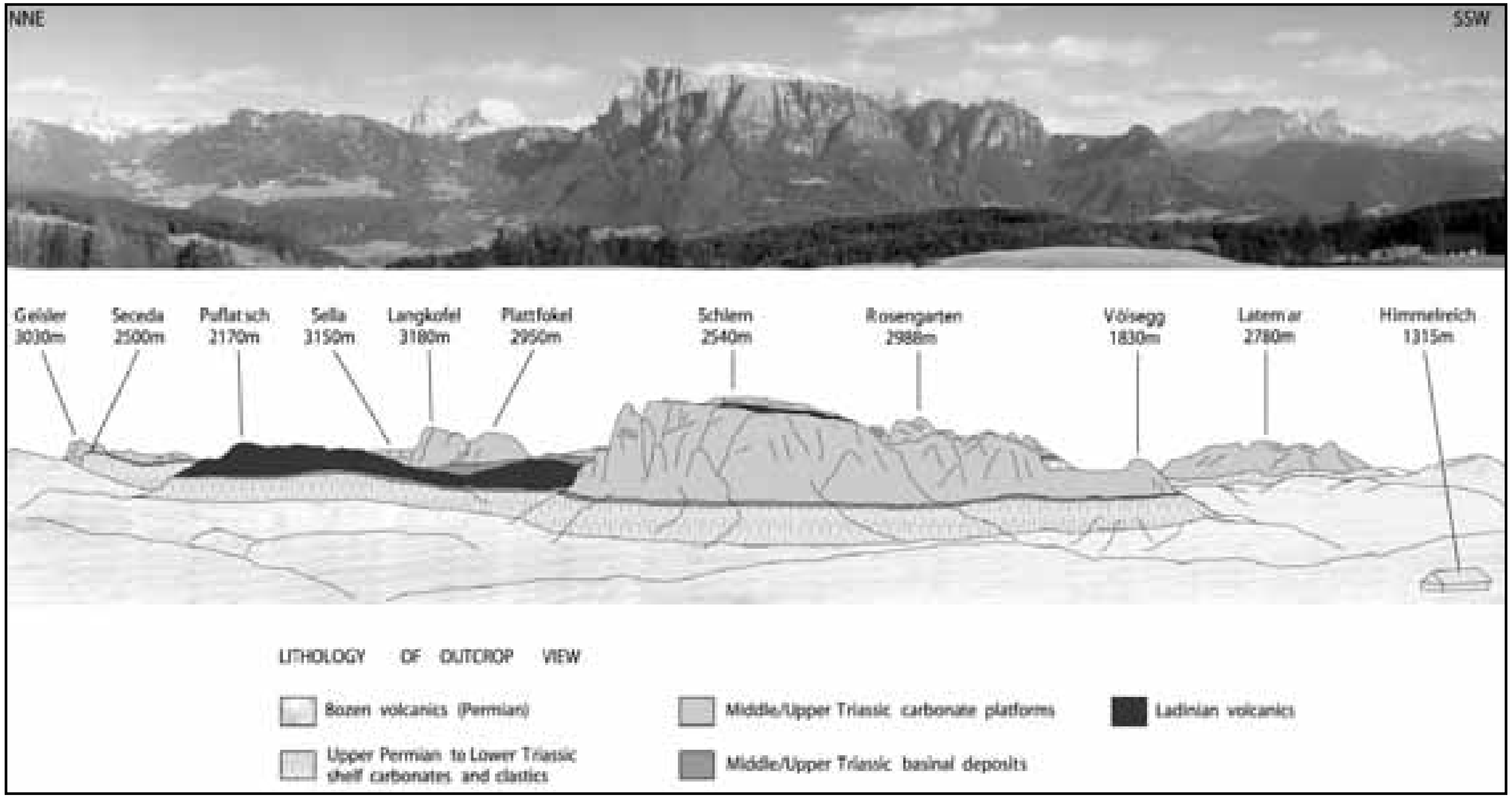


Figure 2.1 - Outline of the geology of the Western Dolomites as seen from stop 1.

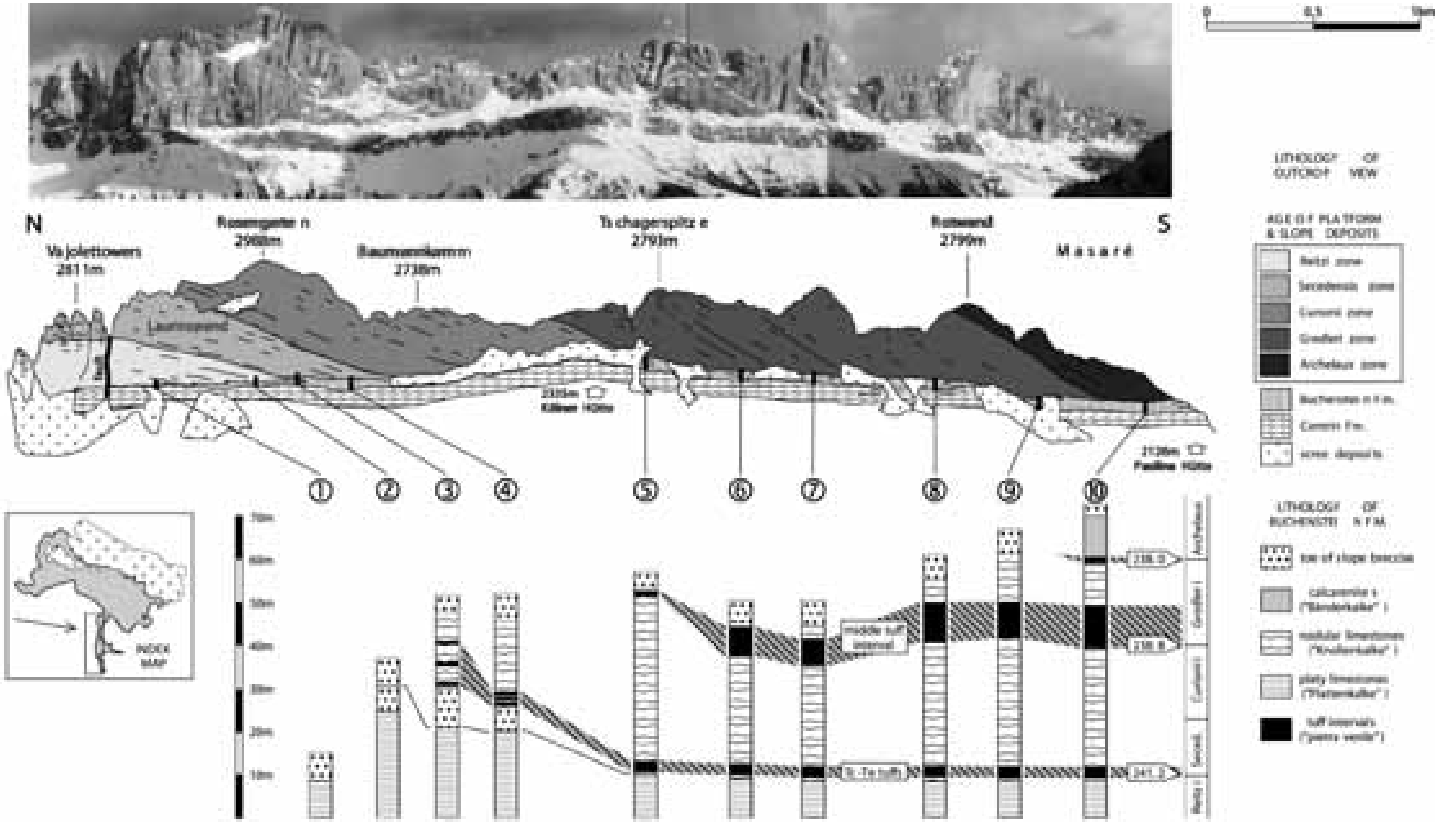


Figure 2.2 - Correlation of platform slope (Schlern/Sciliar Fm) and basinal deposits (Buchenstein/Livinallongo Fm) at the Rosengarten. At the southern end of the ridge the basinal sediments are preserved in their whole stratigraphic range; moving in a northward direction they are progressively replaced by time-equivalent foreslope clinoforms. The slope sediments at Laurinswand (Reitzi- to Curionii zones) correspond to the aggradation phase of the platform, while southerner slope deposits were formed during progradation (Gredleri and Archelaus zones). The sections 1-10 can be correlated by different basinal lithologies and tuffitic intervals (Pietra Verde layers). The radiometric dating (in Myr; from Mundil et al. 1996) and the biostratigraphic range of the Buchenstein Fm are listed at the right of the sections. Slightly modified from Maurer (2000).

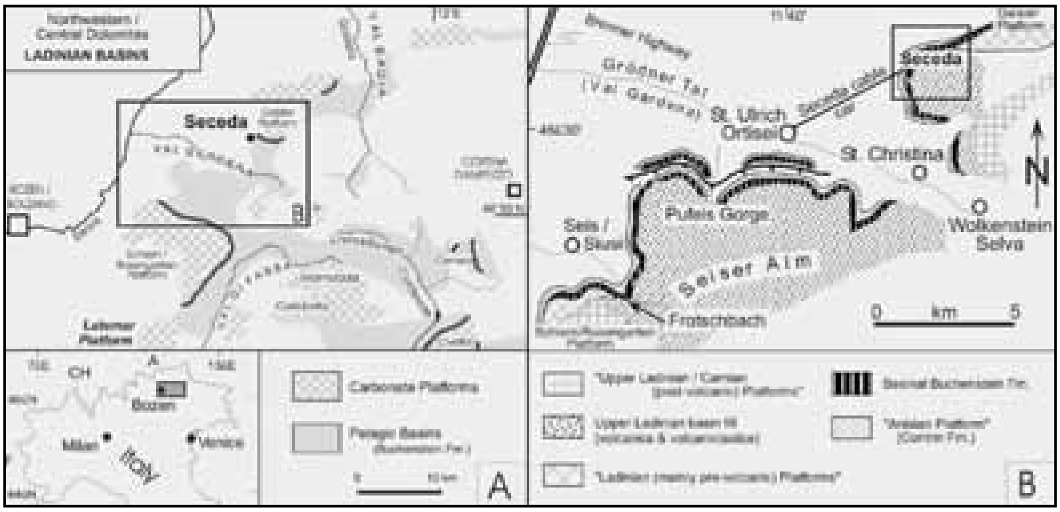
Anisian to Ladinian age found in the Dolomites. To the east, the Buchenstein beds are gradually replaced by the coeval slope deposits of the Geisler Platform, whereas to the southwest, near Kuka Sattel/Sella Cucca, the succession is overlain by Ladinian pillow basalts and siliciclastic basinal Wengen/La Valle Formation. These basinal siliciclastics interfinger with base of slope carbonates of the Schlern Dolomite to the SE of Pana Scharte, recording a synvolcanic platform growth. These lavas and sediment layers at Seceda belong to the lowermost part of a thick pile of volcanic and volcanoclastic rocks which is preserved to the south of Col Raiser (2 km SE of Seceda) and in the slopes around Seiser Alm/Alpe di Siusi. Along the ridge south of the cable car station at Seceda, a laccolith is visible in the Buchenstein Beds. The nearby basaltic extrusive rocks were probably fed through this subvolcanic body, as suggested by the outcropping geometric relationships visible near Mastlé.

The cored stratigraphic succession

The location of the drill site (Figs. 3.1B, 3.3) was chosen as close as possible to the reference outcrop section, in a narrow area between the toe of the Geisler Platform slope and a N-S running fault, between Seceda Peak and Pana Scharte. The area to the west of this Alpine fault is elevated by a few tens of metres and only the lower half of the Buchenstein succession is preserved there. Average recovery was better than 95% and even the most friable lithologies, such as marls and certain ash layers, were recovered with only minor losses. Geophysical well logging was also performed in the uncased well, providing further data for subsurface correlation, particularly useful for actual hydrocarbon exploration and exploitation. The core material was carefully examined from sedimentological, palaeontological, mineralogical, geochemical and magnetostratigraphic points of view and is presently stored for reference at the Bozen/Bolzano Natural History Museum. The bore hole penetrated around 88 m of stratigraphic thickness. From top to bottom, the following main units were distinguished: Interval A, representing a transitional unit at the base of the Wengen Beds; interval B, characterised by abundant coarse-grained, platform-derived carbonate brecciae; intervals C – E, typical members of the Buchenstein Formation, i.e. the “Baenderkalke”, the “Knollenkalke” and the “Lower Plattenkalke” respectively. Interval F is the topmost part of the Contrìn Formation. The comparison between the core and the outcrop shows a high degree of correspondence, even at the level of individual centimeter thick beds, such as pelagic limestone beds, breccia layers, and the Tc and Td and other tuff layers.

The alternation of bioturbated and anoxic laminated intervals is clearly visible. The layers of calcarenites and calcareous rubble shed by the surrounding platforms are quite scarce at the base of the Buchenstein succession (Plattenkalke, unit E), but they become frequent in the middle part (Knollenkalke, unit D), and further increase to over 30% in the unit C (Baenderkalke). In the breccia

Figure 3.1 - A: Carbonate platforms and basins distribution in the Dolomites during the Ladinian. B: Geological sketch map of Anisian to Carnian units in the Val Gardena area.



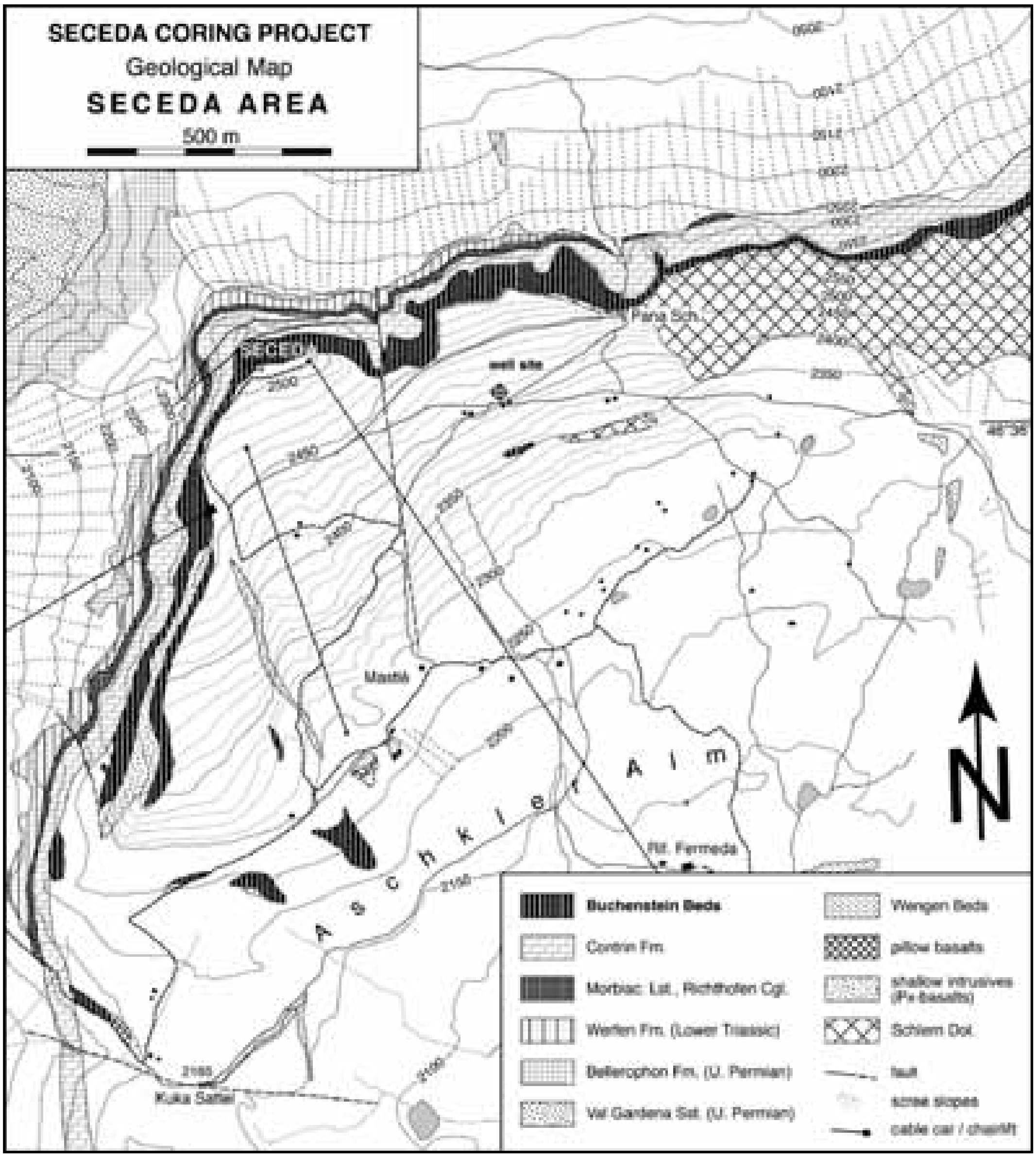


Figure 3.2 - Geological map of the Seceda area (after Brack et al. 2000).

interval (unit B), platform derived debris make up over 60% of the sediment volume (Maurer et al., 2003). This distribution reflects the upbuilding and subsequent progradation of the nearby Geisler/Odle Platform. The upper core interval is characterised by the occurrence of thick breccia layers, with platform derived carbonate clasts. The amount of coarse breccia layers observed in the core, when compared with the outcrop section, suggests a closer vicinity of the drill site with respect to the toe of the Geisler Platform slope.

A conspicuous and unique polygenic breccia, in the 30.3 - 31.45 metre interval of the core, contains clasts of basinal limestones, as well as basaltic volcanics (MB II). This important marker bed is easily recognised in the outcrop section. It postdates the level of pillow basalts, immediately above a horizons with *Daonella pichleri* and *Daonella tyrolensis*, pelagic pelecypods

Figure 3.3 - Aerial view of the Seceda area (after Brack et al. 2000). The location of the well site and of the excursion stops are indicated. The arrival of Seceda cable car is close to Site A.

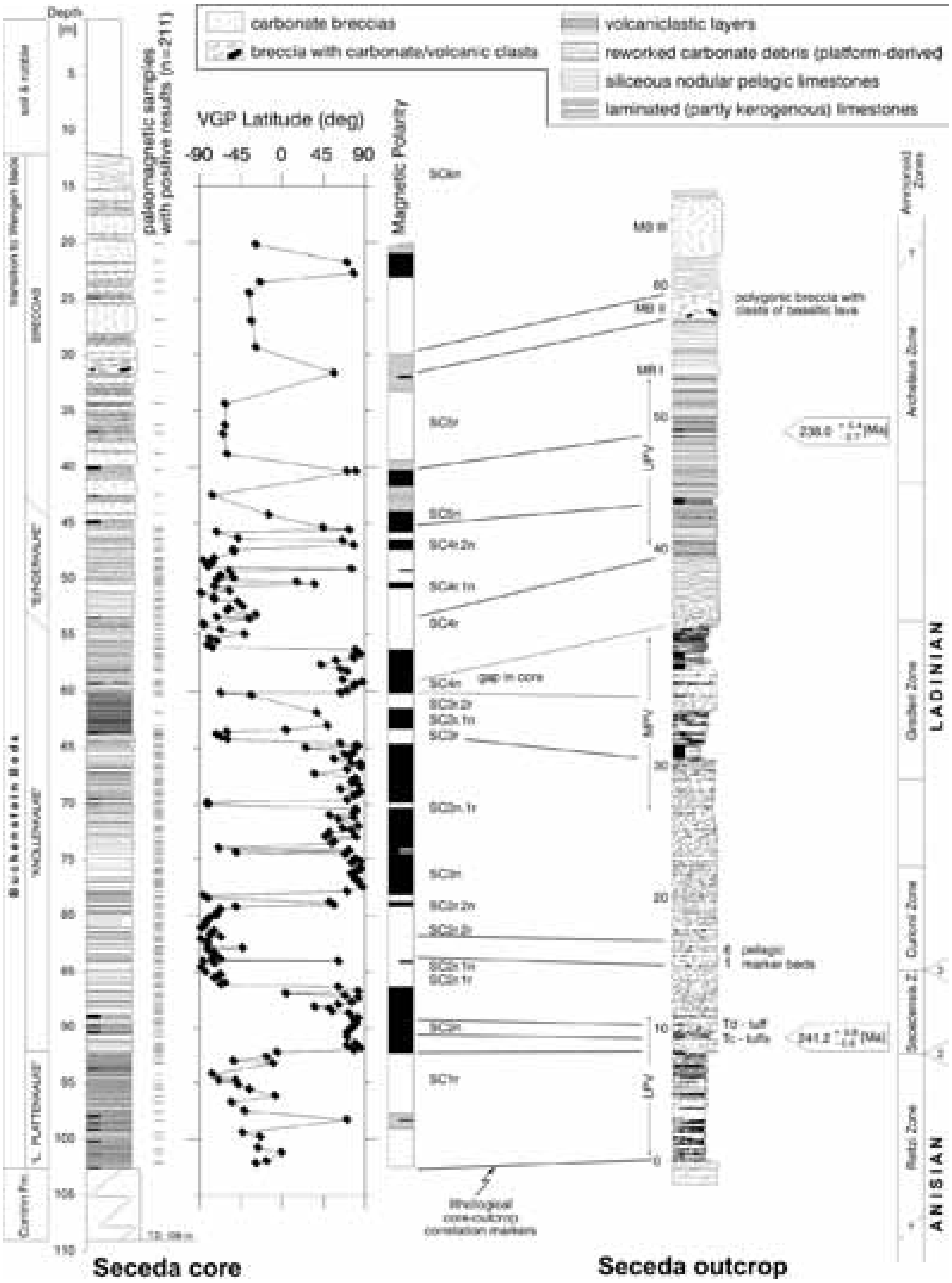


Figure 3.4 - Correlation of core and outcrop reference section and corresponding magneto-stratigraphic data. Radiometric ages after Mundil et al. (1996). (Slightly modified after Muttoni et al., subm.).

Figure 3.5 - Spectacular Permo-Triassic outcrop beneath the Seceda. Wf: Werfen Fm, R: Richthofen Cgm, Mb: Morbiàc, Co:Contrin Fm, Lv: Buchenstein/Livinallongo Fm; on the left the Odle, a visible consisting of Schlern Fm slope deposits.

bearing a significant biostratigraphic significance, in the stratigraphic successions outcropping to the SW (Mastlè and Kuka Sattle/Sella Cucca) , and SE, close to the Cisles Creek, south of Col Raiser. The stratigraphic framework suggests that platform carbonate growth continued at least during the initial stages of basaltic volcanism and deposition of the Wengen Formation, in this area, as well as in the Schlern region (e.g. Val Duròn).

Excursion stops

The day itinerary will involve transport by cable car from Urtajai/Ortisei/St.Ulrich to Seceda, a walking trip from Seceda to Col Raiser, with 6 stops and picnic lunch in the field, cable car descent from Col Raiser to St. Christina.

From the cable car, the Upper Permian and Lower-Middle Triassic formations can be observed. These include fluvial red beds, the Val Gardena Sandstones (upper Permian), deposited on top of the Permian Bozen Volcanics, visible in the nearby Rasciesa Ridge; the Bellerophon Formation (uppermost Permian), with conspicuous white gypsum layers (Sabkha evaporite cycles), locally site of tectonic detachment levels; the Werfen Formation (Lower Triassic), consisting of shallow marine reddish to grey clastics and carbonates; the upper Anisian erosional unconformity, covered by red conglomerates and sandstones (Richthofen Cgl); the Morbiac Formation, shallow-marine nodular limestones and marls (upper Anisian); the Contrin Formation, a cliff-forming compact dolomite interval, cupped by a breccia level and by a drowning surface (Upper Anisian); the thin bedded basinal Buchenstein Formation, forming the grassy slopes at the Seceda top.

Stop 2.1:

View from trail north of cable car arrival

This stop will show the drowning top surface of the Contrin Formation, the lowermost 25m of the Buchenstein Fm, below intrusive basalts and a laccolith body. In the lower portion of the basinal succession, anoxic black shales will be visible.

Stop 2.2:

Panorama from the Seceda summit.

The view from Seceda summit gives a good idea of the geometry and dimension of the interplatform Buchenstein basins (Figure 3.1), the distance between coeval carbonate buildups (Geisler and Schlern/Rosengarten Platforms) and the distribution of postvolcanic platform deposits (Sella, Plattkofel). The tectonic telescoping of the area, for instance associated with the Bullaccia Overthrust (Figure 3.1) has however to be taken in mind in evaluating the primary palaeogeographic relationships.

Stop 2.3:

Small ridge at the north of the Seceda summit

View of the fully exposed reference section of the Anisian-Ladinian basinal succession (Buchenstein Formation, Brack & Rieber 1993). outcropping in a cliff 300 m to east, and details of the platform-basin depositional relationships. Sedimentology, fossils and acidic volcanoclastic layers (pietra verde) of Buchenstein Fm (‘Lower Plattenkalke’ and

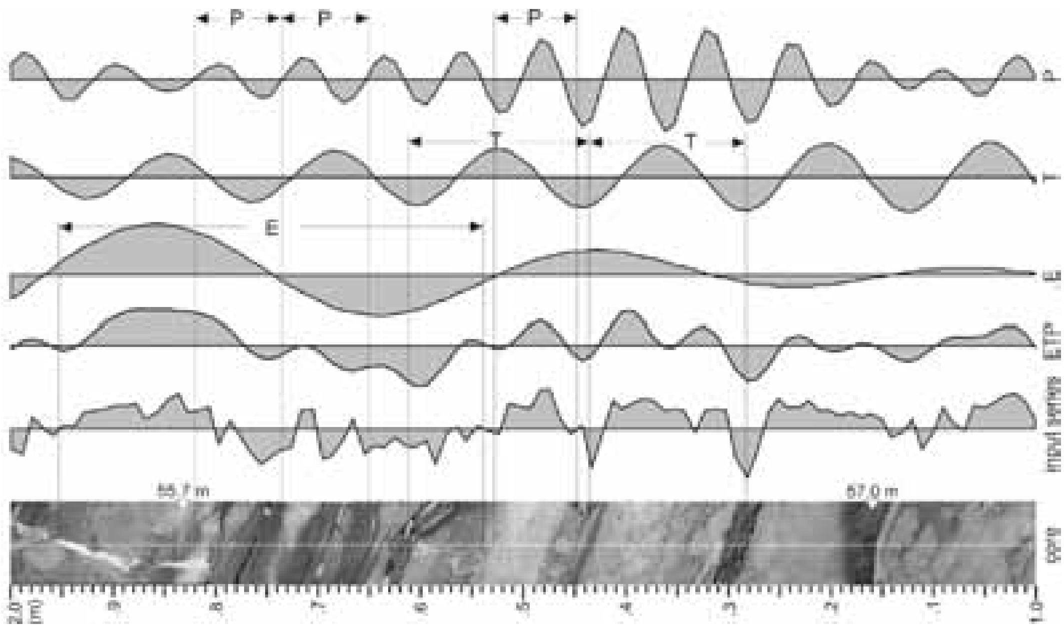


Figure 3.6 - Comparison between a core section cleaned of turbidites and corresponding greyscale scan with the presumed composite Milankovitch signal (ETP), which is the sum of the greyscale scan's bandpassed signal components on the right (E - eccentricity, T - tilt, P - precession). Note the fairly good recognition of the different cycles in the core photograph. From Maurer (2003).

'Knollenkalke') will be also discussed, as well as the core-outcrop correlation (Figure 3.4), an interesting topic for an outcropping analogous for subsurface hydrocarbon systems.

Stop 2.4:

Trail to Pana Scharte

Close-up view of the upper Buchenstein Fm ('Upper Bänderkalke' and breccia interval) and transition to Wengen Beds. This stop will provide a view of the late history and ending of the pre-volcanic deposition in a basinal setting, at the onset of the Ladinian volcanism.

Stop 2.5:

Surroundings of Pana Scharte

Examination of carbonate breccia bodies in upper Buchenstein Fm and transition to slope carbonate of the Geisler Platform. The outcrop provides a base of slope record of a platform progradational evolution and illustrate the depositional geometry of potential hydrocarbon carrier bodies.

Stop 2.6:

Surroundings of Mastlé Alm

Early syndepositional basaltic magmatism. The basinal record of the volcanism onset in the area will be discussed, since it dramatically affected the depositional evolution of the region. Vesicular subintrusive basalts with piroxene crystals and their transition to submarine pillow basalts will be examined. The sedimentary cover of basalts includes a siliciclastic succession (Wengen Fm), with nicely preserved plant remains and *Daonella lommeli* planktic pelecypod.

The day trip will end through a walk to Col Raiser lift arrival and transport by cable car to St.Christina

Bedding rhythms in the Buchenstein Fm

F. Maurer

A distinct bedding pattern is present in the nodular limestones of the Buchenstein Fm. which allows tracing of individual beds over several kilometers within the Dolomites. The origin of this bedding rhythm was a central topic of research in the Seceda core study and was approached in a detailed sedimentological analysis of the drilled succession. The Buchenstein basin was found to have been fed by different sediment sources, namely detritus from surrounding carbonate platforms, volcanic material as well as test of marine microorganisms and clay. Calciturbidites and volcaniclastics change significantly in thickness and percentage in the Buchenstein basin and were deposited at extremely high sedimentation rates compared to the rates of perennial background sediment. Such changes in sedimentation rates are one of the major obstacles in cyclostratigraphy, because they rule out the simple approach that bed thickness represents time. The separation of these deposits from the background sediment allows the construction of a residual succession, where the effect of changes in sedimentation rate is minimised. This kind of tuning, which is exclusively based on the sedimentology of the formation, was used to detect quasi-periodic signals in the greyscale scan of the core interval between 59 and 45 m ("Bänderkalke" of Buchenstein Fm.). The great advantage of this technique is that one can go back to the core and look at the residual sediment and its bedding patterns. In the figure below a 1 m long interval of the perennial succession used for time series analysis is visually restored and the presumed orbital signals are plotted next to it for comparison. The composite curve of the bandpassed frequency components (ETP, stands for Eccentricity, Tilt, Precession) fits very well to the underlying greyscale scan.

DAY 3

The Sella Platform

L. Keim & C. Neri

Introduction

This day is aimed at observing the well preserved depositional geometry of an atoll-like, high-relief postvolcanic carbonate platform, showing up in the Sella Massif (Figure 4.1). The whole of the Massif is made up by two superimposed carbonate platforms, forming two steep cliffs, separated by a distinct ledge (Figure 4.2). The lower cliff is cut into a Ladinian buildup (Sella Platform proper), the second one pertains to the Upper Triassic; younger thin deposits occur only at the very summit of the Massif (Piz Boè), showing condensed pelagic limestones (Ammonitico Rosso, Mid-Upper Jurassic) and hemipelagic marls (Puez Marls, Lower Cretaceous). The upper wall if made up by the Dolomia Principale – Hauptdolomit consisting of flat lying region-wide peritidal deposits, here about 250 m thick. The peritidal Dolomia Principale is overlain by some tens of meters of Rhaethyan shallow water Dachstein Limestone. The ledge in between the Triassic platform carbonates consists of well-bedded dolomite and marlstone alternations, traditionally referred to as "Raibl Beds". As several litho- and biostratigraphic evidences point out that this correlation is incorrect, they are herein attributed to the Schlernplateau Formation (L. Keim). Towards the centre of the mountain, the thickness of this unit decreases distinctly and is locally reduced to zero.

The lower platform was probably subround in shape, measuring 7-8 km in diameter. This unit consists mainly of clinostratified slope deposits, associated with relatively thin topset beds (Figure 4.3 and 4.4). This carbonate body attracted considerable attention in the study of large-scale depositional geometry of isolated platforms (Leonardi & Rossi, 1957, Bosellini, 1982, 1984, Kenter, 1990, Bosellini & Neri, 1991, Keim & Schlager, 1999, 2001; Keim & Brandner, 2001), and is presently referred to a late Ladinian time interval. The northern side of the Sella Massif shows a peculiar stratigraphic succession, characterised by the occurrence of a prominent megabreccia body, the "Gardena Megabreccia", up to 200 m thick (Bosellini, 1982; Bosellini & Neri, 1991). These breccias are interbedded within the topmost portion of the volcanoclastic basinal sediments (La Valle - Wengen Fm, Figs. 4.2-5).

Remarks on lithostratigraphic terminology

The intricate lithostratigraphic nomenclature of the rock bodies making up the Sella Massif is summarized in Figure 4.2. Different research groups have indicated the same rock-units with different names: thus, the Sella Platform is referred to as Upper Schlern Dolomite by German-speaking authors (including Keim & Brandner, 2001, and L. Keim, this work) and as "Cassian Dolomite" by Italian authors, at least since Assereto et al. (1977); it should be noted, however, that the name "Cassian Dolomit" was firstly proposed by Mojsisovics (1879).

The so-called "Raibl beds" of the Sella, not correlatable to the Raibl Formation in the eastern Dolomites, which is Tuvalian in age and is characterized by red and green shales, whitish dolomicrites, sulphate evaporite, were referred to as "Schlernplateau beds" by Keim & Brandner (2001). This nomenclature is based on the possible correlation of the interval at the Sella with the uppermost part of the Schlernplateau beds cropping out at the top of the Schlern (Sciliar)

Mountain. In the Sella Massif, the Schlernplateau Fm. was informally subdivided into two laterally interfingering members (Keim & Brandner, 2001): (a) Pordoi Mb: it consists of well-bedded dolomites, interbedded with marlstones; its base is marked by a key-layer consisting of volcanoclastic sandstones, unconformably lying on the top of the "Cassian" Sella Platform and locally infilling open fractures, possibly enlarged by karst; (b) Stevia Mb: it consists mainly of lagoonal mixed terrigenous-carbonate sediments and bivalve coquinas (Myophoria kefersteini kefersteini). The sedimentation pattern of the Schlernplateau Fm. was strongly influenced by synsedimentary tectonics (Keim & Brandner, 2001), resulting in the significant change in thickness shown in Figure 4.2A. Extensional tectonics led to local fissures, block-tilting, graben structures and breccia deposits.

According to L. Keim (this work) the formational name "Schlernplateau" has to be extended to the so-called "Dürrenstein Dolomite" sensu Bosellini (1984), cropping out on eastern flank of the Sella Massif (Campolongo Pass) and interpreted by Bosellini & Neri (1991) as an aggrading carbonate body nucleating from the basin floor and onlapping the former Cassian platform slope (Figure 4.2C). A comparison between Figures 4.2A and 4.2C clearly shows that, also in this case, the difference in nomenclature reflects two distincly differing stratigraphic interpretations, that will be discussed at Stop 6 (Campolongo Pass).

Biostratigraphy and age

The available biostratigraphic data derive from several basinal sections outcropping around the

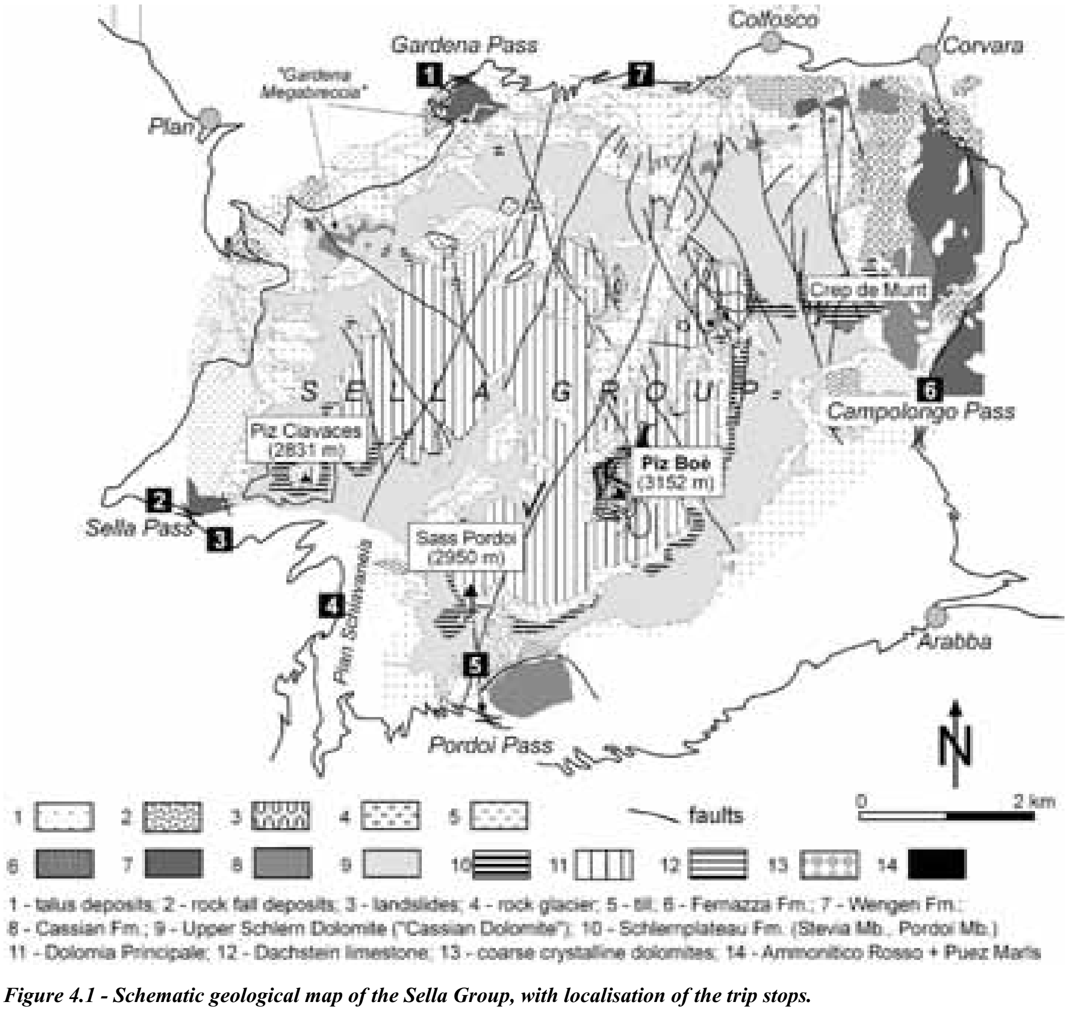


Figure 4.1 - Schematic geological map of the Sella Group, with localisation of the trip stops.

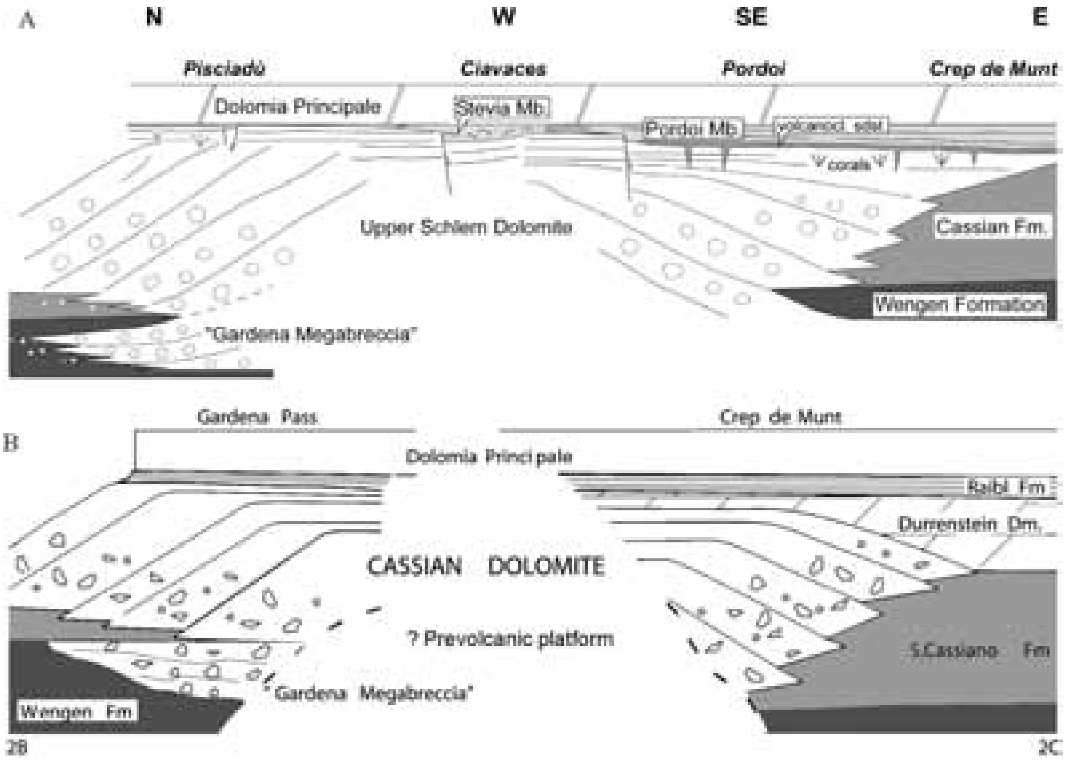


Figure 4.2 - Two alternative interpretation of the Sella Platform stratigraphy, see main text for discussion.
The thickness of the Sella Platform is at least 500 m.

Sella Massif and from the sediments immediately overlying the platform top at the Ciavaces Plateau. The ammonoid faunae of the Wengen and S. Cassiano sections around the Sella Massif (Reithofer, 1928; Mietto & Manfrin,1995; Baracca, 1996) clearly indicate an upper Ladinian Age (*Regoledenus* Zone). The S. Cassiano Fm section outcropping above the "Gardena Megabreccia" (Col de Frea) was assigned by Mietto & Manfrin (1995b) to the Daxatina cf. *canadensis* Subzone (corresponding to upper part of the *Regoledanus* Zone of Krystyn, in Zapfe, 1983). Recently, the genus Daxatina was proposed as the marker for the Carnian Stage base (Mietto & Manfrin, 1995 a,b; Broglio Loriga et al., 1999), but, since any official decision by the Subcommission on Triassic Stratigraphy is lacking, we still refer the Sella Platform to the Upper Ladinian, according to Krystyn (in Zapfe, 1984).

Conodonts form the Wengen and S.Cassiano Fms (Mastandrea et al., 1997, 1998) at the Gardena Pass and Sella Pass sections also clearly indicate an Upper Ladinian age. The faunae are dominated by genus *Budurovignathus* and belong to the *diebeli* Assemblage Zone sensu Krystyn (1983) and Gallet et al. (1998), corresponding to the standard *Regoledanus* Zone (Upper Ladinian). The age of the Schlernplateau Fm is inferred on the basis of the frequent occurrence of the bivalve *Myophoria kefersteini kefersteini* (Ciavaces plateau, Keim & Brandner, 2001). According to Urlichs & Tichy (2000) this taxon is Early Carnian in age (Aon Zone, base of Julian 1 of Krystyn, 1979).

Tectonics

Alpine compressional deformation is often comparatively mild in the Sella Massif, mainly recorded by small offset faulting (Mollema & Antonellini, 1999), or gentle folding (i.e. the Plan Anticline, the southern flank of which form the N-side of Sella, see Figure 4.5). A marked exception is represented by the eastern flank, involved in important overthrusting and dissected by several, nearly N-S trending, high-angle faults (Doglioni, 1985,1992, Keim & Brandner, 2001). The uppermost portion of the massif is caracterized by some klippen structures known as "summit-thrusts" (German: "*Gipfelfaltungen*"; Italian: "*sovrascorrimenti di*

Figure 4.3 - View of the northern side of the Sella Group. The lower wall corresponds to the "Gardena Megabreccia" at the Gardena Pass (Groedner Pass – Frara), note the wedging out of the carbonate tongues within the uppermost portion of the basinal La Valle – Wengen Formation; the upper wall is cut into the clinostratified Sella Platform slope; in the topmost portion a thin level of horizontally stratified platform top beds is locally visible.

vetta") and spectacularly exposed at Piz Boè. As a result, while the primary geometric-stratigraphic relationships between Cassian basin and platform deposits are quite well preserved throughout most of the Sella Massif, the geometry at the eastern side of the Sella are not entirely settled and are still a matter of debate.

Geometry and sedimentology of the Sella platform

The steep (30-35°) clinoforms of the Sella show radial progradation and interfinger on all sides with the basinal sediments of the S. Cassiano Formation. Judging by the height of the clinoforms, the platform reaches a maximum thickness of 600 m; the inner core, however is not outcropping. The shallow water topset layers show even tabular bedding, 0.1-1 m thick. Sedimentary structures are rarely preserved, being represented by occasional cross-bedding and by meter-size tepees. At Pisciadù, within the topset beds, nice *Thecosmilia* like coral colonies have been found in growth position. The margin between platform-top and slope deposits is quite narrow, a few tens of meters wide at the most. At upper slope settings, the shape of the clinostratifications is often planar, although it exhibits erosional scars (Kenter, 1990). On the lower slope, the shape of clinostratifications is distinctly concave, as the dip gradually flattens out towards the basin floor, particularly where the base of slope is characterized by a climbing progradation (e.g., Sella and Pordoi passes). In the Val di Mesdì area, where tabular progradation occurs over a thin wedge of basin deposits, the clinostratifications show an oblique parallel geometry (Bosellini & Neri, 1991). Intensive downslope transport is recorded by debris aprons at the toe-of-slope; these aprons, however, are rather narrow (a few hundred metres width) and the slope carbonates pass rapidly into basinal marls and shales, as for instance visible at the Gardena Pass, at the "Locomotiva" (Sella Pass), and in Val de Mesdì. The aprons consist of calciturbidites, debrites and swarms of meter-size boulders (Bosellini & Neri, 1991). In addition, the basins were fed with volcano-derived siliciclastics and extra-basinal shales.

Microfacies and Carbonate Production

Although the whole platform is affected by pervasive dolomitization, it is still locally possible to recognize the depositional fabrics. The best preserved depositional fabrics, however, are derived from gravitatively displaced blocks ("Cipit boulder"), which are embedded in marly-shaly deposits at the toe-of-slope (Russo et al., 1997, 1998). These olistoliths are considered as deriving form margin settings. The most striking sedimentary feature is the occurrence of automicrite facies (defined as an intimate association of automicrite s.s., vugs filled by primary marine cements, detrital carbonates stabilized by microbial crusts) in all the different platform domains (Keim & Schlager, 1999, 2001). Automicrite fabrics s.s. include typical microbial textures, e.g. laminitic-peloidal, thrombolitic-peloidal or simple crusts of clotted micrite. The widely occurring cements are dominated by isopachous layers of recrystallised, former radiaxial fibrous calcite and by fan-shaped arrays of needle-like botryoidal crystals, deriving from aragonite precursors, ad suggested by the very well preserved olistoliths microfacies (Russo et al.,1997; 1998). Automicrite, associated with micro-organisms such as *Tubiphytes*, and widespread marine cements formed a rigid framework at the platform margin that extended in layers and tongues onto the upper slope. From the evidence deriving from both platform and olistoliths samples, the margin-upper slope deposits mainly consisted of microbial boundstones, with large cement-filled cavities, with a subordinate skeletal component, including *problematic*a (*Tubiphytes*, *Macrotubus*), skeletal cyanophyta (such as *Rivularia*, *Cayeuxia*, *Hedstroemia*, *Girvanella*, *Ortonella*), rare sphinctozoan sponge, and, occasionally, bivalves, ostracods, gastropods, echinoderms, foraminifers, dasycladacean, solenoporacean (Keim & Schlager, 2001). Skeletal grains represent generally less than 5% of the whole rock and, in most cases, they are totally recrystallised. Automicrite and carbonate cement precipitation therefore played a major role in the carbonate production dynamics of this platform. The clinostratified breccias and megabreccias of the mid-lower slope contain abundant boulders, up to 5-6 m in diameter. Clasts and boulders show a microbial boundstone texture. Microbial automicrite was probably deposited also in the slope setting, where it was prone to gravitative resedimentation. The planar shape and steep angle of the clinostratifications, however, indicate that the large-scale geometry of the slope was not controlled by the automicrite but rather by non-cohesive sand and rubble layers piled up to the angle of repose (Kenter, 1990, Keim & Schlager, 1999, 2001).

Excursion stops

The excursion starts from the Gardena Valley and will proceed in a counter-clockwise direction around the massif, from the Gardena Pass to the Sella Pass and

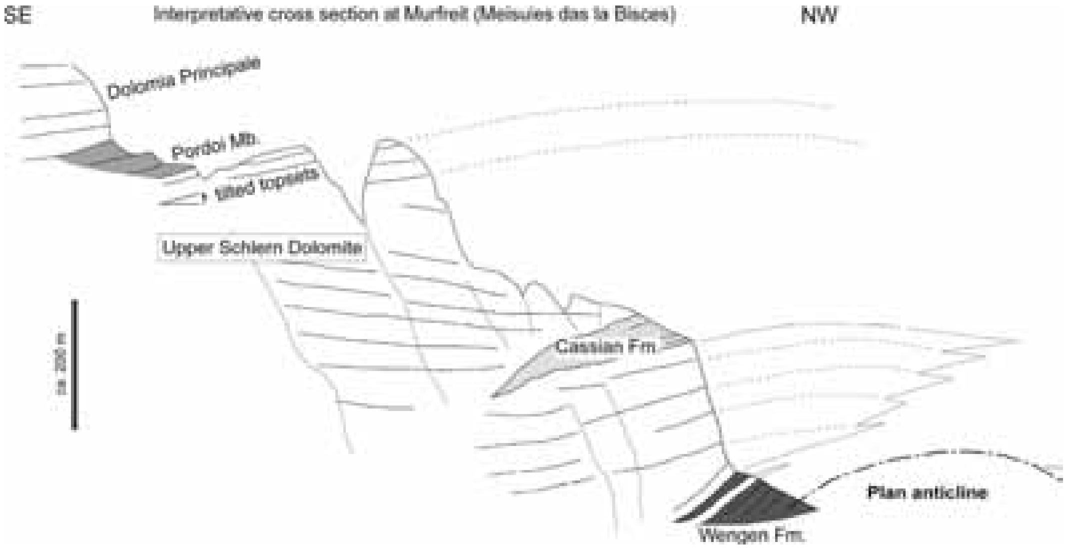


Figure 4.4. - The stratigraphic relations at Muntfreit (according to Keim's interptetation).

Figure 4.5 - View of the northern slope of the Sella Platform at the SW of Colfosco. A thin level of San Cassiano Fm argillaceous carbonate basinal deposits separates the "Megabreccia di Passo Gardena" lower wall from the clinostratified slope brecciae.

then to the Pordoi Pass. Here we will assent to Sass Pordoi (2950 m) by cable car and walk back down observing the stratigraphic succession. Then we will proceed towards Arabba, Campolongo Pass, Corvara and Colfosco (Figure 4.1).

Stop 3.1:

Gardena Pass

The northern flank of the Sella Platform, including the outcrops at Meisules da la Bisces - Murfreit, is a quite interesting example of controversy in the interpretation of depositional geometries (e.g. Leonardi & Rossi, 1957, Bosellini, 1982, Bosellini & Neri, 1991).Two main carbonate bodies occur: (1) a lower one, the so-called "Gardena Megabreccia" (Bosellini, 1982), lying within the uppermost portion of the Wengen Fm and overlain by the S. Cassiano Fm; (2) an upper unit, composed by the steeply clinostratified slope deposits and by the thinner flat-lying top-set beds of the Sella Platform proper. The megabreccia is distinctly stratified. At the Gardena Pass, the beds are nearly horizontal; at Meisules/Murfreit, however, the megabreccia dips *c.* 15° to SE; the same tectonic dipping affecting also the adjacent basinal formations, the Wengen and S. Cassiano ones, thought to be originally horizontal in nature, as well as the platform-top sediments of the Cassian platform (Figure 4.5). The thickness of the "Gardena Megabreccia" varies between about 200 m, at Meisules/Murfreit, and zero, at the Gardena Pass, where the megabreccia tongue pinchs out by interfingering with the basinal Wengen Formation; outrunner blocks ("Cipit boulders") are clearly visible within the basin sediments (Figure 4.3). The "Gardena Megabreccia" consists mainly of breccia tongues of boulders, up to several metres in diameter, and of some dm-thick beds of calciturbidites intercalations. The boulders largely consist of automicritic boundstones, with microproblematica like *Tubiphytes*, scarce metazoans (sponges, corals), peloidal-skeletal packstones and cement-filled cavities (Russo & Mastandrea, in Bosellini & Neri, 1991; Russo et al., 1998). The "Gardena Megabreccia" was interpreted as a channalized body, resulting from multiple collapses of a "pre-existing carbonate platform, rather than a buildup" by Bosellini & Neri (1991, p. 24). One of the authors of the present paper (C. Neri) still shares this interpretation; moreover, he thinks that the Gardena Megabreccia may be correlatable to a number of other megabreccia bodies or olistolith swarms cropping out in several localities of the Dolomites (i.e. the Col Rossi-Padon belt; Sella Pass; the lower part of the basin sequence below Grohman Spitze, etc.), all stratigraphically located near or at the top of the Wengen succession. An alternative interpretation

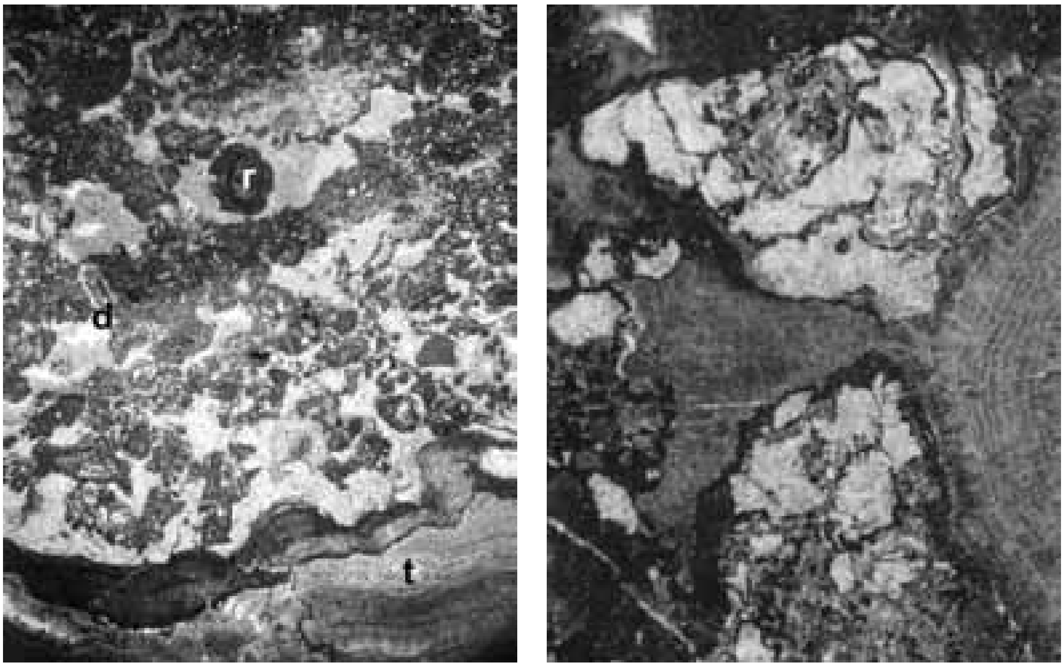


Figure 4.6 - LEFT - Automicrite and skeletal detritus from topset beds. The main part of the picture consists of a network of automicrite with pellet structure. Note occasional lithoclasts, fragments of red algae (r), dasycladacean thalli (d) and cement filling irregular vugs. The fibrous cement layer at the tepee-level (t) is partially dissolved. (Val de Mesdì, width of picture = 2 cm). (After Keim & Schlager, 1999); RIGHT - Thin section photomicrograph of automicrite facies on the marginupper slope, composed of dark crusts of peloidal clots, limpid botryoidal cement, numerous generations of fibrous cement as well as internal sediment. Automicrite forms constructional cavities and gravity-defying fabrics indicating that automicrite lithified almost immediately upon formation. (Val Lasties, width of picture = 3 cm). (After Keim & Schlager, 2001).

of the Northern Sella stratigraphy proposed by L. Keim (Keim & Schlager, 2001) is essentially a step back to the model of Leonardi & Rossi (1957), who assumed a lateral interfingering between the "Gardena Megabreccia" and the basinal sediments. In this interpretation, the strong thickness variation (0-200 m) of the megabreccia body is related to the oblique erosive cut of the proximal-distal parts of these deposits and the inclination of the megabreccia bedding (flat-lying, SEdip) is though to be the result of Alpine tectonic deformation (Plan anticline).

Stop 3.2:

Sella Pass

The section at the Sella Pass shows the Wengen Fm basinal succession grading up-section into the S.Cassiano Fm and eventually into W-dipping clinostratified dolomite megabreccia of the so called "Locomotiva". The section consists mainly of marlstones, siltstones, volcanoclastic sandstones and conglomerates, skeletal and lithoclastic calciturbidites and carbonate breccias. The section top shows the interfingering of basinal beds and clinostratified Cassian Platform slope. These clinostratifications are distinctly flattening out basinwards, since their dip angle decreases from about 30° in Val Lasties to 20° at Sella Towers (Kenter, 1990). The topsets are here only 10-20 m thick; the transition zone to the steeply dipping clinoforms is rather massive and apparently structureless.

Stop 3.3:

Road curve (2200 m) just below the Sella Pass

This stop offers a panoramic view of the WNW-exposed wall of Sass Pordoi with its topsets and clinostratifications and provides some insights into the interior of the Sella Platform, outcropping in the Val Lasties. The thinning out of the recessively weathered Schlernplateau Fm (Pordoi Mb = Raibl Fm *Auctorum*) above the platform top can also be observed.

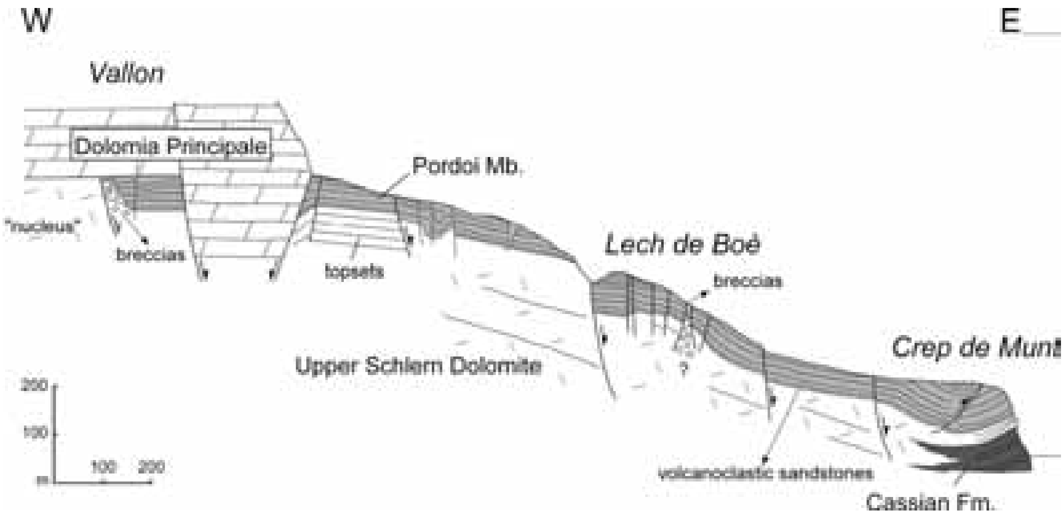


Figure 4.7 - Cross section at the Sella eastern side (modified after Keim & Brandner, 2001)

Stop 3.4:

Rif. Monti Pallidi (Pian Schiaveneis; 1850 m)

From this topographic view point, the full platform dimension and its diverging progradation directions (W-dipping clinoforms at Pic Ciavaces and S-dipping clinoforms below Piccolo Pordoi) can be well observed.

Stop 3.5:

Pordoi Pass-Sass Pordoi-Piccolo Pordoi

The stop is aimed at the observation of the post-Cassian Dolomite succession and at a cross-walking of the Cassian platform-to-basin transition. The trail from Sass Pordoi to Piccolo Pordoi (2,692) crosses the Norian Dolomia Principale cyclic peritidal succession. Below, a monotonous alternation of light and greenish coloured dolostones with burrows, fenestrae and desiccation cracks, interbedded with minor marls, crops out. At the base of this unit (Piccolo Pordoi) the Cassian platform top is sharply overlain by 2 m thick, cross-bedded greenish sandstones, mainly consisting of volcanic lithoclasts, quartz, detrital feldspars, minor carbonate grains (ooids, lithoclasts, echinoderm fragments), scarce volcanic glass, glauconite and opaque minerals (Keim & Brandner, 2001). The sandstones occur also as fissures-fillings within the Upper Schlern Dolomite. The fissures are some dm's wide, taper downward to a depth of several meters to tens of meters. These structures may be interpreted as karst dikes or dissolution-enlarged fractures develloped during subaerial exposure of the platform (Keim & Brandner, 2001).

Stop 3.6:

Campolongo Pass

The successions outcropping on the eastern flank of the Sella, from Crep de Munt to Vallon (Sasso delle Dieci), has led to many different stratigraphic interpretations (Mojsisovics, 1879, Bosellini & Neri, 1991, Doglioni, 1992; Keim & Brandner, 2001). Bosellini and Neri (1991) suggested an onlap geometry of the "Dürrenstein Dolomite" onto Cassian Dolomite clinofroms, whereas Doglioni (1992) assumed a thrust plane between the two formations. In both interpretations, however, the Dürrenstein Dolomite was interpreted as an aggrading sedimentary body, nucleating from the basin floor as a response to basin shallowing due to sedimentary infilling and, possibly, to a sea-level drop (Bosellini, 1984). The result is the deposition of an even-bedded carbonate body infilling the residual basins and onlapping the slopes of former Cassian platforms (Figure 4.2C). The peculiarity of the interpretation of Doglioni (1992) is that he puts in evidence that the original onlap geometry has been modified by compressional stress, resulting in moderate thrusting of the Dürrenstein Dolomite over a ramp represented by the inherited Cassian slope. An alternative interpretation has been proposed by Keim & Brandner (2001) and is here presented by L. Keim, following a model formerly suggested by Schlager et al. (1991) for the Picco di Vallandro (Dürrenstein) Cassian platform. This model suggests a progressive infilling shallowing of the Cassian basins, matched with a dip-angle reduction of the platform-slope, climaxing into a lateral palaeogeographic homogenisation into a gently deepping ramp-like, shallow water depositional system. The uppermost part of the S.Cassiano Fm exposed at Crep de Munt, including hummocky-cross-bedded oolitic grainstone and peloidal packstone, has been interpreted by various authors as a response to the shallowing of the Cassian basin (Bosellini & Neri, 1991, Keim & Brandner, 2001). According to Keim & Brandner (2001), the last tongues of the Cassian platform overlaid these deposits with a very low depositional angle, probably <2°. L. Keim (this work) concludes that all deep basins around the Sella atoll were filled up at the ending of the Cassian Dolomite deposition. Based on this assumption, the Pordoi Mb (Dürrenstein Dolomite of Bosellini & Neri , 1991, and Keim & Brandner, 2001) does not form an onlap on a steep palaeo-slope surface, but was rather deposited on a very gently dipping slope (Keim & Brandner, 2001). The postulated filling up of the former relief between platform top and the S. Cassian basin is supported by the presence of volcanoclastic sandstones, which can be traced with a rather constant thickness from the former basin towards the platform top (Figs. 2A, 7). On a steeply flanked platform, the input of coarse volcanoclastic material would not have reached the platform top. At Crep de Munt, the Pordoi Mb can be subdivided into a lower subtidal and an upper peritidal unit. The subtidal unit (c. 50-60 m thick) wedges out towards the platform top, where it is reduced to a few meters. In the opinion of L. Keim (this work) this reduction in thickness could be explained by the gently east-dipping, low-gradient palaeo-relief of the underlying Cassian slope or by newly created accommodation space related to synsedimentary extensional tectonics. In the interpretation of Bosellini & Neri (1991) this is, on the contrary, a clear evidence of the onlap relationships on an inherited slope.

Stop 3.7:

Road to Gardena Pass

The last stop provides us with a panoramic view of the spectacularly exposed clinostratifications at the Val de Mesdì, along the NNW-facing flank of the Sella.

Acknowledgements

We gratefully acknowledge R. Brandner (Innsbruck), P. Gianolla (Ferrara), A. Mastandrea and F. Russo (Cosenza) for stimulating discussions. Special thanks go to A. Gruber and H. Gruber (Innsbruck) for substantial help during fieldwork, and to M.Stefani (Ferrara) for scientific discussion and extended reviewing.

DAY 4

The pre-volcanic Cernera and the Post-Volcanic Nuvolau and Lastoi de Formin Platforms

A. Riva, P.Gianolla, M. Stefani

Introduction

This day will offer a wealth of opportunity to examine pre- and post-volcanic carbonate platform systems, developed within the Eastern/Western Dolomites hinge belt. As discussed in the introduction (cf. Figure 1.6), the less subsiding western region is characterised by upper Anisian carbonates almost directly lying on a single sequence bounding unconformity, deeply cut into the Lower Triassic and older units; these carbonates were followed by thick Anisian-Ladinian platforms (Sciliar Fm), aggrading and widely prograding over thin basinal limestones (Livinallongo Fm), until the onset of the volcanic event; the Upper Triassic is thin and gap-prone. The eastern and northern area is on the contrary typifies by various generations of Anisian carbonate platforms, separated by gently eroded boundaries, followed by long-lasting terrigenously influenced basinal deposits; the Ladinian volcanism did not directly affect the area and the Upper Triassic successions are quite thick and more continuous in nature. In the hinge belt, several brittle (trans)-tensive Middle Triassic structures developed, to be variously reactivated by the Alpine compression. The visited area therefore offers:

(i) The good preservation of three superposed Anisian platform generations and depositional sequences.

(ii) The record of an isolated carbonate pinnacle evolution (Cernera Platform), during younger Anisian and earliest Ladinian times “bravely fighting for survival” against fast subsidence, but eventually giving up to retrogradation, deepening and final drowning into aphotic conditions, where a pelagic shroud of limestones slowly accumulated. Thick terrigenous and volcanoclastic successions then onlapped the former platform slope.

(iii) Spectacular post-volcanic platforms (Gusela del Nuvolau and Lastoi de Formìn), conquering the area again during the Carnian Time, when fine grained calcarenitic slopes, significantly less inclined than the pre-volcanic ones, prograded onto the San Cassiano basinal Fm, eventually filling up all the available accommodation space.

(iv) A nice example of a potential hydrocarbon reservoir in a carbonate pinnacle sealed by low permeability volcanic and volcanoclastic deposits and sourced by Anisian black shales. Actual hydrocarbon impregnation are locally visible, as well as a widespread permeability-enhancing hydrothermal karstification. Middle Triassic lead sulphide and fluorite mineralizations are also visible in the visited area.

The stratigraphic succession of the visited area starts with the shallow marine Bellerophon and Werfen Fms, outcropping in the hangingwall of a regional-scale overthrust, the Selva Line (cf. Figure 1.1). The Lower Triassic unit was followed by an early Anisian regional peritidal platform (Lower Serla Dolomite), in turn directly overlain by coarse fluvial conglomerates (Voltago Cg), filling up erosive channels (Blendinger, 1983; Blendinger et al., 1984; De Zanche et al., 1992, associated with a significant chronological gap, encompassing the accumulation time of a here eroded depositional sequence. The conglomerate is part of the transgressive system tract of the third Anisian sequence (An 3 sensu Gianolla et al., 1998a), which was totally eroded out only a few kilometres to the west, before the deposition of the forth Anisian sequence. The third sequence evolved here into a basinal succession (Recoaro and Dont Fms), subject to a terrigenous input. The coeval platforms (Upper Serla Fm) then prograded onto the basinal units, as documented by the clinostratifications visible in the western side of the Cernera Massif. At the margins of this prograding platform, patch reefs largely developed, often involved in synsedimentary sliding toward the slope. The whole of these outcrops, including the reef deposits, were included in the Dont Fm by previous authors (Gaetani et al., 1981; Blendinger et al., 1984; Blendinger, 1983).

Another relative sea level drop marked the sequence boundary between An 3 and An 4 sequences: the erosional surface is covered by fluvial conglomerates (Richthofen Cg), made up mainly by Werfen Fm and Lower Serla Fm clasts. Pebble imbrication locally indicates a northward palaeoflow direction (Mt Verdàl). Marine environments were re-established through transgression, as witnessed by the deposition

Figure 5.1 - The Cernera platform-top is very rich in oncoidal facies, developed in high energy subtidal environments.

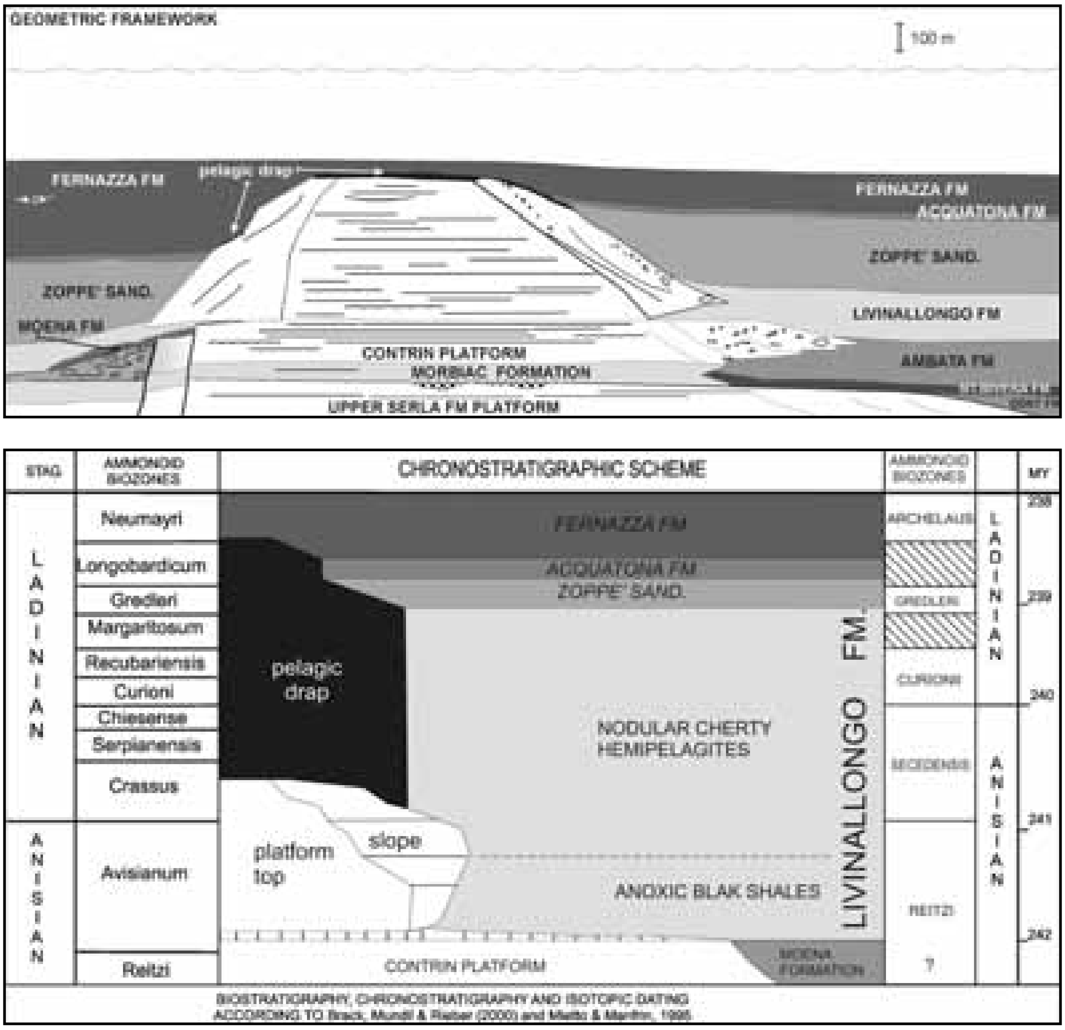


Figure 5.2 - TOP - Geometric scheme of the stratigraphic relationships between the Cernera Platform and the adjacent units. BOTTOM - Chronostratigraphic scheme of the Cernera successions.

of Morbiàc and Contrìn Fms. In this area, the Contrìn carbonate platform is quite thick, reaching 150 m in thickness, recording the starting of a fast subsidence evolution. During this time interval, spatial variations in the subsidence speed are also recorded by the development of intraplatform anoxic basins, in the more subsiding areas, recorded by organic rich micrites and resedimented carbonate megabrecciae (Moena Fm, Masetti and Neri, 1980; De Zanche et al., 1995; Masetti & Trombetta, 1998). Outcrops of this basinal unit are visible in the at the western of the Cernera, between Val di Zonia and Mt. Pore. The top of Contrìn platform is very sharp and is normally directly overlain by the Sciliar Fm platform; to the N, the two platform generations are however sometimes separated by a few metres of basinal micrites and redeposited calcarenites (basal Livinallongo Fm).

The fast aggradational evolution of the Sciliar Fm is recorded by more than 600 m of succession, a huge thickness accumulated in a very short time span, probably in the order of one million of years, as suggested by the correlation with the most recent geochronometric data from the Latemar (Mundil et al. 2003). This evolution records a very fast subsidence, within a tectonically active geodynamic framework, probably forerunning the magmatism onset. The

Cernera platform-top is made mainly of oncoidal calcrudites and calcarenites, associated with abundant dasycladaceans and gastropods, deposited in high hydrodynamic energy subtidal euphotic conditions. The platform-margin and slope geometry of the Cernera Platform is quite different in its various sides: the eastern flank records a backstepping evolution of the margin, with very thin slope deposits, in an area where the platform exportation was negligible, whereas the western side developed an aggrading breccia slope, retrograding only at a later stage. The sharp difference between the two sides of the platform could be connected to: (i) differential subsidence between two margins, associated to a platform tilting; (ii) windward versus leeward effect (Blendinger & Blendinger 1989); (iii) nutrient supply difference between open-marine areas (eastward) and semi-enclosed basins westward. During the aggradational evolution of the platform, while the flanks were dramatically lengthening, the euphotic platform top area was shrinking, further reducing the carbonate factory potential. The imbalance between carbonate production and the fast creation of accommodation space eventually forced the platform to die, probably during the Crassus Sbz (sensu Mietto & Manfrin 1995a). During the deepening last phase of the platform, encrinitic shoals accumulated, eventually giving up to ammonoid and pelagic pelecypods rich limestones, slowly accumulating onto the dead platform, through Ladinian times.

Thick terrigenous turbidites in the meanwhile onlapped and fossilised the lower part of the slope; sedimentation was particularly fast in the eastern side of the drowned platform, facing the incoming turbiditic fluxes, slower in the sheltered western flank. These turbidites (Zoppè Sandstones) were fed by the erosion of an emerged crystalline basement (Viel, 1979; Brusca et al. 1981), now deeply buried under the Po and Venetian Plain. But known through hydrocarbon exploration. These sandstones gave place to a temporary return to hemipelagic sedimentation (Acquatona Fm), suddenly interrupted by the appearing of basic volcanoclastics and by catastrophic gravitational driven megabreccia deposits (Caotico Eterogeneo), associated with an erosive and often deeply chanalised base. This unit is bearing olistoliths ripped up from as down as the Lower Triassic. After the first explosive phase, quiet volcanic activity with fissural eruptions (Castellarin et al. 1977) deposited here about 100 m of submarine hyloclastites, interbedded with volcanoclastic turbidites (Viel, 1979). During volcanism, strong hydrothermal circulation induced hypogenic palaeokarstic systems within the Cernera Platform carbonates, due to CO_2 and H_2S rich corrosive fluids (Hill 1995, Palmer 1995). The sulphur-rich circulation developed the important lead mineralisation of Col Piombìn and a palaeokarst networks, particularly in proximity of vertical hydraulic barriers (Fm Dont, Fm Livinallongo, etc.) The Cernera area lacking sin- and early post-volcanic buildups, a new platform generation developed here only during early Carnian times. The Lastoi de Formìn and Gusela del Nuvolau (Bosellini , 1984; De Zanche et al., 1993) mountains provide excellent outcrops for the observation of the platform-to-basin relationships: comparatively steep clinostratifications link the terrigenously influenced basin floor to the platform-top carbonate succession. The slopes progressively reduced their inclination, during a fast progradational evolution of platforms, matched with a shallowing up evolution of the basinal successions, the two factors combining to fill up any available accommodation space of the area, up to the renewed Upper Triassic subsidence.

Excursion stops

Stop 4.1:

Carbonate platforms showing up in the geological landscape form Forcella Zonia

Mount Cernera shows up at the south of this site (Figure 5.3), consisting of a thick late Anisian carbonate platform, drowned at an early evolutionary stage. Toward the south east, in closer proximity, the Col Piombìn is well visible, quite likely to consist of a huge block of Middle Triassic platform carbonates, probably involved into a chaotic synvolcanic complex as a gigantic olitstolith (Caotico Eterogeneo). At the south, the platform top succession of the Cernera are directly visible, since deposits are hear lacking, probably because of Triassic collapses. This area derives its name form the lead mines (= piombo in Italian), related to late Ladinian sulphides hydrothermal mineralisation, exploited until the 1950s. During this top, our feet will stay on the volcanoclastic deposits, separating the Cernera and Lastoi de Formìn Platforms. Behind the Col Piombìn, the Lastoi de Formìn are visible, made up of a thick late Cassian Platform and of a thin Duerrenstein Fm succession, both Carnian in age. Toward the north, the Gusela del Nuvolau platform, made up of Cassian Dolomite, shows her slope deposits clearly prograding

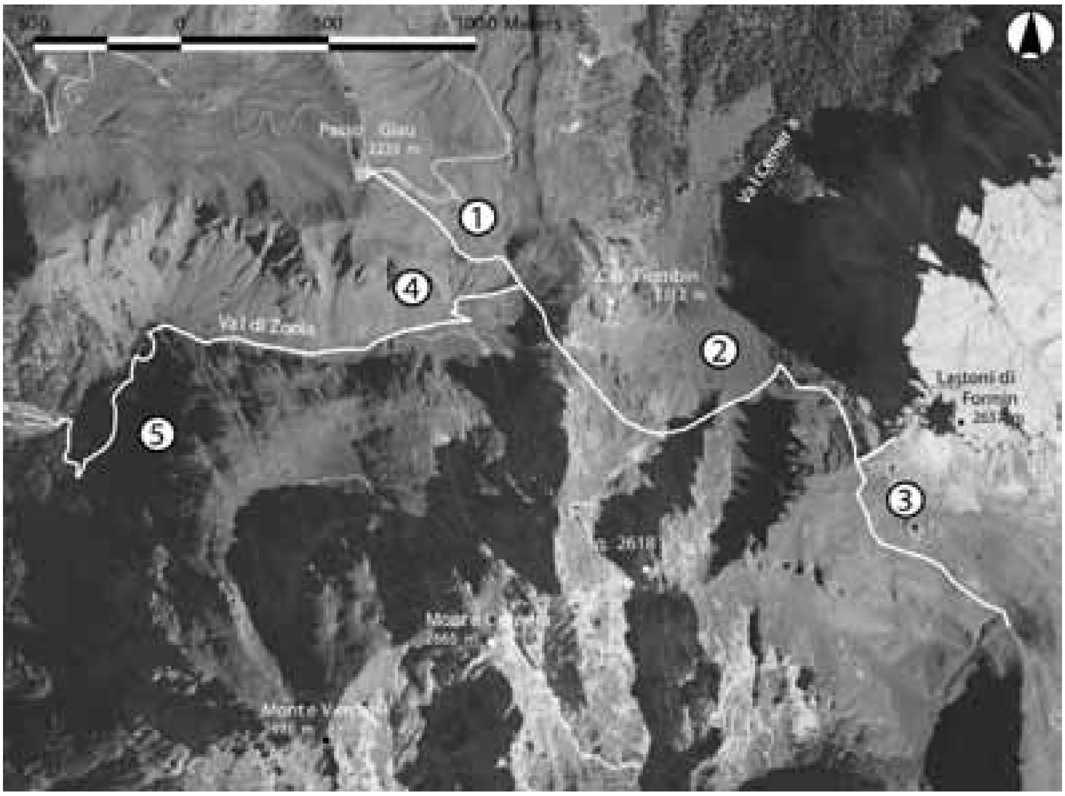


Fig 5.3 The day excursion itinerary with stops. Stop 6 is located outside the map, near Villagrande di Colle Santa Lucia.

onto the basinal Cassian Formation.

Stop 4.2:

Val Cernera: drowning and basinal resediments onlapping the Cernera Platform

The stop will be mainly focused on the discussion of the “post-mortem” evolution of the drowned platform. Along the walked through trail the drowning succession of the platform is visible, covered by ammonoid rich facies, showing associations ranging from the Crassus to the Recubariensis Sbz, according to the Mietto & Manfrin (1995a) biozonation. Ammonoids also occur in yellowish-pink coloured sedimentary dikes, cutting through the drowned platform top. The eastern slope of the Cernera Platform is onlapped by a thick succession of terrigenous (Zoppè Sandstones) and volcanoclastic sediments (Fernazza and La Valle Fms).The Cernera suffered small scalloping during and after drowning, producing detachment niches that were to be filled up by basinal materials. The whole of the drowned Cernera Platform was to be slowly covered by a thin level of Hallstadt-type red nodular limestones (Blendinger et al., 1984; Brack & Rieber 1993; De Zanche et al., 1993). Ammonoid and pelecypod rich facies are widespread on the eastern slope and they laterally grade into the nodular Livinallongo Fm (Knollenkalke Mb), as in the Forcella Vallazza area (Cros & Houel, 1983). Ammonoid-rich Middle Triassic facies have been found also as reworked limestone blocks redeposited into synvolcanic chaotic deposits (Caotico Eterogeneo Fm); these fragments were probably eroded from the Cernera Platform cover.

Stop 4.3:

Forcella Giau and Lago delle Baste: the eastern Flank of Cernera Platform and the post-volcanic Lastoi de Formìn prograding platform

The geological landscape visible from the pass clearly illustrates the Triassic evolution area (Figure 1.1, 5.4). On the left (South), the thick upper Anisian Cernera Platform is visible, involved into minor brittle tectonic Alpine deformation. The sharp top of the carbonate edifice is a drowning unconformity, associated with

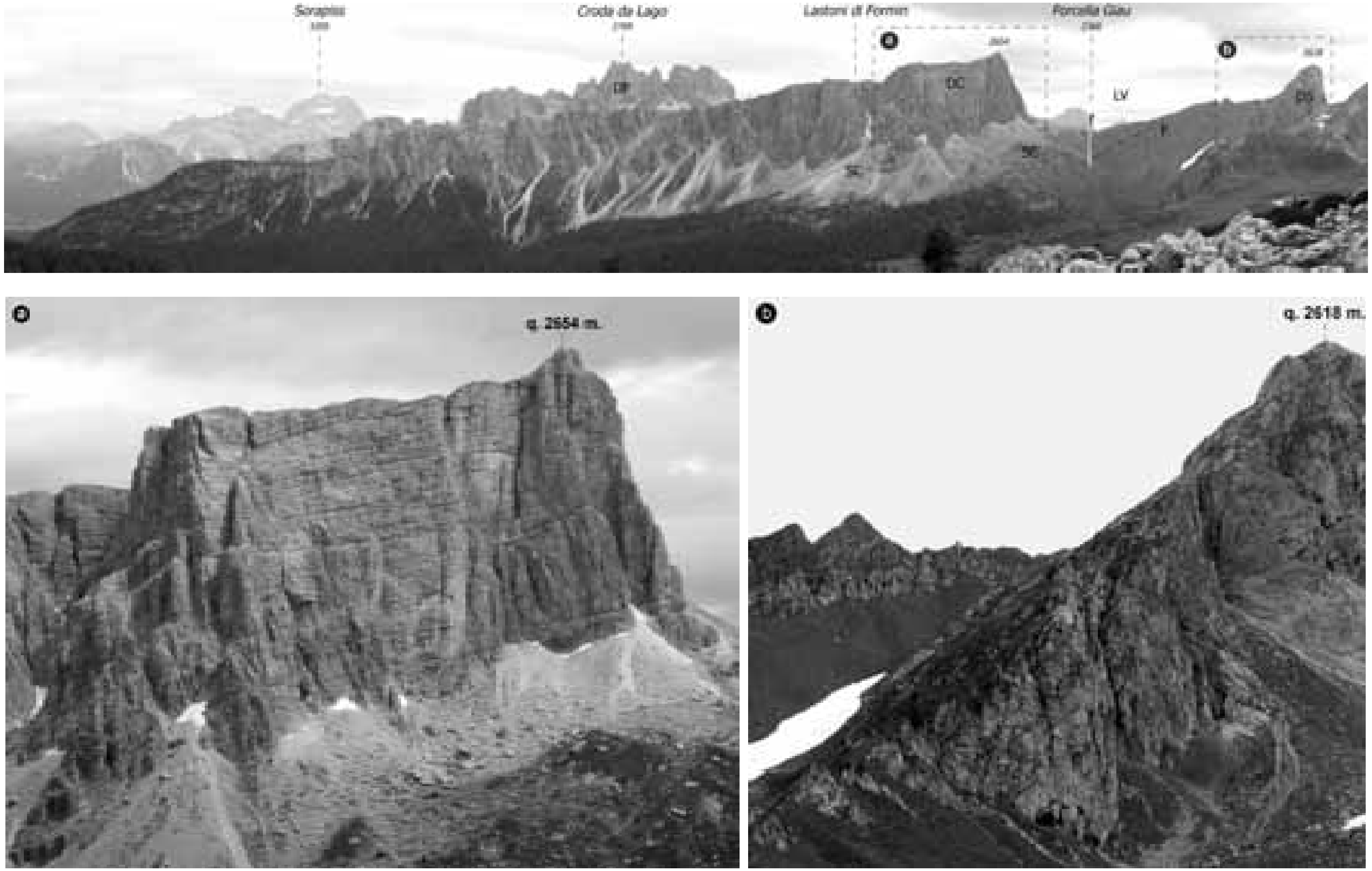


Figure 5.4 - A: The northward dipping, clinostratification of a Cassian platform, forming the Lastoi de Formìn. The slope dolomite body is affected by several minor Alpine strike slip faults. Figure 5.4 - B: Onlap of basinal resedimented beds (Zoppè Sandstones, Caotico Eterogeneo and Fernazza Fms) onto the eastern slope of the drowned Cernera Platform. The platform is tilted toward the east (right) of about 20°, the contact is slightly reactivated by Alpine tectonics.

the shallow water depositional system termination. The onlap of the volcanoclastics onto the drowned Platform was gently reactivated by the alpine tectonics. The following stratigraphic succession (Figure 5.6) record a shallowing up evolution, from a relatively deep volcanoclastic-fed basin to peritidal carbonate environments. A subvertical Neogene strike-slip faults apparently lower the left (eastern) side, putting the volcanoclastic unit (La Valle Fm) in contact with a terrigenous-carbonate shallowing up succession (S. Cassiano Fm). A carbonate slope prograding toward the SE then progressively expanded onto these deposits (Lastoi de Formìn). The slope angles were now much smaller than the pre-volcanic one, since micritic facies and slumped beds are common in this late generation of post-volcanic platform. The apparent angle visible in the sub-vertical one is however reduced, since the clinostratification are not cut along their actual stratigraphic dip. Horizontally bedded platform-top dolomites then prograded onto the slope units. In the uppermost portion of the cliff, emersion surfaces separates several peritidal platform top units (cf. Lastoi del Formìn section in Figure 5.4).

At the north of the Giau Pass, a different platform slope is visible, dipping northwards, because of both the primary clinostratification immersion and a gentle tectonic tilting (Gusela del Nuvolau, Figure 5.9). At the north Upper Triassic carbonate platforms are visible, which will be visited during the fifth day of excursion. (Passo Falzarego-Tofane area).

Stop 4.4:

Punta Zonia: condensed base of slope succession of Anisian -Ladinian age

The Punta Zonia condensed carbonate section (Figure 5.5) accumulated in near base of slope settings of the Contrìn and Sciliar platforms. The outcrop was for the first time examined by Cros & Houel (1983) and then analysed in detail by Vrielynck (1984), Brack & Rieber (1993), and De Zanche et al. (1993, 1995). This 10 m thick succession is placed in close proximity to the coeval Cernera Platform, showing a thickness of about 800 m, a sharp stratigraphic contrast recording a dramatic lateral change in the sedimentation rate. The succession records a progressive reduction of the accumulation rates, during the growth time of the Contrìn Fm and the aggrading-retrograding evolution Sciliar Fm, followed by an even stronger condensation after the eventual Cernera Platform demise. The succession can be subdivide into four intervals, differing in both the nature and amount of the carbonate importation; (i) the lower unit is rich in skeletal calcarenites, coquinas and megabrecciae, forming a resedimented wedge at the side of a collapsed Contrìn platform margin; (ii) the following interval consists in a centimetre level of dark laminated carbonates, draping and suturing the previous chaotic wedge, (iii) the third interval is characterised by fine-grained resedimented calcarenites, recording the early aggradational history of the Cernera Platform, (iv) in the uppermost unit, the rapid disappearing of the calciturbidites and the establishment of purely pelagic condensed sedimentation, with levels rich in ammonoid and pelagic pelecypods, documents the drowning termination of the Cernera carbonate factory. Ammonoids were found in several levels through the section, ranging from the Reitzi to Recubariensis subzones, developed around the Anisian-Ladinian boundary (Figure 5.5). Some of these faunae have been spectacularly fossilised as fluorite molds, a feature that unfortunately prompted the destructive illegal fossil collection to impact on the outcrop. A few tuffites (“Pietra Verde”) are intercalated into the succession, providing key levels for both isotopic dating and physical correlation.

Stop 4.5:

Zonia Valley: Anisian depositional sequences and relative sea level fluctuations

This short walk will be focused on the large depositional geometry of the Anisian Upper Serla platform and the sequence boundary separating the first and third Anisian depositional sequences, the second one being lacking here. In lower part of the Zonia Valley, walking down the trail, we shall observe the succession in a reverse stratigraphic way, i.e. moving toward older units.

In the western part of the Cernera Massif (Mt Verdàl), the lower portion of the Upper Serla Fm mainly consists of small patch reefs, developed in a marginal area, both preserved in situ or, more often, involved into gravitational syndepositional sliding (Figure 5.7). These patch reefs are very similar to those described to the north, in the Braies area (“*Rutschblocke*”, Bechstädt & Brandner, 1970). These facies are dominated by microbial boundstones rich in microproblematica and calcareous sponges, with taxa such as *Olangocoelia otti* Bechstädt & Brandner, *Celyphia* sp. and *Tubiphytes* (Gaetani et al. 1981). These patch reefs, only few metres wide, are gravitationaly displaced toward the east, as also suggested by the deformation of underlying Dont Fm beds. This margin unit makes transition eastward to

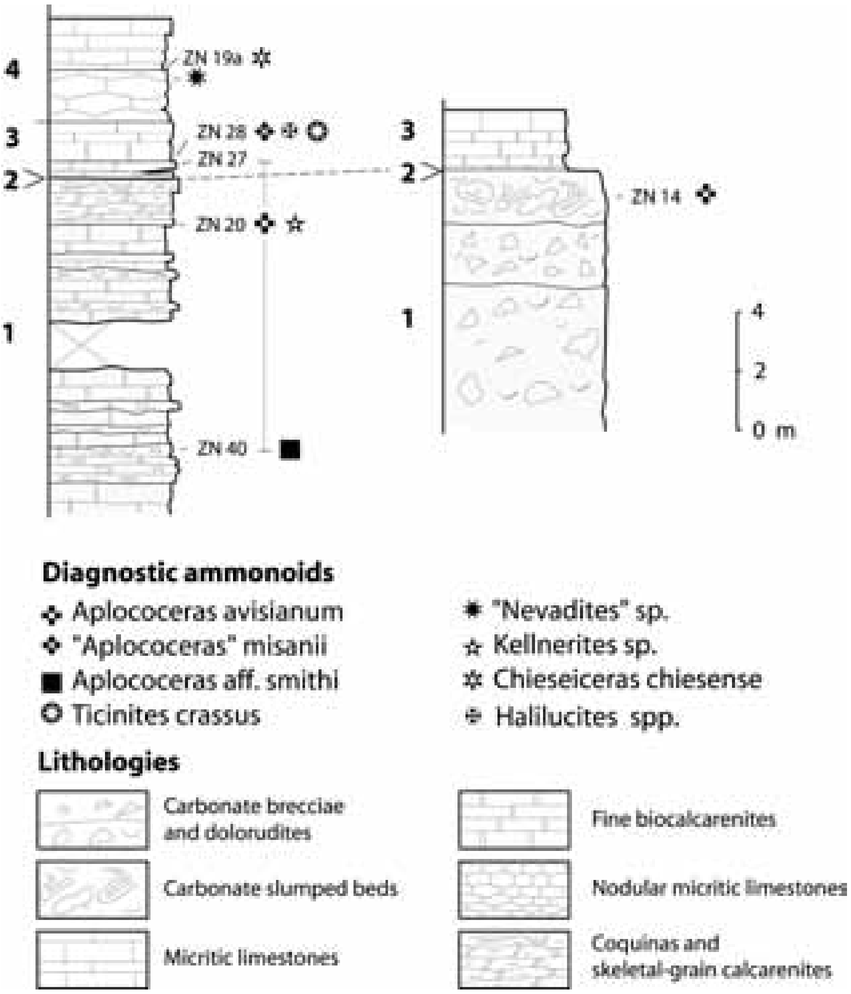
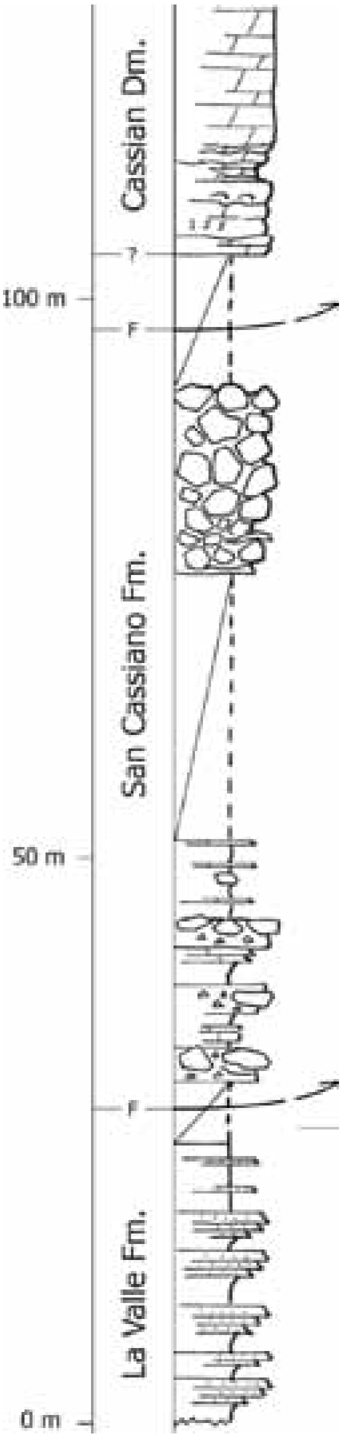


Figure 5.5 - Punta Zonia Section, modified from De Zanche et al., 1995; Numbers (1-4) correspond to the units described in the text.

slope and basinal deposits, as visible at the east of a sinistral strike slip faults, probably reactivating a syndepositional structure (Loschiesuoi Fault).

The middle-upper portion of the Upper Serla platform records a progradation evolution, since the slope deposits and the margin patch reefs and shoals are followed upward by horizontally bedded limestones and dolostones, consisting of sponge/algae boundstones and representing a back-margin platform-top unit. The Upper Serla Fm is directly overlain by a subaerial erosive sequence boundary, cutting down into the basinal Dont Fm (Mt Verdàl area) and associated with palaeokarstic cavities. The boundary between sequence 3 and 4 provides the base for the Richthofen Conglomerate, of fluvial unit including lithoclasts ranging from the Werfen to the Upper Serla Fms; lamination and imbrication structures indicate a local palaeocurrent direction toward the north. At the lower end of the Zonia Valley, an important section is outcropping, where the sharp boundary between the An 1 and An 3 sequence boundaries is well visible, the second sequence being absent in the area (De Zanche et al., 1992, 1993).

The Lower Serla Fm consists of whitish-gray microcrystalline dolostones, with stromatolites and birdseyes, arranged into peritidal cycles. The Lower



Serla Fm top is cut by a subaerial erosive sequence boundary, followed by a terrigenous unit, the Voltago Cg, here formed by fine grained conglomerates dispersed as lenses into a prevailing sandstone matrix, deposited in coastal environments. The emerging lands conditions are also documented by terrestrial plant remains. On the southern side of the Cernera, the Voltago Cg is on the contrary made up by coarse pebbles, derived from the erosion of the Lower Serla and Werfen Fms. In this terrigenous unit, a lateral transition is visible, along a N-S stretching section, from coarser fluvial conglomerates to shallow storm wave influenced siliciclastics, with hummocky cross stratification, to more open marine environments (Zonia Section). The unit record a globally transgressive evolutionary trends, belonging to the TST of this sequence.

Stop 4.6:

Villagrande di Colle Santa Lucia: view of the Cernera Platform and Anisian sequences

This day excursion will end with a spectacular view of the western flank of the Cernera Massif (Figure 5.8), where the whole of the Middle Triassic depositional sequences is visible. Four carbonate platform generations can be clearly observed from this site: Lower Serla, Upper Serla, Contrìn and Sciliar Fm As a whole the section records a dramatic increase of the accommodation space, induced by a speeding up of the subsidence speed. The different platform generation form steep walls, interspaced by grassy ledges, corresponding to the transgressive terrigenous deposits and to the basinal units. The Sciliar Fm Cernera Platform at the Mount Verdàl clearly shows Northwest-dipping clinostratifications, inclined at about 30ø toward the basin floor, where the Livinallongo Fm was accumulating. The basinal unit is clearly pinching-out under the peak top, where the Contrin and Sciliar platforms are bound together in physical continuity. On the eastern flank of the mountain, well bedded subtidal limestones and dolomites compose the platform-top succession.

The gothic church and renaissance buildings visible during the stop were related to the ancient mining activity of the nearby Triassic ores, which was indeed so important in the area to generate the Ladin name of the region (Fodom, from the Latin fodere = mining).

Figure 5.6 - Stratigraphic section stretching from the volcanoclastic conglomerates to the Lastoi de Formìn Platform base of slope. Courtesy of C. Neri, unpublished.

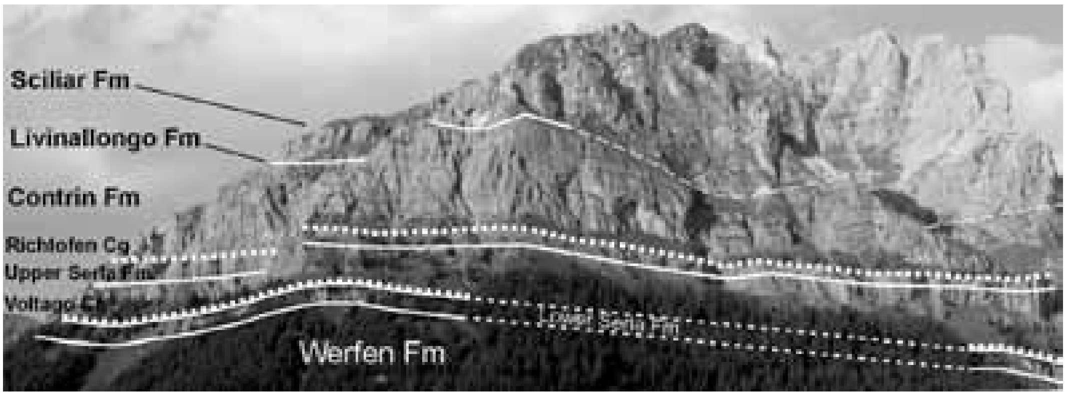


Figure 5.7 - View of Cernera and Verdàl Mountains from Villagrande, spectacularly showing the vertical succession of the different Anisian-Ladinian carbonate platform generations and depositional sequences, punctuated by subaerial sequence boundaries.

Figure 5.8 - The western wall of the Mount Cernera. The Contrìn Fm records the stratigraphic transition to a small intraplatform basin (Moena Fm) to the left. The Sciliar Fm here consists of slope brecciae.

DAY 5

The demise of the Upper Triassic (Cassian) platforms and the palaeo- topography flattening

P. Gianolla, N. Preto, M. Stefani and C. Neri

Introduction

This day excursion is focused on the stratigraphic and palaeogeographic evolution of Upper Triassic carbonate platforms around the Passo Falzarego (Figure 5.1). The successions outcropping in this area are made up by Upper Triassic units: the Cassian platforms and the coeval basinal successions (San Cassiano Fm), the Heiligkreuz (Duerrenstein) shallow marine formation, subdivided into several members, the argillaceous Raibl Fm and the thick peritidal Dolomia Principale platform. Attention will be particularly addressed to the climatic forcing and the sequence stratigraphic organisation of the Cassian platforms. The seismic scale outcrops around Falzarego Pass (2,105 m) allows the detailed reconstruction of the facies stacking pattern and the spatial relations between platform-top, slopes and basins. The demise of the rimmed platforms, giving way to terrigenous-carbonate ramps, the flattening out of the palaeogeography (Heiligkreuz Fm) and the start up of the widespread Dolomia Principale tidal flat will be also discussed.

The southern block (Nuvolau Platform) must be considered as an attached platform, because of the presence of a diversified and widespread tetrapod ichnofauna, documented in the stratified platform interior succession (Avanzini et al., 2000); up to know, no evidence of continental tetrapods footprints was on the contrary found in the northern isolated Lagazuoi Platform. These rimmed platforms record two superimposed aggradation/progradation phases, separated by an interval of no carbonate exportation and basinal shale onlapping onto the slopes, probably recording a third order depositional cyclicity (Fois & Gaetani, 1982; De Zanche et al., 1993, Gianolla et al., 1998a). The Cassian Dm consists of a light coloured crystalline dolomites, showing an indistinct or massive bedding. The platform top succession is here thicker than in the Sella area and is characterised by tens of metres of well bedded, finely crystalline dolostones, with birdseye structures, stromatolites and pisoids, indicating deposition in very shallow water environments or tidal flats. The slope deposits are characterised by thick bedded, clinostratified slope breccia, interfingering with basinal sediments. The slope angle changed through time from 35-30° to 15-10°, during the shallowing evolution of the basin.

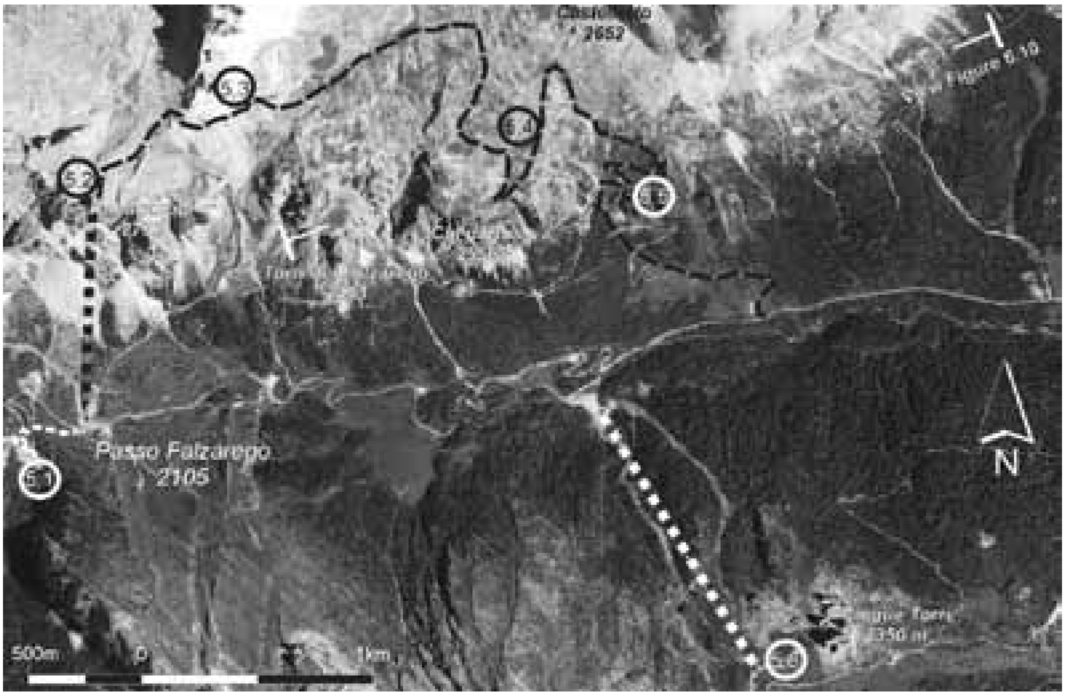


Figure 6.1 - The day excursion itinerary and stops on an aerial photo of the Passo Falzarego area

Cassian Dolomite and San Cassiano Formation

These units record a complex framework of rimmed carbonate platforms and basins. In the excursion area, two different platforms, the Nuvolau and Lagazuoi ones, are visible in close proximity (Bosellini et al., 1982), the originally interspaced basinal area being largely telescoped by a major Alpine overthrust. The age of these units is constrained by ammonoids, conodonts and palynomorphs to the uppermost Ladinian – lower Carnian (Ulrichs, 1974, 1994; Mastrandrea, 1995; Mastrandrea et al., 1997; Gianolla et al., 1998; Keim et al., 2001).

Figure 6.2 - Topmost portion of the Carnian peritidal succession outcropping along the main road at the south of Passo Falzarego, showing the massive development of intersupratidal structures and emersion brecciae. At the left, the terrigenous succession forming the lower portion of the Heiligkreuz succession.

The basinal San Cassiano Fm predominantly consists of brown to yellowish marls, alternated with carbonate turbidites, resedimented bioclastic wackstones and micrites, and siliciclastic sandstones. At the toe of slope, large olistoliths and isolated boulders are often present, within much finer grained deposits. In the excursion area, the outcrops of this unit are poorly exposed, because of the widespread vegetation cover, but they are quite similar to those seen during the Sella excursion.

Santa Croce - Heiligkreuz (Dürrenstein) Formation

This unit records the flattening of the lower Carnian complex topography and a period of anomalously abundant coarse siliciclastic supply (De Zanche et al., 1993; Neri & Stefani, 1998; Bosellini et al,. 2003; Preto & Hinnov, 2003). This interval records a period of particularly moist climatic conditions. This formation consists of mixed clastic-carbonate successions, recording large shallow-water carbonate areas and zones subject to strong terrigenous input. The Heiligkreuz Fm lies both onto the Cassian Dolomite or on the basinal shales and limestones of the San Cassiano Fm, and it is in turn unconformably overlain by the sabkha and paralic facies of the Raibl Fm Its age is constrained to a narrow stratigraphic interval, close to the Julian-Tuvalian boundary (Carnian), by ammonoid and palynomorphs findings (Gianolla et al., 1998b; De Zanche et al., 2000). The Heiligkreuz Fm is a roughly isochronous unit, representing a complete 3rd order depositional sequence (Russo et al., 1991; De Zanche et al., 1993; Gianolla et al., 1998a,b; Preto & Hinnov, 2003), here named Car3, according to the sequence stratigraphic framework of Gianolla et al. (1998b). In the study are, the formation can be subdivided into several informal members.

Borca member is confined to the former basinal areas and conformably lies on the uppermost shallowed portion of the San Cassiano Fm; this aggrading unit onlaps the former Cassian platform slopes. It consists of a mixed carbonate-terrigenous unit, comprising skeletal grains calcarenites, oolitic-bioclastic packstone/grainstone and hybrid arenites. In the lower portion of the member, metre scale patch reefs can be found, with spectacularly preserved faunae, rich in corals (Member A in Russo et al., 1991). This interval is followed by a distinct lithozone organised in peritidal cycles (Ltz *D*), several metre thick, characterised by stromatolitic dolostones, marly limestones with plant roots, and claystones rich in

Figure 6.3 - Pisoids are widespread in the visited peritidal platform-top succession. Photo and finger: M.Morsilli.

plant debris and ambers. This unit is developed both on top of the Borca member that above the top of the former Cassian platforms (Figure 6.8). This lithozone is topped by a well defined palaeosoil, which can be traced for several kilometres (Preto & Hinnov, 2003). **Dibona member** (*cf.* Bosellini et al., 1982) consists of a mixed siliciclastic-carbonate lithozone, characterised by a progressive upward decrease in siliciclastics and by a deepening trend. A detailed lithofacies database is discussed in Preto & Hinnov (2003). This unit ends with nodular, bioturbated marly limestones, with *Chondrites sp*. and sometimes abundant pelagic fossils, condensed on the maximum flooding surface. The following **Lagazuoi member** consists of dolostones with herringbone cross bedding, calcareous sandstones and massive dolostones. It forms a well recognisable carbonate unit, that can be traced for several kilometres, corresponding to the carbonate equivalent of the "Arenarie del Falzarego" (Bosellini et al., 1982). The Lagazuoi member is laterally replaced by a more terrigenous unit, named as **Falzarego sandstone member,** (Bosellini et al., 1978), showing spectacular tractionary lamination and tidal current structures. In the northern shelf areas unreached by siliciclastics, the Heiligkreuz Fm is mainly made up by well stratified shallow water carbonates, named **Vallandro member**, organised in metre scale peritidal cycles, with peloidal and stromatolitic dolostones, and rare marly and varicoloured argillaceous layers, particularly abundant in its lower portion.

Raibl Formation (Travenanzes fm)

In the visited area, this formation is dominated by monotonous alternations of fine grained, light-coloured dolostones and red, green and gray marls and shales, with minor, decimetre-thick sandstone intercalations. These facies probably accumulated into wide coastal mudflats and lagoons. Arid to semi-arid climatic conditions are inferred on the basis of the occurrence of calcrete palaeosoil and sulphate evaporates, well developed a few kilometres eastward of the visited sections, in the Cortina valley. At the very base of the unit, metre-thick quartz-conglomerate and sandstone may occur (i.e., Falzarego Pass). The coarse siliciclastics increase in thickness and frequency to the south, to prevail on all other lithofacies at the southern border of the Dolomites. This terrigenous facies associations show metre thick cross-bedded sandstone bodies, with evidence of lateral accretion, erosionally cutting reddish and gray claystones, in turn characterised by mud-cracks and occasional tetrapod foot-prints. This facies association clearly indicates a fluvial depositional setting, gradually merging into coastal sabkha-lagoon environment. The thin coarse siliciclastic documented as north as Falzarego Pass may record the fringing out of such a fluvial system.

Dolomia Principale

The impressive well stratified cliffs spectacularly characterising the landscape of the Dolomites are mainly made up by the vertical stacking up of shallowing upward peritidal cycles, pertaining to the Dolomia Principale, a widespread Late Triassic formation recording the gigantic carbonate tidal flat of a rimmed platform, which have the margins located at the E and NE of Dolomites (Bosellini & Hardie, 1985;

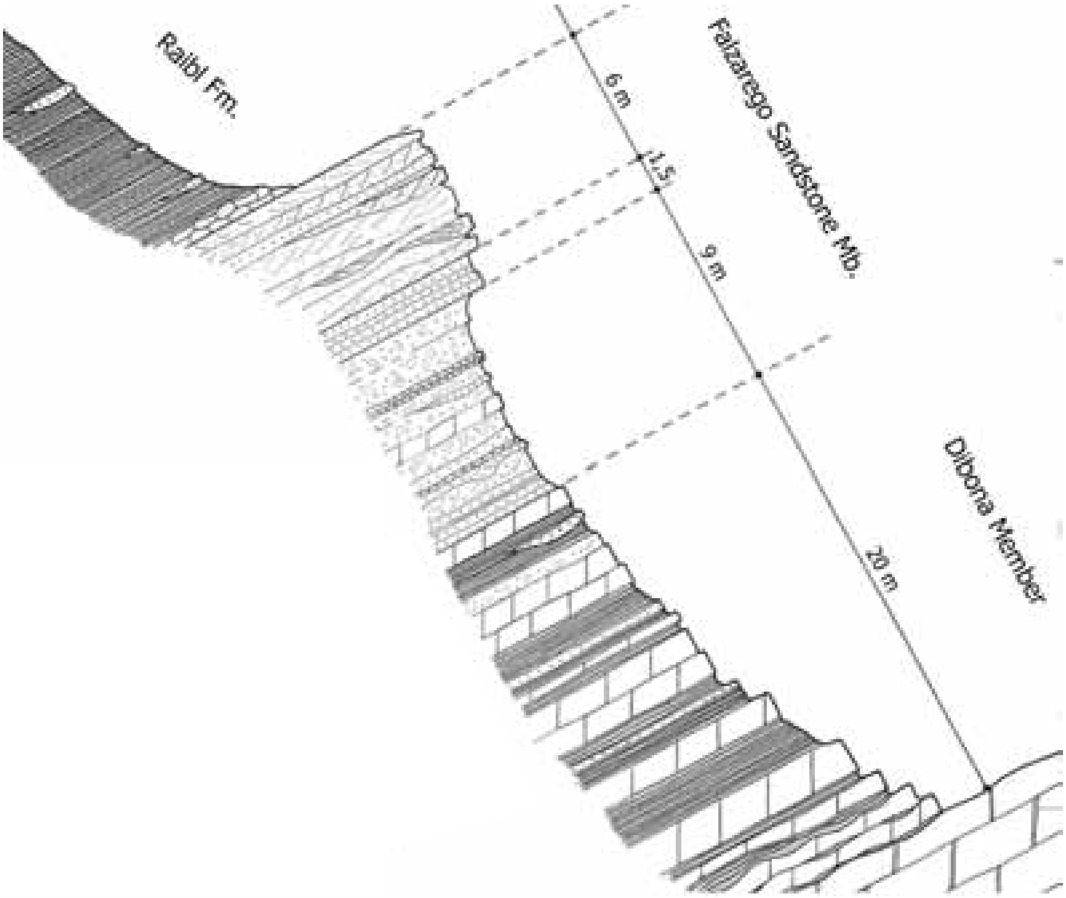


Figure 6.4 - The Heiligkreuz Fm succession at Passo Falzarego, subdivided into a lower argillaceous-carbonate unit (Dibona mb) and an upper mainly arenaceous high-energy unit (Falzarego sandstones). The formation rests on the subaerial karstic sequence boundary topping platform-top peritidal dolomites and is followed by red claystones with subordinated sandstones and dolomites (Raibl Fm). Modified after Bosellini et al. (1978).

De Zanche et al., 2000; Gianolla et al., 2003). The huge thickness, ranging between 250 and 2,000 m, record fast but laterally strongly variable subsidence. In the visited area, this unit forms the high wall of the Tofane mountains, showing a stratigraphic thickness in the order of one kilometre.

Excursion Stops

The excursion will start from Pass Falzarego and will proceed in a somewhat reverse stratigraphic order. Beside showing some spectacular depositional geometry and facies, the excursion will offer the opportunity to observe First World War fortification, still witnessing the violence of the fitting in this very steep Alpine landscape.

Stop 5.1:

The Cassian platform interior and the Heiligkreuz siliciclastics at Passo Falzarego.

Slightly SW of Pass Falzarego, the platform top of the Cassian Dolomite is particularly well exposed, along the main road; in the geological literature this outcrop is often quoted as “Dürrenstein Dolomite” (Hardie et al., 1986, Bosellini, 1991 etc.). The platform interior is characterised by peritidal sedimentary cycles, capped by subaerial exposure surfaces, associated with tepee structures and caliche palaeosoils. Marine pisoids are also common through the section (Figure *6.3*). A thinning-upward trend in the sedimentary cycles thickness, matched with the upward increase in the quantity and maturity of palaeosoils, indicates

Figure 6.5 - High energy tractionary laminations formed under tidal current influence in the upper portion of the Falzarego sandstones at the homonymous pass.

a shallowing evolution of the platform and a progressive decrease in the available accommodation space. Platform sedimentation came abruptly to an end through emersion and a palaeokarstic breccia developed on the top of the peritidal succession (Figure *6.2*). Above this discordance surface, sedimentation started again with the deposition of shallow water terrigenous-carbonate succession (Dibona member; Figure *6.4*), here not well exposed. At the nearby Falzarego Pass, the upper portion of the siliciclastic succession (Falzarego member) spectacularly shows sedimentary structures, recording a high energy shoreface depositional environment, with spectacular tractionary structures (Figure *6.5)*.

Stop 5.2:

Cassian platform interior and carbonate-siliciclastics at Rif. Lagazuoi; panoramic view on the stratigraphy and structural geology of the surroundings

The Lagazuoi Mountain is chiefly made up by the slope and platform-top facies of a lower Carnian rimmed carbonate platform. The platform top facies are here quite similar to those seen at Passo Falzarego; however, the karstic erosive surface marking the top of the platform top succession is here more pronounced. The Heiligkreuz Fm features are here on the contrary sharply different from those previously seen, being formed by mixed carbonate-siliciclastic sediments, deposited in a ramp environment (Preto and Hinnov, 2003). This formation is here relatively thin; its upper part records a shoal environment, subject to strong tidal current influence, recorded by nice herringbone structures. From Rifugio Lagazuoi, we will observe the 360° panorama on the Carnian platforms and on the main Alpine tectonic structures of the area. Falzarego Pass and the outcrops of stop 5.1 will be also visible from above, in the footwall of the major south-vergent Falzarego Pass overthrust (Bosellini et al., 1982). Here, the northern carbonate block (Lagazuoi-Tofane) thrusted over the southern one (Sasso di Stria, Col Gallina, Nuvolau) and a large flake of a Carnian basinal succession, originally deposited at some distance form any carbonate platform, is now pinched along a thrusting plain bifurcation.

The lower Carnian Cassian Dm records an articulate system of attached platforms including, from west to east, the Settssas – Richthofen Reef, Sass de Stria, Col Gallina, Nuvolau, Averau, and Lastoi di Formin. Other well known Triassic platforms are also visible, as the Sella and Marmolada ones.

In the walk to stop 5.3, large breccia bodies at the top of the Heiligkreuz Fm will be shown. They probably accumulated as mass flows and represent the local

Figure 6.6 - The spectacular scenery visible looking south while descending from the Lagazuoi, with the erosional top of the Cassian platform followed by the terrigenous-carbonate Heilgkreuz Fm; in the background the late Cassian platform of the Lastoi di Formìn is visible, tectonically inclined towards the left (East), whereas the skyline is dominated by the Upper Triassic carbonate of the Croda da Lago and Pelmo.

expression of an important sequence boundary (Car4 SB of De Zanche et al., 1993; Gianolla et al., 1998a). Similar breccia bodies, in the same stratigraphic position, were observed through a large area, from S.Croce/Heiligkreuz (Badia Valley) to Lastoi del Formin and further.

Stop 5.3:

Forcella Travenanzes. The Upper Triassic tidal flats: Raibl and Dolomia Principale Fms

The upper Carnian Raibl Fm is here visible, mainly consisting of polychrome shales, marls, aphanitic or stromatolitic dolostones, deposited into tidal flat, sabkha and flood plain environments. The uppermost part of the Raibl Fm (Forcella Travenanzes) is characterised by well stratified dolomites, with minor shales intercalation, heralding the Dolomia Principale depositional style in their being organised into metre-size shallowing-up peritidal cycles (Bosellini & Hardie, 1985). These cycles are characterised at their base by bioturbated lagoon deposits, frequently yielding poorly diversified bivalve faunae, dominated by *Megalodon* ssp., followed upward by planar stromatolite horizons, often showing subaerial exposure features. The boundary between the Raibl and Dolomia Principale formations may be placed at the disappearance of the argillaceous input: from this point onward, the deposits are fully carbonate in nature and form steep cliffs, in sharp contrast with the smooth ledges generated by the Raibl beds (Fig *6.7*). From the excursion trail, the huge thickness (about 900 m) of the Upper Triassic peritidal deposits is visible, spectacularly exposed in the nearly vertical cliff of the Tofana di Rotzes. It is worthy to compare this Dolomia Principale outcrop with those seen at Sass Pordoi (Day 3), where this unit is only 250 m thick.

Stop 5.4:

Col dei Bos: a closer view of the Heiligkreuz Fm facies.

At Col dei Bos (Ox Hill in Ladin), this formation is much thicker than at the Rif. Lagazuoi (stop 5.3); a further thickness increase is visible moving eastward (Rif. Dibona, at 3.7 km to the east, Figure *6.9*). This unit can be here subdivided into three intervals: (1) lithozone D, consisting of white peritidal dolostones, with coloured shale and arenite intercalations and palaeosoils; (2) Dibona mb, a complex unit comprising arenites, oolitic and bioclastic packstone-grainstones, regular alternations of bioturbated micritic limestones and gray marls; the granular facies show flaser bedding, wave ripples and wave-current megaripples; (3) Lagazuoi mb, a massive strongly dolomitised unit, where the rock textures and sedimentary structures are often poorly visible

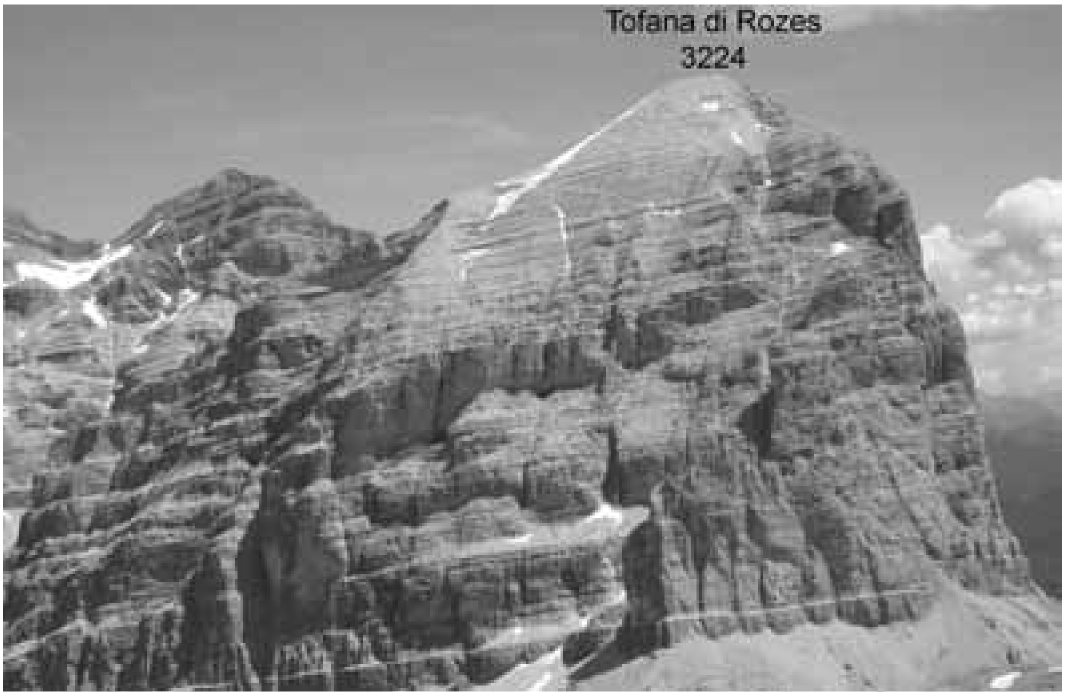


Figure 6.7 - The impressive eastern wall of the Tofane Massif, formed by the Upper Triassic peritidal cyclic succession of the Dolomia Principale Fm, recording a period of substantial subsidence, heralding the Jurassic evolution of the future passive continental margin.

because of the diagenetic overprinting; however, in the visited outcrop, herringbone and dm-scale cross bedding are preserved. During this stop, the breccias and palaeokarst structures marking the discordance top of the Cassian Dm will be visible, as well as the tidal flat facies of the lower Raibl Fm, exposed at the Col dei Bos summit.

Stop 5.5:

Cassian platform slope facies and their indentation with the basinal San Cassiano Fm

Moving downward from the Forcella Col dei Bos, along a First World War Italian military road, we will move toward older units. A closer view of the carbonate slope deposits of the younger progradational phase of the Cassian platform will be therefore available. The clinostratificate deposits consist of carbonate breccia and calcarenites, interbedded with the basinal shale and micritic mudstone of the San Cassiano Fm. The apparent dip angle visible in the sub-vertical cliff is much lower than the real one, since the clinostratification are not cut along their actual stratigraphic dip. Walking down along the road, toe of slope calcarenites and carbonate olistoliths (Cipit boulders) will be visible, interbedded with basinal shales. At the site of an Italian army camp kitchen, used during World War I, well bedded mudstones and very fine-grained calcarenite of the San Cassiano Fm are exposed, showing an onlap relationship with a base of slope tongue of the Cassian Dm. According to Gianolla et al. (1998), this onlap relationship records the transgressive phase of the Car 2 depositional sequence. The slope facies of the lower Carnian Cassian platform will be visible along the lowermost part of the trail, consisting of roughly clinostratified massive dolostones and brecciae.

Stop 5.6:

Panorama of the field trip area from Rif. Scoiattoli: the rimmed platform geometry of the lower Carnian platforms versus the ramp geometry of the upper Carnian sediments.

From the southern side of the Falzarego valley, a panoramic view of the field trip area will be visible under an afternoon light, showing the dramatic changing in depositional style occurred during the Carnian Time. The lower Carnian buildups show a flat top and steep slopes, with a typical rimmed platform

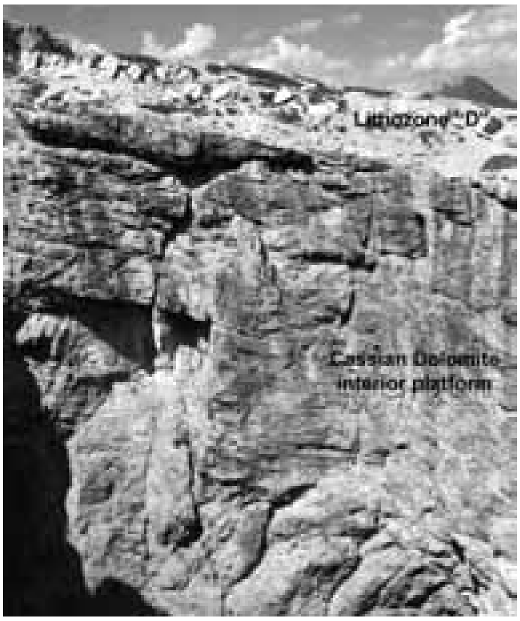


Figure 6.8 - The Cassian platform-top succession capped by a subaerial sequence boundary, followed by the terrigenouscarbonate Heiligkreuz Fm, at Col del Bos.

geometry. Two generations of carbonate platforms can be identified (Cassian Dm. 1 and 2), a pattern recognised throughout the Dolomites. The (mostly) upper Carnian Heiligkreuz Fm is instead formed by a wedge of carbonate-clastic sediments, recording the very reduced topographic gradients of a mixed terrigenous-carbonate ramp depositional system (Preto and Hinnov, 2003).

Amber from the Heiligkreuz/ Dürrenstein Formation

G. Roghi and E. Ragazzi

The Heiligkreuz/Dürrenstein Formation provides some of the most ancient and quantitatively substantial amber deposits of the world, firstly indicated by Koken (1913) and later described by Zardini (1973) and Wendt & Fürsich (1980). More recently, a research group of the Padua and Ferrara Universities extensively studied the palaeobotanical and physico-chemical features of this fossil resin (Gianolla et al., 1998b; Roghi et al., 2002, 2003; Ragazzi et al., 2003). Amber was found in the lower and middle part of the Heiligkreutz/Dürrenstein Formation, corresponding to the late Julian-early Tuvalian. In the same chronostratigraphic interval, amber was found also in the Schilfsandstein deposits (Germany), Raibler Schicten and Lunzerschicten (Austria) and in the Chinle Formation (Arizona). Discovery of this fossil resin through a wide area in deposits of the same age suggests that resin exudation from the ancient trees could be influenced by both evolutionary factors and palaeoclimatic fluctuations.

Fossil resin drops show typical globe-shaped forms (Figure 6.11) with a little stem and main diameter of 2-3 millimetres. Sometimes, outer drop surface shows characteristic reticular structures, suggesting a fast desiccation.The amber of the HeiligkreuzDürrenstein Formation were found in palaeosoils, associated with plants remains, indicating autochthonous finding, and from hybrid sandstones with marine pelecypods and plant debris, suggesting that the amber were transported and redeposited.

In a palaeosoil, a considerable abundance of cuticle-preserved leaves allowed the correlation of the amber-producing species to the Cheirolepidiaceae Family, a group of conifers present from Upper Triassic to Cretaceous (Roghi et al., 2002).

The abundance of small amber drops allowed the physico-chemical characterisation of this fossil resin (Ragazzi et al., 2003). Laboratory analysis with infrared spectrophotometry (FTIR), nuclear magnetic resonance (NMR), thermogravimetry (TG), differential thermogravimetry (DTG), and automated elemental analysis produced a whole physico-chemical characterization of the fossil resin from the Dolomites, enabling the comparison with it with younger ambers and resins (copals) from other world sites.The infra-red spectrum of the Triassic amber (Figure 6.12) is a typical one of fossil resins. The diagnostic region of the spectrum, the so-called "fingerprint region" between 8 and 10 mm, shows unique patterns. A strong degree of resin maturation is confirmed by the lack of labile functional groups peaks. Also the NMR spectrum is compatible with an old age, and a history of high pressure exposure in the embedding sediment, during Mesozoic and Palaeogenic burial. Thermogravimetry analysis permitted the finding of main thermal event peaks and the comparison with the main exothermal peak, corresponding to the maximal rate of weight loss, of amber and copal of different ages and from many sites of the world (Ragazzi et al., 2003). The value of the main exothermal peak of Triassic amber, located near 437°C, was the highest among the fossil resins examined. Study on the fossil microrganisms included in the amber, still preserved at an astonishingly pristine state, is in progress. The whole of these data

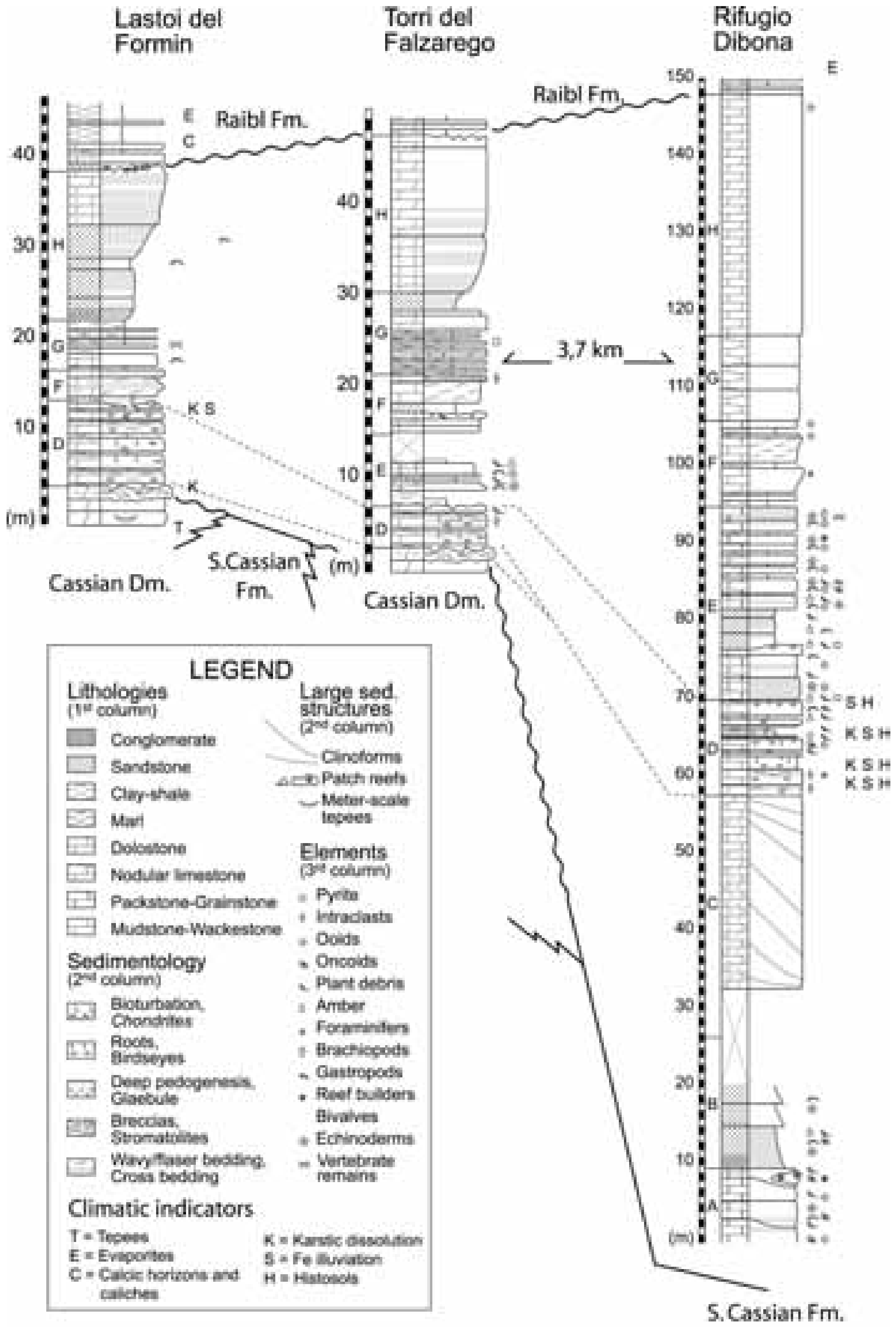


Figure 6.9 -The strong lateral variation of the shallow-water, terrigenous-carbonate Heilgkreuz Fm over short distances. Between the Lastoi de Formìn and Torri del Falzarego a major Alpine overthrust makes the evaluation of the primary distance difficult. Lithofacies subdivisions (A-H) as in Preto & Hinnov (2003).

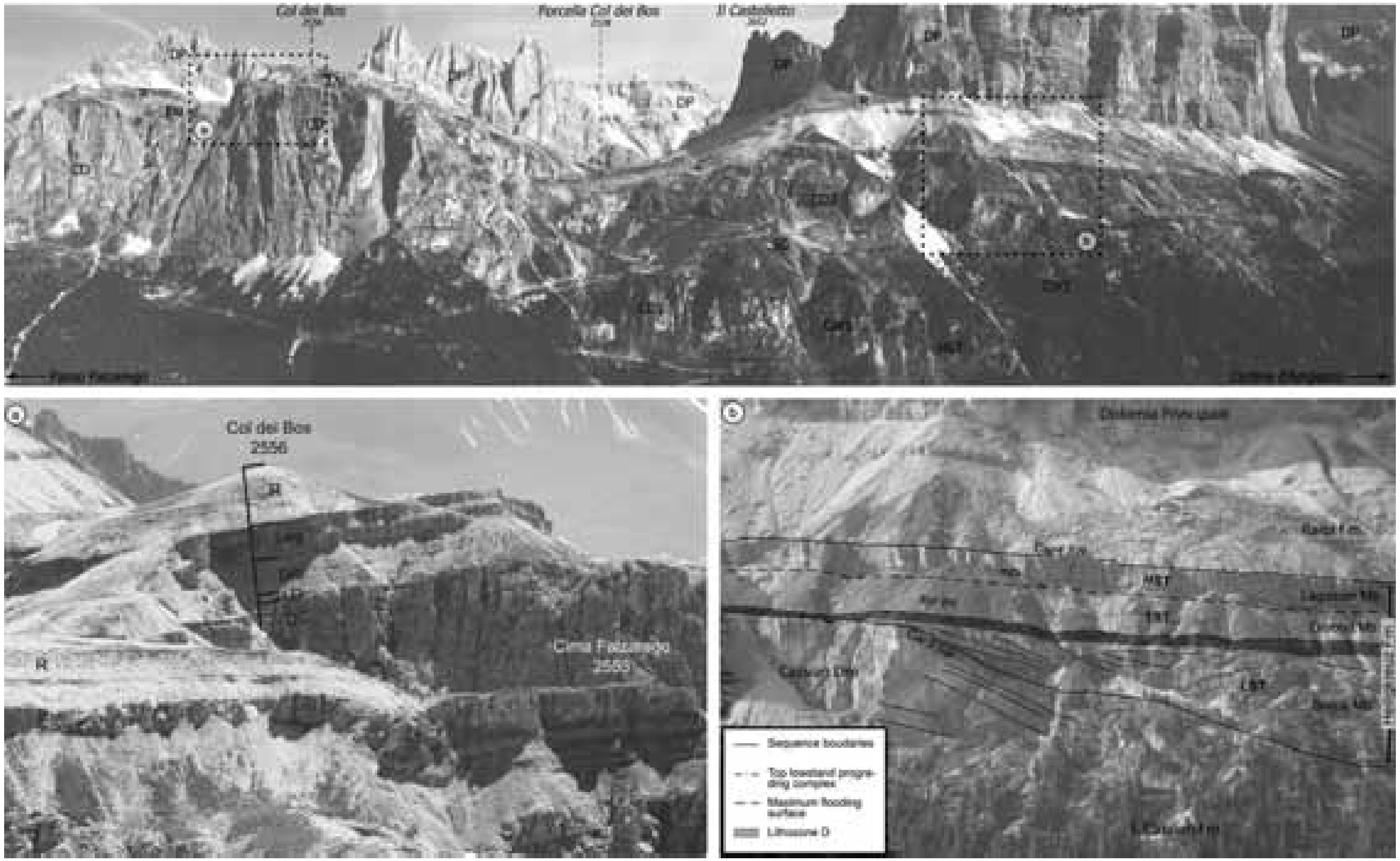


Figure 6.10 - Panoramic view of the southern cliff of the Falzarego-Tofane massif, spectacularly showing the depositional geometry and the depositional sequence architecture. The Col del Bos was photographed from the west (cf. Figure 6.6, 6.8).

Figure 6.11 - Amber drops form the Heiligkreuz Fm in the Falzarego-Lagazuoi area.

suggest that the Triassic amber of the Dolomites is a unique kind of fossil resin with interesting potentials also as a paleoenvironmental indicator.

DAY 6

The Marmolada Massif: a carbonate platform dominated by syndepositional cements

F. Russo, A. Mastandrea, M. Stefani, C.Neri.

Introduction

The Marmolada Platform (Schlern/Sciliar Fm) was part of an archipelago of small carbonate islands, scattered within a deep water basin. The platforms were involved into important polyphase Alpine tectonics (Figure 7.7, 7.8) The slope sediments belong to the "Calcare della Marmolada" (Leonardi, 1967); whereas the platform-top successions are ascribed to the "Calcare del Latemar" . The outcropping thickness of the platform-top succession is approximately of 200 m; an original thickness in the order of one kilometre is however likely (Stefani & Caputo, 1998). The well-bedded platform-top succession outcrops in comparatively small areas. The margin facies are preserved *in situ* as very narrow belt. The slope facies, on the contrary, largely dominates the massif.

The stop regards an isochronous palaeogeographic transect, stretching from platform-top to the margin and upper slope settings in the northeastern side of the Marmolada Platform (Figure 7.1). The ammonoid fauna suggests an uppermost Anisian age (Secedensis Zone, Brack & Rieber, 1993; 1994). The profile is located in the northern slope of the Marmolada, and at the Marmolada Glacier front (Pian dei Fiacconi, between Q 2650 and 2750). The transect (Figure 7.1) exhibits no faults breaking its continuity. The excellent outcrop was only recently exposed by the retreat of the glacier.

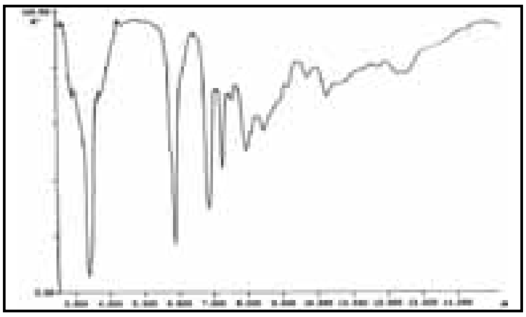


Figure 6.12 - Infra-red spectrum of similar Carnian amber.

≠The majority of the Dolomites platforms was affected by a facies-destroying dolomitization often preventing analyses of sedimentary and early diagenetic features. The Marmolada underwent weak dolomitization and can be studied in good outcrops, which are reasonably easy to sample. The most impressive feature of the Marmolada is the abundance of striking concentric cement crusts which characterize the upper slope facies (Figure 7.8).

These peculiar cements in the Triassic buildups were already recognized by Stoppani (1858), in the western Southern Alps. The author interpreted these structures as encrusting sponges and created a new genus *Evinospongia*. He underlined the lithogenetic importance of the "evinospongiae", making the point that the Middle Triassic was actually the realm of sponges (Stoppani, ibidem). These structures, also known as *"Großoolith"* in the Austroalpine Triassic (Leuchs, 1928; Schmidegg, 1928), were more recently interpreted as early diagenetic precipitates, modified by freshwater diagenesis (Brandner & Resch, 1981; Henrich & Zankl, 1986). Frisia Bruni et al. (1989) performed a comprehensive study in the Middle Triassic of the Western Southern Alps. The authors, recognized a low-Mg calcite composition, but drew no final conclusion with regard to the origin and primary mineralogy (Mg calcite versus aragonite) of the structures.

The role of organically-induced carbonate cementation in the platforms of the Dolomites is emphasized in several recent studies (Mastandrea et al., 1991; Russo

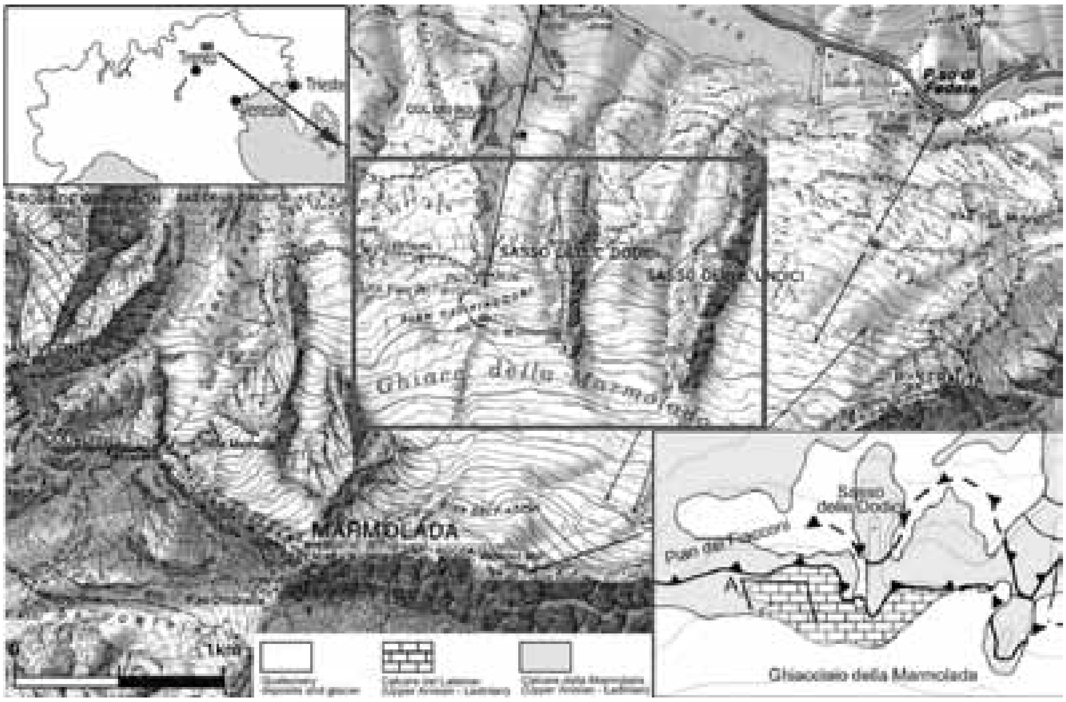


Figure 7.1 - Location map of the study area, in the northern slope of the Marmolada, Western Dolomites. The geological sketch-map illustrates the relationships between the platform-top (Calcare del Latemar) and the slope deposits (Calcare della Marmolada), together with the location of the transect (A). The western margin of the platform is well preserved and nicely outcropping; outcrops of the platform-top are limited to the north by an Alpine overthrust and at the south by the front of the Marmolada glacier.

et al., 1997; 1998a; 1998b); in particular Russo et al. (2000) proposed a similar origin for the spectacular cement crusts of the Marmolada Massif.

Platform top facies

The platform-top succession consists of intra-bioclastic calcarenites and calcirudites and to a minor degree of peloidal boundstones (Figure 7.2A-B; Figure 7.3). Coarse grainstones are common (Figure 7.4). Packstones are rare, mudstones and wackestones almost absent. Micrite is commonly preserved only within syndepositionally lithified boundstones, but was winnowed in other subtidal environments. Graded storm layers and wave structures are visible, together with rare current laminations despite the widespread bioturbation. The platform-top facies are organized in meter-scale shallowing upward cycles. Surfaces marking the cycle tops and recording a subaerial diagenesis are visible throughout the platform, but they are particularly common in near-margin settings, as well as in the coeval Latemar Platform (Egenhoff et al. 1999). Several surfaces are associated with decimeter to meter-scale teepees, recording a massive inter-supratidal cementation.

Microfacies and Biota

The macrofossil content of the subtidal units is rich and diversified. Particularly abundant are gastropods, benthic pelecypods, articulate brachiopods, echinoids and crinoids. Green algae are also common; solitary corals and sponges are rare. Some transgressive levels yield abundant pelecypods pelagic and ammonoids.

The boundstones facies (Figure 7.3) is made up by early lithified peloidal micrites, organized in thrombolitic clots or, more rarely, in thin stromatolitic laminae. This facies is very rich in primary cavities, lined by isopachous fibrous cements. Microbiota are not particularly frequent and consist of skeletal cyanobacteria (porostromata) and dasycladacean algae, with a small amount of foraminifers, gastropods, echinoids, and pelecypods.

The grainstones facies (Figure 7.3) is dominated by well lithified boundstones intraclasts. Bioclasts are also common and include in decreasing order

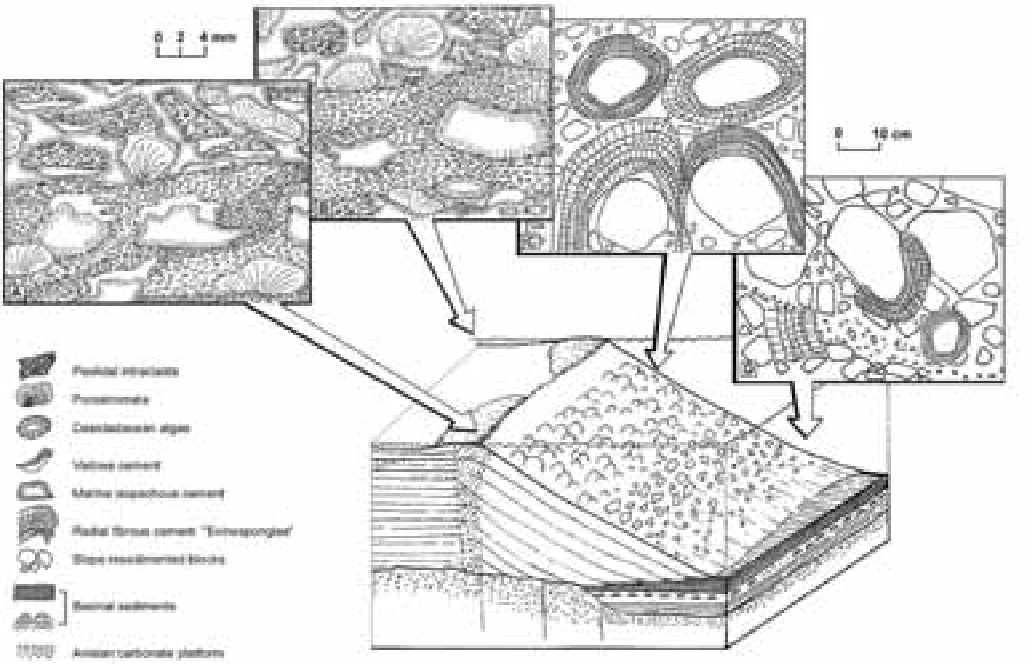


Figure 7.2 - Schematic drawing (not to scale) of the facies and geometric relationships between platform-top, margin, slope and basin during the early aggrading phase of the Marmolada Platform. (A) Frequent emersions of the inner margin induced the vadose diagenesis of peloidal-porostromata boundstones and grainstones. (B) Boundstones and grainstones of the platform-top were only affected by marine-phreatic diagenesis. (C) Massive precipitation of abundant concentric crusts consisting of radiaxial fibrous marine cements ("evinospongiae") took place at the outer margin and on the upper slope. (D) The slope sediments were predominantly formed by cement-rich blocks derived from the syndepositional erosion of the narrow platform margin belt. Note the different scale of A and B versus C and D drawings.

of frequency, porostromata, dasycladacean algae, gastropods, pelecypods, foraminifers, echinoderms, microproblematica, and a few sponges. Porostromata are common. Most taxa belong to the genera *Ortonella*, *Hedstroemia*, *Bevocastria* and *Cayeuxia*. Many thalli occur as micritized and coated ghosts structures. Dasycladacean algae are recorded by *Macroporella alpina* Pia, *Diplopora annulata* Schafhautl, *Diplopora nodosa* Schafhautl, *Gyroporella* cf. *ampleforata* (Gümbel) and *Oligoporella* sp. This association indicates an upper Anisian-lower Ladinian age, which is in good agreement with ammonoid dating (Brack & Rieber, 1993; 1994; De Zanche et al., 1995).

Calcareous microproblematica, which are common in the post-volcanic platforms (Brandner et al., 1991a; 1991b; Russo et al., 1997), are relatively rare. They are represented by *Tubiphytes obscurus* Maslov *Tubiphytes carinthiacus* (Flügel) and *Plexoramea cerebriformis* Mello. Sponges only were found as isolated specimens. Some forms are can be attribuited to the genus *Deningeria*. More frequent is *Olangocoelia otti* Bechstädt & Brandner. Foraminifers are represented by agglutinated forms (*Endothyranella* sp.; *Earlandinita* sp.); duostominids and miliolids. These groups are less frequent as compared with agglutinated foraminifers. Some decapod coprolites, belonging to the genus *Favreina*, were observed.

Cements

Both grainstones and boundstones facies show impressive isopachous rims formed by marine cements (Figure 7.3, 7.4). The isopachous fibrous cements have a "cloudy" appearance probably, due to organic matter inclusions and consist of low-Mg calcite (2-4 mol % Mg). Vadose subaerial meniscus and pendent cements (Figure 7.3, 7.4) are well developed in supratidal levels, marking the top of shallowing upward cycles. Pendent cements bind grains in situ as shown by conform geopetal infillings.

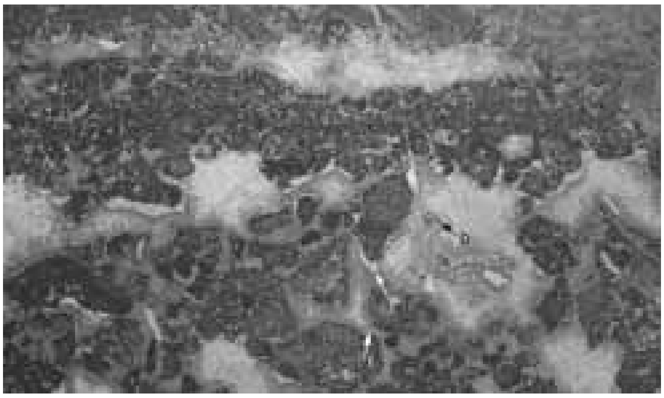


Figure 7.3 - Cavity-rich peloidal boundstones with skeletal cyanobacteria (porostromata). The cavities are lined by isopachous marine cements and filled with late sparry calcite, P = vadose pendent cement, I = marine isopachous cements; D = late dolomite substituting sparry calcite. X 7

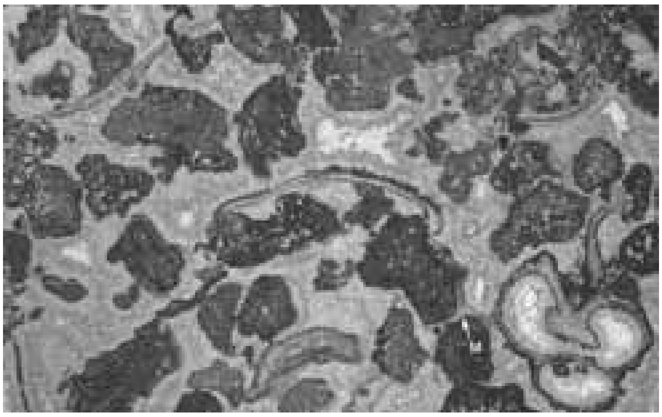


Figure 7.4 - Grainstones consisting of boundstone intraclasts, skeletal cyanobacteria, bivalve, and gastropod bioclasts. Note the random orientation of the clast, the large amount of isopachous marine cements, and the conspicuous vadose cements (M = vadose meniscus cements). X 7.

Tilted pendent cements are common within reworked intraclasts (Figure 7.4). Despite the impressive amount of syndepositional cements, a significant porosity was left to be filled at a later stage by sparry calcite. This late calcite has been partially substituted by quasi-stoichiometric dolomite (Figure 7.3).

Similar late diagenetic calcites and dolomites occur in the margin and upper slope carbonates.

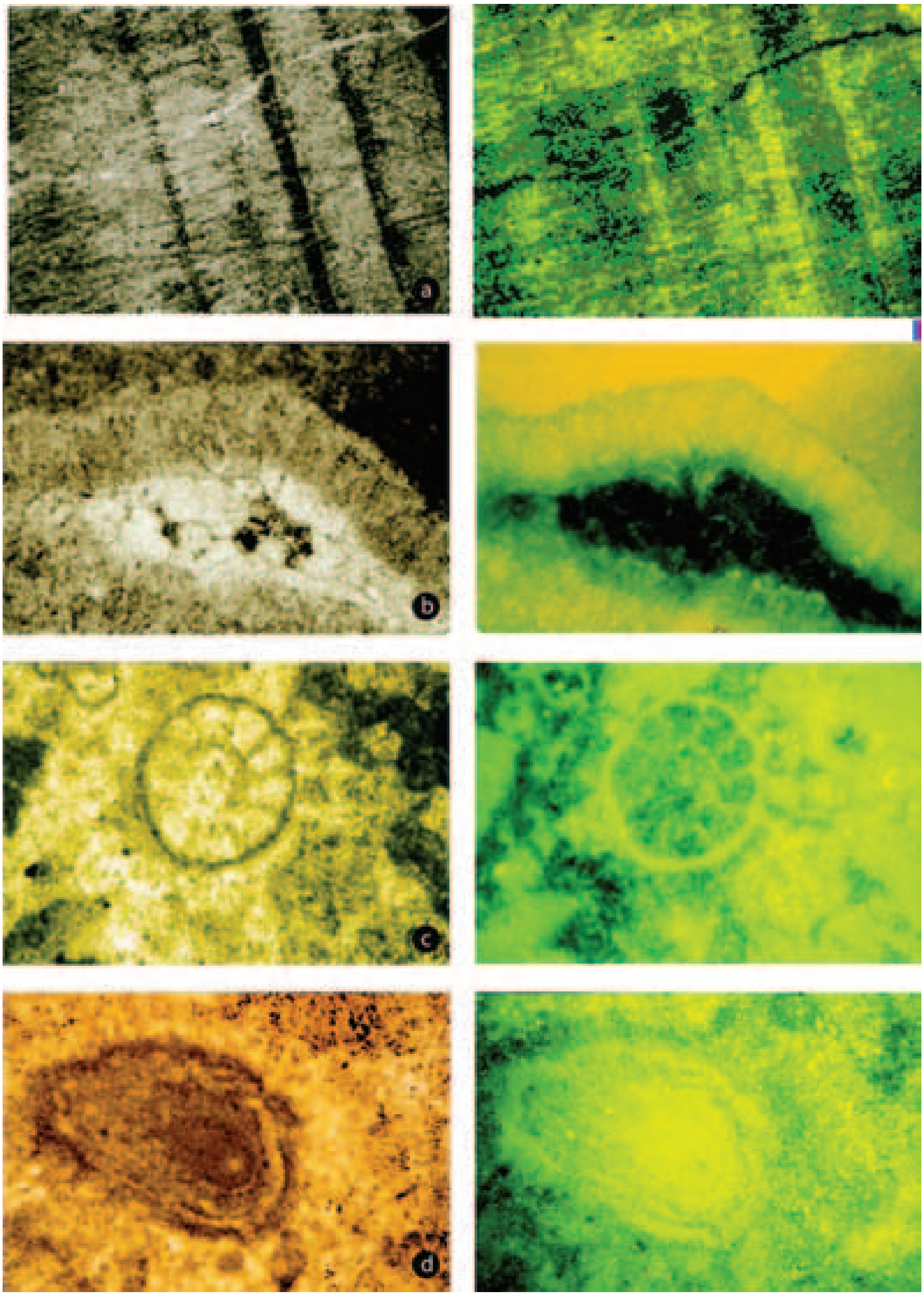
Margin and upper slope facies

The platform margin is characterized by a complex patchwork of depositional sub-environments, developed within a narrow belt between the shallow-water platform-top and the steeply deepening slope. Moving from the platform-top down the slope, three facies belts are visible: a) a poorly bedded coarse intra-bioclastic belt; b) a relatively narrow massive margin, rich in boundstones and early marine cements; c) an outer-margin and upper-slope area, characterized by impressive radiaxial fibrous cement crusts (“evinospongiae” auct.) (Figure 7.2C; Figure 7.8).

The narrow margin is dominated by peloidal boundstones, similar to those found in the platform-top succession. A primary framework formed by sessile metazoans is lacking; the skeletal remains comprise less then 5% of the boundstones volume. Aphanitic micrite which are most abundant in the post-volcanic carbonate platforms (Russo et al., 1997), are nearly absent. Millimeter- or centimeter-scale cavities lined by isopachous cements are abundant.

The outer margin and upper slope facies are characterized by decimeter-sized boundstones nuclei, coated and interconnected by large amounts of radiaxial fibrous cements, arranged in concentric bands (Figure 7.5). These cements form thick crusts, from a few millimeters to several centimeters in size. These crusts form laterally linked spheroidal or more or less separated structures (Figure 7.8). Broken and overturned

Figure 7.5 - Transmitted and epifluorescence light observation of strongly cemented margin facies; (a) radiaxial fibrous cements from a large syndepositional crusts (evinospongia); (b) isopachous marine cements partially infilling a primary cavity. In both facies, note the vivid green epifluorescence displayed by the early phreatic marine cements, particularly so in the levels richer in micro-inclusions, looking less transparent in transmitted light; this excited light emission is likely to be associated with microdispersed organic matter, which probably played a significant role also in the carbonate crystal precipitation. Late diagenetic cements in figure b are on the contrary not flourescent under the same conditions. High hydrodynamic energy platform-top calcarenites (c and d), observed under identical observation conditions. Note the vivid fluorescence of the coated grain (d) and the foraminifer (c), again rich in microdispersed organic matter. Marmolada Platform at Pian dei Fiacconi.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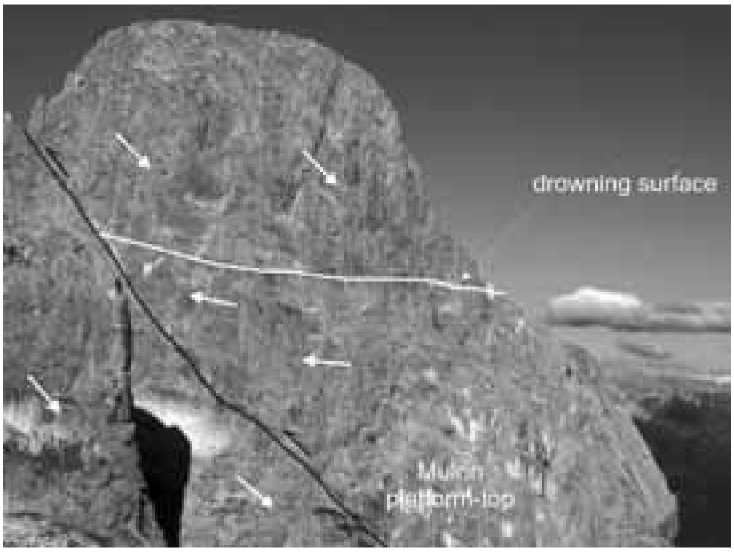

Figure 7.6 - In the Roda del Mulòn, the tilted depositional geometry of a drowned early pinnacle shows up, downlapped by the northward prograding clinostratified slope deposits of the Gran Vernèl Platform (From Caputo & Stefani, 2003).

fragments of these crusts are widely distributed in adjacent slope deposits (Figure 7.2D). These cements represent the major constituent of the outer margin and upper slope facies, but are also abundant in the slope deposits forming more then 50% of the platform rock volume.

Organic matter and syndepositional cementation

Bio-induced carbonate precipitation can be more important for the formation of carbonate buildups of the Dolomites than the metazoan growth (Russo et al. 1997; 1998; 2000). Many organisms, particularly microbes, can induce carbonate precipitation (Chafetz, 1986; Chafetz and Buczynski, 1992; Neumeier, 1998; Folk and Chavetz, 1999; Castanier et al., 1999; Reitner et al., 1999), either by biochemical processes, or indirectly, by alternating the chemical microenvironments or by trapping of dissolved Ca^{+2} on organic templates. Accurate analytical studies on modern reef cavities have underlined the importance of organo-mineralization related to the interaction of organic acidic macromolecules with inorganic compounds (Reitner, 1993; Reitner and Neuweiler, 1995; Reitner et al., 1996).

In the Marmolada Massif, the understanding of the primary precipitation mechanisms is limited by the pervasive recrystallization. However, in order to detect the presence of dispersed organic matter, uncovered thin-sections of the different microfacies were checked for epifluorescence. Bright epifluorescence characterizes the different kinds of bioclasts as well as the peloidal boundstones. The isopachous marine cements exhibit intensive epifluorescence too. These phreatic cements, rich in fine-grained brownish inclusions, produced a vivid green fluorescence.

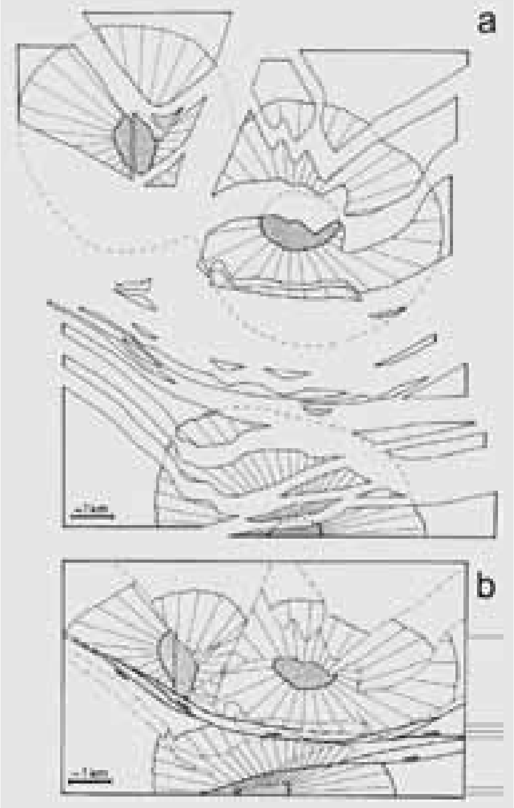

Figure 7.7 - The Marmolada Massif is made up by three independent carbonate platforms, telescoped and overthrusted one upon each other by the Alpine compression and then affected by Neogene strike slip deformation. Diverging lines indicate the radial clinostratification dip (From Caputo et al., 1999).

Figure 7.8 - Field view of a cement crust network ("evinospongiae"). This facies largely dominates the outer margin and the upper slope settings (Pan dei Fiacconi at about Q 2750 m at the present day glacier front). The cavities correspond to primary voids in the wave-resistant outer margin, and probably re-opened by recent karstification.

On the contrary, the late diagenetic calcites and the dolomite show no fluorescence. Fluorescence intensity variation are most probably related to fluctuations of the residual organic matter preserved in the limestones (Cercone and Pedone, 1987; Klotz, 1989).

The most conspicuous fluorescence occurs in cement crusts ("evinospongiae") of the upper slope facies. In trasmitted light, the crusts are characterized by wide bright belts alternating with narrow dark brown bands, with abundant fine-grained inclusions. The bright belts do not fluoresce, while the dark bands show an intense green fluorescence (Figure 7.5).

Organic matrix templates could have played a significant role in supporting the widespread syndepositional cementation during the fast growth of the cement crusts, dominating *in situ* the margin and upper slope facies and, as redeposited fragments, the whole of the platform volumes.

Minor elements in carbonates

The Mg content of the calcite on platform-top, margin and upper slope facies is surprisingly uniform independently from the original composition. Peloidal micrites, bioclasts, thick radiaxial crusts, isopachous marine cements, pendent vadose cements, share a common Mg content in the range of 2-4 mol%. The Fe and Sr contents are always beneath the detection limit. Even late sparry calcites lack any detectable Fe^{+2} content.

These data, together with the microscopic observations, suggest a diffuse fine-grained recrystallization, causing a widespread chemical homogenization. The lack of Fe^{+2} and the presence of Mg in the late sparry calcite may indicate an ion mobilization phase, probably occurring at a relatively recent stage, and under comparatively oxidizing conditions, associated with the Neogene uplifting of the Dolomites. This late diagenetic phase was possibly associated with a slow but long-lasting fluid flux, taking place subsequent to a deep burial cementation.

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Chronostratigraphic scheme of the Permo-Triassic of the Dolomites.
For discussion see the guide introduction.
1) Continental red beds;
2) Coastalmarine; locally tidal flat and coastal plain facies;
3) Low relief carbonate platforms;
4) High relief carbonate platforms;
5) Terrigenous-carbonate basinal facies;
6) Dis-anoxic basinal facies;
7) Cherty basinal limestone;
8) Basic volcanites, mainly subacqueous;
9) Basinal volcanoclastites;
10) Evaporites.

AVG Arenarie di Val Gardena; Be Bellerophon Fm (evaporitic carbonate); Bc Bellerophon Fm (marine carbonate); W Werfen Fm; DSei Lower Serla Dm; CgPP Piz da Peres Cg; G Gracilis Fm; DR M.te Rite Fm; CgV Voltago Cg; A Agordo Fm; DSes Upper Serla Dm; D Dont Fm; CgR Richthofen Cg; Am Ambata Fm; Mb Morbiac Fm; C Contrin Fm; M Moena Fm; Lvp Livinallongo/Buchenstein Fm Plattenkalke Mb; Lvk-b Livinallongo Fm Knollenkalke -Bänderkalke Mbs; DS Sciliar/Schlern Fm (including Marmolada and Latemar Lm); AZ Zoppè Sand.; Aq Acquatona Fm; V: Volcanites and Caotico; Eterogeneo Fm; F Fernazza Fm; Wg La Valle/Wengen Fm; MG Megabreccia di Passo Gardena; SC San Cassiano Fm; DC Dolomia Cassiana; Hk Heiligkreuz-Dürrenstein Fm; R Raibl Fm; DP Dolomia Principale/Hauptdolomite; CD Dachstein Lm.

FIELD TRIP MAP

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