

Permian–Triassic terrestrial ecosystems of the Dolomites (Southern Alps): Field trip on the occasion of the Paleodays 2018

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ABSTRACT

This paper provides a guide to the field trip of the 2018 edition of the Paleodays, the annual congress of the Società Paleontologica Italiana (Trento, 6–8 June 2018), dedicated to the terrestrial ecosystems of the Dolomites between the late Permian and the Middle Triassic. It is structured into three stops (Fig. 1). We will first visit two outcrops located near Tramin/Termenno, where the Permian–Triassic boundary is exposed, and in the Bletterbach Gorge, where the late Permian crops out in an extensive and spectacular succession. The third stop offers a visit to the Geological Museum of the Dolomites, in Predazzo, which allows us to discuss about carbonate platforms and the diversification of plants and tetrapods in the Middle Triassic.

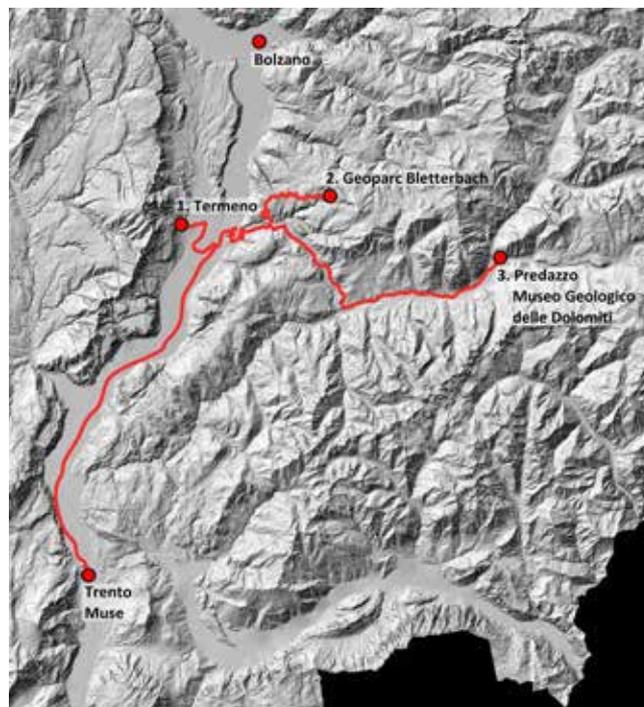


FIG. 1: The itinerary of the field trip.

1. THE TRAMIN/TERMENO SECTION: PERMIAN-TRIASSIC BOUNDARY IN A NEAR-SHORE ENVIRONMENT

1.1. GEOLOGICAL SETTING

The subject of this stop is a stratigraphic section located just upstream of the Tramin/Termenno village (Fig. 2), at the base of the eastern slope of the Mendel/Mendola chain, the mountain ridge that borders to the W the Etsch/Adige Valley in a N-S direction, in the stretch south of Lana and Bozen/Bolzano. The general structural setting of the area is represented by a monocline gently dipping towards SW, where it is possible to observe the regular overlap of volcanic and sedimentary units belonging to the South Alpine domain. Morphologically, it is a huge *cuesta* with the eastern slope shaped into high sub-vertical cliffs that overlook the Adige Valley.

At the base of the Mendel/Mendola chain crops out the uppermost unit of the Athesian Volcanic Group (lower Permian), out of which the morphologically conspicuous terraces of Gandberg/Monte Ganda and Mitterberg/Monte di Mezzo are shaped (Fig. 2, 3). Climbing up the eastern slope of the Monte Roen-Monte Penegal ridge, above the volcanic products lie the continental upper Permian deposits of the Gröden/Val Gardena Sandstone followed by the Bellerophon Formation (which disappear just NW of Caldaro) and the Triassic sedimentary succession represented by the Werfen Formation, the lower Anisian mixed carbonate-terrigenous units (Lower Sarl/Serla Formation, Voltago Conglomerate, Giovo Formation), the Middle Triassic carbonate

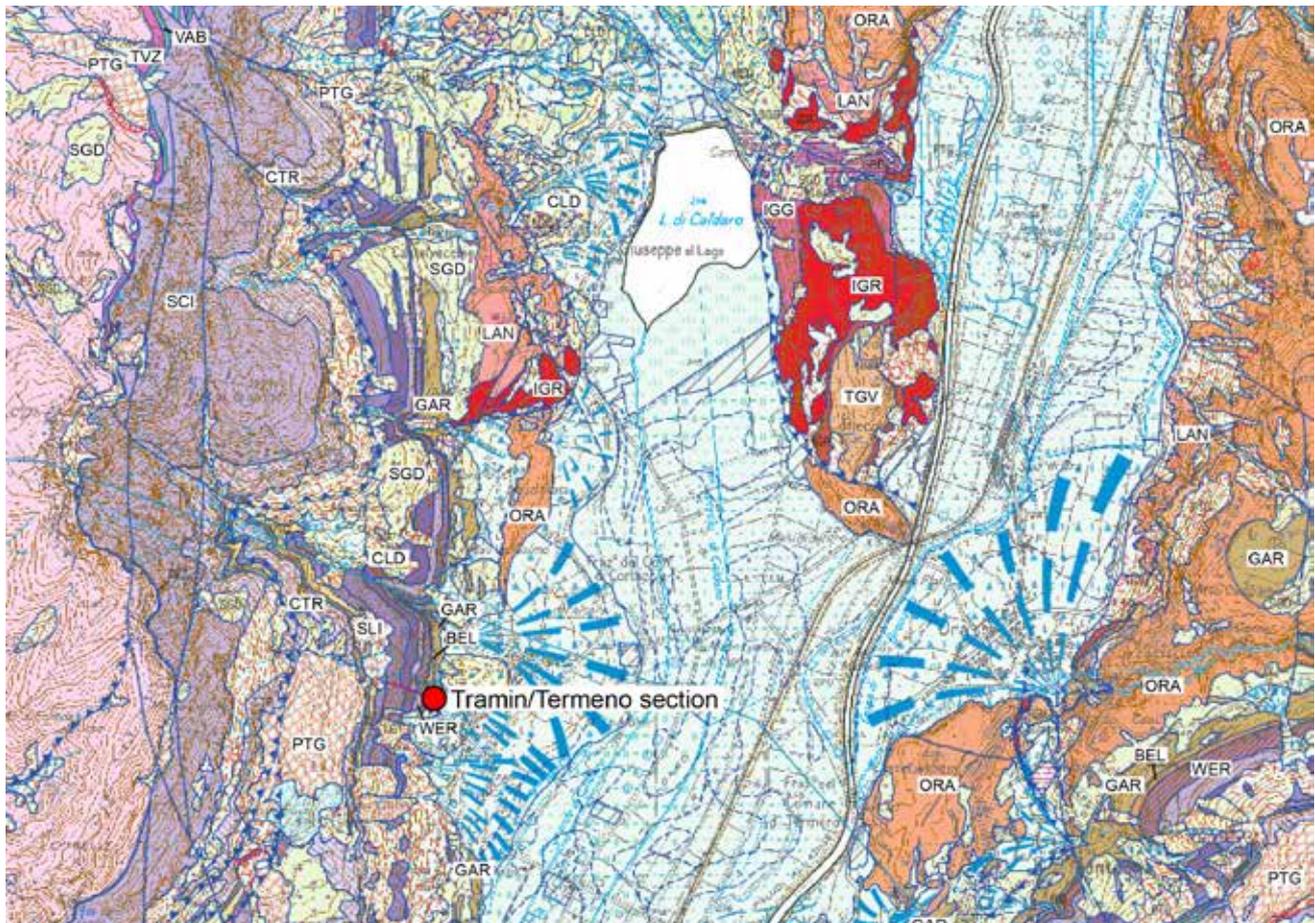


FIG 2: The geological map of the Etsch/Adige Valley near Tramin/Termeno. Modified from the Geological Map of Italy 1:50.000, sheet "043-Mezzolombardo".

platform deposits (Contrin and Schlern/Sciliar formations) and their heteropic basinal counterparts (Moena and Buchenstein formations and Val Vela Limestone). Locally, the Middle Triassic units are topped by the andesitic-basaltic volcanic rocks of the Ladinian cycle and by a few tens of metres of alternating calcareous-terigenous deposits (Travenanzes Formation; Carnian) on which rests the Norian carbonate platform unit (Hauptdolomit/Dolomia Principale). In this area, a sharp reduction in thickness of the Bellerophon Formation can be observed (from 20–30 metres to 0 metres NW of Caldaro), where the Werfen Formation directly overlaps the Gröden/Val Gardena Sandstone.

On the whole, the Mesozoic formations of the Mendel/Mendola chain can be distinguished by their relatively lower thickness compared to the same units in the western Dolomites, reflecting the relative high structural organisation that characterized this part of the Southern Alps during the Mesozoic. As far as

the Neogene structural evolution is concerned, the Mendel/Mendola chain is characterized by a system of superimposed thrust sheets: Mezzocorona – Magrè and Vigo di Ton – Tramin/Termeno, with a direction running from ENE–WSW and NNE–SSW (Fig. 3; Avanzini et al., 2012). The thrusts are limited by two kinematic junctions represented to the W by the Mezzolombardo – Taio Line (right) and to the E by the Ruffrè Line (left). Towards the N the fault displacement decreases, and the structures do not continue beyond the Ruffrè Line (N of Tramin/Termeno), while towards SW they continue in the Paganella Thrusts System (Fig. 4).

The thrusts represent the imbricated frontal sector of a deep regional structure and show, in their propagation towards SE, a stepped trajectory, in accordance with the different lithologies of the stratigraphic succession, which is marked by an alternation of more competent levels and more plastic intervals. These

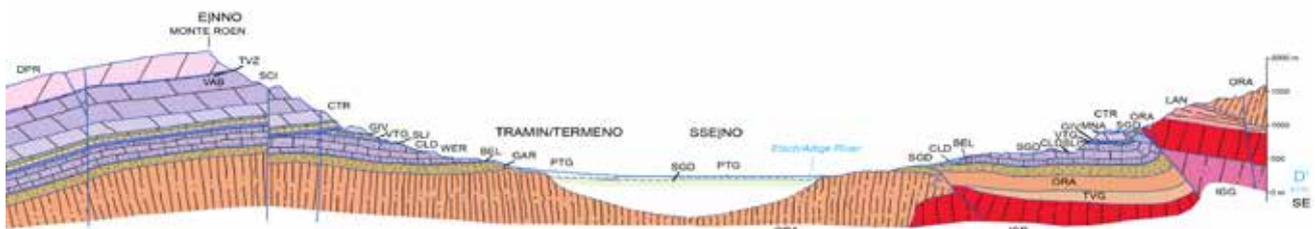


FIG 3: Geological section through the Etschtal/Val Adige near Tramin/Termeno. Modified from the Geological Map of Italy 1:50.000, sheet "043-Mezzolombardo".
 Legend: DPR – Hauptdolomit/Dolomia Principale, TVZ – Travenanzes Formation, VAB – Basaltic Volcanites, VVL – Val Vela Limestone, BHL – Buchenstein Formation, SCI – Schlern/Sciliar Formation, MNA – Moena Formation, CTR – Contrin Formation, GIV – Giovo Formation, VTS – Voltago Conglomerate, SLI – Lower Sarl/Serla Formation, WER – Werfen Formation, BEL – Bellerophon Formation, GAR – Gröden/Val Gardena Sandstone, ORA – Auer/Ora Formation, Athesian Volcanic Group.

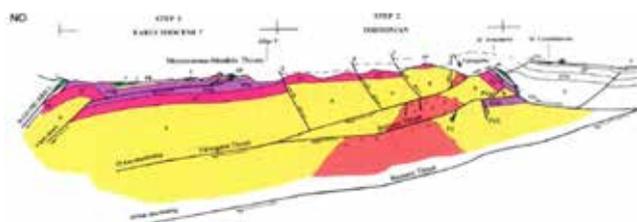


FIG. 4: Schematic section between the Giudicarie Line and the Valsugana System (modified from Selli, 1998).

geometries are developed in the imbricated strip overlooking the Adige Valley, where the most evident doublings are visible in correspondence with the ramp areas. In particular, the Contrin Formation, the Schlern/Sciliar Formation and the Hauptdolomit/Dolomia Principale (an intermediate competent unit about 1 km thick) are the units of the main ramp areas where the thrust inclines from 30° to 50° and often develops wide, strongly fractured and cataclased bands. The main along-bed detachments (lower flat area), which connect the deep ramp with the thrusts overlooking the Adige Valley, develop within the Werfen Formation, Lower Sarl/Serla Formation, Voltago Conglomerate, Giovo Formation (lower plastic unit), and locally in the Val Vela Limestone. The main tectonic transport direction is toward SE and is oriented about 330°N, which corresponds to the axis of maximum compression that generated the thrusts.

1.2. STRATIGRAPHY

The Tramin/Termeno section crops out in three different portions located just to the west of Tramin/Termeno. The first portion (Fig. 5, 6), about 22 meters thick, shows the transition between the uppermost Permian Bellerophon Formation and the overlying Lower Triassic Werfen Formation (basal oolitic Tesero Member).

The first 0.8 m (I-1) consist of an alternation of grey dolostones, organized in 10 cm thick layers, and dark grey and thinly bedded pelitic layers. Dolostones are often characterised by the presence of small to large dissolution cavities (Fig. 6). The section continues upwards with 0.7 m of light grey dolostones, sometimes with nodular bedding, cross-stratification, root trac-



FIG. 5: The Bellerophon-Tesero boundary at the Tramin/Termeno section.

es and other fossil plant remains (I-2 and I-3). Towards the top of this interval follow 0.8 m of granular dolostones, varying in colour from yellowish-grey to ochre, with grains mainly represented by ooids. This interval (I-4) is interrupted at about half of its thickness by a dark-grey and centimetre-sized pelitic layer. The section then continues for more than a metre with an interval dominated by yellowish dolostones, which show a sharp increase in the frequency of dissolution cavities and, in some cases, levels with nodular structure (I-5). A centimetre-sized, light grey pelitic horizon interrupts the monotony of succession in its middle part. The sequence continues upwards, for about 1.5 m, with well bedded grey and nodular dolostones, preserving roots and other plant traces; the dolostone beds are often interbedded with dark grey, centimetre-sized pelitic layers (I-6 and I-7). At the top of this interval a doloarenite, rich in fossil gastropods, marks the transition to a portion represented by yellowish-grey dolosiltites, with wavy and nodular bedding and numerous roots traces, mostly occurring at the top of each individual layer (I-8). The interval I-8 has been roughly correlated with the II-3 and part of the II-4 intervals of the Tramin/Termeno section II (Fig. 7). The sedimentary sequence continues with a nodular and bioturbated wackestone level, about 1 m thick, whose grains are mainly made of white mica (I-9); the regularity of this level is in some cases interrupted by silty layers showing low-angle cross-stratification. The section is then covered by vegetation for about 1.5 m, which can be approximately correlated with the uppermost part of the interval II-4 (grey dolostone) and the whole II-5 (grey and black dolomitic shale) and II-6 intervals of the Tramin/Termeno II section (cross-bedded dolomitic grainstone) (Fig. 7).

The section crops out again with an alternation of dark-grey micaceous dolosiltites, characterized by numerous dissolution cavities, alternating with dark-grey marly layers; the top of this portion (I-10), is made of yellowish dolostone without any trace of cavities. A centimetre-thick clayey layer marks the transition to pale grey micaceous doloarenites interbedded with dark grey pelites (I-11) containing root traces and highly carbonaceous horizons. The middle portion of this interval is characterized by a bivalve tempestite, load casts and erosional bed boundaries. The interval I-11 ends with a sequence of yellowish dolostone, about half a metre thick. The section is then covered again by vegetation for 7.20 m but the analysis of the Tramin/Termeno II section allowed to reconstruct the lowermost 1.50 m, which can be correlated with the second half of the II-9 and the whole II-10 intervals. The latter comprise an alternation of light dolostone and dark grey clays.

The Tramin/Termeno I section crops out again along the path (third and fourth columns of Fig. 7) with 30 cm of light grey dolostone (I-12), which are followed by about 2 m of pale yellow dolostone, marked in the topmost part of each bed by frequent roots traces, and interbedded with centimetre-sized-dark grey marly levels (I-13). The uppermost part of this interval is characterized by a shallow tidal channel with bivalve specimens mainly assigned to the genus *Permophorus* sp. A dark-grey marly bed, characterized by variable thickness, marks the transition to the overlying portion made of marly dolostone and grey mudstone with roots traces, which pass upwards to a laminated pelitic layer, followed in turn by yellowish dolostone with large cavities and possible ooids. The entire succession described above can be attributed to the Bellerophon Formation. The boundary with the Werfen Formation (Tesero Member) is marked by the occurrence of three tabular beds made up of dolostones with

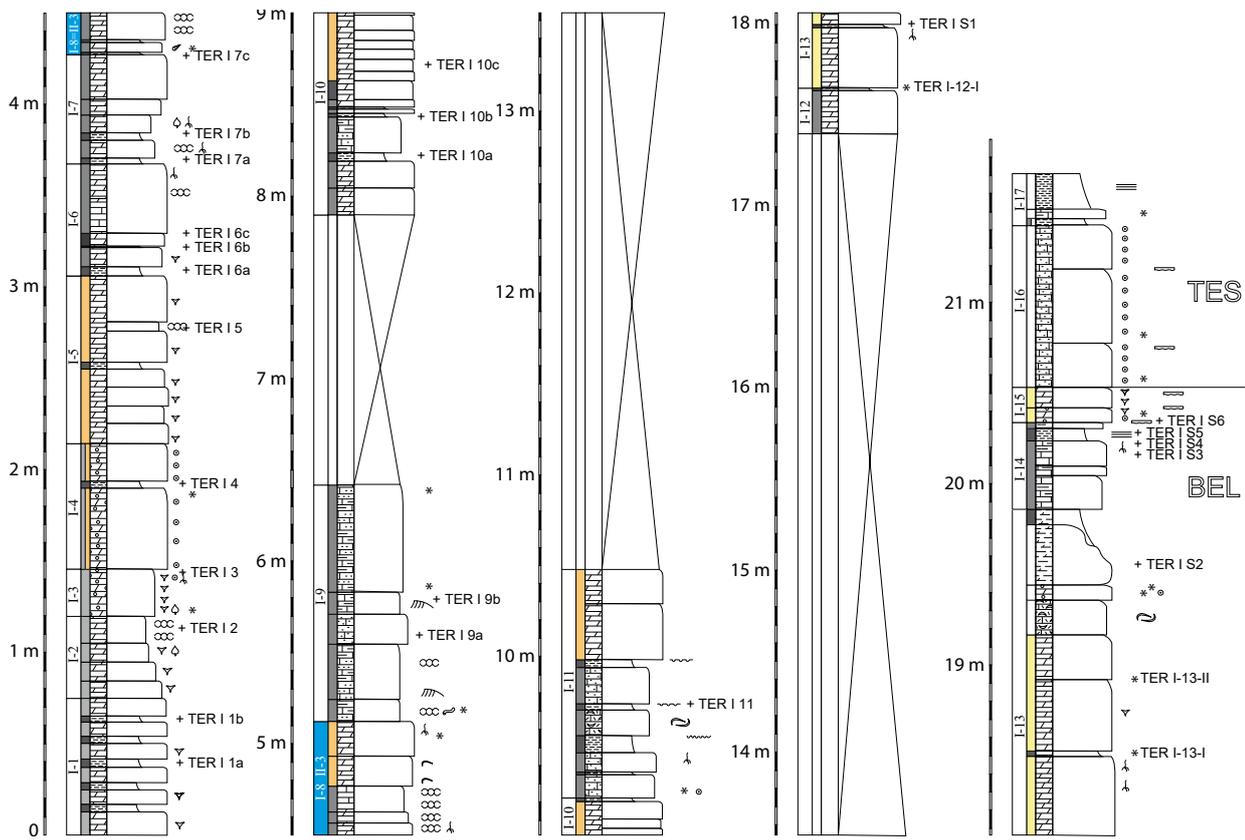


FIG. 6: The section Tramin/Termeno I - lower part.

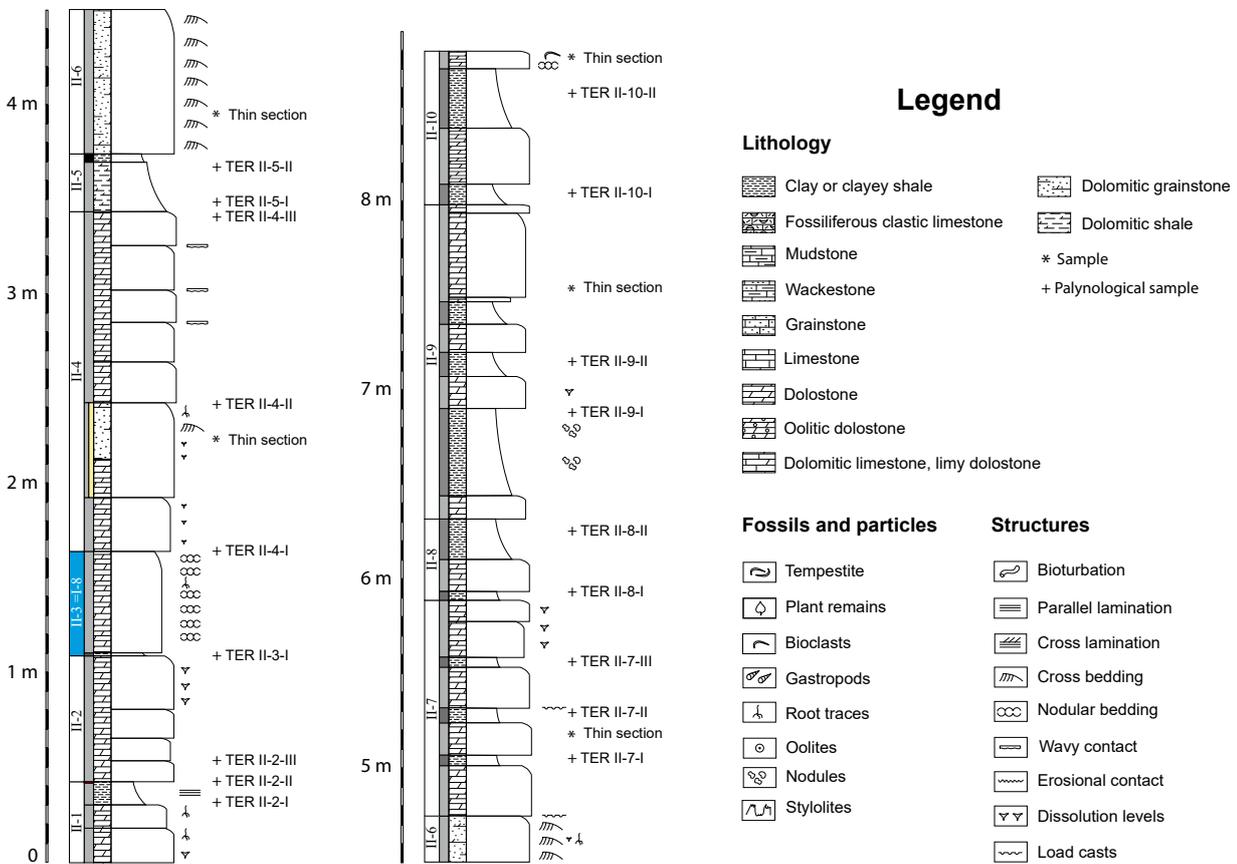


FIG. 7: The section Tramin/Termeno II.

sorted ooids (I-16). The lower portion of the Tramin/Termeno section finally ends with an alternation of greyish to whitish mudstone-wackestone and laminated shales with a total thickness of about 30 cm (I-17).

The upper part of the Tramin/Termeno I section can be observed in the third portion, slightly to the west, where the Permian–Triassic boundary succession is uplifted on the footwall of a direct fault running approximately NW–SE (Fig. 8). This part of the section starts with about 0.5 m of light grey clays, changing abruptly into 30 cm of light yellow micritic dolostone laminated at the base and with large dissolution cavities at the top. The section coarsens upwards into 2.70 m of dolomitic grainstone what is yellowish in colour and rich in ooids (I-18); the lithofacies does not change in the following metre except for its colour, which may vary from light grey to dark grey, and the complete absence of ooids (I-19). The overlying 2.1 m are made up of massive, yellowish to grayish dolomitic grainstone, organized in 20 to 30 cm thick beds, with wavy contacts and abundant ooids (I-20). A centimetre-sized clay interval marks the transition to the subsequent interval, still made up of dolomitic grainstone but devoid of ooids and with stylolites in its uppermost part (I-21). Another covered interval of about 0.5 m interrupts the continuity of the section, which crops out again with about 1.0 m of dolomitic grainstone (I-22) that grades into a grainstone interval bounded above and below by thin (a few centimetres thick) pelitic layers (I-23). The uppermost part of the Tesero Member of the Werfen Formation in the Tramin/

Termeno I section is constituted by 1.0 m of regularly bedded, yellowish to grayish dolomitic grainstone (I-24). The boundary with the overlying Mazzin Member (I-25) is marked by a sharp increase in the pelitic fraction. Upwards follows an about 3.0 m thick interval made up of centimetrically layered marly wackestones, interrupted in its middle part by about 30 cm of dolomitic shales (I-27 and lowerpart of I-28). The Tramin/Termeno section ends with about 1.1 m of centimetrically bedded and grey dolomitic limestone.

1.3 GEOCHEMISTRY

The Permian part of the section has been investigated for the $\delta^{13}\text{C}$ carbon isotopy of bulk organic matter. The isotopic curve in Tramin/Termeno does not present any notable excursion, as is expected for this stratigraphic interval (e.g., Korte & Kozur, 2010), but it is worth comparing the carbon isotopic composition of this locality with coeval intervals in the region (Table 1). The organic matter in Tramin/Termeno has values that on average are heavier than for the rest of the Dolomites. This could be explained by a palaeogeographic position closer to the coastline and consequently with a higher proportion of continental organic matter, which is heavier than marine organic matter during the Lopingian (late Permian).

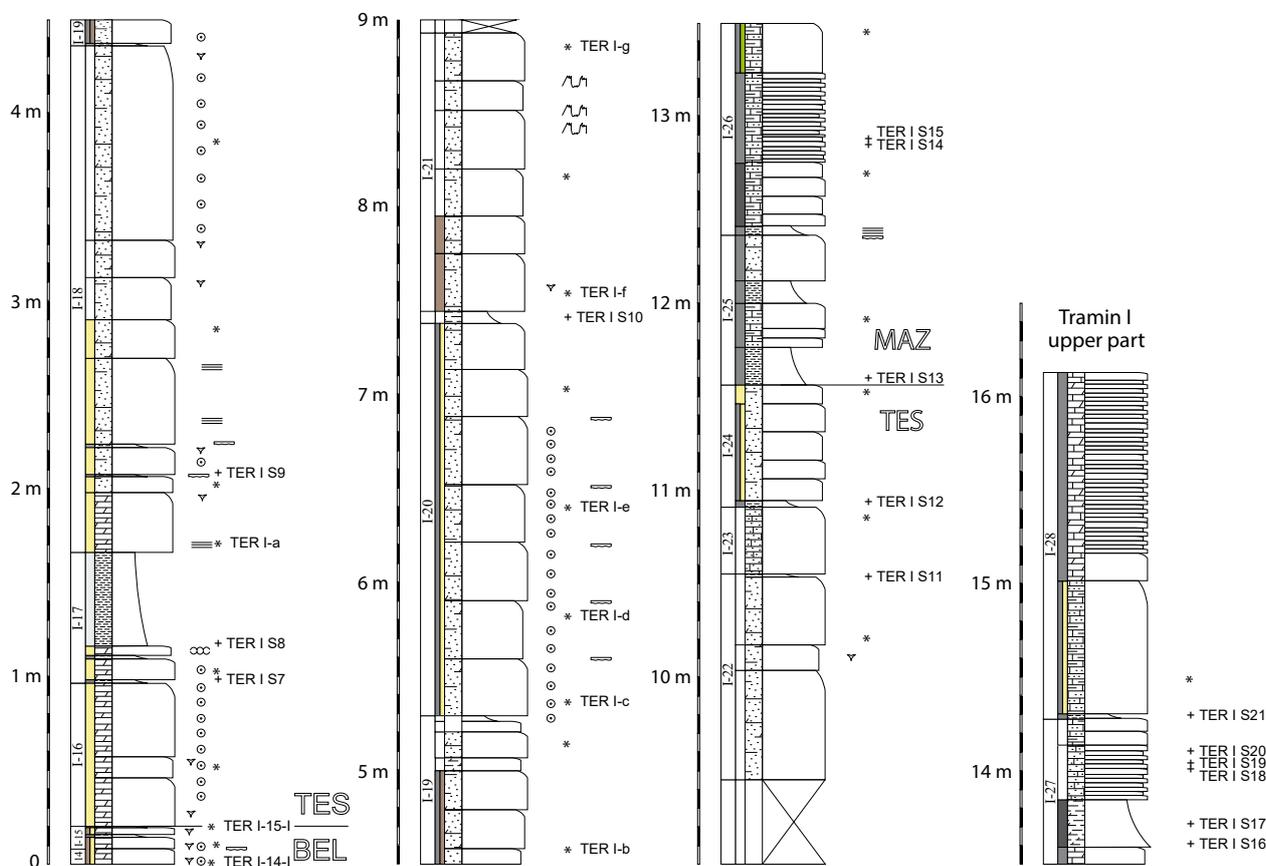


FIG. 8: The section Tramin/Termeno I – upper part.

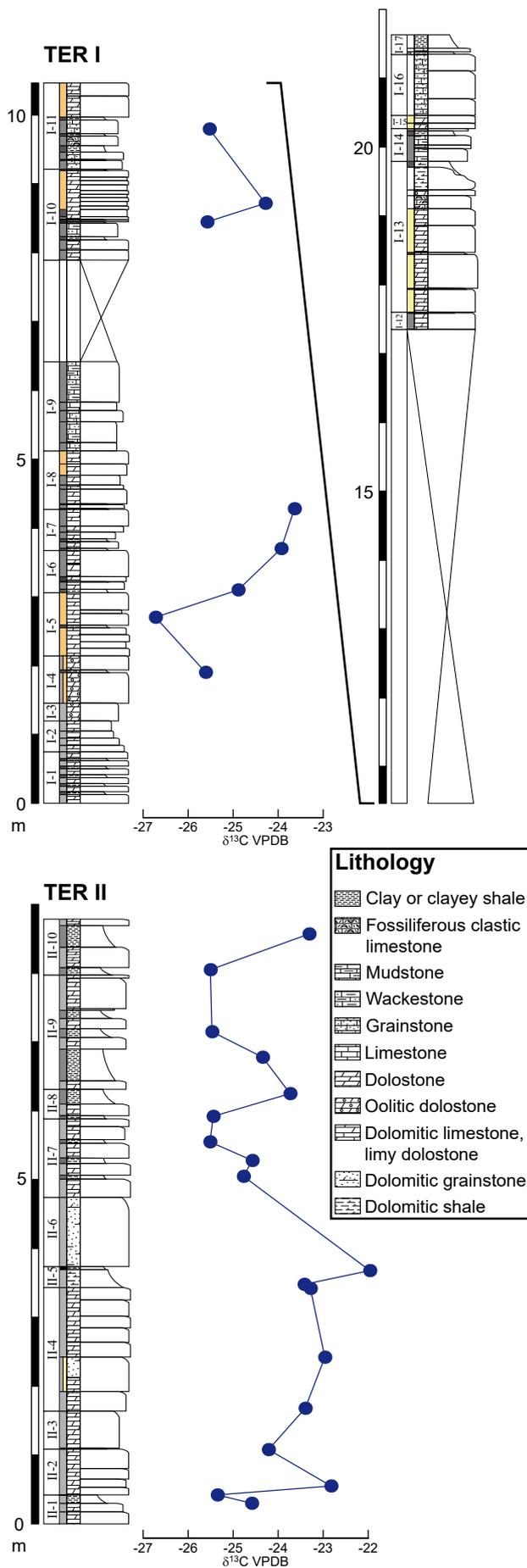


FIG. 9: The isotope plots of the Tramin/Termeno section.

	TRAMIN/TERMENO (ETSCHTAL/VAL ADIGE)	PIZZO FORCA (SAN PELLEGRINO PASS)	SERES (BADIA VALLEY)
AVERAGE $\delta^{13}\text{C}$ (‰ VPDB)	-24.4	-26.0	-26.6
STANDARD DEVIATION (‰)	1.1	1.4	0.9
NUMBER OF ANALYSES	26	28	40

TABLE 1: Average $\delta^{13}\text{C}$ values of the bulk organic matter at three localities in the Dolomites and Etsch/Adige Valley. Among these three localities, Tramin/Termeno is the closest to the palaeo-coastline.

1.4 PALYNOLOGY

Organic-walled microfossils have been extracted from several shaly/marly layers in the Bellerophon Formation and the Tesero Oolite (Fig. 10). Assemblages in the Bellerophon Formation are mostly dominated by non-taeniate bisaccate pollen grains, such as *Klausipollenites* Jansonius, 1962 (Fig. 10D), *Jugasporites* Leschik, 1956 (Fig. 10E), *Labiisporites* Leschik, 1956 (Fig. 10F), *Falcisporites* Leschik, 1956 and *Paravesicaspora* Klaus, 1963. Taeniate and striate forms are represented by *Lunatisporites* Leschik, 1956 (Fig. 10G) and *Protohaploxylinus* Samoiloivitch, 1953 (Fig. 10H). A few specimens of prepollen (*Nuskosporites* Potonié et Klaus, 1954 and *Trizonaesporites* Leschik, 1956) have also been recovered. Spores are very rare. This suggests a vegetation dominated by conifers and seed ferns (Balme, 1995; Meyen, 1997). Plant debris, including wood and cuticle fragments (Fig. 10I), is present in varying abundance. Residues from a black silty layer at the top of the Bellerophon Formation contain a particularly high amount of plant fragments and possible algae. A common component in this assemblage is *Reduviasporonites* Wilson, 1962 (Fig. 10C). *Reduviasporonites* is a problematic group of palynomorphs appearing as single cells or (branching) chains that have alternatively been interpreted as fungi or (freshwater) algae (Eshet et al., 1995; Visscher et al., 1996; Afonin et al., 2001; Foster et al., 2002). Both interpretations are based on morphological and biogeochemical arguments.

The question of the affinity of *Reduviasporonites* is particularly interesting because mass occurrences have been found in multiple places around the world close to the Permian–Triassic boundary, including the Southern Alps. Due to the interpretation as fungal remains, this striking signal came to be known as a “fungal spike” and led to theories of *Reduviasporonites* as a saprophyte that digested the plants which had died in the extinction event or even a pathogen that directly caused the dying (Eshet et al., 1995; Visscher, 1996; Elsik, 1999). However, it should be noted, that *Reduviasporonites* is also an important component of Permian and Triassic palynoassemblages from long before and long after the mass extinction, and that its relative abundance in assemblages around the boundary corresponds to the near- or total absence of most other palynomorph groups. A grey-green marly layer with gypsum and intraclasts about one metre above the base of the Tesero Oolite contains a scarce palynoassemblage with bisaccate pollen, trilete spores, *Reduviasporonites*, and a few plant fragments. The pollen grains resemble the forms in the Bellerophon Formation and might at least partly be reworked. The spores predominantly belong to *Lundbladispota* (Fig. 10A) and indicate the increased presence of lycophytes (club mosses) in the neighbouring flora (Balme, 1995). They are preserved as tetrads (Fig. 10B) with unusual regularity (Looy et al., 2005). A higher spore/pollen ratio and higher amount of spore tetrads is

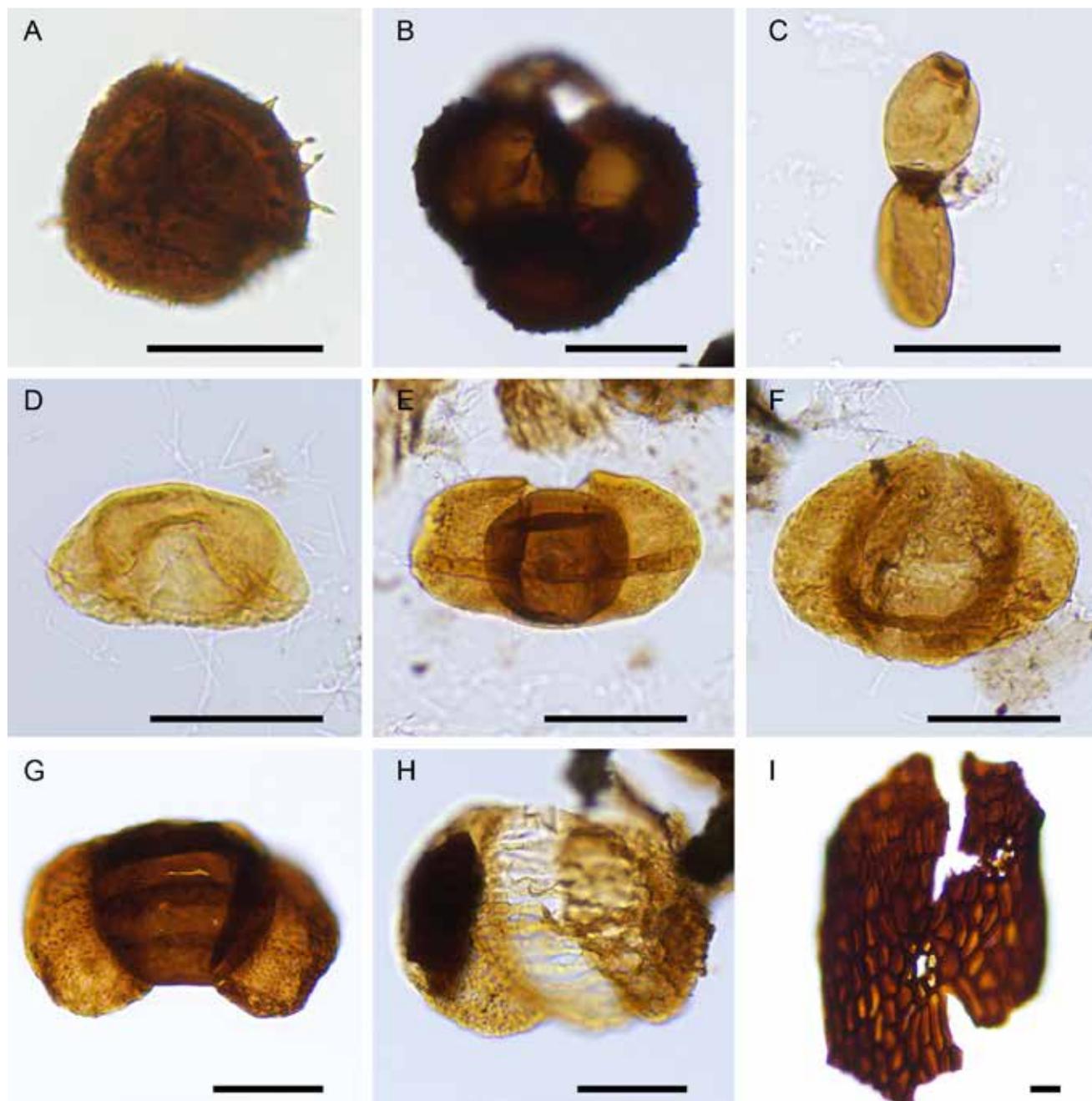


FIG. 10: Palynomorphs from the Permian–Triassic boundary interval at Tramin/Termen. A – *Lundbladispora* sp.; B – *Lundbladispora* tetrad; C – *Reduiasporonites chalastus* Wilson, 1962; D – *Klausipollenites schaubergeri* (Potonié et Klaus, 1954) Jansonius, 1962; E – *Jugasporites paradelasaucei* Klaus, 1963; F – *Labiisporites granulatus* Leschik, 1956; G – *Lunatisporites labdacus* (Klaus 1963) Visscher, 1971; H – *Protohaploxypinus* sp.; I – peltaspermealean cuticle (?*Germaropteris* Kustatscher et al., 2014). Scale bars = 20 µm. A, B Tesero Oolite; C–I Bellerophon Formation.

a typical pattern for post-extinction palynoassemblages (Looy et al., 1999, 2001, 2005; Hochuli et al., 2010; Hermann et al., 2011). This “spore spike” is linked to a disaster flora dominated by lycopsids and ferns. High UV-B radiation due to volcanism has been proposed as a cause for the increased production of permanent tetrads (Visscher et al., 2004; Benca et al., 2018).

2. THE BLETTERBACH GORGE: A LOW-LATITUDINAL LOPINGIAN TERRESTRIAL ECOSYSTEM

2.1. GEOLOGICAL SETTING

The upper Permian sequence of the Bletterbach Gorge, cropping out in a deep canyon excavated on the western side of Corno Bianco/Weisshorn, is one of the classical exposures of the mainly terrestrial Gröden/Val Gardena Sandstone and the Bellerophon Formation that represents a sabkha-like, lagoonal to shallow-marine environment (Fig. 11). Since the original description of the Gröden/Val Gardena Sandstone by Richthofen

(1860), the Bletterbach Gorge succession has received much attention and was the subject of numerous studies on late Permian depositional environments (e.g., Bosellini & Hardie, 1973; Massari et al., 1988; Bernardi et al., 2017), flora and fauna (e.g., Stache, 1877; Mutschlechner, 1933; Leonardi, 1948, 1950, 1968; Klaus, 1963; Conti et al., 1977; Ceoloni et al., 1988).

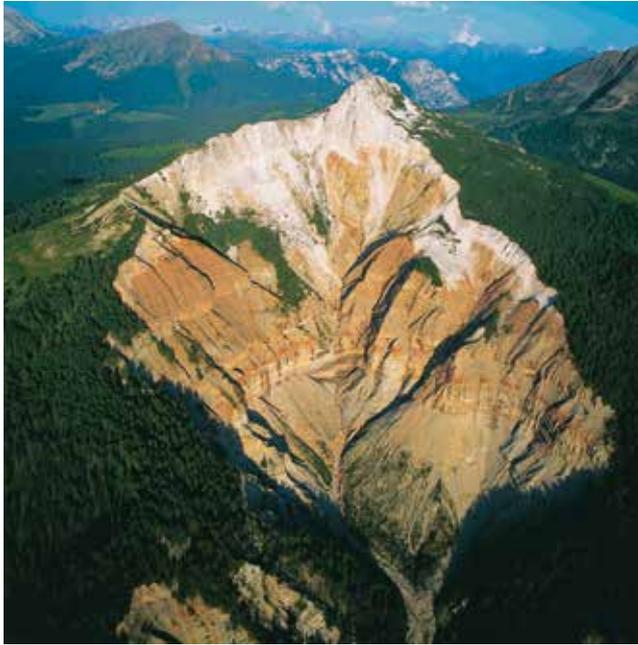


FIG. 11: Aerial view of the Bletterbach Gorge exposing a long rock sequence spanning about 40 million years, from the early Permian to the Middle Triassic.

The Bletterbach stratigraphic section starts with the Auer/Ora Formation (Fig. 3) of the Athesian Volcanic Group (andesites, rhyolites, ignimbrites), formed during the Cisuralian (early Permian) by a mega-caldera-system, having its centre near Bozen/Bolzano (Bargossi et al., 2007; Marocchi et al., 2008). Radiometric dating (U-Pb) indicates an age of 274.1 ± 1.4 Ma for the top of the Auer/Ora Formation at the Bletterbach Gorge corresponding to the late Kungurian (Avanzini et al., 2007; Marocchi et al., 2008). The Athesian Volcanic Group is unconformably overlain by the Gröden/Val Gardena Sandstone with a hiatus of approximately 14 to 27 Ma, which was probably due to subaerial erosion and/or to a sedimentation gap (Cassinis et al., 1999; Morelli et al., 2007).

The Gröden/Val Gardena Sandstone marks the onset of the second Permian tectono-sedimentary cycle *sensu* Cassinis et al. (2002). In the Bletterbach Gorge, the Gröden/Val Gardena Sandstone is about 210 m thick and mainly composed of terrestrial clastics reflecting depositional environments of alluvial plains and proximal to distal floodplains (Italian IGCP 203, 1986; Ori, 1988). Palaeosols are represented by calcic and gypsic horizons, locally with vertical features (Wopfner & Farrok, 1988), suggesting a warm to hot, subhumid to semi-arid climate with strong seasonality (Cassinis et al., 1999). Towards the top, the Gröden/Val Gardena Sandstone is successively replaced by the marine carbonates, shales and evaporites of the Bellerophon Formation, representing coastal sabkhas, evaporitic lagoons and shallow shelf environments (Leonardi, 1968; Bosellini & Hardie, 1973). The step-by-step transgression of the 'Bellerophon Sea' resulted in an interfingering of coastal and fluvial

deposits (Massari et al., 1988, 1994; Neri & Massari in Massari et al., 1999). The distinct stratal pattern architectures of the Gröden/Val Gardena Sandstone to Bellerophon Formation have been used to propose three transgressive/regressive cycles (Farabegoli et al., 1986; Massari et al., 1988; Perri & Farabegoli, 2003) or six 3rd order Lopingian sequences, respectively (Massari et al., 1994; Massari & Neri, 1997; Posenato, 2010) (Fig. 12). The exact age of the Gröden/Val Gardena Sandstone is poorly constrained. Palynological analyses suggest a late Capitanian to Changhsingian age for the Gröden/Val Gardena Sandstone and Bellerophon Formation (Pittau in Pittau et al., 2005). However, according to Visscher (pers. comm., 2012) the age is restricted to the Lopingian since typical Guadalupian elements (e.g., *Crucisaccites*) are missing. The tetrapod footprint record of the Gröden/Val Gardena Sandstone suggests a Wuchiapingian age (lower Lopingian; Avanzini et al., 2011). Additionally, the lower part of the overlying Bellerophon Formation is considered late Wuchiapingian in age (Ceoloni et al., 1988). This would restrict the Gröden/Val Gardena Sandstone to only a part of the Wuchiapingian. If the Cephalopod Bank can be correlated with the main Zechstein transgression (Kustatscher et al., 2017), then the Cephalopod Bank and the megafossil and cuticle horizons discussed below would be middle Wuchiapingian in age.

2.2. DEPOSITIONAL ENVIRONMENTS

The interpretation of the depositional sequences presented here is based on Posenato (2010), Kustatscher et al. (2017) and Bernardi et al. (2017). Nomenclature refers to Fig. 12.

Sequence Lo 1 (Lo = Lopingian)

In the Bletterbach Gorge, only the upper part of sequence Lo 1 is exposed with a thickness of up to 30 m (Fig. 12). The contact between the rhyolite of the Auer/Ora Formation and the Gröden/Val Gardena Sandstone exposes a palaeorelief of about 30 m. From base to top, the sequence Lo 1 represents an asymmetric large-scale fining-upward cycle that is composed exclusively of terrestrial deposits. Accordingly, in the entire western Dolomites the sequence Lo 1 is represented by the Gröden/Val Gardena Sandstone that is considered the proximal equivalent of a symmetric transgressive/regressive sequence in the Carnian Alps where the first Permian ingression is evidenced by marine microfauna (Spalletta & Venturini, 1989; Massari et al., 1994).

Sequence Lo 2

Sequence Lo 2 is represented by a c. 70 m thick succession (Fig. 12). Base and top are drawn at the bases of thicker sandstones that are regionally well correlated within the Dolomites (Massari et al., 1994). In terms of stratal pattern architectures these sandstones represent phases of maximum progradation towards the east. Therefore, bounding surfaces at their bases are considered sequence boundaries (Farabegoli et al., 1986; Massari et al., 1994; Massari & Neri, 1997; Perri & Farabegoli, 2003; Posenato, 2010). In the upper part of the sequence the occurrence of the 'Cephalopod Bank' (Mutschlechner, 1933; Conti et al., 1975, 1977; Broglio Loriga et al., 1988; Massari et al., 1988, 1994) marks the first short-term marine ingression in the western Dolomites and is considered the maximum flooding surface of sequence Lo 2 (Fig. 12; Broglio Loriga et al., 1988; Massari et

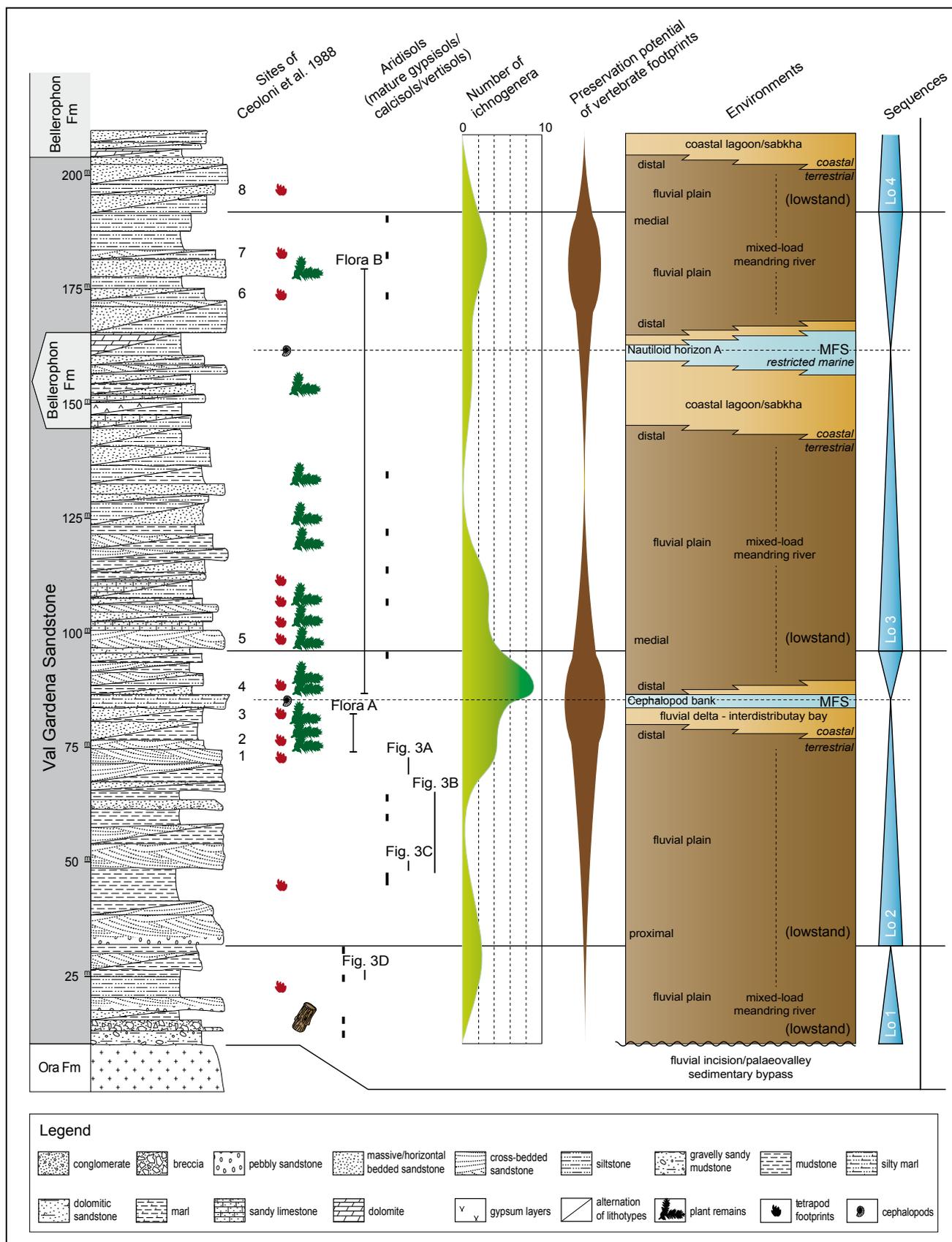


FIG. 12: Lithology, fossiliferous horizons, depositional environments and sequences of the Gröden/Val Gardena Sandstone in the Bletterbach Gorge, as well as the proposed curve of preservation potential.

al., 1994; Massari & Neri, 1997; Posenato, 2010).

The Cephalopod Bank (CB) in the Bletterbach Gorge is a marine sandstone bed that represents the first transgression of the Bellerophon Sea in the Gröden/Val Gardena Sandstone. Because of its hardness, it forms a natural step at the waterfall outcrop that divides the Bletterbach from the underlying Butterloch. It is situated in the lower part of the Gröden/Val Gardena Sandstone, about 75 m above its base. At the waterfall outcrop, it reaches its greatest thickness with 230 cm and gets slowly thinner eastwards. A slight coarsening-upward trend from fine to medium-grained calcite-cemented sandstone can be observed. It is divided into 3 units: A, B and C. The basal Unit A is about 70 cm thick and was deposited during the initial phase of the marine transgression. It presents thin vertical *Skolithos* burrows, presumably left by a worm-like organism. *Skolithos* are typical for unstable sandy substrates in high-energy environments close to the shoreline. The 60 cm thick Unit B documents the intensification of the marine transgression until shallow marine conditions were established. At its base appear small bivalves and the 'Orthoconic Nautiloid Assemblage', dominated by orthoconic nautiloids such as *Neocyloceras* sp. and *Lopingoceras* sp. Also reported in the literature are the coiled nautiloids *Tainoceras* sp., *Metacoceras* sp., *Mojsvaroceras* sp., *Pleuronautilus* sp., *Thuringionautilus* sp., *Germanonautilus* sp. or *Stearoceras* sp., *?Permonautilus* sp. and the ammonoid *?Parapronorites* sp., but probably many of these coiled nautiloids should be assigned to *Tirolonautilus* sp. Comparable rich nautiloid faunas occur in the upper Permian Bellerophon Formation only at maximum flooding surfaces where the marine conditions were less restricted. Most of these nautiloids are preserved as half internal molds, because under low sedimentation the upper half of the shell is dissolved before it can be completely covered by sediment. The uppermost 1 m thick Unit C lacks fossils and shows an increase in grain size. This could be a sign of a regressive trend with stronger marine currents in a nearshore environment (Prinöth, 2017).

Sequence Lo 3

Sequence Lo 3 is represented by an about 90 m thick succession (Fig. 12). The sequence is composed of stacked fining-upward cycles that closely resemble those of sequence Lo 2 in terms of cyclicity, sedimentary architectures and depositional environments. Following the maximum progradation of fluvial environments at the base of sequence Lo 3, the transgressive phase shows stacked fining-upward cycles characterised by decreasing thicknesses towards the top. The retrogradational stratal pattern architectures grade into a c. 20 m thick interval of grey to black shales, silts, carbonates and gypsum representing the second incursion of the 'Bellerophon Sea' in the western Dolomites (Broglia Loriga et al., 1988; Massari et al., 1994; Massari & Neri, 1997; Posenato, 2010). Coastal sabkha to lagoonal environments (Bosellini & Hardie, 1973; Massari et al., 1994; Massari & Neri, 1997) show a marine maximum within an about 3 m thick unit of carbonates and shales with cephalopods (Broglia Loriga et al., 1988). This sedimentary level, known as 'Nautiloid horizon A' is considered the maximum flooding surface of sequence Lo 3 (Massari et al., 1994; Massari & Neri, 1997; Posenato, 2010). Above the incursion interval, fining-upward cycles of fluvial environments indicate progradational stratal pattern architectures of the regressive phase. The maximum progradation of fluvial environments, considered a sequence boundary, was identified about 10 m below the base of the Bellerophon Formation (Fig. 12; Massari et al., 1994).

2.3. VERTEBRATE FAUNA

The Bletterbach has long been known for abundant tetrapod footprints (Kittl, 1891; Abel, 1929) that constitute the most diverse late Permian ichnoassemblage known (Lockley and Meyer, 2000; Lucas and Hunt, 2006; Bernardi et al., 2017) (Fig. 13). Based on data from the literature, the Bletterbach ichnoassemblage includes 10–13 ichnotaxa belonging primarily to various groups of parareptiles (mostly pareiasaurs) and basal neodiapsids, and less frequently to therapsids, archosauriforms and captorhinids. Pareiasaurs, documented by *Pachypes dolomiticus* Leonardi et al., 1975 (Valentini et al., 2009; Voigt et al., 2010; Smith et al., 2015), make up 38% of the ichnoassemblage. Carnivorous therapsids, documented by unnamed ichnotaxa, constitute 4% of the assemblage. Other therapsids (2–3%) are documented by the presence of *Chelichnus tazelwurmi* Ceoloni et al., 1988 (= *Latentitherichnus tazelwurmi* Citton, 2014), *Dicinodontypus geinitzi* (Hornstein 1876) and the enigmatic 'Ichniotherium' footprints. The tracks assigned to *Hyloidichnus tirolensis* by Ceoloni et al. (1988) has been repeatedly attributed to a captorhinid producer (Haubold, 1996, 2000; Voigt et al., 2010; Avanzini et al., 2011) and constitute 5% of the association. A recent review (Marchetti et al. 2017) suggests these tracks should be assigned to the ichnogenus *Procolophonichnium*, in which case the attribution could range from captorhinid to small therapsid (following Klein et al., 2015), or a parareptile. In the absence of a definitive assignment, we rely here on the most commonly accepted interpretation. The presence of lacertoid (basal neodiapsid) early saurians is evidenced by the classical *Rhynchosaurooides-Dromopus* group (Maidwell, 1911; Abel, 1929; Conti et al., 1977; Valentini et al., 2007; Avanzini et al., 2011), which makes up 42% of the ichnoassemblage. Archosauriformes, documented by *Chirotheriidae* indet., cf. *Protochirotherium* Fichter et Kunz, 2004 and the archosauriform-related *Paradoxichnium radeinensis* Ceoloni et al., 1988 constitute 2% of the assemblage (Conti et al., 1977; Ceoloni et al., 1988; Bernardi et al., 2015; Voigt et al., 2015).

The Bletterbach ichnoassemblage documents a numerical dominance of pareiasaurs and small lacertoid neodiapsids – early saurians, with their footprints far outnumbering all others (e.g., Kustatscher et al., 2017; Bernardi et al., 2017). In particular, pareiasaur and captorhinid tracks are markedly more abundant than dicynodont footprints. Captorhinid, dicynodont and indeterminate small therapsid tracks are similarly sized (pes length < 10 cm) and therefore have a similar preservation potential, allowing a meaningful comparison of abundances. The absence or extreme rarity of anamniote footprints seems to be a common feature of Lopingian ichnoassemblages worldwide (Tverdokhlebov et al., 1997; Voigt & Lucas, 2016).

2.4. PLANTS

Plant macrofossils are common in the Gröden/Val Gardena Sandstone of the Bletterbach Gorge (for recent literature see, e.g., Fischer et al., 2010; Kustatscher et al., 2012, 2014, 2017; Bauer et al., 2014; Uhl et al., 2014, for historical literature see references therein) (Fig. 14).

They include compressions and impressions of leaves, branches, stems, shoots, fructifications and seeds, as well as permineralized wood, charcoal and root casts. Plant remains in the Bletterbach are mostly small and poorly preserved. One particular

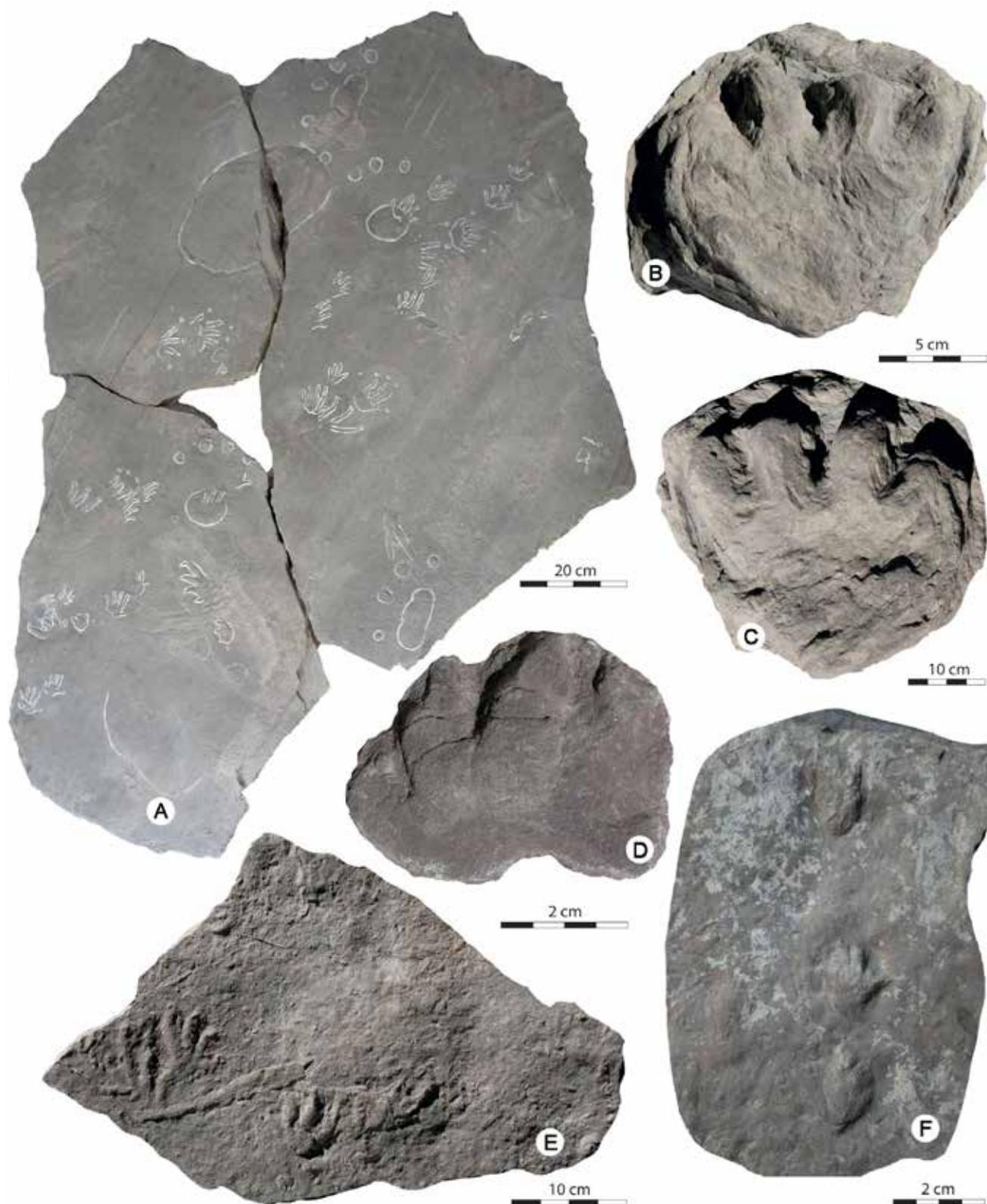


FIG. 13: Overview of the composition of the vertebrate ichnoassemblage: A – *Hyloïdichnus tirolensis* Ceoloni et al., 1988; B–C – *Pachypes dolomiticus* Leonardi et al., 1975; D – Therapsid footprint indet.; E – *Ganasauripus ladinus* Valentini et al., 2007; F – *Chelichnus tazelwurmi* Ceoloni et al., 1988.

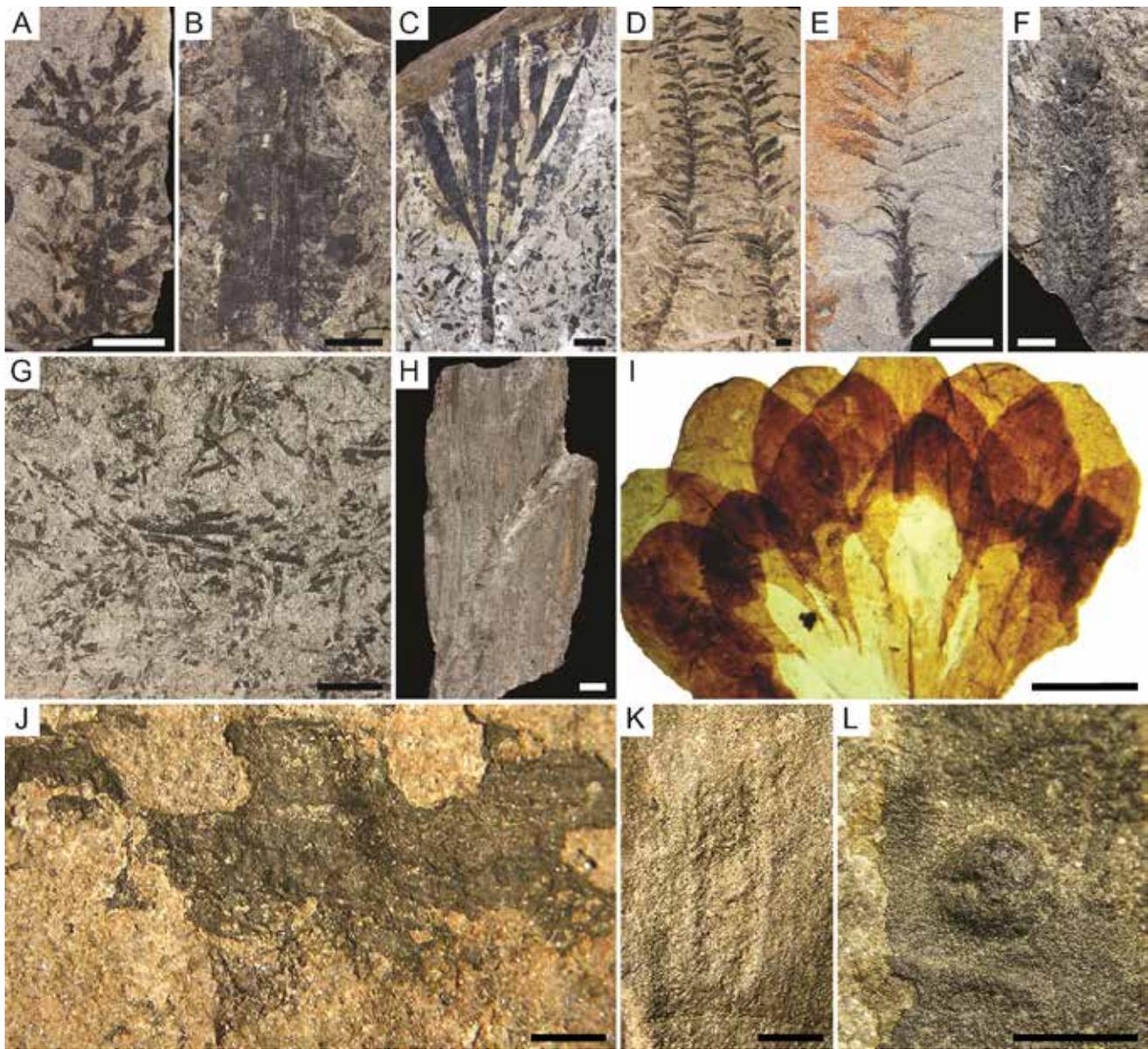


FIG. 14: Plant macro- and mesofossils from the Gröden/Val Gardena Sandstone of the Bletterbach Gorge. I from Kustatscher et al. 2017b; J, L from Bernardi et al. (2017); K from Labandeira et al. (2016); see also Clement-Westerhof et al. (1987), Kustatscher et al. (2012). Scale bars = 1 cm for A-H, 2 mm for I-L. A – *Sphenopteris suessii* Geinitz, 1869 (PAL 1412); B – *Taeniopteris* sp. (PAL 870); C – *Baiera digitata* (Brongniart) Heer, 1876 (PAL2061); D – *Ortiseia leonardii* (Florin) Clement-Westerhof, 1984 (PAL 1100); E – *Pseudovoltzia liebeana* (Geinitz) Florin, 1927 (PAL 821); F – female conifer cone (PAL 2034). G – permineralised wood (PAL 825); H – unidentified plant debris (PAL 858); I – ovuliferous dwarf shoot of *Ortiseia jonkeri* Clement-Westerhof 1984 (e.g. pl. 4, fig. f); J – insect damage: margin feeding; K – insect damage: surface feeding; L – insect damage: galling.

horizon just below the Cephalopod Bank (Prinoth, 2017) is notable for yielding numerous megafossils up to several decimetres in length (e.g. Kustatscher et al., 2012, 2017). Furthermore, several horizons which are also mostly located near the cephalopod bank have yielded well-preserved cuticles.

About 1870 specimens have been studied, representing conifers (*Ortiseia* Florin, 1964, *Pseudovoltzia* Florin, 1927, *Majonica* Clement-Westerhof, 1987, *Quadrocladus* Mäder, 1957, *Dolomitia* Clement-Westerhof, 1987), seed ferns (*Germaropteris* Kustatscher et al., 2014, *Sphenopteris* (Brongniart) Sternberg, 1825), ginkgophytes (*Baiera* Braun, 1843, *Sphenobaiera* Florin, 1936), rare sphenophytes, possible cycadophytes (*Taeniopteris* Brongniart, 1828) and plant remains of uncertain affinity (*Leptostrobus*-like valves, permineralized wood, charcoal). In total, 30 taxa are recognized, with conifers being the most speciose group (Kustatscher et al., 2017).

Two floras are distinguished: Flora A is present in the plant-bearing horizons a few metres below the Cephalopod Bank, including the megafossil horizon. This flora is marked by the dominance of ginkgophytes (> 50%), which is unique among fossil floras from the Permian. Conifers make up about 40% of the flora. The preservation of relatively large conifer remains suggests that they were not subjected to extended transport. Flora B represents the plant fossil assemblages above the Cephalopod Bank and is dominated by conifers, with seed ferns as the second-most common constituents. In contrast to Flora A, ginkgophytes are rare, which might be due to taphonomic bias (Kustatscher et al., 2017). Plant remains in this flora are generally very small fragments (measuring a few millimetres to centimetres), suggesting allochthonous deposition. However, they include well-preserved cuticles allowing identification despite their small sizes.

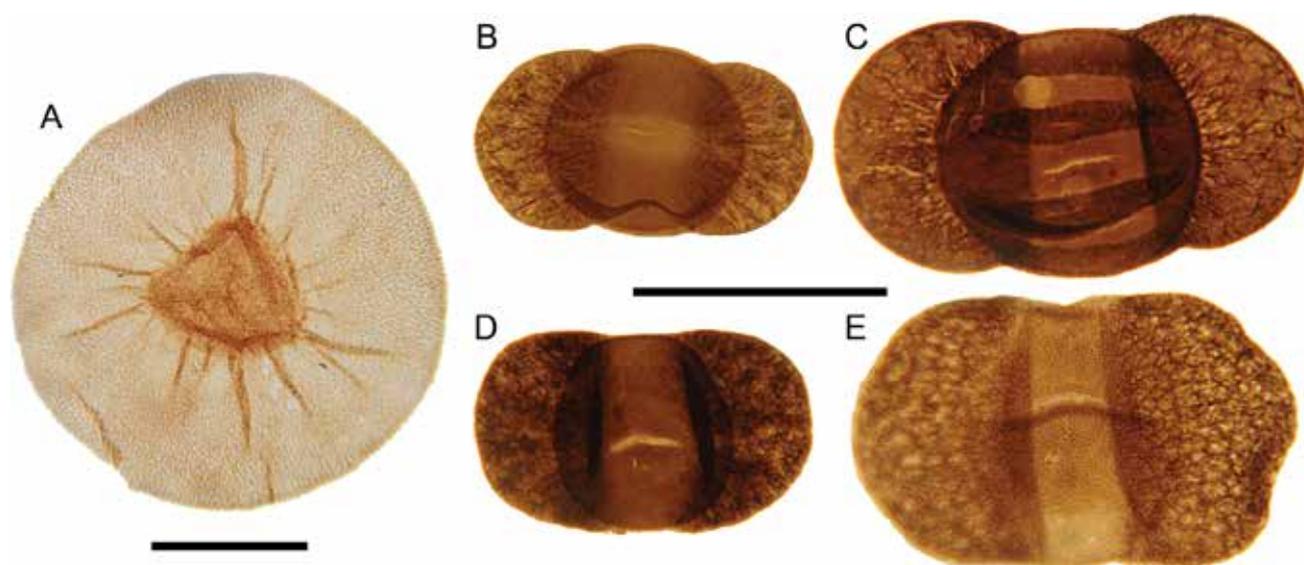


FIG. 15: Sporomorphs from the Gröden/Val Gardena Sandstone of the Bletterbach Gorge (see Klaus, 1963; Draxler, 2010). Scale bars = 50 μ m. A – *Playfordiaspora crenulata* (Wilson, 1962) Foster, 1979; B – *Lueckisporites virkkiae* Potonié et Klaus, 1954; C – *Lunatisporites labdacus* (Klaus, 1963) Visscher, 1971; D – *Jugasporites paradelasaucei* Klaus, 1963; E – *Gardenasporites heisseli* Klaus, 1963.

2.5. PALYNOMORPHS

Pollen has been found *in situ* in a few conifers in the Gröden/Val Gardena Sandstone (Clement-Westerhof, 1987, 1984; Poort et al., 1997; Kustatscher et al., 2012). Large monosaccate prepollen assignable to *Nuskoisporites* Potonié et Klaus, 1954 has been found in *Ortiseia* (Clement-Westerhof, 1984; Poort et al., 1997), the most common conifer genus in the megafossil assemblages, with *Nuskoisporites* also being common in dispersed spore-pollen assemblages of the Bletterbach (Fig. 15). Generally, the dispersed sporomorphs are dominated by taeniate and non-taeniate bisaccate pollen, which can be produced by various conifers and seed ferns (Balme, 1995). The most abundant genera are *Lueckisporites* Potonié et Klaus, 1954, *Klausipollenites* Jansonius, 1962, *Lunatisporites* Leschik, 1955, *Gardenasporites* Klaus, 1963 and *Jugasporites* Leschik, 1956 (Klaus, 1963). Bitaeniate pollen grains of the *Lueckisporites*-type have been found in *Majonica* (Clement-Westerhof, 1987) in the Gröden/Val Gardena Sandstone, but are also known to be associated with other taxa (Balme, 1995). Trilete spores (e.g. *Converrucosisporites* Klaus, 1963, *Playfordiaspora* Maheswari et Banerji, 1975) are relatively rare, but they document the presence of ferns and lycophytes (club mosses), while no corresponding megafossils have been found so far. On the other hand, despite the common to dominant presence of ginkgophytes in the megafossil assemblages, *Ginkgo*-like (i.e. monosulcate) pollen are seemingly absent.

The palynomorph assemblages in the Bletterbach are much more diverse than the megafossils and largely similar between the Gröden/Val Gardena Sandstone and the Bellerophon Formation (Massari et al., 1988, 1994). Putative fungal remains (*Reduviasporonites* Wilson, 1962) are consistently present in the upper part of the Gröden/Val Gardena Sandstone and the Bellerophon Formation (see also stop 1).

2.6. PLANT-ANIMAL INTERACTIONS

Various types of insect damage have been found on less than 2% of the leaves from the Bletterbach (Labandeira et al., 2016). Compared to other fossil floras from the Permian and Triassic of the Dolomites, this rate is low and may be affected by taphonomic limitations. The most common damage type is foliage (margin, apex or surface) feeding (Fig. 14 J–L). Other types of plant-insect interaction are oviposition, galling, seed predation and wood boring. Quantitatively, most of the damage is generalized (79%) rather than specialized (21%) between plant taxa, but the majority of damage types present here (11 of 16) are specialized. The total variety of damage types is much higher than for the Kungurian flora of Tregiovo (7) and lower than for the Middle Triassic floras in the Dolomites (24–38). With four damage types, the insect herbivore component community on *Pseudovoltzia liebeana* is the most diverse on a single species in the Bletterbach flora, but it is depauperate compared to examples from Middle Triassic floras in this region with up to 11 damage types on one species. The same can be seen in other regions, which suggests that insect herbivory generally increased between the Permian and the (Middle) Triassic (Labandeira et al., 2016; Kustatscher et al., 2017).

2.7. TROPHIC NETWORK

Although insect body fossils have not been found at the Bletterbach, the ecologically relevant deposit of insect body fossils in the nearly coeval Salagou Formation of the Lodève Basin (Béthoux, 2008) can be used as a proxy for part of the community. The Lodève insect fauna is composed of several orders of insects, belonging to the palaeopterous lineages Odonatoptera, Diaphanopteroidea, and Palaeodictyoptera, as well as orthopterans and early representatives of modern holometabolous clades (Béthoux, 2008). In contrast, the insect assemblages of the Guadalupian

to Lopingian of European Russia are significantly more diverse (Aristov et al., 2013), and broadly include diverse archaerthopteran, orthopteran and early representatives of several, extant, holometabolous lineages. Accordingly, we tentatively propose that the Bletterbach ecosystem supported an herbivorous insect fauna containing taxa as diverse as mandibulate orthopteroids, piercing-and-sucking hemipteroids and the likely exophytic and endophytic larvae of basal holometabolous lineages. As demonstrated by plant-arthropod interactions, this entomofauna preferentially fed on taeniopterids, conifers and ginkgophytes, and was probably preyed upon by the small secondary consumers documented by footprints, such as lizard-like insectivores (Fig. 16). Some of the plant damage could be ascribed to orthopteroid, hemipteroid and holometabolous insects, although assignments to specific lineages remain uncertain.

Pareiasaurs, small to medium-sized herbivorous therapsids and captorhinids would have been the high-fibre herbivores in this ecosystem. Their feeding mechanisms differed in a number of details, suggesting that they might have had different food preferences,

although this is difficult to ascertain. Pareiasaurs, for example, had leaf-shaped, cuspidate marginal teeth for puncturing and tearing apart fibrous plants (Munk & Sues, 1993; Lee, 1997; Reisz & Sues, 2000). Although no direct evidence exists, crosschecked abundance data suggest that pareiasaurs might have fed upon ginkgophytes and conifers in the Bletterbach flora. Other primary consumers, such as dicynodonts, might have fed on sphenophytes and ferns, as discussed below. Captorhinids, which had broad dentaries, multiple rows of peg-like teeth and highly developed chewing mechanisms (Dodick & Modesto, 1995; Sues & Reisz, 1998; Reisz & Sues, 2000), would have been able to pierce or grind tough plant material such as sphenophytes and some seed plants (Benton, 2015). Herbivorous therapsids, captorhinids and neodiapsids probably were preyed upon by large secondary consumers such as archosauromorphs and therapsids, which constitute the majority of large-sized faunivorous tetrapods represented in the trackway assemblage. Curiously, plant remains of conifer and seed fern ovules (Munk & Sues, 1993) were found within the abdominal cavity

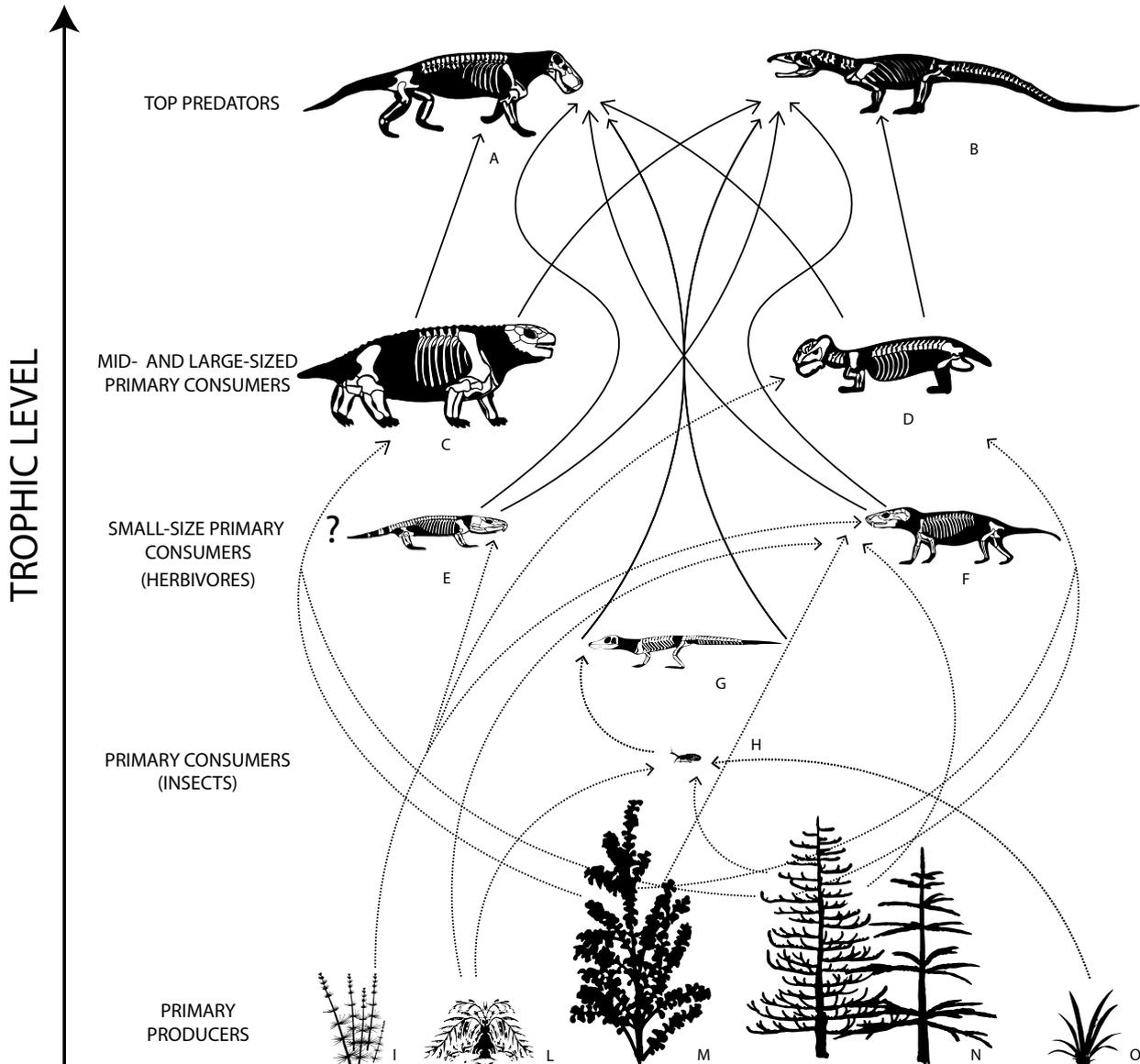


FIG. 16: Trophic network architecture of the Bletterbach Biota (Southern Alps), showing the complex interactions of floral and faunal communities; A – Faunivorous therapsids; B – Archosauromorphs; C – Pareiasaurs; D – Herbivorous therapsids; E – Captorhinids; F – Indet. therapsids; G – Basal neodiapsids; H – Insects; I – Sphenophytes; L – Seed ferns; M – Ginkgophytes; N – Conifers; O – Taeniopterids.



FIG. 17: The lush equatorial ecosystem of the late Permian, about 260 million years ago, as reconstructed in the Dolomites region, Northern Italy. Artwork by Davide Bonadonna.

of *Protorosaurus*, suggesting a mixed diet at least for some late Permian archosauriforms.

Using the classification proposed by Olson (1966), which groups ecological communities into three types based on the relative diversities of tetrapod herbivores and whether sources of primary productivity were dominantly terrestrial or aquatic, the Bletterbach community (Fig. 17) seems to represent a Type II community with fully terrestrial tetrapod herbivores, and to a lesser degree herbivorous insects, forming the primary link between primary producers and tetrapod secondary consumers. This general structure is comparable to what is seen in the dicynodont-dominated ecosystems of southern Gondwana (Olson, 1966).

3. THE 'GEOLOGICAL MUSEUM OF THE DOLOMITES': WINDOWS TO THE MIDDLE TRIASSIC OF THE DOLOMITES.

3.1. THE MUSEUM

"This is the key to the Alps... home to the most diverse and wonderful geological phenomena" (Leopold von Buch, 1827)

At the beginning of the nineteenth century, a sensational discovery made near Predazzo provided key input to the development of a new theory on the origin of rocks and mountains. In the Canzoccoli quarry, the spectacular contact between sedimentary rocks, lying below, and overlying magmatic rocks provided evidence against the Naptunist theory by demonstrating that the 'order' of rocks could be easily overturned by massive geological events, such as – in the Predazzo area – by magmatic events (Ciancio, 1999). It was due to the high cultural importance of this and other discoveries made in the region that the Geological Museum of the Dolomites emerged. Founded in Predazzo in 1899 on the initiative of the Magistral Society of Fiemme and Fassa, the institution was aimed at enhancing the local geological and natural heritage and promoting its knowledge. In 2012,

thanks to the close collaboration between the Municipality of Predazzo and the MUSE Science Museum of Trento, the Geological Museum became part of the territorial sections of the MUSE network. Since 2015, it has been completely renovated according to modern museological and museographical approaches focused on the needs of the visitors. The museum focuses on geology, but also on the history of the Dolomites of the Fiemme and Fassa valleys and the close relationship between man and territory. The new exhibition is presented on two of the four floors of the building in the main square of Predazzo. The ground floor is dedicated to the Dolomites UNESCO World Heritage Site and its nine systems (Fig. 18). The narrative inspiration around which the museum is structured is illustrated by the evocative reconstruction of the Hotel Nave d'Oro in Predazzo, where during the nineteenth century distinguished naturalists, geologists and other scientists of that time used to stay overnight before exploring the local territory.

From this first hall begins a journey of discovery of the Dolomites that continues downstairs, where the geological and environmental features of the mountain groups surrounding



FIG. 18: The ground floor of the museum is dedicated to the Dolomites as a UNESCO world heritage site.



FIG. 19: Floor -1 deals with the geological, environmental and landscape features of the mountain groups near Predazzo: Lagorai, Latemar, Monzoni-Marmolada, Rosengarten/Catinaccio and Sella. Five thematic islands offer the visitor a journey in and out of these mountains telling the story of the Dolomites of Fiemme and Fassa and their millennial relationship with the local populations.



FIG. 20: The Geotrail Dos Capel is the natural extension of the museum in the field; an open-air laboratory to learn about the geological history of the Dolomites, landscape evolution and to reflect on the future of this territory.

Predazzo are presented: Lagorai, Latemar, Monzoni-Marmolada, Rosengarten/Catinaccio and Sella (Fig. 19). Five thematic islands offer the visitor a journey in and out of the mountains between geology, landscapes and their millennial relationship with the local populations.

The specimens on display are part of the rich collections of the museum, totalling over 12,000 specimens including unique samples and the richest collection of invertebrate fossils of the Middle Triassic reefs preserved in Italy. A specialized geological and palaeontological scientific library with more than 8,000 items completes the services offered by the museum. The museum houses also the library of the Italian Paleontological Society: 150 periodicals from around the world and about 200

monographs. The museum is also equipped with laboratories and classrooms for the renewed educational offers dedicated to schools. A natural extension of the museum is the Geotrail Dos Capel, an open-air laboratory developed to engage with the geological history of the Dolomites, landscape evolution and the future of this territory (Fig. 20).

In its new configuration, the Geological Museum of the Dolomites plays a pivotal role in the Dolomites region, and becomes the centre where reflections and actions on the topics of research, protection, and valorisation of the Dolomites take place. It is a museum built to think about the future of the Dolomites and to connect the small and big institutions aiming at developing a shared vision of the UNESCO World Heritage.

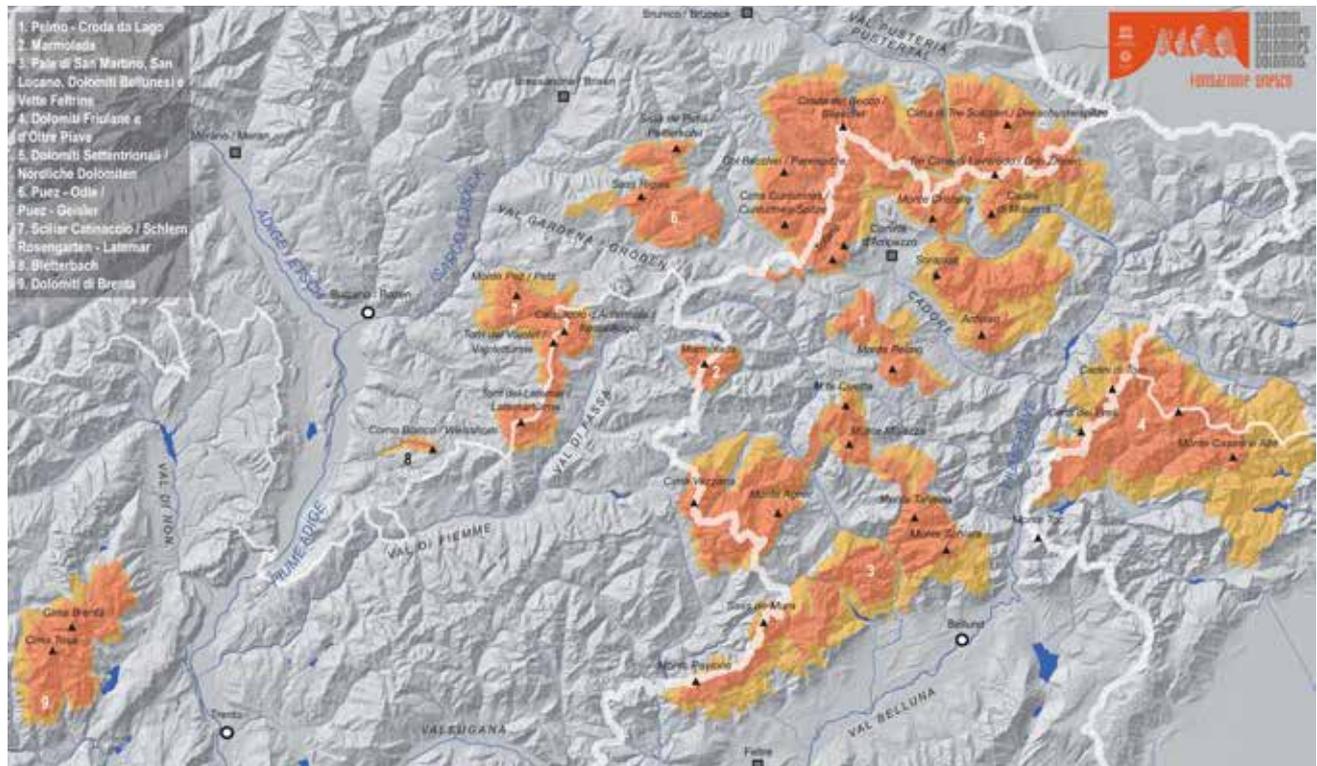


FIG. 21: The nine systems of the Dolomites UNESCO World Heritage Site.

3.2. THE DOLOMITES – UNESCO WORLD HERITAGE SITE

On June 2009, the Dolomites were inscribed in the World Heritage List (Fig. 21), because of their exceptional beauty and unique landscape, but also for their scientific importance in terms of geology and geomorphology (criteria vii and viii). The area meets the criterion viii – providing outstanding examples of major stages of the Earth’s history – due to its importance for Triassic stratigraphy (Gianolla et al., 2009). The inscription declaration states that: *“The Dolomites are of international significance for geomorphology, as the classic site for the development of mountains in dolomitic limestone. The area presents a wide range of landforms related to erosion, tectonism and glaciation. The quantity and concentration of extremely varied limestone formations is extraordinary in a global context, including peaks, towers, pinnacles and some of the highest vertical rock walls in the world. The geological values are also of international significance, notably the evidence of Mesozoic carbonate platforms, or “fossilized atolls”, particularly in terms of the evidence they provide of the evolution of the bio-constructors after the Permian/Triassic boundary, and the preservation of the relationships between the reefs they constructed and their surrounding basins. The Dolomites also include several internationally important type sections for the stratigraphy of the Triassic Period. The scientific values of the property are also supported by the evidence of a long history of study and recognition at the international level. Taken together, the combination of geomorphological and geological values creates a property of global significance.”* (Declaration of outstanding universal value, UNESCO World Heritage Committee, Seville 26.06.2009).

3.3. THE MAJOR CONTRIBUTION OF THE AREA TO THE DEVELOPMENT OF EARTH SCIENCES

While the UNESCO declaration is quite recent, the Dolomites have been playing a major role in the development of the geological sciences since the 18th century (cf. Gianolla et al., 2009; Schlager & Keim, 2009). The study of the plentiful literature on the area is complicated by its multilingual nature, since Neo-Latin (Ladin, Venetian, and Italian) and Germanic (Tyrolean and German) languages and civilizations have been interacting in this region since ancient times. This complexity is reflected by the toponymy and the deriving stratigraphic terminology, often characterized by the coexistence of Ladin, Italian, and German names.

During the 18th century, Giovanni Arduino, while studying the Venetian Prealps, introduced the four stratigraphic subdivisions from Primary to Quaternary that led to the current Phanerozoic erathems. Later in the same century, the dolomite mineral was identified and named after Déodat de Dolomieu, who had sampled a dolomite rock in the Adige Valley, at the border of the region that has since then come to be known as Dolomites.

The name “Dolomites” for the mountain region was derived from the mineralogical terminology during the 19th century and was popularized by the mountaineering literature during the Victorian Age. During the early 19th century, the region played a major role in the demise of the neptunist theory. In the south-western part of the Dolomites, granitoid intrusions had metamorphosized limestone units bearing Middle Triassic fossils. This was observed first by Marzari Pencati near Predazzo and was hard to explain under the assumption that intru-

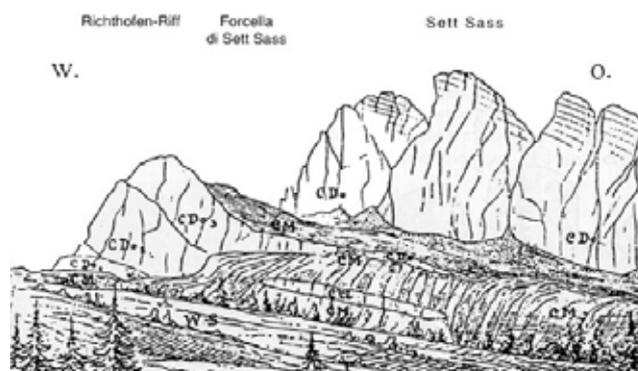


FIG. 22: A historical drawing by von Richthofen 1860 of the Sett Sass, viewed from Mt. Castello. Between brackets the present-day lithostratigraphic terminology is introduced. WS – Wengener Schichten (Wengen Formation); CM – Cassianer Mergel (St. Kassian/San Cassiano Formation); CCi – Cassianer Riffsteine (Cipitkalk); CDo – Cassianer Dolomit (Cassian Dolomite).

sive rocks are the most ancient (“protogynous”) lithotypes of the Earth. These geological relationships were investigated by some of the most prominent geologists of the time, such as Alexander von Humboldt and Christian Leopold von Buch. During the same century, the basinal successions of the Dolomites, together with those of the Northern Calcareous Alps, played a major role in the establishment of the ammonoid biostratigraphy and the stage stratigraphic subdivision of the Triassic system (cf. Balini et al., 2010). Although the tripartition of the Triassic period derives from the German Basin, its worldwide stratigraphic subdivision is instead deeply rooted in the Alps.

Meanwhile, the wealth of rocks and minerals associated with the Triassic magmatism and metamorphism of the Dolomites was classified, often introducing scientific names deriving from local toponyms (e.g., Monzonite from the Monzoni Mountain near Passo San Pellegrino; the pyroxene Fassaite from the Fassa Valley, etc.). During the third quarter of the 19th century, the research of the Austrian geologists Richthofen and Mojsisovics climaxed in the discovery of the biogenic nature of many Triassic carbonate buildups (Fig. 22). Their studies also provided a first sound stratigraphic interpretation of the “carbonate reefs”, with their subdivision into pre-, syn-, and post-volcanic edifices (von Richthofen, 1860; von Mojsisovics, 1879). Even the seminal concept of facies heteropy, i.e., the idea that a sedimentary body can correlate laterally with completely different facies, was for the first time recognized in the Dolomites (Mojsisovics, 1879).

It was after the First World War that Italian geologists started to play some significant role in the area. The geological mapping of the region was refined in many places, and fossil faunas were investigated. After the Second World War, radiometric dating solved the uncertainty about the age of the intrusive rocks of Predazzo and Monzoni. Since the 1970s, the earth science activity in the area experienced a multifold rise. Permian red beds and several Triassic levels revealed a large amount of tetrapod footprints, while the Permian–Triassic boundary strata played a major role in our understanding of the most severe mass extinction of the entire Phanerozoic (e.g., Twitchett & Wignall, 1996; Cirilli et al., 1998; Twitchett, 1999; Farabegoli et al., 2007; Posenato, 2009). The large-scale depositional geometry of the Triassic carbonate platforms was reinterpreted (Leonardi, 1967; Bosellini, 1984; Doglioni et al., 1990). More recently, the value of the carbonate platforms of the Dolomites as analogous model for hydrocarbon reservoirs also emerged (cf. Gianolla et al.,

2011; Preto et al., 2017). Integrated stratigraphic analyses of the Triassic successions synthesized biostratigraphy, magneto-stratigraphy, tephra stratigraphy, and U-Pb radiometric dating of zircons to produce significant advances in the refinement of the Geologic Time Scale (e.g., Mundil et al., 1996; Hounslow & Muttoni, 2010; Mietto et al., 2012; Wotzlaw et al., 2018). Nowadays, the scientific interest on the sedimentary geology of the Dolomites is greater than ever.

3.4. THE GEOLOGICAL IMPORTANCE OF THE DOLOMITES

The Dolomites region forms the central-northern portion of the Southern Alps, a south-verging portion of the Alpine chain that was not affected by alpine metamorphism (Doglioni, 1987; Castellarin et al., 1998; Castellarin & Cantelli, 2000). The Dolomites are dominated by thick Triassic successions, encompassing large carbonate platforms, which grew in an intertropical sea at the western termination of the Tethys Ocean (Fig. 23). The area is renowned for its spectacular landscape, which provides a revealing geomorphic expression of the geological complexity of the region. The Plio-Pleistocene topographic rising of the chain, the intense erosion associated with the Quaternary glacial-interglacial fluctuations, the frequent landslide instability of cliffs and the high-altitude climate limiting the vegetation cover combine to provide the spectacular outcropping conditions of the region. The landscape reflects the close proximity of lithotypes with sharply different erosional behavior, such as red beds, evaporites, platform carbonates, turbiditic sandstones, intrusive and volcanic rocks, etc. The relationships between sedimentary bodies are often very well exposed, to the point that some of the Triassic carbonate platforms are now outcropping as isolated mountain groups, retaining their original geometry. This is the case, for example, with the Anisian Latemar and of the Carnian Sella platforms (Preto et al., 2017). Km-scale exposures often allow the carbonate platforms to be observed at the seismic scale. The Dolomites therefore provide a valuable opportunity to investigate outcropping analogues of subsurface hydrocarbon systems. The exceptional exposures of carbonate platforms in the Dolomites allow complete 3D reconstructions of sedimentary architectures, fracture, porosity and permeability distributions to be accomplished. Geological mapping of the sedimentary bodies can be based on field studies and remote sensing techniques, supported by the high topographic elevation and the paucity of vegetation. High-resolution topography based on airborne LIDAR provides a major contribution to the geological understanding of the area.

3.5. CARBONATE PLATFORMS AND CARBONATE-SILICICLASTIC BASINS PUNCTUATED BY SUBAERIAL EXPOSURE SURFACES (LOWER AND MIDDLE ANISIAN)

During the early Anisian, the initiation of a differential subsidence regime, connected to an increased tectonic activity, terminated the flat topography that characterized the region since the late Permian. This dynamic controlled the sedimentation during most of the Anisian. While subsidence was active in the eastern Dolomites, the western areas experienced significant uplifting and subaerial erosion, which locally reached down

into the Permian units (Bosellini, 1968). Anisian deposits are organized into depositional sequences (cf. De Zanche et al., 1992; 1993; Gianolla et al., 1998, 2018; Zühlke, 2000; Neri et al., 2007) that are bounded by subaerial unconformities, each followed by a continental conglomerate (e.g., Voltago Formation), shallow-water terrigenous-carbonate deposits (e.g., Recoaro Formation), and possibly deep-water limestone-marl alternations (e.g., Dont Formation).

Carbonate platforms (e.g., Monte Rite and Upper Sarl/Serla formations; Fig. 24) prograded from topographical highs onto the basinal deposits (see Fig. 23 for the lithostratigraphic nomenclature). These platforms witnessed the appearance of the oldest biogenic reefs known in the Dolomites, and were associated with pervasive syndepositional cementation. The Anisian platforms were dominated by binder and buffer biota, mostly microbial communities (microbialites), but also sphinctozoans and bryozoans (Gaetani et al., 1981; Fois & Gaetani, 1980; Senowbari-Daryan et al., 1993). Crinoidal calcarenites were locally abundant. Moist climate phases are documented in this Anisian interval (Kustatscher et al., 2006; Kustatscher & Roghi, 2006; Kustatscher et al., 2010; Stefani et al., 2010), particularly by marine sediment enriched in continental plant remains (Dont Formation). The younger of the Anisian sequences starts with the fluvial deposits of the Richthofen Conglomerate, followed by the shallow-marine muds of the Morbiac Formation (Fig. 24), which grades upward into the dysoxic-anoxic basinal deposits of the Moena Formation (Masetti & Neri, 1980; Masetti & Trombetta, 1998) or into the platform carbonates of the Contrin Formation.

At the same time, in the central-southern portion of the eastern Dolomites, deep-water basinal successions (Ambata Formation) started to accumulate (De Zanche et al., 1993; Dal Corso et al., 2015).



FIG. 24: Subaerial exposure surface (sequence boundary) separating an Anisian carbonate platform (Upper Sarl/Serla Formation) from fluvial deposits (Richthofen Conglomerate), followed by marine marls and carbonates of the Morbiac Formation on the southwestern slope of the Cerner Massif.

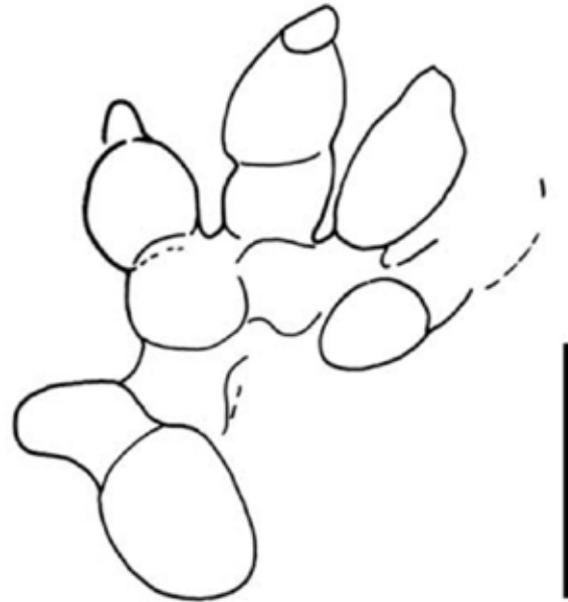


FIG. 25: A well preserved specimen of *Chirotherium barthii* Kaup, 1835. Manus-pes set, hyporelief, from Val Duron (TN; from Todesco et al., 2008). Scale bar = 10 cm.

3.6. THE ANISIAN FOOTPRINT FAUNA OF VAL DURON

In the Southern Italian Alps, Early and Middle Triassic tetrapod footprints are known since the first decades of the 20th century (Abel, 1929), but extensive research has been performed only in the last 30 years with the discovery of vertebrate tracks at many sites in the Dolomites region and surrounding areas of Northern Italy (Avanzini et al., 2011). The main ichnoassociations are preserved in terrigenous and carbonate sediments of Anisian age, deposited in marginal marine environments.

They consist of continental layers rich in vertebrate tracks interbedded with marine and volcanic levels, both of which are datable. This mixed succession has allowed the dating and the correlation of the levels containing ichnoassemblages (Avanzini et al., 2011). Discovered in the early 2000, a new ichnosite was described by Todesco et al. (2008) in the Morbiac Formation (Illyrian; Delfrati & Farabegoli, 2000) in Val Duron near Campitello (Fassa Valley, Trento) (Fig. 25).

The ichnoassociation of Val Duron represent a typical Anisian Alpine ichnoassemblage, in which *Rhynchosauroides tirolicus* Abel, 1926, *Chirotherium barthii* Kaup, 1835, *Isochirotherium delicatum* Courel & Demathieu, 1976 and *Brachychirotherium* isp. are dominant. These provide evidence for a mixed lepidosaur – archosaur assemblage comparable to those described in north-central Europe (Haubold & Klein, 2002).

3.7. PRE-VOLCANIC AGGRADING AND PROGRADING CARBONATE PLATFORMS (UPPER ANISIAN TO LOWER LADINIAN)

In the late Anisian, the Dolomites underwent an active phase of trans-tensional or extensional tectonics (e.g., Masetti & Neri, 1980; Gianolla et al., 1998; Preto et al., 2011). The carbonate platform of the Contrin Formation was fragmented into isolated horsts at the beginning of a phase of very fast subsidence, and large areas drowned into deep-water environments. From isolated tectonic blocks carved into the carbonates of the Contrin Formation, small carbonate edifices started to aggrade and became isolated pinnacles, reaching a relief of hundreds of meters relative to the surrounding basins (e.g., Cerner Massif in Fig. 26, 27).

Many of these aggrading pinnacles started to backstep and eventually drowned (e.g., Cerner), whereas others were able to survive, thus providing the nuclei of early Ladinian prograding platforms (e.g., Latemar, Schlern/Sciliar and Rosengarten/Catinaccio). In these pinnacles, the carbonate production supported aggradation at the impressive speed of up to one thousand metres per million years (cf. Brack et al., 2007). During this fast subsidence phase, a thin level of organic-rich silicified shales accumulated in the basins (Plattenkalke Member of the Buchenstein Formation), followed by a few metres of nodular cherty limestones with volcanic ash intercalations (lower



FIG. 26: Landscape showing the outstanding stratigraphic succession of the Central Dolomites, in a northward aerial view from above Alleghe. The mountain on the foreground is the Cenera Massif, while the sharp peak behind marked "DPR" is the Tofana di Rozes near Cortina d'Ampezzo. Lower Triassic shelf deposits (WER – Werfen Formation; SLI – Lower Sarl/Serla Formation); Anisian continental conglomerates (VTG – Voltago Conglomerate; RIC – Richthofen Conglomerate); Anisian isolated carbonate platforms (SLS – Upper Sarl/Serla Formation; CTR – Contrin Formation); uppermost Anisian aggradational–retrogradational carbonate pinnacle (Sciliar Formation); onlapping Ladinian turbiditic sandstones (ADZ – Zoppè Sandstones), synvolcanic Ladinian basinal deposits (IMF – Fernazza Formation); Upper Ladinian turbiditic volcanoclastics (WEN – Wengen Formation); Lower Carnian prograding carbonate platforms (DCS – Cassian Dolomite) and associated shallowing upward basinal sediment (SCS – St. Kassian/San Cassiano Formation); Carnian terrigenous–carbonate shallow marine and coastal deposits (HKS – Heiligkreuz Formation; TVZ – Travenanzes Formation); thick Upper Triassic peritidal dolomites (DP – Dolomia Principale).

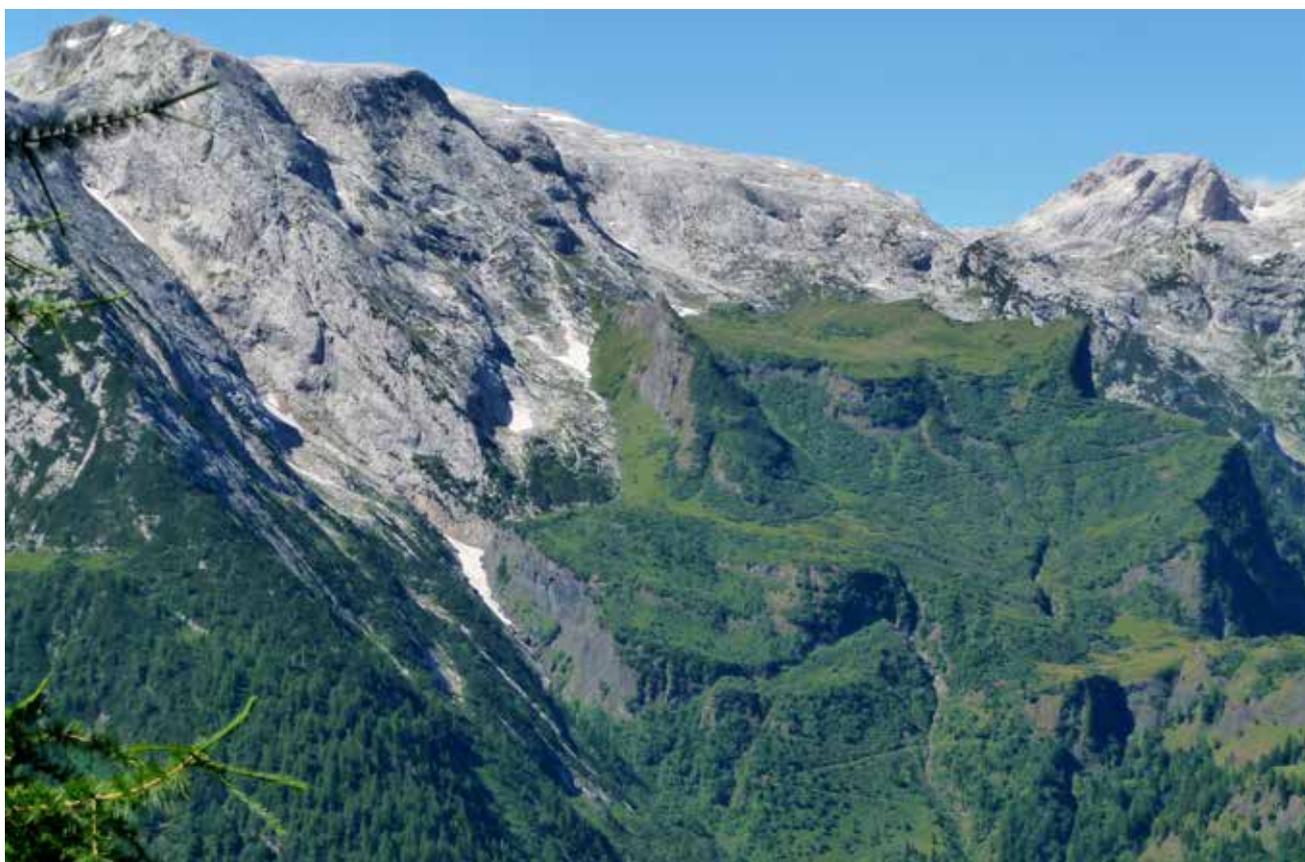


FIG. 27: Volcanic and volcanoclastics onlapping the slope of pre-volcanic carbonate platform (Pale di San Lucano).

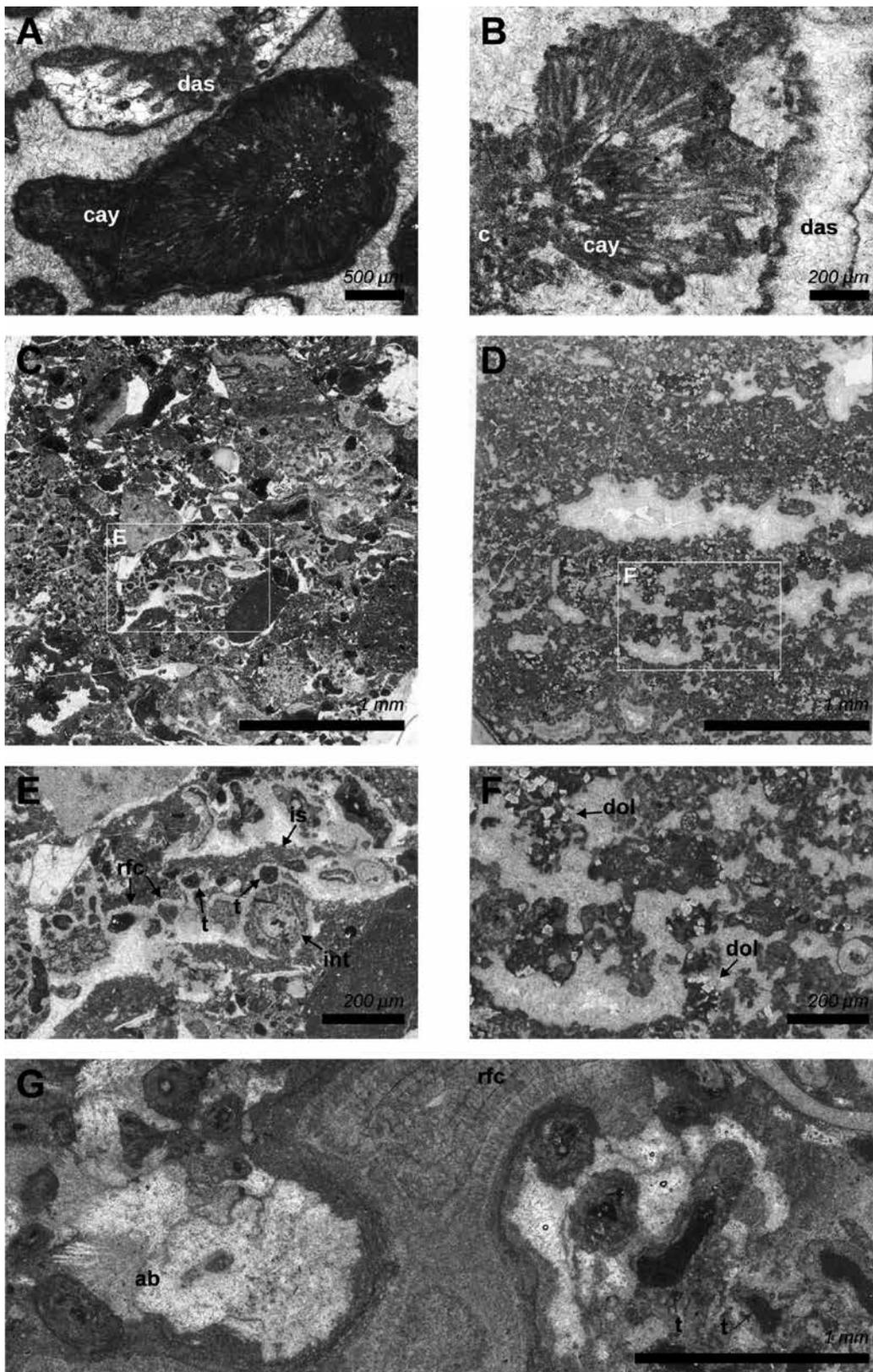


FIG. 28: Microfacies of the mainly microbial carbonates from the Latemar platform. A – A calcimicrobe (*Cayeuxia* sp.; cay) and a segment of dasycladacean green alga (das) from the well layered platform interior facies at Cimon del Latemar (see Marangon et al., 2011; Preto et al., 2011 for precise location). B – *Cayeuxia* sp. (cay), a calcimicrobe, grown on clotted peloidal micrite (c) from the well layered platform interior facies at Cimon del Latemar. The recrystallized skeletal grain on the right side is a fragment of dasycladacean green alga (das). C – Poorly sorted rudstone from the lower part of the southern slope. This sample contains small *Tubiphytes* spp., intraclasts and angular carbonate clasts reworked from a microbial facies on higher parts of the platform. See detail in E. D – Microbial boundstone with stratiform primary cavities, filled partially by radiaxial fibrous cement, from the outermost platform of the southern Latemar platform. See detail in F. E – Detail of the slope rudstone in C. Intraclasts with clotted peloidal fabric (int) and *Tubiphytes* spp. (t) are surrounded by a rim of radiaxial fibrous cement (rfc), intraparticle cavities were then partially occupied by a geopetal sediment filling (is). This suggests that rfc precipitated here when the pore space was still open to sea water, and sediment of a successive depositional event could still filter into the intraparticle pore network of the rudstone. F – Close-up of the microbial boundstone in D. This image highlights the thrombolitic fabric and clotted peloidal composition of this boundstone. Skeletal grains are rare; only a foraminifer test and a small gastropod are visible here. Clotted peloidal micrite is partially substituted by rhombs of dolomite in this sample. G – Cementstone, or *Tubiphytes* spp. boundstone, from the shelf break on the sampled transect of the southern Latemar platform. This rock parcel is volumetrically dominated by formerly aragonite botryoids (ab), now substituted by a mosaic of clear calcite, and radiaxial fibrous calcite cement (rfc). The rock framework is made of well separated *Tubiphytes* spp. branches (t).

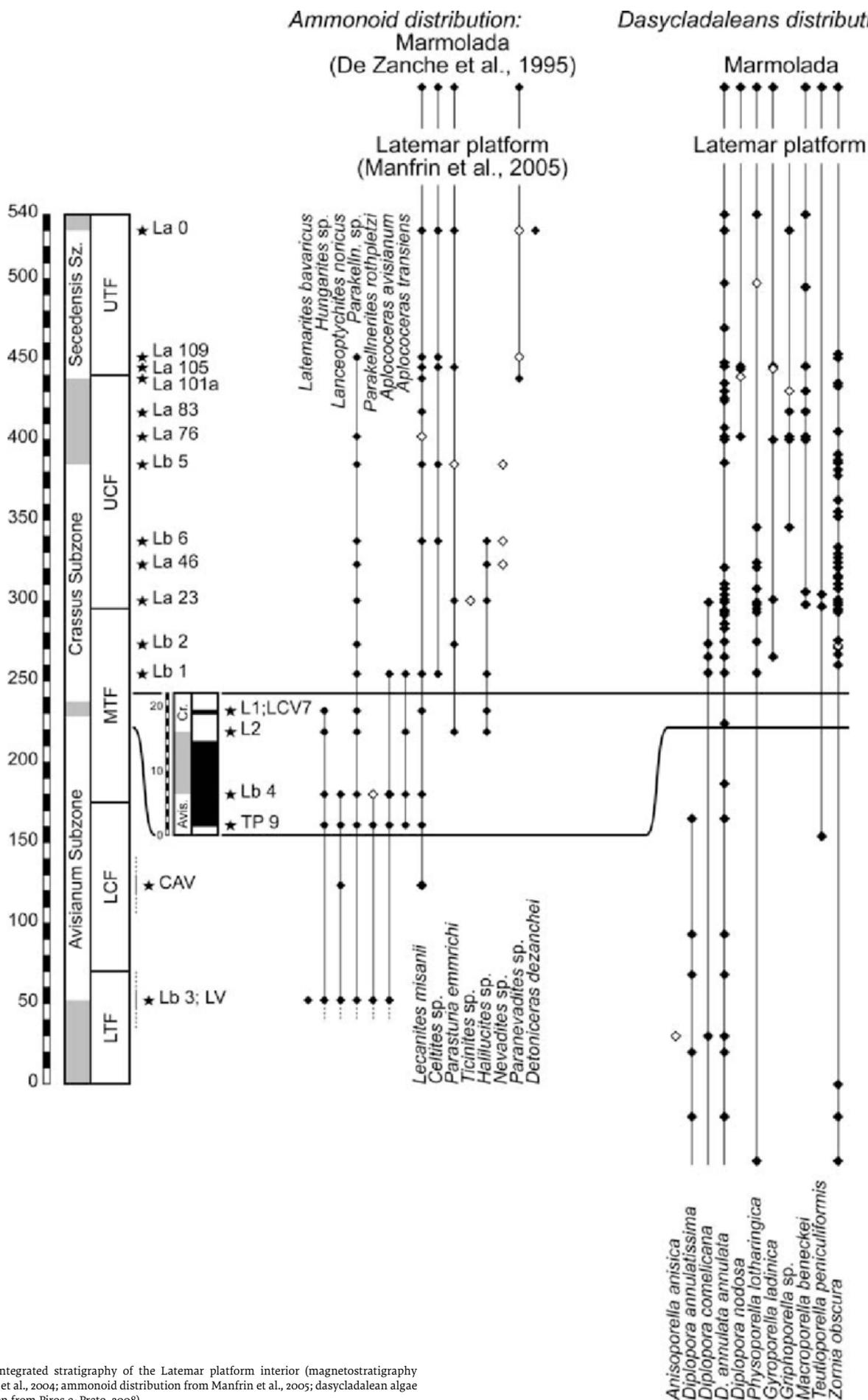


FIG. 29: integrated stratigraphy of the Latemar platform interior (magnetostratigraphy from Kent et al., 2004; ammonoid distribution from Manfrin et al., 2005; dasycladalean algae distribution from Piros & Preto, 2008).

Knollenkalke Member of the Buchenstein Formation). Meanwhile, a thick succession of metre-scale, initially subtidal and then peritidal cycles was accumulating in carbonate platform areas, with microbial boundstones forming on the shelf break and upper slopes (e.g., Gaetani et al., 1981; Harris, 1993, 1994; Blendinger, 1994; Marangon et al., 2011). During the early Ladinian, the subsidence slowed down considerably and the isolated pinnacles expanded into 5–10 km wide isolated platforms (e.g., the Schlern/Sciliar-Rosengarten/Catinaccio platform) and exceeding one km in thickness (Schlern/Sciliar Formation). Slope deposits show spectacular steep clinostratifications (Bosellini, 1984). The majority of these platforms experienced widespread facies-destructive dolomitization, with exceptions in the Western Dolomites, where several platforms preserved a calcareous composition (e.g., Marmolada and Latemar).

The platform tops experienced subaerial exposure episodes in a high frequency, while marine phreatic cements and microbialites still formed in the margin and upper slope facies. Skeletal organisms played a reduced lithogenetic role, even if they were characterized by a much greater taxonomic diversity and abundance than during the aggrading phase (e.g., Fois & Gaetani, 1981; Brandner, 1991). The basinal deposits coeval with the progradational phase of the platforms consist of a few tens of metres of nodular-cherty limestones, which are extremely poor in platform-derived granular carbonates (Knollenkalke Member of the Buchenstein Formation). The younger portion of the basinal successions shows reduced bioturbation and is enriched in calciturbidites (Bänderkalke Member).

3.8. MIDDLE TRIASSIC FOSSIL ASSOCIATIONS

Some Anisian–Ladinian carbonate platforms of the Dolomites are also renowned for the marine faunas (and algal floras) they yield. Although not strictly related to terrestrial environments, fossil localities on these carbonate platforms offer a marine counterpart to terrestrial floras that is important to understand the Middle Triassic ecosystems of the Dolomites. The best collection of macro-remains for these marine faunas and floras is kept at the Predazzo Museum. Middle Triassic carbonate platforms of the Dolomites were unlike the coral reefs we know from present tropical seas. The main carbonate producers in these carbonate depositional systems were consortia of microbes, and the main type of carbonate is microbialite (Fig. 28). Nevertheless, the shallow-water sedimentary environments of these platforms sustained a relatively diverse fauna (Fig. 29, 30) and flora (Fig. 28, 29). Among the most common fossilized constituents in the platform interior facies are calcimicrobes, i.e., fossilized cyanobacteria, and in particular *Cayeuxia* spp. *Tubiphytites* spp. are instead very common at the shelf break and on the upper slope, where they acted as proper reef builders (Fig. 28). The most common Eukaryota on the platform were dasycladacean algae. These are very common in the platform interior facies, and are often reworked into the slopes as well. Eleven species of Dasycladales were identified in the Latemar and Marmolada platforms. They have a distinct stratigraphic distribution (Piros & Preto, 2008; Fig. 29), which is potentially useful for correlation purposes, at least within the Southern Alps. Less common shallow-water macrofossils are calcareous sponges and corals as accessory reef builders (e.g., Gaetani et al., 1981; Harris, 1993; Emmerich et al., 2005) and gastropods in the platform interior.

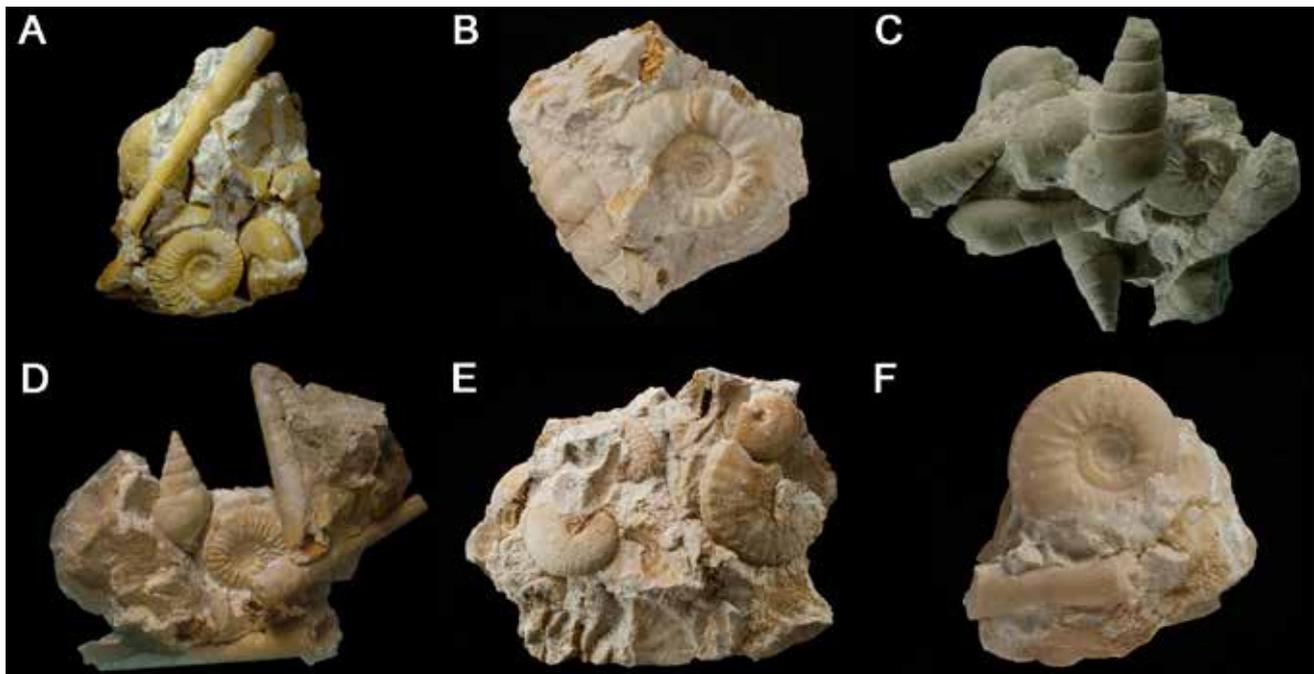


FIG. 30: The spectacular molluscan fauna of the Latemar Platform as preserved in the collections of the Geological Museum of the Dolomites, Predazzo. A – *Latemarites bavaricus* (Reis, 1900); *Proarcestes* sp.; *Michelinoceras* sp.; B – *Latemarites bavaricus* (Reis, 1900); C – *Omphaloptycha heeri* (Kittl, 1894); *Wortheniopsis* cf. *tomquisti* (Assmann, 1937); (gasteropods); D – *Latemarites bavaricus* (Reis, 1900); *Omphaloptycha tumida* (Hörnes); *Michelinoceras* sp.; E – *Parakellerites rothpletzi* (Salomon, 1895); *Lanceoptychites noricus* (Mojsisovics, 1882); F – *Latemarites bavaricus* (Reis, 1900); *Michelinoceras* sp.

Quite surprisingly, shallow water facies of the Anisian carbonate platforms of the Dolomites yielded an abundant and diverse ammonoid fauna. The richest fossil localities are on the Latemar and Marmolada platforms (De Zanche et al., 1995; Brack & Rieber, 1993; Manfrin et al., 2005), but ammonoids are also common on the Viezzana and on the Anisian–Ladinian platforms exposed along the Etsch/Adige Valley, between Trento and Bozen/Bolzano (e.g., Manfrin & Mietto, 1991). However, studies on the taphonomy of ammonoid accumulations are only available for the Latemar platform.

Most of the ammonoid localities at the Latemar correspond to the cavities in tepee structures. Tepees are convex-up structures that are formed by desiccation of carbonate mud in shallow subtidal to supratidal environments and subsequent precipitation of calcite cement in the pores of the sediment. Polygons of sediment thus gain in surface because of the displacive growth of cement in pores, to the point that the polygons push each other up at the cracks, gaining an arched shape and leaving a triangular cavity underneath (Fig. 31). These cavities often acted as sedimentary traps for the shells of pelagic organisms occasionally floating atop the platforms, such as ammonoids at the Latemar (Manfrin et al., 2005).



FIG. 31: A well-formed tepee structure of the Latemar inner platform. In this case, the tepee cavity was filled by a gastropod coquina (not visible at this scale).

The ammonoids at Latemar cover a stratigraphic interval of three Anisian biozones; ammonoids from the Marmolada platform are overlapping in part the age of those at Latemar, and in part are younger, but never reach the Ladinian (Fig. 33). Gaetani et al. (1981) mention Ladinian ammonoids from neptunian dykes at Latemar. These neptunian dykes do occur, and are widespread in the Latemar platform (Preto et al., 2011), but only rarely yielded ammonoids.

3.9. VOLCANICS AND LARGE MEGABRECCIA BODIES (UPPER LADINIAN)

During late Ladinian times, an intense tectono-magmatic event affected the Dolomites (Assereto et al., 1977; Viel, 1979; Bosellini et al., 1982; Doglioni, 1984, 1987; Castellarin et al., 1988; Doglioni & Carminati, 2008; Abbas et al., 2018). Massive intrusive and effusive magmatic activity developed in the western

Dolomites, while vertical displacement in the order of several kilometers locally took place on crustal-scale faults. The western carbonate platforms were cut by basaltic dikes and carved by large collapsing structures, while huge heterogeneous megabreccia bodies (Caotico Eterogeneo) accumulated in the adjacent depressions (Viel, 1979; Castellarin et al., 1998; Brandner et al., 2016). Volcanic products were basaltic (pillow lavas, hyaloclastites) and partially filled the former basins, fossilizing the previous platform morphology by onlapping their slopes (Fig. 34). A few platforms, proximal to the magmatic centres, were buried beneath the volcanic and pyroclastic products (e.g., Agnello platform). However, some carbonate production remained active, even close to the magmatic centres (e.g., Schlern/Sciliar platform). The onset of the basaltic volcanism was matched with a sudden change in the carbonate production style, evidenced by a sharp reduction in marine phreatic cements and by the appearance of loose calcarenites and micrites (Stefani et al., 2010). In areas more distal to the volcanoes (eastern and northern Dolomites), the platform carbonate production was able to keep pace with subsidence, and the lack of any depositional break makes the distinction between pre- and post-volcanic successions locally difficult. However, the change in the carbonate production style induced by environmental change is well recorded across widespread areas.

3.10. THE FLORA OF THE LATE LADINIAN OF MONTE AGNELLO

Fossil plants of Ladinian age from the Dolomites have been known for over 150 years (e.g., Wissmann & Münster, 1841; Mojsisovics, 1879; Ogilvie Gordon, 1927, 1934; Leonardi, 1953, 1968; Wachtler & Van Konijnenburg-van Cittert, 2000; Kustatscher, 2004; Kustatscher & Van Konijnenburg-van Cittert, 2005). The stratigraphic attribution of the historical collections is often complicated or even impossible. The common feature of all of these Ladinian floras, however, is a dominance of conifers, whereas cycadophytes, seed ferns, ferns, horsetails, and lycophytes are rare. This was related to climatic conditions (an arid climate on the mainland), edaphy (immature soil), or mostly taphonomy (caused by selection during transport; Kustatscher & Van Konijnenburg-van Cittert, 2005).

Thus, the existence of the Monte Agnello flora from the early late Ladinian is of special interest. The several decimetre-long remains do not show any orientation or sorting due to transport, indicating that the transport must have been short; thus, the assemblage can probably be considered parautochthonous. The plants are preserved in subaerially deposited pyroclastic layers due to significant volcanic activity in the Dolomites during the late Ladinian. The volcanic complexes were mostly submarine, although locally – such as in the area of Predazzo – subaerial eruptive centres also existed (Kustatscher et al., 2014). Monte Agnello represents an area that was only marginally influenced by these events and has therefore a well preserved stratigraphic succession. The flora was preserved in an about 50 cm thick layer of tuffs, locally rich in accretionary lapilli or, more rarely, small lithic lapilli, below the “explosion breccia” of the volcanic succession at Predazzo (Calanchi et al., 1977, 1978). Most plant remains are preserved as detailed impressions, with three-dimensional casts and completely degraded organic material (Fig. 35). The leaves are characterized in some cases by “holes” related to the lapilli present in the rock.



FIG. 32: Plant macrofossils from the Ladinian of Monte Anello (A-G from Kustatscher et al., 2014). Scale bars = 1 cm. A – ?Dipteridaceae indet. (MGP 194/2B); B – *Cladophlebis ladinica* Kustatscher et al., 2014 (MGP 194/65B); C – *Cladophlebis* sp. (MGP 194/88); D – *Chiropteris monteagnellii* Kustatscher et al., 2014 (MGP 197/69A); E – *Phlebopteris fiemmensis* Kustatscher et al., 2014 (MGP 191/11A); F – *Phlebopteris fiemmensis* Kustatscher et al., 2014 (MGP 191/11B); G – *Voltzia* sp. (PAL AF 3801-1); H – *Bjuvia* sp. (AF 3559); I – unidentified cycad leaf (AF 3084); J – unidentified cycad leaf (AF 3035f); K – *Voltzia* sp. (AF 2107).

Due to the short transport of the plant remains the flora is markedly distinct and much more diversified than other Ladinian floras of the Dolomites. This includes a wide range of ferns with the typical Middle Triassic osmundaceous fern *Neuropteridium elegans* (Brongniart) Schimper in Schimper and Schenk, 1879 but also new species (e.g., *Cladophlebis ladinica* Kustatscher et al., 2014, *Chiropteris monteagnellii* Kustatscher et al., 2014) and some of the oldest representatives of the fern families Matoniaceae (*Phlebopteris fiemmensis* Kustatscher et al., 2014) and Dipteridaceae (*Thaumatopteris* sp.). The flora thus gives us new insights in the first appearance of these families in the fossil record, especially in Europe. Moreover, seed ferns are represented by leaf fragments of *Scytophyllum bergeri* Bornemann, 1856, cycadophytes by leaf fragments with entire lamina probably belonging to the genera *Bjuvia* Florin, 1933, *Taeniopteris* Brongniart, 1828 and/or *Macrotaeniopteris* Schimper, 1869 and segmented leaves resembling *Nilssonia* Brongniart, 1828 and *Apoldia* Wesley, 1958. The conifers are represented mostly by shoots belonging to the genera *Voltzia* Brongniart, 1828 and *Pelourdea* Seward, 1917. The new flora from Monte Agnello is the first Ladinian flora from the Southern Alps showing the “hygrophytic” vegetation elements of the flora, corroborating due to its high diversity and abundance in ferns the theory of a humid interval in the late Ladinian of the Southern Alps (Kustatscher et al., 2014). So far, a detailed taphonomical study has been carried out only on the ferns, whereas the study of the other groups of the flora is still pending and essential in understanding whether the conifers, seed ferns and cycadophytes show high diversity in this parautochthonous flora as well or if the typically “hygrophytic” elements described above were contaminated in the transport. The special preservation permitted also a detailed study of the plant-animal interactions (Wappler et al., 2015). This evidenced that about 12 % of all foliage, axes, stem fragments, fructifications and dispersed seeds exhibited some sort of damage represented by 20 different damage types. The highest frequency of damage was observed on cycadophytes (36.5 % of all specimens) and conifers (44 %), whereas damage in seed fern (8 %) and ferns (8 %) was much rarer. This suggests that selective feeding by insect herbivores in the Monte Agnello flora preferentially targeted particular seed plants. Moreover, the herbivory recorded for the Monte Agnello flora represents nearly all of fundamental modes of herbivory, excluding fungal infection, which was not observed. Seven distinctive functional feeding groups have been detected on the foliar elements from Monte Agnello, most of which occur on particular plant hosts. External foliage feeding was observed most frequently on the cycadophytes and on the seed fern *Scytophyllum bergeri* Bornemann, 1856. On the other hand, evidence of galling, the most complex of all major interactions, is more or less evenly distributed among conifers, ferns and seed ferns (Wappler et al., 2015).

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