Field trip to Permo-Triassic Palaeobotanical and Palynological sites of the Southern Alps

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1. Introduction

The Dolomites represent one of the classical areas for the study of Permo-Triassic stratigraphy. Spectacular outcrops allow an exceptional insight into the genesis of the Permian continental-marine succession as well as the Middle-Upper Triassic carbonate platforms and adjacent basins. This area has played also an important role in the history of geology. During the 18th century, Giovanni Arduino, studying the Venetian and Recoaro Dolomites, introduced the subdivisions from Primary to Quaternary that now identify the four Erathems. Later in the century, Déodat de Dolomieu sampled the carbonate rock at the border of the Dolomites, in the Adige Valley called *Dolomie* by Nicolas de Saussure in the 1792 (Zenger et al., 1994; Mckenzie & Vasconcelos, 2009). During the early 19th century, the geological architecture of the region played also a major role in the demise of the Neptunist Theory: near Predazzo and Passo San Pellegrino, granitoid intrusions metamorphosed older limestone rocks bearing Middle Triassic fossils as published by the Vicentinian mining inspector Marzari-Pencati in 1820. These outcrops were investigated by some of the most famous geologists of the time, such as Alexander von Humboldt and Christian Leopold von Buch. Since the late 19th century the Southern Alps and the Northern Calcareous Alps have been used to define Permian–Triassic stratigraphy and biostratigraphy (e.g., Richthofen, 1860; Mojsisovics, 1879, 1882; Mojsisovics et al., 1895; Bittner, 1892; Brack et al., 2005, Mietto & Manfrin, 1995; Mietto et al., 2003, 2012; cf. Balini et al., 2010). During World War I geological mapping became part of the war strategies. Since 1970, the number of studies in petrology, stratigraphy, sedimentology and palaeontology conducted in the area has increased substantially (Gianolla et al., 2009; 2010). The depositional mode and the timing of rhythmic sedimentation of the Middle Triassic platform carbonates (e.g. Latemar), as well as of the coeval basinal sediments have been extensively discussed in terms of orbital forcing (e.g. Goldhammer et al., 1990; 1993; Brack et al., 1996; Preto et al., 2001; Zühlke et al., 2003; Kent et al., 2004; Maurer et al., 2004; Spahn et al., 2012). The integration of numerous well-correlated basinal sections throughout the Southern Alps has resulted in a reliable biostratigraphic framework (ammonoids, bivalves, conodonts and sporomorphs) especially for the P/T boundary, and the Anisian–Ladinian and the Ladinian-Carnian boundary intervals (e.g. Benton & Twitchett, 2003; Erwin, 2006; Farabegoli et al., 2007; Brack & Rieber, 1993; Brack & Muttoni, 2000; Muttoni et al., 2004; Mietto et al., 2007, 2008, 2012). This framework is tied to radioisotope age data and to the succession of magnetic reversals (Mundil et al., 1996; Kent et al., 2004; Brack et al., 2007) leading to the definition of the GSSP of the base of the Ladinian stage beeing fixed at Bagolino in the western Southern Alps and with the Seceda succession designated as the principal auxiliary section in the Dolomites (Brack et al., 2005). Is also remarkable the definition, in the Dolomites, of the GSSP for the base of the Carnian in the Stuores Wiesen section (Broglio Loriga et al., 1999; Mietto et al., 2012). The Southern Alps are a classical area for the study of Tethyan Triassic palynological successions. Records include the classical studies of Van der Eem (1983) and Brugman (1986) but also newer works such as those by Roghi (1997), Kustatscher & Roghi (2006), Kustatscher et al. (2006), Mietto et al. (2012), Hochuli et al. (2014) and Dal Corso et al. (2014).

The Dolomites, a part of the eastern Southern Alps, are renowned for their spectacular landscapes, which reveal the geomorphic expression of the complex geological architecture of the region and due to which it has been included in the UNESCO natural world heritage list in 2009 (Gianolla et al., 2009). The Dolomites provide an exceptional opportunity to fathom the fascinating geological and palaeontological richness of the Permo-Triassic of this sector of the Alpine chains (Gianolla et al., 2009). The region has also a complex multilingual history, typical of an area were Germanic (South Tyrolean, Austrian and German) and Neo-Latin (Ladinian, Venetian and Italian) languages and cultures have been interacting since ancient times. This complexity is reflected also by the place names, characterized by superimposition of Italian and German toponyms over the Mediaeval Ladinian ones (Gianolla et al., 2009, 2010).

The stratigraphic framework of the Dolomites includes Permian to Cretaceous units (for a more detailed overview see Gianolla et al., 2009), but the area is mainly dominated by the Triassic formations, making the region a classical study area for this period. The stratigraphic basement is given by lower Palaeozoic rocks, deformed and metamorphosed by the Carboniferous Variscan Orogeny. An early Permian (trans-)tensional rifting resulted in important subsidence and in the massive accumulation of a thick volcanic package, the Athesian Volcanic Complex (Avanzini et al.,2007, 2013; Morelli et al., 2007). The sedimentary succession started with the locally developed early Permian Waidbruck/Ponte Gardena Conglomerate/Conglomerato basale AUCT., cf. Avanzini et al., 2007, 2010) and the late Permian fluvial red beds of the Gröden/Val Gardena Sandstone (Massari & Neri, 1997). Westward transgressions from the Palaeo-Tethys triggered the accumulation of shallow marine evaporites and carbonates (Bellerophon Formation) while the early Triassic is represented by storm-dominated, shallow marine carbonate and terrigenous deposits of the Werfen Formation that palaeontologically characterizes the aftermaths of the end-Permian mass extinction (Benton & Twitchett, 2003; Farabegoli et al., 2007). The Anisian of the area is characterized by an active tectonic that terminated the flat topography and established basins (especially to the east) and emerged areas (especially to the west) (Bosellini, 1968). The first carbonate platforms are established in the area (Lower Serla Formation). Repeated emersion episodes and differential subsidence divide the Anisian successions in several depositional sequences (De Zanche et al., 1992; 1993; Gianolla et al., 1998a). These sequences are punctuated by subaerial unconformities followed by continental conglomerates, shallow-water terrigenous carbonate deposits, evolving into deep-water sediments or into prograding carbonate platforms. A moist climate phase is documented for the Anisian interval, particularly by marine deposits enriched in continental plant remains (Dont Formation; Kustatscher et al., 2010; Stefani et al., 2010; Dal Corso et al., in press). During the late Anisian the Dolomites underwent a strong phase of trans-tensional tectonics; large areas drowned to form deep water environments. At many spots, small carbonate edifices aggraded and became isolated pinnacles, providing the nuclei of early Ladinian prograding platforms. During the early Ladinian, the subsidence slowed down considerably and the isolated nuclei expanded to become 5-10 km wide isolated platforms (Bosellini, 1984). These up to thousand meters thick edifices dominate the western Dolomites landscape and are known as Sciliar Dolomite (Marmolada and Latemar Limestones the non dolomitised lithofacies). The coeval basinal deposits consist of few tens of metres of nodular-cherty limestones, extremely poor in carbonates but including acidic volcanic ash beds ("Pietra Verde" of the Buchenstein/Livinallongo Formation). During the middle Ladinian, a violent tectono-magmatic event in the Predazzo and Monzoni area lead to a massive intrusive and effusive magmatic activity. The carbonate platforms were cut by basaltic dykes while huge heterogeneous megabreccia bodies (Caotico Eterogeneo), pillow lavas and hyaloclastites partially filled the basins. After the magmatic activity, the carbonate production restarted with a widespread progradation (Cassian Dolomite). The high basinal sedimentation rate (St. Cassian/San Cassiano Formation), a relative sea-level drop, probably coinciding with a climatically driven increase in the siliciclastic input induced a shallowing of the basins (Stefani et al., 2010). The latest evolutionary stage of these platforms was characterized by the appearance of patch reefs, for the first time rich in "modern" colonial corals (Alpe di Specie, Russo et al., 1991). The remaining depressions were filled up by the mixed terrigenous-carbonate deposits of the Heiligkreuz Formation. The Heiligkreuz Formation registers several moist phases and is famous for yielding some of the oldest known amber, witnessing a great variety of previously unknown micro-organisms (e.g. Gianolla et al., 1998b; Schmidt et al., 2006; Sidorchuk, 2014b). During the middle-late Carnian, a flat coastal area with continental, paralic and shallow-marine mixed sediments developed (Travenanzes Formation), witnessing a return to aridity. A gradual decrease in the siliciclastic input is registered, leading to the onset of a purely carbonate peritidal platform of regional extension (Hauptdolomit/Dolomia Principale; Bosellini & Hardie, 1988). The Early Jurassic is represented by shallow water limestones (Calcari Grigi); or missing due to a stratigraphic gap (Sella and

Puez-Gardenaccia Groups; Masetti & Bottoni, 1978; Sauro et al., 1995). Due to the passive margin evolution of the Adria microplate during the Jurassic , the region experienced a gene-ralized drowning and remained under pelagic conditions until the latest Cretaceous. This phase is recorded by encrinites and condensed nodular limestones (Rosso Ammonitico, Masetti & Bottoni, 1978). During the Cretaceous, the deposition of deep water clay, marls and micrites (Marne del Puez) was eventually interrupted by the onset of turbiditic sand input (Flysh di Ra Stua), recording the early stages of the Alpine deformation (Sauro et al., 1995).

This field trip guide wants to give an overview of some of the most interesting and easy visitable outcrops of Permian and Triassic age that are important for the palaeobotanical history of the Southern Alps.

2. The flora of the Cisuralian (early Permian) intravolcanic successions of Sinnich/Sinigo

Sinnich/Sinigo is located northwest of Bozen/Bolzano, the capital of the South Tyrol Province. The section crops out on the orographic left side of the Etsch/Adige Valley.

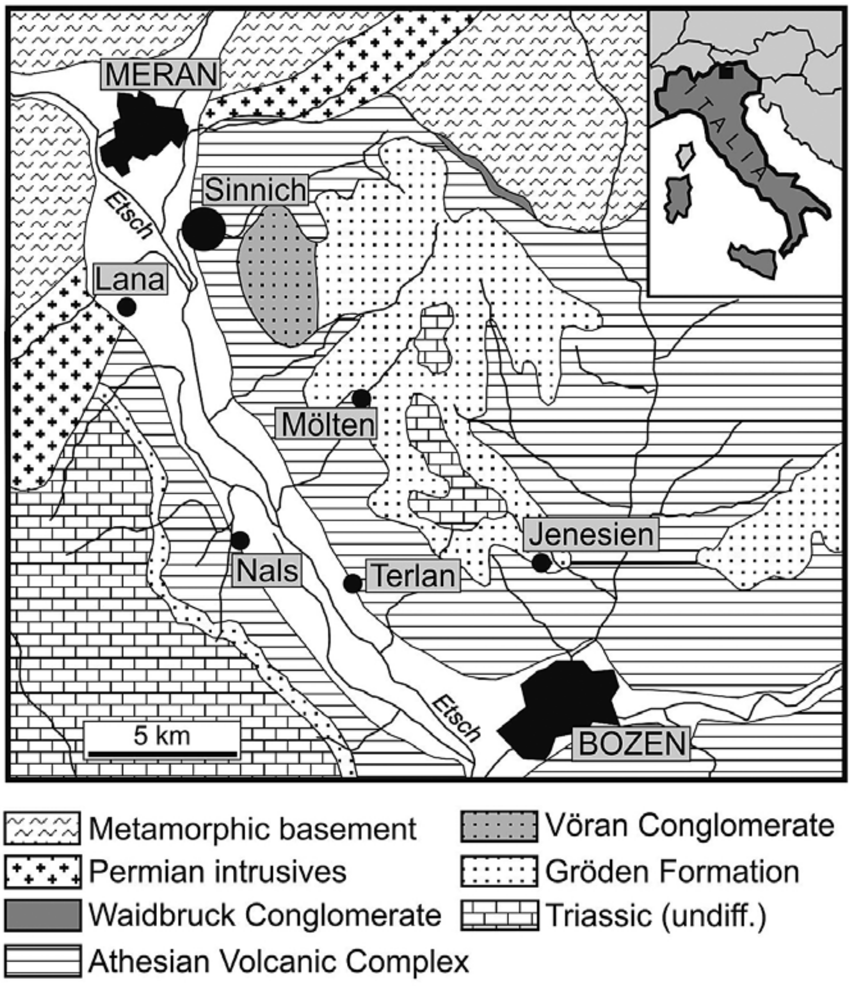

Fig. 1: Geologic overview of the area with the position of the succession of the Sinnich/Sinigo section (from Fritz & Krainer, 2006, mod.).

The geology

The Athesian Volcanic Complex represents the most extensive continental volcano-sedimentary succession of the Cisuralian in the Southern Alps, with an average thickness of about 2000 m (Marocchi et al., 2008). Volcanic activities lasted about 11 Ma (285-274 Ma) and took place on the South-Alpine metamorphic basement in a continental environment. Several sedimentary intercalations occur within the Athesian Volcanic Complex. During the inactive phases small basins formed by volcano-tectonic processes were filled with fluvio-lacustrine sediments (e.g. Fritz & Krainer, 2006; Hartkopf-Fröder et al., 2001; Krainer & Spötl, 1998; Cassinis et al., 2011). The successions of these mostly fine-grained deposits are up to 200 metres thick and yield various types of plant fossils and/or exceptionally preserved palynomorphs (e.g. Tregiovo, Grissian/Grissiano, Vöran/Verano, Sinnich/Sinigo; Remy & Remy, 1978; Fels & Paul-Koch, 1985; Cassinis et al., 1988; Hartkopf-Fröder & Krainer, 1990; Cassinis & Doubinger, 1991, 1992; Barth & Mohr, 1994; Cassinis & Perotti, 1997; Krainer & Spötl, 1998; Aspmair & Krainer, 1998; Fritz & Krainer, 2006; Marchetti et al. submitted; Forte et al., submitted).

The Sinnich/Sinigo succession is about 40 metres thick but only about 25 metres are actually accessible along the brook and the waterfall (Figs 2, 3). The lower part of the Sinnich/Sinigo section is intercalated with the extensive volcanic

Fig. 2: Panorama of the waterfall with the sedimentary succession.

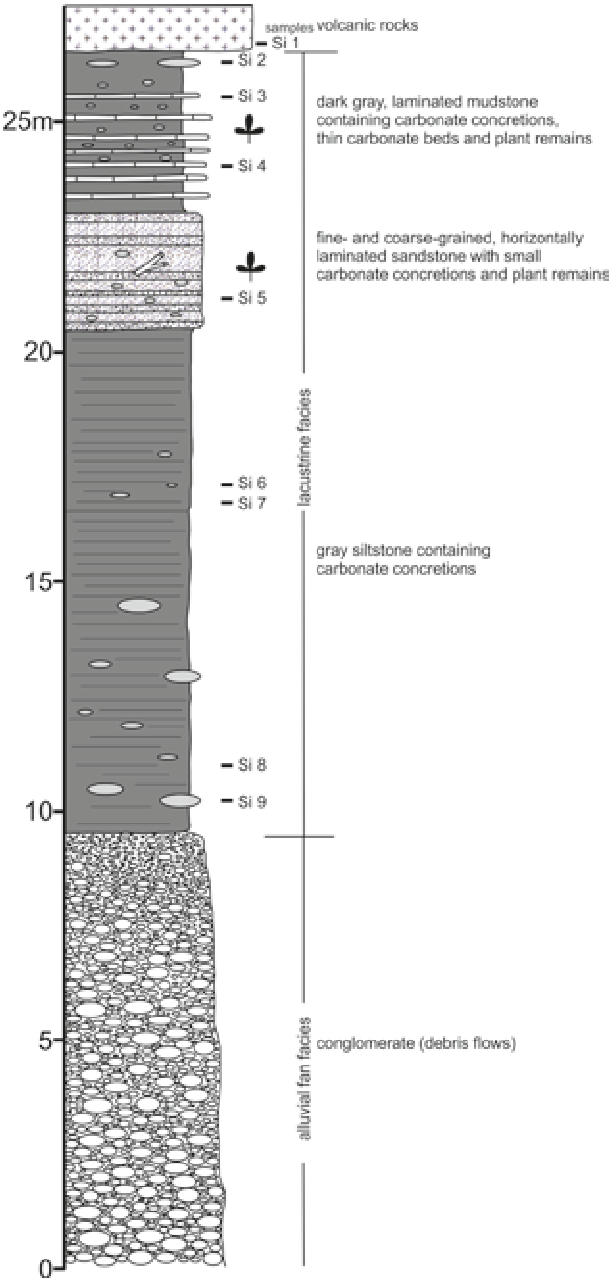

Fig. 3: Profile of the sedimentary succession of the Sinnich/Sinigo section with the levels containing plant fossils and the *in situ* stem horizon (Fritz & Krainer, 2006, mod.).

sequence of the early Permian Athesian Volcanic Group (Marocchi et al., 2008, Morelli et al., 2007). The quiescence phase of the Sinnich/Sinigo section has been dated with U/Pb on zircon to about 278.4±1.5 million years. The epiclastic lenses containing the plant remains belong to the upper part of the Monte Luco Formation and correspond to sandstones and siltstones of some tens metres in thickness interlayered inside rhyodacitic lava flows.

The succession of Sinnich/Sinigo was studied in detail by Fritz & Krainer (2006) and is composed as follows: The lower part consists of badly exposed unsorted fluvial conglomerates unbedded, and with a coarse sandy matrix. Upwards this conglomerate becomes slightly finer grained. Above the conglomerate follow 11 metres of grey silty and finely laminated lacustrine sediments containing, especially in the lower part, up to 40 cm thick carbonate concretions. The siltstone is composed of quartz, feldspar, mica (Muscovite), rare chlorite and small fragments of plants. It is followed by 2.5 metres of alternating fine and coarse-grained sandstone layers, poorly bedded, bearing centimeter-thick, roundish concretions and plant remains. The sandstones are poorly sorted and composed of angular to subangular detrital grains (quartz, feldspar, mica, volcanic rocks fragments) and a clayey to carbonatic matrix. In these sandstones several centimeter-thick oncoid-like algal crusts and algal laminae have been observed. Above the sandstone horizon 3 metres of dark grey, laminated fine sediments follow, containing small (~ 1 cm) roundish to oval carbonate concretions. Several carbonate beds, up to 3 centimetres thick and composed of thick oncoids (up to 1 cm) are interlayered within this sedimentary portion (Fig. 4). The nuclei of the oncoids are formed by ostracod valves, which are also common in the sediment. The matrix is calcisiltitic, fine grained with angular to subangular quartz grains. Fragments of larger valves are rare, perhaps belonging to bivalves. The top of the succession is characterized by a 0.5 meter thick silty horizon with up to 20 cm thick carbonate concretions, which is in turn overlain by volcanic rocks.

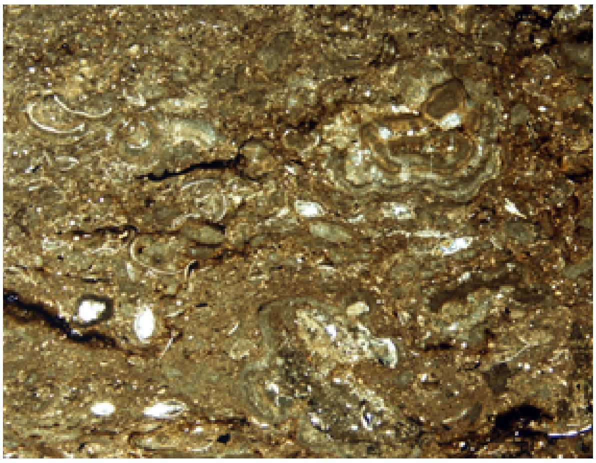

Fig. 4: Thin section showing the algal mats, oncoids and various ostracod valves (Fritz & Krainer, 2006, mod.).

The macroflora

Two distinct horizons containing plant remains are preserved in the succession. The coarse grained sandstone horizons yielded three-dimensionally preserved stems in original life position (Fig. 5). In some other lenses the plants are preserved in the sediment as three-dimensional casts while the organic matter is long gone. In the most fine-grained levels the plant remains are preserved as normal compressions (for more details see Fritz & Krainer, 2006).

Fig. 5: Overview of the horizons with the *in situ* stems. The surface is exposed over several square metres allowing to extrapolate the spatial distribution of the trunks.

Compressions and impressions of plant remains have been studied by Fritz & Krainer (2006). The Cisuralian flora of Sinnich/Sinigo includes seed ferns, cordaitaleans, conifers and perhaps ferns. The presence of the cordaitalean is confirmed by a permineralised stem fragment with three apically arising primary shoot fragments as well as a leaf fragment (50 x 15-30 mm) with a distinct parallel venation, resembling *Cordaites principalis* (Fritz & Krainer, 2006). Additional permineralised wood has been attributed to *Cordaioxylon* and *Dadoxylon* due to its wood anatomy (Fig. 6a; Fritz & Krainer, 2006). Most compressed plant remains belong to the conifers. Dispersed conifer shoots were identified and putatively assigned to *Walchia* or *Ernestiodendron filiciforme* (Fig. 6b-c; Fritz & Krainer, 2006). Some cone fragments were interpreted as male conifer cones (*Walchianthus* sp.; Fig. 6d-e) while some female ovuliferous complexes were attributed to *Walchiostrobus* (*Otovicia hypnoides* (Brongniart) Kerp et al., 1990) and *Pseudovoltzia* (Fig. 6f). Bilaterally symmetrical oval seeds have been assigned to *Samaropsis* and *Trigonocarpus* and to a putative seed fern. Also the male seed fern fructification *Thuringia* has been putatively identified (Fritz & Krainer, 2006). An isolated pinnule has been assigned to *Pecopteris* sp. (Fig. 6g). Remains of sphenophytes, lycophytes and *bona fide* ferns are so far not confirmed but this can be also due to a preservation bias.

The *in situ* horizon composed of coarse-grained sediment with three-dimensionally preserved stems is still under study. Dispersed over an area of several square metres, *in situ* stems and roots still in their original position are preserved (Fig. 7, 8). A first chemical analysis showed that permineralisation took place both via silification and carbonification. This double permineralisation process makes a taxonomic identification of the stems difficult.

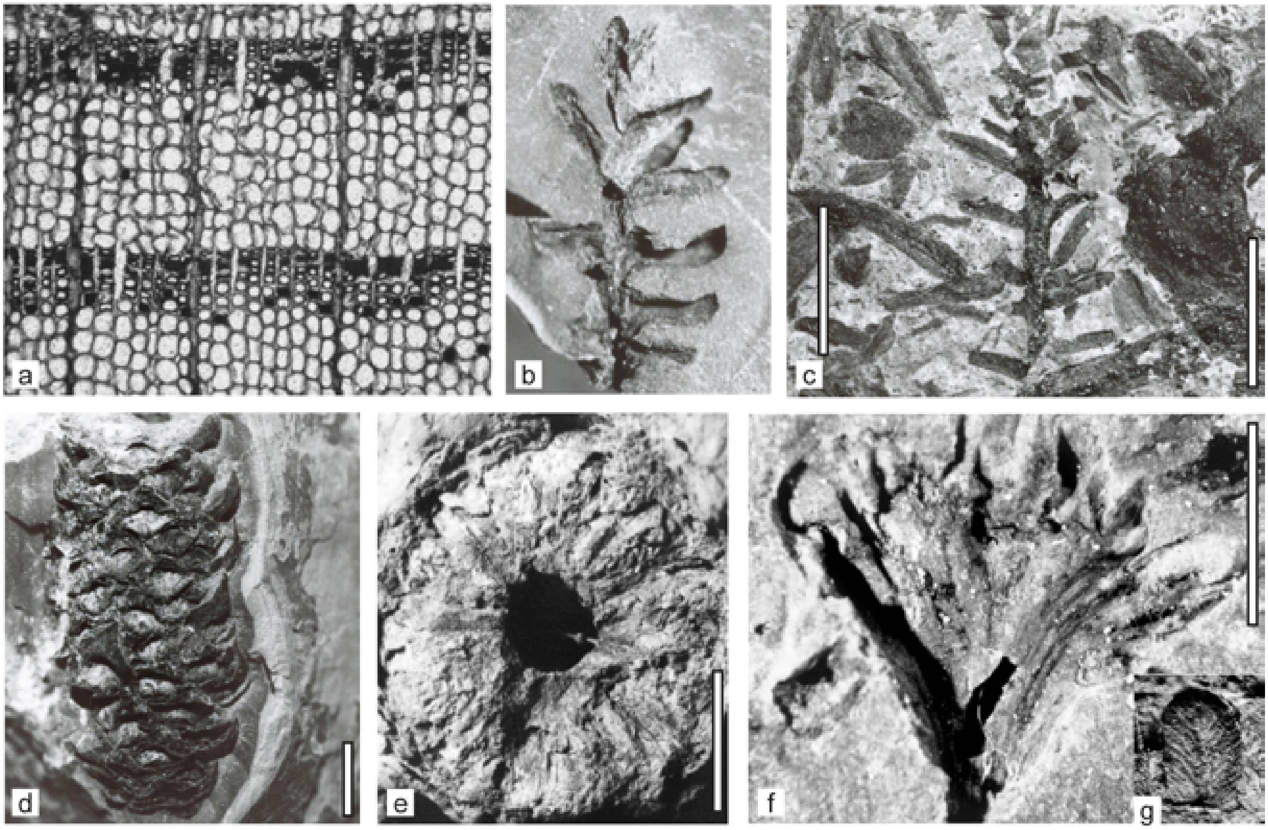

Fig. 6: Plant remains from Sinnich/Sinigo (det. Fritz & Krainer, 2006), scale bar = 1 cm:
- a Conifer wood of the stem horizon (*Dadoxylon* sp.)
- *b Walchia*, secondary shoot
- *c ?Ernestiodendron filiciforme*, shoot of penultimate order, leaves attached to the rachis
- d Cones of *Walchianthus* sp.
- e Cross section through a cone of *Walchianthus* sp.
- f Ovuliferous complex of *Walchiostrobus* sp.
- g Isolated single fragment of *Pecopteris* sp.

Fig. 7:
Horizon with *in situ* stem sections and root traces.

Fig 8:
Isolated stem fragments from the *in situ* horizon.

3. The Lopingian flora and fauna of the Bletterbach

The Bletterbach gorge lays southeast of Bozen/Bolzano and is, since 2009, part of the Dolomites UNESCO world heritage site. Apart from its undisputed scientific importance the Bletterbach is also easily accessible through some walking paths that are widely used in the summer (extimated 60.000 visitors each year); events and guided tours are coordinated by the visitor center of the Geoparc Bletterbach. Additionally the beauty of the landscape, the colors of the rocks – especially on a late summer or autumn afternoon or evening – are exquisite and have given the gorge the nickname of "Gran Canyon of South Tyrol". The succession exposed in the gorge starts at the bottom with the Cisuralian Athesian Volcanic Group and finishes at the top with the early Middle Triassic Contrin Formation preserving changing landscapes, climate and environmental conditions as well as the evolution of life, both plant and animals, through time.

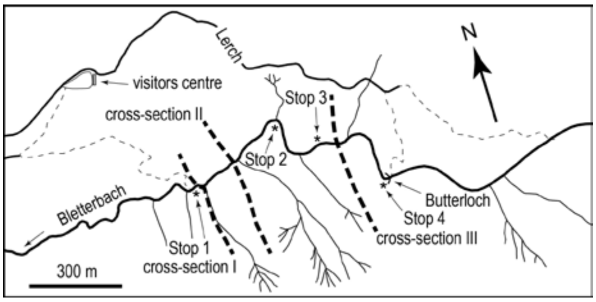

Fig. 9: Overview of the Bletterbach gorge with tributaries, location of stops and valley transects.

Stop 1 – The Auer/Ora Formation of the Athesian Volcanic Group

The Bletterbach Gorge exposes the upper part of the Auer/Ora Formation, the youngest volcanic unit of the Athesian Volcanic Group, earlier termed "Bozner Quarzporphyr". The Auer/Ora Formation, dated about 274 mya, represents pyroclastic flow deposits accumulated in a tectonically controlled graben-like structure between Bozen/Bolzano and Auer/Ora (Morelli et al., 2007). The formation is mainly formed of coherent and homogeneous welded rhyolitic lapilli-tuffs of pink-red to orange-red colours. Up to 4 mm large sanidine, pink plagioclase and quartz phenocrysts float in a felsic groundmass. Due to smaller phenocrysts and crystal fragments this groundmass appears heterogeneous (Morelli et al. 2007). Fiamme formed of dark aphanitic or juvenile porphyric inclusions occur frequently. A regular network of subvertical joints and 8-10 m spaced discontinuity lines cutting the rock parallel to the orientation of the fiamme are noticeable features at outcrop scale. The latter may be attributed to different ignimbrite flow units (Morelli et al., 2007).

Stop 2 - The boundary between the Auer/Ora Formation and the Gröden/Val Gardena Sandstone

The base of the Gröden/Val Gardena Sandstone follows older Permian rhyolitic ignimbrites of the Auer/Ora Formation (Morelli et al., 2007). This boundary is associated to an unconformity of about 14-27 Ma (Cassinis et al., 1999). The onset of the second Permian tectono-sedimentary cycle *sensu* Cassinis et al. (2002) initiated with filling up of a palaeorelief.

The contact rhyolite/Gröden Sandstone is exposed along the main gorge between the decent trail from the visitor centre and the waterfall (Fig. 9). By optic levelling of the top rhyolite between the main gorge and its tributaries an upfilled palaeorelief of about 30 m can be reconstructed (Fig. 10).

Stop 3 - Mature gypsisols in the lowermost part of the Gröden/Val Gardena Sandstone

The lowermost part of the Gröden/Val Gadena Sandstone, sequence Lo 1 *sensu* Posenato (2000), represents an about 30 m thick succession of exclusively terrestrial strata composed of stacked up to 8 m thick fining upwards cycles (Massari et al., 1994). Internally, these cycles start with up to 3 m thick coarse-grained sandstones or conglomerates at their bases and grade into shaly sands and silts towards their tops. Conglomerates, matrix supported conglomerates to conglomeratic sandstones, commonly form the base of the lower cycles whereas coarse grained sandstones form the bases of the upper cycles. Conglomeratic beds often appear massive and unstratified and sandstones are formed of horizontally laminated, low-angle cross-bedded and trough-cross bedded sandstone lithofacies. Both lithologies form tabular bodies that have a sharp but almost non-erosive base and show lateral shifts to finer grained lithofacies towards the West and South. Internal bounding surfaces are horizontally oriented or low-angle inclined; the resulting architectures of sandstone units appear sheet-like to splay-like, respectively. Comparable architectures are described from proximal parts of aggradational floodplains that underwent crevassing and sheet flooding. The splay-like sandstone bodies with low-angle inclined subordinated bounding surfaces resemble architectures of crevasse splays (Allen, 1965; Coleman, 1969; Brierley, 1996; Bristow et al., 1999; Bridge, 2003) and the tabular and sheet-like sandstone bodies may originate from subaerial unconfined flows (Fisher et al., 2007).

Conglomerates and sandstones are followed by reddish to sometimes variegated shaly siltstones to silty sandstones. These sediments representing the upper part of individual cycles experienced substantial modification by pedogenic processes. Destratification due to repeated shrinking and swelling is very common and resulted in typical slickensides. However, the most prominent visible feature are up to 3 m thick petrogypsic and

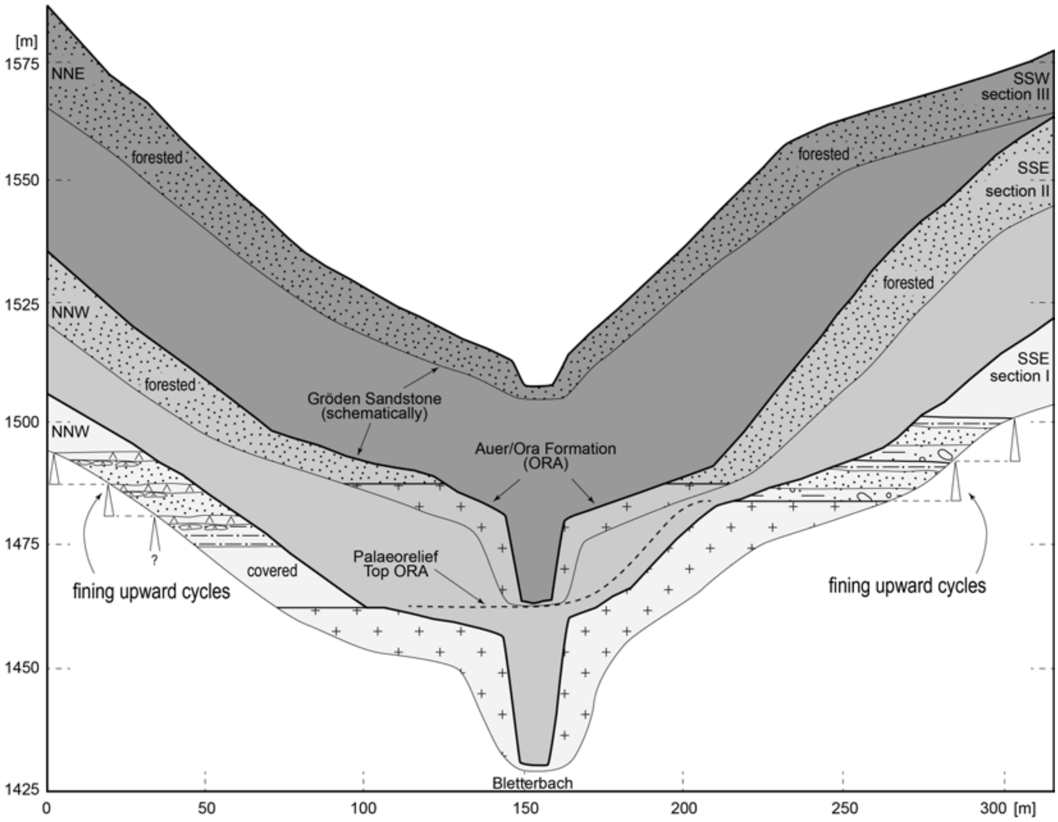

Fig. 10: Schematic transects across the Bletterbach gorge. The contact of Gröden/Val Gardena Sandstone and Ora Formation is considered to be associated with long time-gap of 14–27 Ma (Cassinis et al., 1999). In the Bletterbach gorge this contact exhibits a palaeorelief of about 30 m between the southern and the northern slope possibly representing a palaeovalley. The Gröden/Val Gardena Sandstone is composed of large-scale fining upward cycles showing significant coarsening towards the South (this figure) and East (Massari et al., 1994) accompanied by decrease of pedogenesis.

petrocalcic horizons of mature gypsisols and calcisols. At the base of petrogypsic/petrocalcic horizons a few gypsum/carbonate nodules occur scattered, become larger and more common towards the top and finally coalesce in forming massive gypsum or carbonate crusts, often with an undulating top. The gypsisol exposed at the floor of the Bletterbach is well recognised for its pseudo-anticlinal structures (gilgai relief) highlighted by secondary gypsum veins demonstrating that precipitation of gypsum followed vertic processes (Fig. 11). Thicknesses and maturities of gypsisols clearly show that crevassing and sheet flooding on the floodplains were followed by longer times of subaerial exposure under climates characterised by precipitation < evaporation.

Stop 4 – The first marine incursion into the Gröden/Val Gardena Sandstone

The Gröden/Val Gardena Sandstone exposed in the valley cliffs below the Cephalopod Bank represents the transgressive part of sequence Lo 2 (sensu Posenato, 2000). In terms of cyclicities, lithofacies and sedimentary architecture the succession corresponds more or less to the succession exposed below. Up to 8 m thick fining upward cycles show successively decreasing thicknesses towards the Cephalopod Bank accompanied by a reduced number of pedogenic modified horizons (Figs. 12B, 13A). Sharp based sheet-like to splay-like sand bodies, dominantly formed of upper flow regime bed forms, grade vertically into shaly lithologies that comprise mature gypsisols,

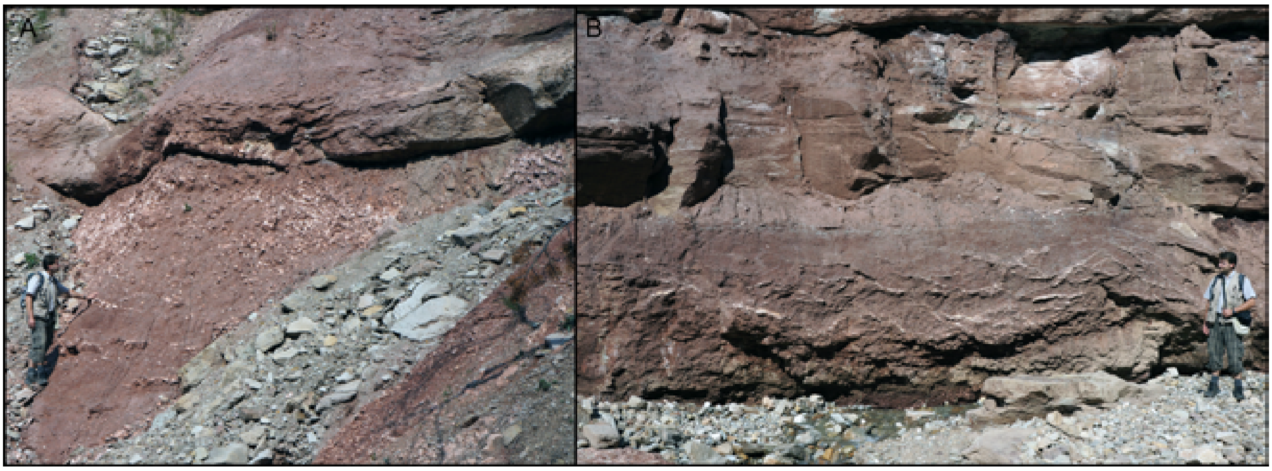

Fig. 11: Example of outcrop with mature gypsisols within sequence Lo 3. (A) Gypsisol with few and scattered nodules at the base. To the top gypsum nodules become common, coalesce and from a massive petrogypsic horizon. Person for scale is 1.9 m. (B) Prominent gypsisol showing pseudo-anticlinal structures (gilgai relief) highlighted by secondary gypsum veins. The lower part comprises gypsum nodules of a petrogypsic horizon. Person for scale is 1.9 m.

Fig. 12: Example of sedimentary architectures of the Gröden/Val Gardena Sandstone within the lower (transgressive) part of sequence Lo 2. (A) Lateral shifting sand body with internal bounding surfaces dipping with 15-30° towards SE indicating lateral accretion of point bar sheets (black arrows) due to subsequent migration of a meander. The sheet-like sandstone at the top (white arrow) dips gently towards North and represents the proximal part of a levee/crevasse splay complex. Scale bar is 5 m. (B) Sharp based splay-like sand body with shallow inclined (<15°) bounding surfaces show downlapping pattern (arrows). The overall architecture simplifies a progradational pattern of convex-up crevasse splay lobes to the South.

calcisols or vertisols, respectively (Figs. 12-13). Accordingly, these tabular sand bodies are considered proximal crevasse splays and sheet sands of an aggradational floodplain. In contrast to that, a northern tributary of the main gorge exposes an up to 7 m thick sandstone that is formed of sheet-like sigmoidal sand bodies that are separated by 15-30° inclined bounding surfaces. This indicates a lateral shifting architecture similar to the 'epsilon' cross-bedding *sensu* Allen (1963) or the lateral-accretion macroform (LA) sensu Miall (1985) (Fig. 12A). The lateral accreting sand body is interpreted as point bar sheets that were formed due to subsequent migration of a high-sinuous meandering channel. As both, the channel fill and floodplain deposits, are formed of bed load and suspended load, the river type has been interpreted as mixed-load meandering river (Massari et al., 1994; Massari & Neri, 1997).

Fig. 13: Example of sedimentary architectures of the Gröden/Val Gardena Sandstone. (A) Succession of stacked tabular and sheet-like sedimentary units with sharp, flat and only slightly erosional bases (arrows). The units are characterised by internal fining upward from coarse- to fine-grained sandstones to shales and pedogenic modification at their tops. Scale bar is 5 m. (B) Detail from A. The lower part is dominated by low-angle cross-bedded and horizontal laminated lithofacies, the few cross-bedded sets present show tangential to low-angle concave shaped toe sets. Both is indicative of increasing portions of suspended load under higher transport velocities. The fine-grained lithofacies at the top suggest settling from suspension followed by subaerial exposure and pedogenic modification. The unit represents a 'sheet sand' in the classical sense that originates from a unconfined subaerial flow on an aggradational floodplain (Colombera et al., 2013). Scale bar is 5 m.

The short-term ingression evidenced by the Cephalopod Bank shifted this channel-floodplain system towards the West, and the Bletterbach area was transformed into a coastal-deltaic area. At the waterfall an about 3 m thick intercalation of thin silty sandstones and dark grey to black clays is exposed below the Cephalopod Bank. The succession is bioturbated and rich in plant remnants. The 2.5 m thick Cephalopod Bank shows coarsening upwards from fine-grained to medium-grained sandstones. In the lower part bedding appears horizontal with individual layers of wave ripples. Towards the top, hummocky cross-bedding indicates successive shallowing (Massari et al., 1994). Above the Cephalopod Bank a plant rich intercalation of silty sandstones and dark clays, comparable to the intercalation below, is exposed. In the succession pedogenic features are lacking and lithofacies, bedding features and the high content of plant remnants (the so called "cuticle horizon" of Clement-Westerhof, 1984, 1986, 1987, and Poort & Kerp, 1990) suggest deposition under subaquatic conditions. The vertical succession of lithofacies can be best explained within a fluvio-deltaic setting. The situation around the waterfall is considered to represent the transition from a floodplain to an interdistributary bay and via a delta plain back to floodplain (Walker & Harms, 1971; Bhattacharya & Walker, 1991).

The macroflora

Only a few floras from the Southern Alps are Lopingian in age, i.e. Mölten/Meltina (Fritz & Krainer, 1999; Krainer, 2000), Auer/Ora (Leonardi, 1948), Cuecenes (e.g. Florin, 1964, Leonardi, 1968), Seiser Alm/Alpe Siusi (Jung, 1977), various localities in the Recoaro area (e.g. De Zigno, 1862; Massalongo, 1863; Bittner, 1879, 1881; Clement-Westerhof, 1984; Aspmair & Krainer, 1998; Fritz & Krainer, 2006) and, last but not least, Bletterbach (e.g. Clement-Westerhof, 1984, 1986, 1987; Poort & Kerp, 1990; Kustatscher et al., 2012). Gümbel (1877) reported *Voltzia hungarica*, *Baiera digitata*, *Ullmannia bronnii*, *U. geinitzii*, *Carpolithes*, *Calamites* or *Equisetites* and a fern fragment from the "Grödner Sandstein" near Neumarkt/Egna, very close to the Bletterbach. Perwanger (1946) was the first to mention plant fossils from the Bletterbach gorge, including a "*Lepidodendron*-Stengel". During the following years, Leonardi (1948, 1951, 1968) studied the Butterloch area of the Bletterbach gorge, mentioning and figuring "*Lepidodendron* cf. *sternbergi* Lindley et Hutton vel *Schizolepis permensis* Heer, *Lepidodendron* cf. *veltheinianum* Sternberg, *Lepidodendron* sp., *Lebachia* (=*Walchia* auct.) *laxifolia* Florin and *Lebachia* (?) sp." (Leonardi, 1948). So far most macroremains were badly and fragmentarily preserved. In the 1980's a research group from Utrecht University started a detailed study in the area finding horizons yielding plant fragments with exceptionally preserved cuticles. Clement-Westerhof (1984, 1986, 1987) and Poort & Kerp (1990) described and figured several conifers and seed ferns: *Ortiseia leonardii* Florin, 1964, *O. jonkeri* Clement-Westerhof, 1984, *O. visscheri* Clement-Westerhof, 1984, *Dolomitia cittertiae* Clement-Westerhof, 1987, *Pseudovoltzia liebeana* (Geinitz) Florin, 1927, *P. sjerpii* Clement- Westerhof, 1987 and *Peltaspermum martinsii* (Germar) Poort et Kerp, 1990. Some of the male cones yielded also *in situ* pollen: *Nuskoisporites* Potonié et Klaus, 1954 was found *in situ* in male cones of *Ortiseia* Florin, 1964 and *Lueckisporites* Potonié et Klaus, 1954 in *Majonica alpina* Clement-Westerhof, 1987 (Clement-Westerhof, 1974, 1988). Studies of the Bletterbach flora were used also for paleoecological and paleoclimatic reconstructions (e.g., Uhl & Kerp, 2005; Vörding & Kerp, 2008).

Bulk macerations reveal a flora dominated by conifers with seed ferns and ginkgophytes as additional elements (Kerp & Kustatscher, 2005). However, it should be noted that the composition of a bulk maceration flora is strongly biased towards gymnosperms with thick and resistant cuticles. Pteridophyte cuticles are underrepresented since they are comparatively thin and thus have a lower preservation potential. On the other hand, palynological studies show that hygrophyllous taxa (especially ferns) are rare in the assemblage (only up to 5%; Pittau et al., 2005). Nonetheless spores are moderately diversified and represented by 27 different species (out of 97 species in total; see also Massari et al., 1994 and below).

Thus, of great importance is the discovery of a lens with well-preserved plant megafossils in the lower part of the Gröden/Val Gardena Sandstone of the Bletterbach gorge a few years ago. In the context of a project of the Museum of Nature South Tyrol and the Geoparc Bletterbach several hundreds of plant fossils have been collected between 2003 and 2011. They are now stored at the Museum of Nature South Tyrol in Bozen/Bolzano (Kustatscher et al., 2012, 2014). These finds represent the first well diversified late Permian flora with cuticles known from Northern Italy and connect for the first time the gross morphology of plant taxa with the hitherto known small remains and/or dispersed cuticles.

The plant fossils were assigned to 33 distinct organ morphotypes, including foliage, stem fragments, fructifications, and dispersed seeds of sphenophytes, seed ferns, taeniopterids, ginkgophytes and conifers (Kustatscher et al., 2012, 2014; Bauer et al., 2014).

Among the plant remains, the ginkgophyte leaf fragments dominate the fossil plant assemblage (51%) suggesting that the ginkgophytes were important elements in certain vegetation types (probably forests) as early as the late Permian. The ginkgophyte remains belong to the foliage taxa *Baiera digitata* (Brongniart) Heer, 1876, *Sphenobaiera* sp., putative *O-ha-tsuki-* type fertile leaves, seeds, and several ginkgophyte-like leaf types of uncertain affinities (Fischer et al., 2010; Bauer et al., in press). *Baiera digitata*, a characteristic ginkgophyte of the Lopingian of Europe (Bauer et al., 2013) has leaves differentiated in lamina and petiole (up to 120 x 70 mm). The lamina is wedge-shaped and divided once to three times into linear segments (Fig. 14). *Sphenobaiera* sp. is characterized by non-petiolate leaves (up to 90 x 40 mm) that are at least one bifurcated. The segments are broadly lanceolate with a basal angle of up to 50°. Very thin and linear leaves could belong to the Dicranophyllales, a group which is considered to represent a ginkgophyte or ginkgophyte precursor (Bauer et al., in press).

The conifers represent the second most common plant group (~40% of the flora) with *Ortiseia* Florin, 1964, *Quadrocladus* Mädler, 1957 and *Pseudovoltzia* Florin, 1927 as the most common conifer taxa. *Ortiseia* is the most important conifer of the Lopingian of the Southern Alps. Two different species are distinguished, *Ortiseia leonardii* Florin, 1964 (Fig. 15) and *Ortiseia visscherii*

Fig. 14: Leaf of *Baiera digitata*.

Fig. 15: Shoot fragment of *Ortiseia leonardii*.

Clement-Westerhof, 1984 (e.g., Clement-Westerhof, 1984), differing mostly in leaf shape and size and on the female ovuliferous scales. *Ortiseia leonardii* having the bigger and coarser leaves and overall structure. Less common are *Quadrocladus*, characterized by strap-like narrow leaves with rounded apices (40 x 2 mm) and *Pseudovoltzia*, characterized by heterophyllous, helically arranged leaves that are attached with a slightly enlarged basis (10-40 x 4-5 mm). Both taxa are well known from the Lopingian of Germany (e.g., Schweitzer, 1963, 1968; Uhl & Kerp, 2005). Apart from the above-mentioned genera Clement-Westerhof (1984, 1986, 1987, 1988) described also cuticle of *Majonica* and *Dolomitia*; a detailed study of the conifers of the Bletterbach gorge is still in progress.

The seed ferns are rare in the flora. The most common are *Sphenopteris suessii* Geinitz, 1869, a species to date only described from the Permian of the Southern Alps (Kustatscher et al., 2014) with (sub)oppositely to oppositely attached pinnules that are inversely lanceolate with a constricted base. The second *Sphenopteris* species is characterized by irregularly dichotomizing pinnules (sub)alternately attached to a striate rachis. More important is *Germaropteris martinsii* (Germar in

Fig. 16: Ovuliferous disc of *Germaropteris martinsii*.

Kurtze, 1839) Kustatscher et al., 2014, formerly known as *Peltaspermum martinsii* (Germar) Poort et Kerp, 1990, one of the most common seed fern taxa in the Lopingian of Europe (see Poort & Kerp, 1990; Kustatscher et al., 2014). Bipinnate fronds characterize the taxon with intercalary pinnules in the primary rachis and ovuliferous organs consisting of peltate discs with a central stalk and marginal lobes (Fig. 16). The thick and fleshy pinnules are small, semi-circular to elongate linguiform and broadly attached to the rachis. Also rare in the flora are some dispersed pinnae with alethopteroid pinnules attached (sub)alternately and at c. 45° to the thin rachis. Pinnules are oblong to slightly falcate with a rounded apex and a decurrent proximal base that extends to a wing along the rachis between adjacent pinnules.

Taeniopterid leaf fragments are also rare in the flora (< 1.5%) and are represented by two different leaf types. *Taeniopteris* sp. A is represented by linear, entire-margined leaves with a thick midvein and almost perpendicular lateral veins that never bifurcate and reach a density of 15-18 per centimetre (Fig. 17). *Taeniopteris* sp. B has bigger, entire-margined leaves with a stout midvein. The lateral veins arise at an angle of 70°, slightly arch and then run almost perpendicularly to the lateral margin with a density of 12-18 veins per centimetre.

The horsetails are the rarest group in the flora (0.2%) with a few dispersed hexagonal sporophyll heads, leaf sheaths and stem fragments. More common are the reproductive organs with dispersed seeds (ginkgophytes, seed ferns or conifers) as well as female and male conifer cones. Charcoal fragments were also found in the fossil assemblage, evidencing the presence of wild fire"(Uhl et al., 2012).

Plant-animal interactions

Fig. 17: Leaf fragment of *Taeniopteris* sp. B.

The Palaeozoic–Mesozoic transition is characterized not only by the most massive Phanerozoic mass extinction at the end of the Permian, but also extensive aftermath and a prolonged period of major biotal recovery during the succeeding Middle to Late Triassic. All the available ecological models indicate the presence of: (1) a broad spectrum of insects; (2) seed plants, principally cycads, peltasperms, ginkgophytes, bennettitaleans, voltzialean conifers and gnetophytes; and (3), their varied ectophytic and endophytic associations, were the major elements for keystone communities in terrestrial ecosystems worldwide. The Gröden/Val Gardena Sandstone of the Bletterbach gorge is characterized by low frequency

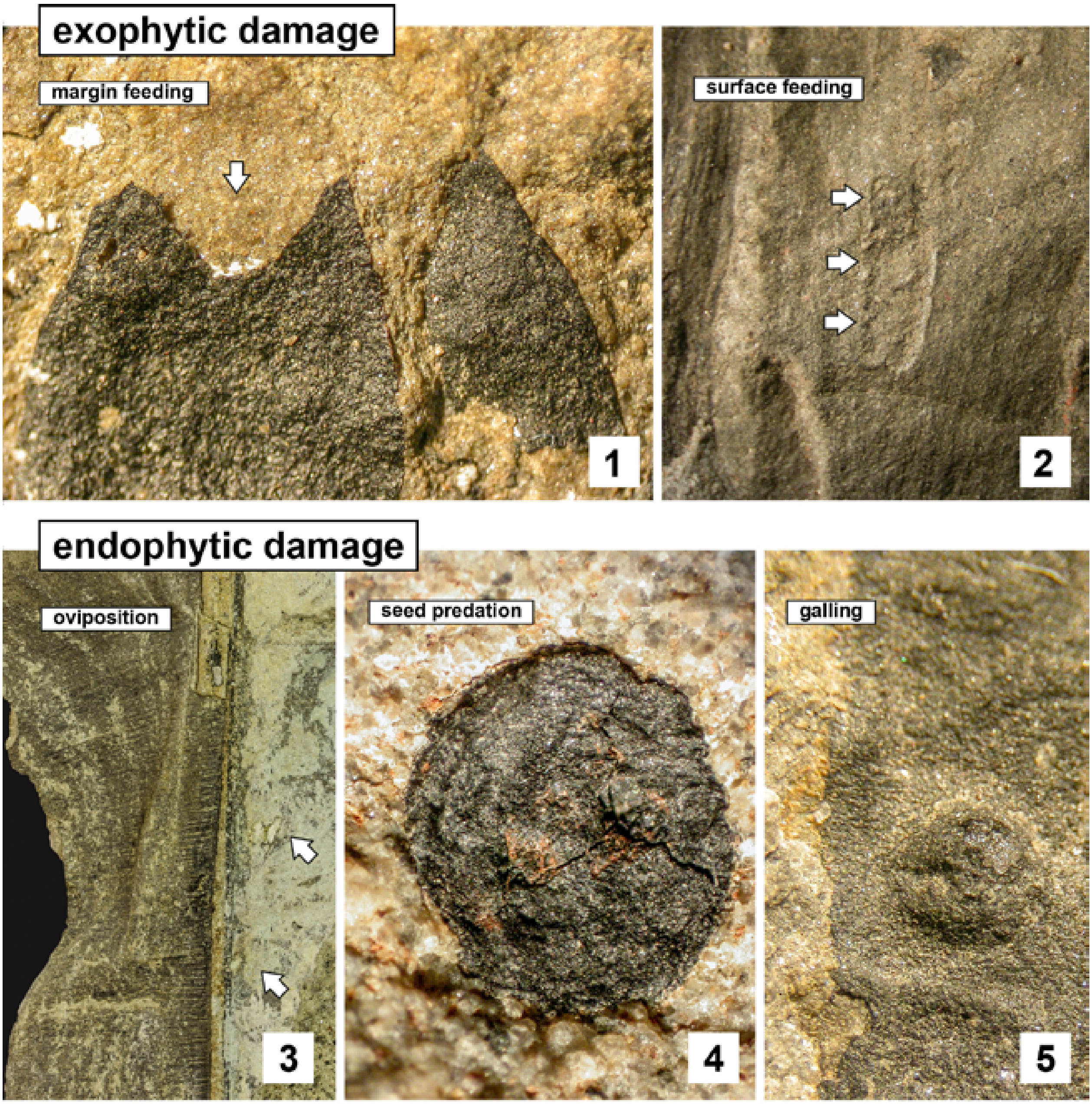

Fig. 18: Insect-mediated damage of leaves from the Bletterbach Gorge (Western Dolomites). 1. Excision of leaf apex (DT13) on *Ortiseia leonardii* (PAL 2020). 2. Window feeding with a distinct callus on an undetermined gingkophyte (PAL 1455). 3. Insect interactions on a cycadophyte with oviposition on the midvein (DT76; white arrows). 4. Seed predation (DT74) on PAL 1088. 5. Woody spheroidal leaf gall on *Quadrocladus* sp. (PAL 1464).

of insect damage patterns (Fig. 18), but nevertheless comparable, albeit with a high interlocality variability, to those from the early (Beck & Labandeira, 1998; Labandeira & Allen, 2007; Schachat et al., 2014; Marchetti et al., in review) and late Permian localities of Euramerica and Gondwana (Prevec et al., 2009; Adami-Rodrigues et al., 2004a, 2004b; de Souza Pinheiro et al., 2012; Gallego et al., 2014). The rather low values of herbivory at Bletterbach probably are attributable to taphonomic factors. Nevertheless, the observed plant-insect associations indicate the following three patterns: (1) herbivory levels are much lower in Laurasia throughout the entire section, (2) oviposition is the dominant Late Permian association in South Africa, but virtually absent in Italy; (3) there is an increase in plant-insect interactional diversity during the Middle to Late Triassic in both regions. Future studies will considerably refine these patterns.

The microflora

The first palynological study of the Gröden/Val Gardena Sandstones and Bellerophon Formation of the Bletterbach gorge was carried out by Klaus (1963), followed, among others, such as Clement-Westerhof (1974), Massari et al. (1986, 1988, 1994, 1999), Visscher & Brugman (1988), Conti et al. (1995) and Cirilli et al. (1998).

The palynological studies of the Bletterbach section were carried out from 25 fossiliferous levels and are characterized by a high diversity of coniferous pollen (at least 97 taxa) that also represent the most abundant elements of the sporomorph assemblages (90–100%). Throughout the section the palynological assemblages are very similar (Pittau et al., 2005). The most abundant groups are the alete disaccate pollen (*Klausipollenites schaubergeri*, *Paravesicaspora splendens* and *Alisporites nuthallensis, Vesicaspora* spp., *Falcisporites zapfei, Platysaccus papilionis*) and monolete disaccate pollen (*Gardenasporites* spp. *Limitisporites* spp., *Jugasporites* spp.), while taeniate disaccate pollen (*Lueckisporites* spp., *Lunatisporites* spp.) and multitaeniate disaccate pollen are less frequent. Spores represent a low proportion in the palynological samples (0-5%) but are still moderately diverse (27 different species). They reach their highest frequency in two different stratigraphic levels of the succession (5-10%), whereas in the remaining part of the successions they are virtually absent.

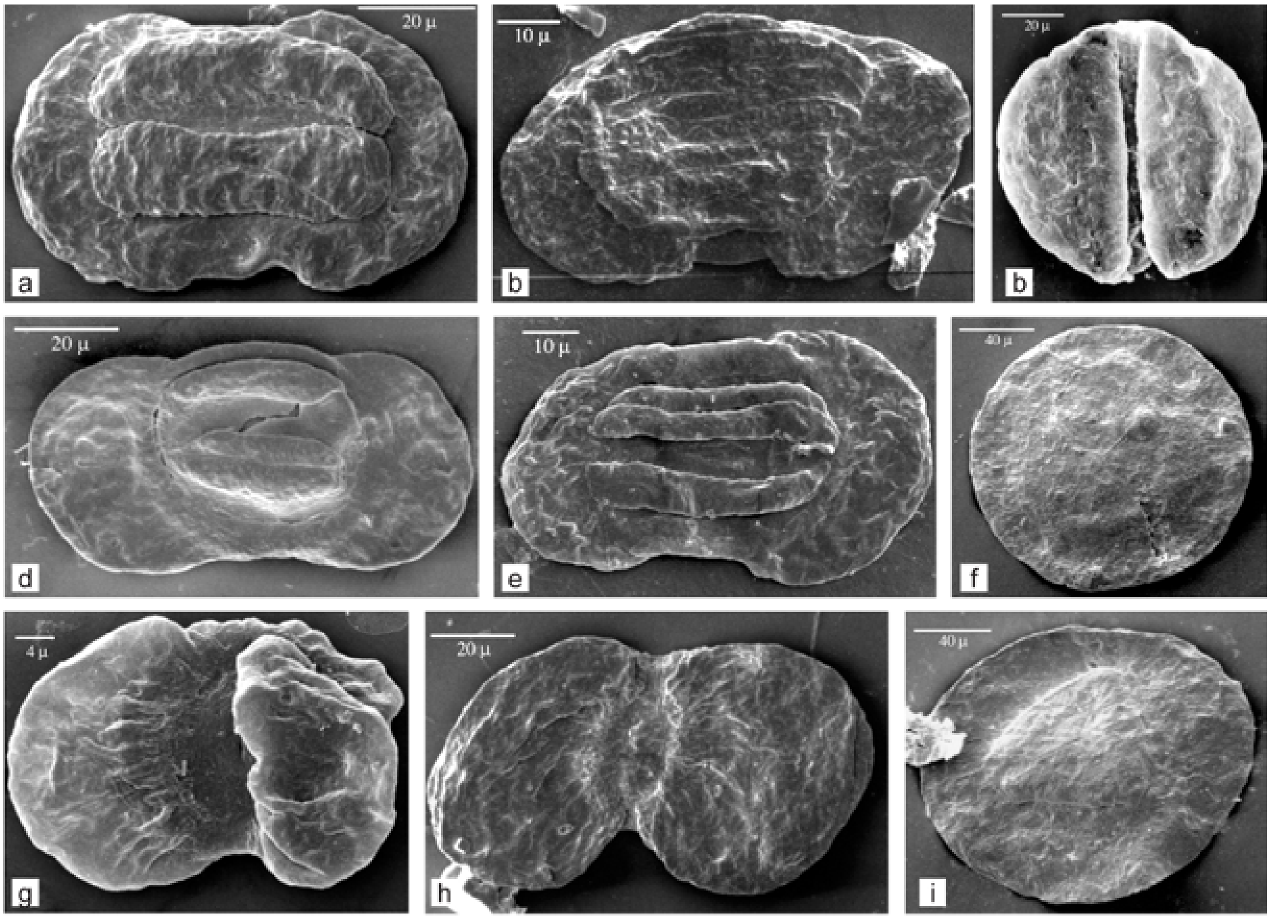

Fig. 19: Palynomorphs from the Gröden/Val Gardena Sandstone and Bellerophon Formation (foto curtesy P. Pittau):

a *Lueckisporites globosus* Klaus
b *Striatopodocarpites pantii* (Jansonius) Balme
c *Sulcatisporites* sp.
d *Circumstriatites* sp.
e *Lunatisporites pellucidus* (Goubin)
f *Nuskoisporites dulhuntyi* Potonié et Klaus
g *Tumoripollenites* sp.
h *Platysaccus papilionis* Potonié et Klaus
i *Playfordiaspora hexareticulatus* Klaus

Based on the relative frequency and distribution the taxa may be distinguished into different groups:

- Ubiquitous taxa: They represent the bulk of the palynological assemblages with typical taxa of the European late Permian like *Lueckisporites virkkiae, Nuskoisporites dulhuntyi, Lunatisporites* spp., *Jugasporites delasaucei* and *Klausipollenites schaubergeri*, species of *Alisporites*, *Falcisporites, Vesicaspora* and *Paravesicaspora*.
- Taxa randomly distributed through the section representing taxa which are abundant only in certain horizons such as *Strotersporites* spp., *Striatopodocarpites* spp., *Striatoabieites* spp., *Jugasporites* (*J. latus, J. perspicuus, J. tectus*), *Gardenasporites leonardii*, *G. moroderi, G. oberrauchi, Scheuringipollenites* spp., *Perisaccus granulatus, Inaperturopollenites dolomiticus* and *Gigantosporites* spp.
- Minor components with erratic distribution: This group includes lycophyte (*Densoisporites holospongia, D. playfordii, Lundbladispora iphilegna, Kraeuselisporites*) and fern spores (*Osmundacidites, Cyclogranisporites, Punctatisporites*), as well as monolete and trilete monosaccate pollen/pre-pollen grains (*Mosulipollenites circularis, Potonieisporites bilateralis, Sahnites turingiacus, Cannanoropollis*). These components have been successfully used to define ecostratigraphic intrabasin correlative events (M1-Sp1; M2-Sp2; Pittau in Massari et al., 1994) corresponding to the two marine bands yielding cephalopods (Fig. 26 in Massari et al., 1994).

In the Bletterbach section *Nuskoisporites dulhuntyi* shows an increasing frequency from the base up to the first marine bank (max. 25%), followed by an abrupt decrease after which this species remains very rare up to the top of the succession. Peculiar is that this record is not correlatable with other sections of the Southern Alps and seems to be strictly related to local factors.

In the Bletterbach section marine palynomorphs, like michrystrids and marine algae are restricted to the uppermost levels of the Bellerophon Formation, but they never reach significant numbers. Fresh-water Zignemataceae spores (*Planctonites* sp.), and *Tetraporina* sp. have been very rarely found suggesting the ephemerous character of the fresh-water environments. Additional cells and spores of organisms of still uncertain origin (*Chordecysta chalasta* or *Tympanicysta stoschiana* vs. *Reduviasporonites* spp.) are widespread and locally very abundant. Either these fungi or algae, but they are almost certainly of terrestrial origin (Pittau in Massari et al., 1999).

The fauna

The first report of a fossil fauna in the Bletterbach gorge area dates back to the 19th century when Ernst Kittl collected a single tetrapod footprint downstream the gorge, nearby the village of Egna (Kittl, 1881; see also Abel, 1929). The first deliberate palaeontological explorations were organized in the 1940s by Piero Leonardi who surveyed the canyon looking for plants and footprints (Leonardi 1951, 1952, 1953a, 1953b, 1955, 1957, 1960, 1968). Excavations continued in the following years and numerous tetrapod tracks were collected from distinct fossiliferous horizons (e.g., Conti et al., 1975, 1977, 1980; Ceoloni et al., 1988; Leonardi & Nicosia 1973; Leonardi et al., 1975; Wopfner, 1999). From then on the Bletterbach became globally known for its Lopingian tetrapod association (just to cite a few international fieldtrips were run in this locality see Conti et al., 1986, Pittau et al., 2005; Gianolla et al., 2010). Thirteen footprint-bearing horizons were recognised within 180 m thick succession corresponding to the Lo 1-3 sequences of Posenato (2010). Most of these findings come from the lower and middle part of the Gröden/Val Gardena Sandstone (first 120 meters), but some footprint-rich beds have been found within the continental deposits interfingering with the marine sediments of the overlying Bellerophon Formation, at the top of the 3rd depositional sequence recognized in the upper Permian succession. One of the most productive horizons lays some hundreds metres upstream of the waterfall. Tetrapod vertebrates are documented from the Gröden/Val Gardena Sandstone only by footprints; to date, no skeletal remains have been found. The ichno-assemblage is abundant and shows high diversity allowing a detailed reconstruction of the tetrapod vertebrate fauna. The abundance of fossil footprints has probably been favoured by their high preservation potential, due to the sedimentological context and high sedimentation rate (Avanzini & Tomasoni, 2004).

The ichnoassemblage is composed of at least thirteen ichnotaxa belonging to various groups such as pareiasaurs (*Pachypes*), therapsids (indet.), captorhinids (*Hyloidichnus*), neodiapsids, younginiformes (*Rhynchosauroides*, *Ganasauripus*), and archosauriformes (chirotheriids; see Conti et al., 2000; Avanzini et al., 2011; Bernardi et al., 2014).

The Bletterbach ecosystem was characterized by large-sized primary consumers (pareiasaurs, diadectomorpha) that possibly fed on high-fibrous plants, such as ginkgophytes and conifers that constitute the largest part of the floral association. Small herbivores (captorhinids, small therapsids) were probably effective in shredding and crushing plant material. Large sized carnivorous predators (archosauriformes, gorgonopsids) seem to be less abundant, even though a preservational bias cannot be excluded. Small secondary consumers (undetermined neodiapsids) were probably carnivorous-insectivores and would have fed on the entomofauna documented by foliage insect feeding traces described above (Fig. 21; Bernardi et al., 2014; Kustatscher et al., in prep.).

Among the various features of the vertebrate association we here highlight two key components, which give particular relevance to this locality worldwide. The site contains (1) the (abundant) presence of pareiasaur footprints, and (2) the occurrence of the oldest archosaur footprints worldwide. One of the most common fossil footprints in the Bletterbach association is *Pachypes dolomiticus* Leonardi et al., 1975, a track attributed to pareiasaurs (Leonardi et al., 1975; Valentini et al., 2008, 2009). Pareiasaurs were heavy built herbivores with armoured skin and massive skulls, which include some of the largest Permian reptiles (Lee, 1997a, 1997b). Pareiasaurs skeletal remains are mainly known from Russia, China and South Africa, although specimens have been

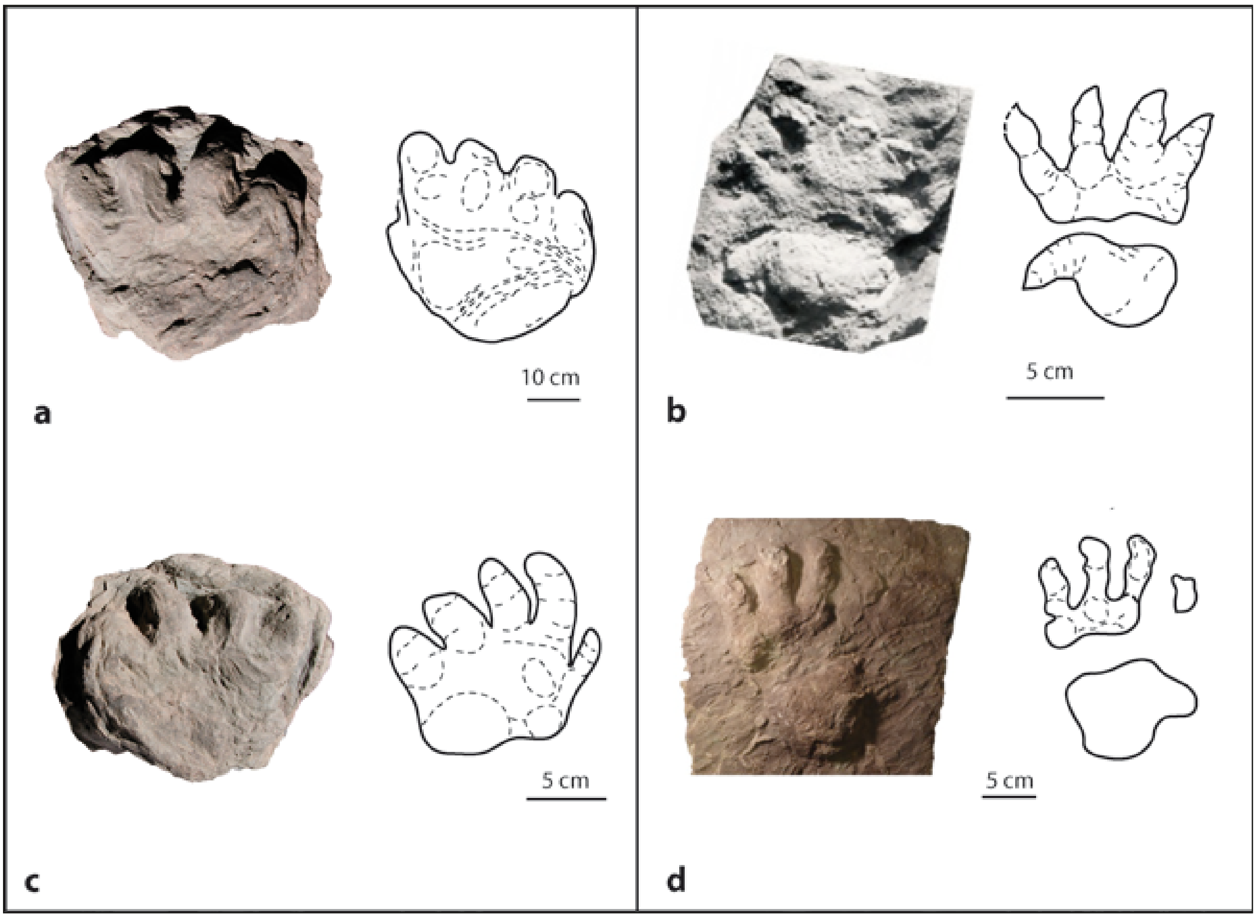

Fig. 20: Two key features of the Bletterbach ichnofauna. a, c: The well preserved pareiasaur tracks *Pachypes dolomiticus* Leonardi et al., 1975, abundant in the Gröden/Val Gardena Sandstone succession. b, d: Two chirotheriid footprints attributed to archosaurian trackmakers, from Leonardi et al. (1975); Conti et al. (1977); Valentini et al. (2009); Bernardi et al. (2014, submitted).

found also in northern Africa (Morocco), Southern America (Brazil) and Europe (Germany, Scotland). *Pachypes* is the only known footprint convincingly referred to pareiasaurs (Valentini et al. 2009). Here *Pachypes* occurs from about 2 m above the "Cephalopod bed" up to the levels which interfinger with the Bellerophon Formation (Valentini et al., 2009). About 40 specimens (tracks and trackways) are known to date, all preserved as natural casts (Fig. 20a, c). *Pachypes dolomiticus* is a pentadactyl, semiplantigrade track (both pes and manus). Manus is smaller than the pes and shows sturdy, short and rounded digits as in the pes. The other exceptional features of the Gröden/Val Gardena Sandstone outcropping in this area are chirotheriid footprints (see Bernardi et al., 2014), which documents new findings and re-discusses previous ones (Conti et al., 1977; Wopfner, 1999). These tracks, assigned to "chirotheriid indet." or to cf. *Protochirotherium*, can be confidently attribu-ted to archosaurian trackmakers (Bernardi et al., submitted; Fig. 20b). Archosaur tracks show synapomorphic compact anterior digit group I-IV and postero-laterally positioned, strongly reduced digit V. Archosaurs radiated from the Early Triassic, but the occurrence of chirotheriid tracks in the Lopingian of the Dolomites indicates that derived archosauriforms were already present before the Permian-Trassic boundary. Together with the occurrence of the recently discovered fragmentary archosauriform *Eorasaurus* from the late Permian of Russia (Ezcurra et al., 2014), these tracks provided evidence for a broader evolutionary radiation of archosauriforms in the late Permian than expected (Bernardi et al., 2014; Bernardi et al. submitted), further highlighting the scientific relevance of the Bletterbach palaeontological site worldwide.

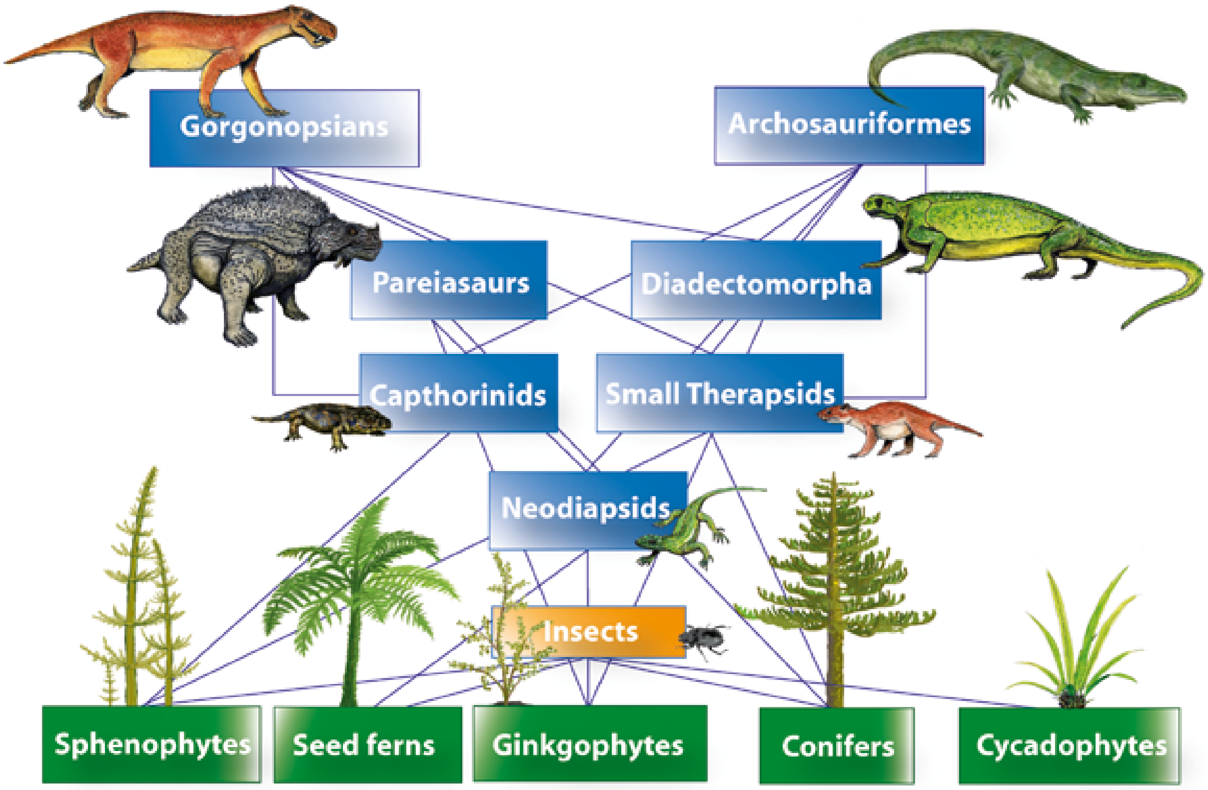

Fig. 21: The Bletterbach trophic network as derived from vertebrate ichnoassociations, foliage damage, and fossil plant remains. Original drawings from Avanzini & Kustatscher (2011).

4. The late Permian to Middle Triassic Seceda section

The Seceda section is located northeast of Bozen/Bolzano at the western margin of the Dolomites. The Seceda section is exceptional in its beauty of the landscape starting with the red sandstones of the late Permian Gröden/Val Gardena Sandstone and ranging up to the grey shales of the basinal Buchenstein/Livinalongo Formation of Middle Triassic age. In 1998 the top of the Seceda section was cored and studied a geological, sedimentological, magnetostratigraphical and palaeontological point of view (e.g. Cros & Houel, 1983; Brack & Rieber, 1993; Mundil et al., 1996; Brack et al., 2000, 2005; Maurer 2003; Maurer & Rettori, 2002; Maurer & Schlager, 2003; Maurer et al., 2003, 2004; Hochuli et al., 2014). The section has been designated as the principal auxiliary GSSP section of the Ladinian stage (Brack et al., 2005).

The geology

The Seceda is famous for its extremely well represented Buchenstein/Livinallongo Formation with an outcrop of about one hundred metres of thickness. This formation was deposited during late Anisian to Ladinian times in the deep basins including some isolated platforms of the Dolomites, such as the Rosengarten/Catinaccio, the Geisler/Odle, the Marmolada and the Latemar. This unit is overlying the early Middle Triassic Contrin Formation with a marked drowning unconformity. The black shales of the Plattenkalke ("platy limestones") represent a very rapid deepening of the basins reflected by strong sediment condensation. This deepening corresponds to the aggradational phase of the carbonate platforms, where more than 800 m of shallow water carbonates

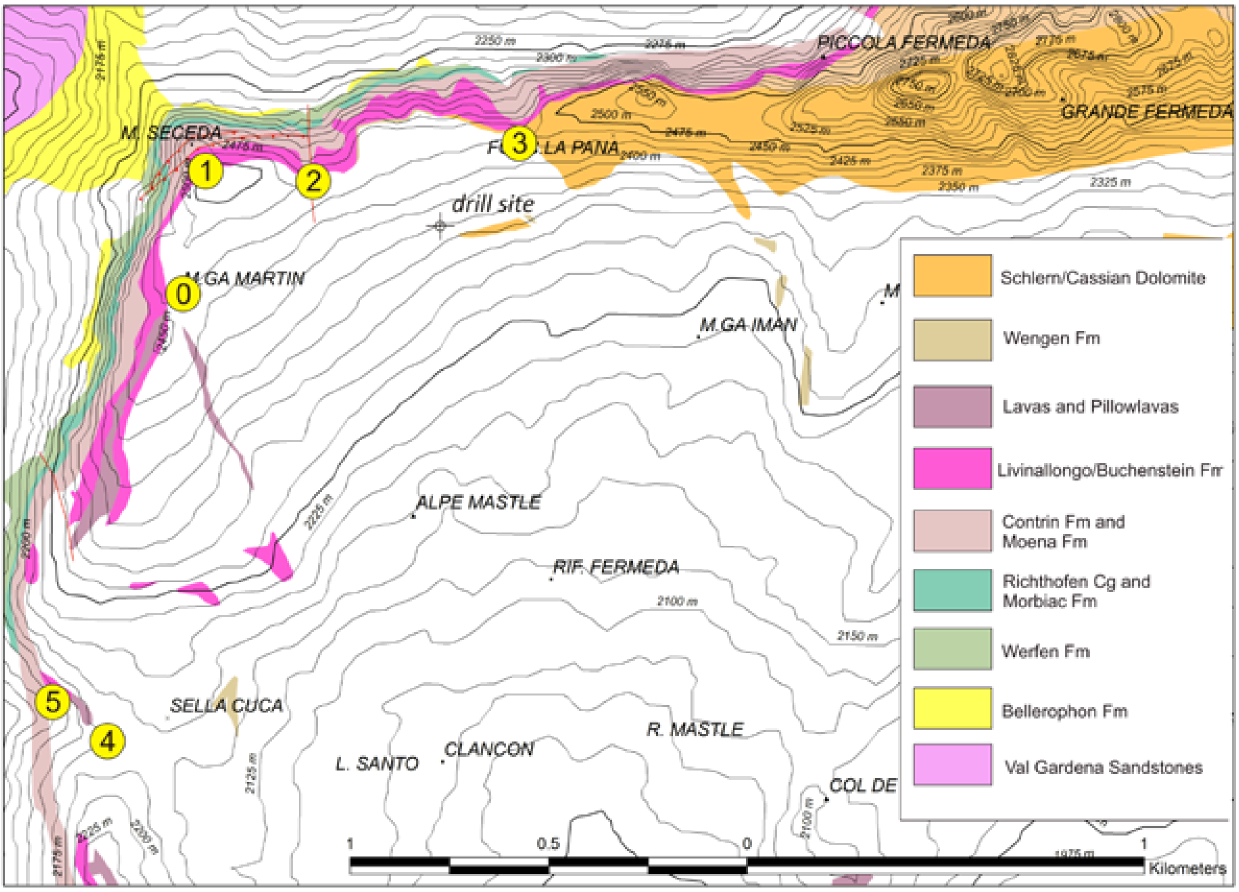

Fig. 22: Geological Map of the Seceda with the indication of the main stops (from Brack et al. 2000, mod.).

were deposited in less than 2 million years. The succession also includes several green ash-tuff-horizons called "Pietra Verde". The sudden change towards nodular limestones (Knollenkalke) marks the halt of the subsidence, allowing the carbonate platform to start to prograde quickly towards the deep basins. It also records a marked paleooceanographic change with a deepening of the ACD and with a cooling of seabottom waters (Preto et al., 2005). This succession contains the maximum number of Pietra Verde horizons, both primary and reworked by currents. The uppermost member of this unit (Bänderkalk) is composed again of platy limestones rich in calciturbidites and Pietra Verde. As demonstrated by several papers (e.g. Brack & Muttoni, 2000, Muttoni et al., 2004) these ash layers represent excellent physical key horizons for the correlation of basinal successions in this sector of the Tethys, ranging Italy to Austria and Hungary. Ammonoids, planktic pelecypods (*Daonella*) and some small plant fragments are known from this section, as well as the skeleton of an ichthyosaur found in 1969 (Kuhn-Schnyder, 1979).

The Buchenstein/Livinallongo Formation derives from the interplay of three sediment sources (Maurer 2003): (a) planktic material, mostly radiolaria, pelecypod and organic matter; (b) carbonate material (mud and bioclasts) shed from the surrounding carbonate platforms; (c) volcanic material in the form of ash falls, including one important lapilli layer; the amount of volcanic material is variable and tends to increase upward.

The borehole drilled in 1998 in a joint academic project provided continuous coring and electrical logging and improved characterization of the Buchenstein/Livinallongo succession at Seceda (Brack et al., 2000).

The sedimentological study on the core was performed by Florian Maurer for his PhD thesis (Maurer, 2003, Maurer & Rettori, 2002, Maurer & Schlager, 2003, Maurer et al., 2003, 2004), while other specialists covered other specific aspects.

The borehole penetrated around 88 m of stratigraphic thickness. From top to bottom, the following units were distinguished (Brack et al., 2000): Interval A, representing a transitional unit at the base of the Wengen Beds; interval B, characterized by abundant coarse- grained, platform-derived carbonate breccias; the intervals C-E represent the typical members of the Buchenstein Formation, i.e. the "Bänderkalke", the "Knollenkalke" and the "Lower Plattenkalke", respectively. Interval F corresponds to the topmost part of the Contrin Formation.

The excursion starts at the mountaintop using the cable car's, from where several stops are planned, first at the top of the mountain and afterwards along a forest road down to the cable car's intermediate station. From the cable car, the entire succession from the late Permian up to the early Middle Triassic can be observed. The formation include the fluvial red beds of the Gröden/Val Gardena Sandstone deposited on the top of the Permian volcanics, the late Permian sabkha evaporites and dolomites of the Bellerophon Formation, the Early Triassic Werfen Formation with the lower five members, the Anisian Richthofen Conglomerate marking a sharp erosional unconformity, the Anisian Morbiac Dark Limestones and the shallow water Contrin Formation capped by the Buchenstein/Livinallongo Formation.

Stop 1 – Overview of the main outcrop of the Mount Seceda

The view from Seceda summit offers an outstanding panoramic view on the northwestern Dolomites, evidencing the size of the Buchenstein basins, spanning from the Geisler/Odle to the Rosengarten/Catinaccio carbonate platforms, and of the distribution of the post-volcanic carbonate platforms (Sella, Gardenaccia, Langkofel/Sassolungo). Just below the ridge it is possible to see the entire reference section of the Buchenstein/Livinallongo Formation outcropping towards the east and to appreciate the relationships with the nearby Geisler/Odle carbonate platform (Fig. 23).

The different members of the Buchenstein Formation are quite evident, ranging from the Plattenkalke, to the Knollenkalke and the Bänderkalke, with some evident horizons of green ash tuffs ("Pietra Verde" auct.).

Fig. 23: View from the top of the Seceda toward the Geisler/Odle carbonate platform.

Stop 2 – The upper part of the Seceda succession and the onset of volcanism

At this stop the upper part of the Seceda succession is visible, represented by the fine volcanocaniclastics of the Fernazza Formation intercalated with a peculiar breccia event where carbonate clasts are imbedded in a volcaniclastic matrix. This interval registers the onset of the Ladinian volcanism in the area and is mostly expressed by fine-grained volcanoclastic, by pillowlavas (Stop 4) and by a subvolcanic body outcropping in the western part of the mountain.

Stop 3 – Pana Scharte, the interfingering with the toe of the slope deposits

Moving closer to the Geisler/Odle carbonate platform, the downlap surface can be observed, where the carbonate platform toe-of-slope deposit are interfingering with the Buchenstein/Livinallongo Formation. In this case, the toe of-slope deposits represented the final stage of the Anisian-Ladinian carbonate platforms, just before the onset of the Ladinian volcanism (Fig. 24, Maurer, 2000). In this case, the progradation of the platform was roughly 3 km large, following a strong aggradation.

Stop 4 – Pillow lavas at Kuka Sattel

Near the Kuka Sattel, the roadcut is enhancing some nice outcrops, including pillowlavas of Ladinian age. They document the effusive activity in the area, on a seafloor of an estimated depth of about 900-1000 m However, in this area the submarine volcanic activity was quite weak compared to the rest of the western Dolomites. The sedimentary cover of the basalts includes a fine-grained siliciclastic succession (Fernazza Formation), with well-preserved plant remains and *Daonella lommeli* (planktic pelecypod; Schatz, 2004).

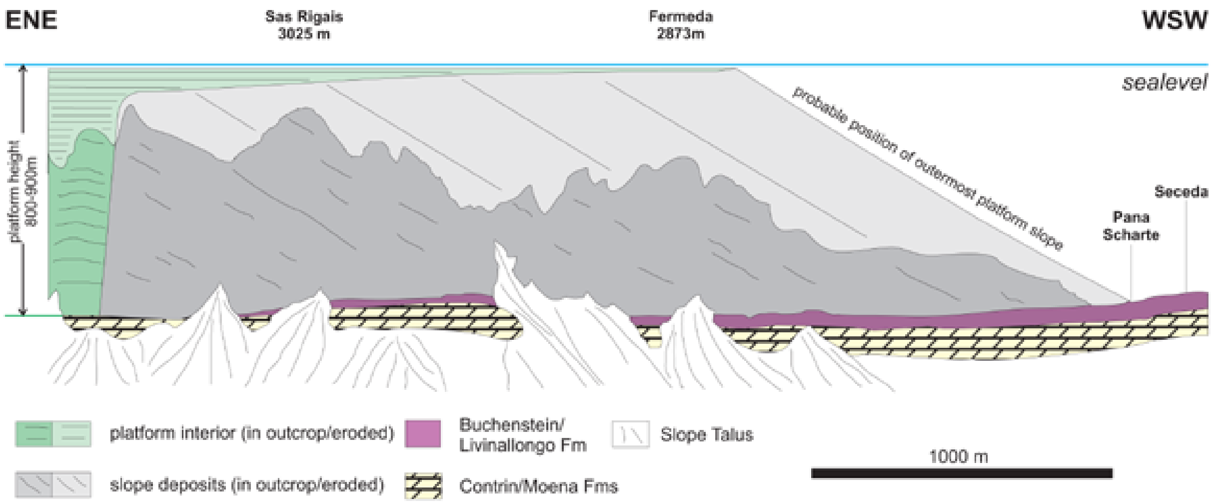

Fig. 24: The position of the Seceda outcrop in the respect of the Geisler/Odle carbonate platform (from Maurer, 2000, mod.).

Fig. 25: The Knollenkalke member of the Buchenstein/Livinallongo Formation just below the Kuka Sattel.

Stop 5 – The Buchenstein/Livinallongo Formation near Kuka Sattel

Few meters below the pillow lavas, we can observe a good outcrop of the Buchenstein/Livinallongo Formation, with the Knollenkalke and the Bänderkalk at the top. The lower part, represented by the Plattenkalke is not well visible, as often happens for this interval. In the lower part of the succession, ash beds ("Pietra Verde") are visible, enhanced by the higher erodibility of these volcanic materials.

Stop 6 - Overview of the Permian and the Lower Triassic succession

Descending towards the intermediate station of the cable car, the lower part of the succession can be observed with the Lower Triassic Werfen Formation, the uppermost Permian Bellerophon Formation and the red beds of the late Permian Val Gardena/Gröden Sandstone. The Richthofen conglomerate (not outcropping) marks the top of the Werfen Formation, here it is represented only by the first five out of nine members. The missing members, eroded here during the Anisian, are documented in the eastern and northern Dolomites (Broglio Loriga et al., 1983, 1984). The Bellerophon Formation consists mostly by bituminous dolomites and in its lower part subordinately represented by evaporites, close to the contact with the red beds of the Val Gardena/Gröden Sandstone.

The macroflora

From a palaeobotanical point of view the Seceda is also well known, always not under this name. The locality Cuecenes near St. Ulrich/Ortisei represents the bottom of the Seceda section. From this site *Ortiseia leonardii* has been described for the first time by Florin (1964). The fossil was found by a local collector (E. Moroder) who gave it to Prof. Piero Leonardi from the Ferrara University. The latter sent the material to Stockholm where Florin (1964) described it.

The horizons yielding *Ortiseia leonardii* and other well preserved but very fragmentary plant remains come from the late Permian Val Gardena/Gröden Sandstoneage. The fine-grained dark grey siltstones containing the plant remains are slightly tectonized and very brittle making the recovery of bigger plant remains very difficult or almost impossible. The holotype of *Ortiseia leonardii* and some fragments of it are stored at the Museum de Gherdeina; they represent the best known and biggest specimens of this species. *O. leonardii* is characterized by planar shoots with lateral shoots arising suboppositely to alternately from the primary shoot, at an angle of 45-60°. The leathery leaves (15-20 x 7-8 mm) are broad oval with a pointed to slightly obtuse apex and are arranged in a narrow helix around the axis. The leaves are amphistomatic. The epidermal cells are polygonal to isodiametric, the stomata are arranged in rows. Other characteristics are the abundant trichome bases between the stomata rows and the bi- to three-cyclic stomata complexes with 5-7 subsidiary cells.

Ortiseia is the most important conifer of Lopingian age of the Southern Alps, but has lately also been described from the Kupferschiefer of Gera (Germany; Bödige, 2007).

The microflora

The palynological study of the Seceda was carried out on the core allowed proposing a new palynostratigraphic subdivision of the Middle Triassic of the Western Tethyan realm (Hochuli et al., 2014). The six zones (TrS-A–TrS-F) cover the interval between the late Anisian (Illyrian) and the late Ladinian (Longobardian; Fig. 26). The zonation is based on the first and last appearances of individual taxa as well as on the quantitative distribution of major groups of sporomorphs. Within the studied interval the distribution of sporomorphs shows some major changes such as a major reduction of seed ferns (e.g. taeniate bisaccate pollen). Seed fern pollen grains are abundant in the lower part of the section (zone TrS-A) and are subsequently replaced by conifers (e.g. *Triadispora*, *Ovalipollis* and Circumpolles (Fig. 27).

In the studied 48 samples the preservation of the palynomorphs varies from mediocre to poor, showing distinct differences between the marine and the terrestrial forms. Marine palynomorphs,

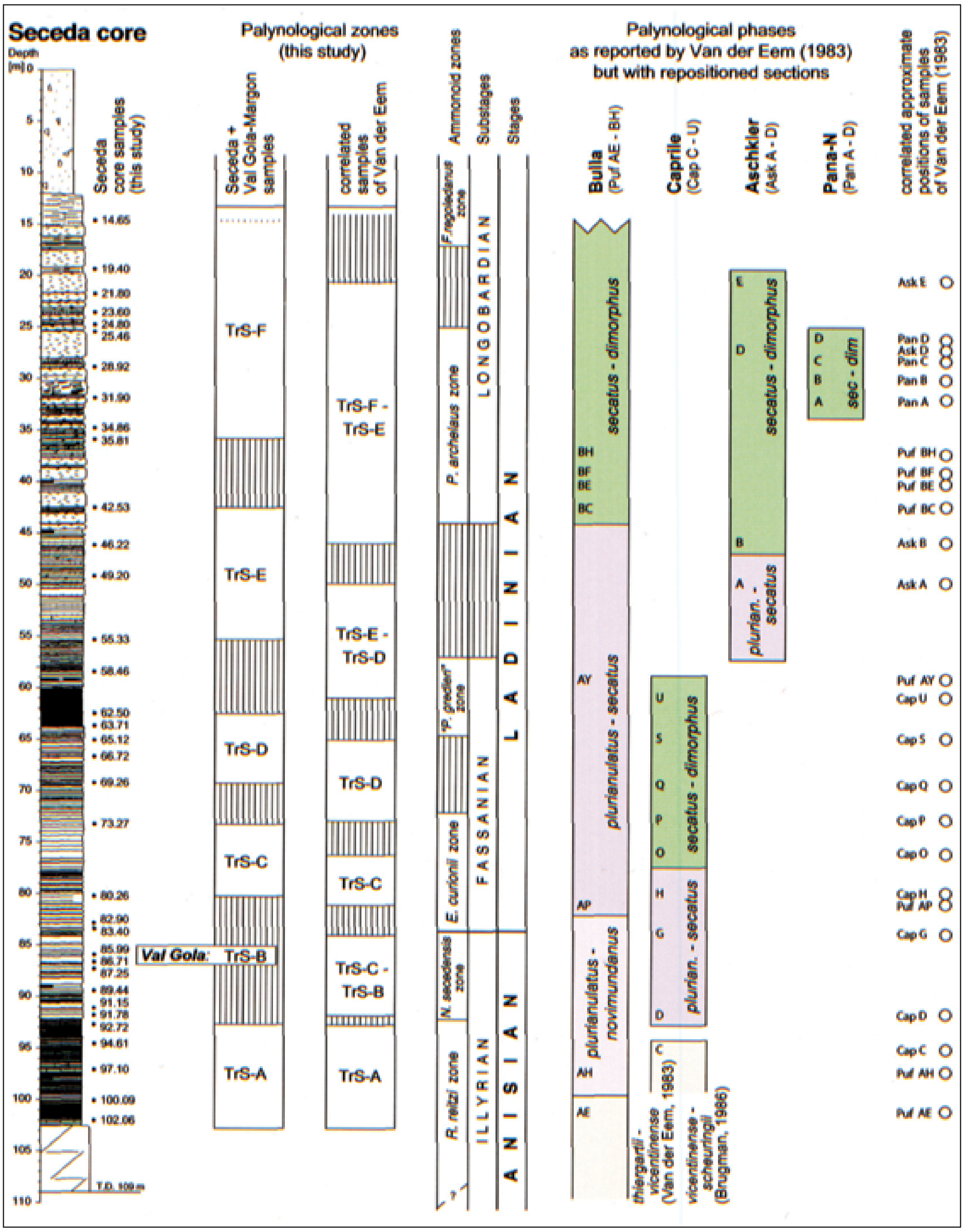

Fig. 26: Stratigraphic distribution of the 6 pollen zones and correlation with other coeval sections of the Dolomites (from Hochuli et al., 2014, mod.).

algae and acritarchs, are generally well preserved, whereas most sporomorphs show traces of severe degradation and are often strongly fragmented. Despite the limitations caused by the preservation the observed assemblages proved to be quite rich (Fig. 28).

Aratrisporites group: The representatives of this group are generally rare, especially in the lower part of the section, while they occur more regularly in the upper part of the studied interval (see Fig. 27).

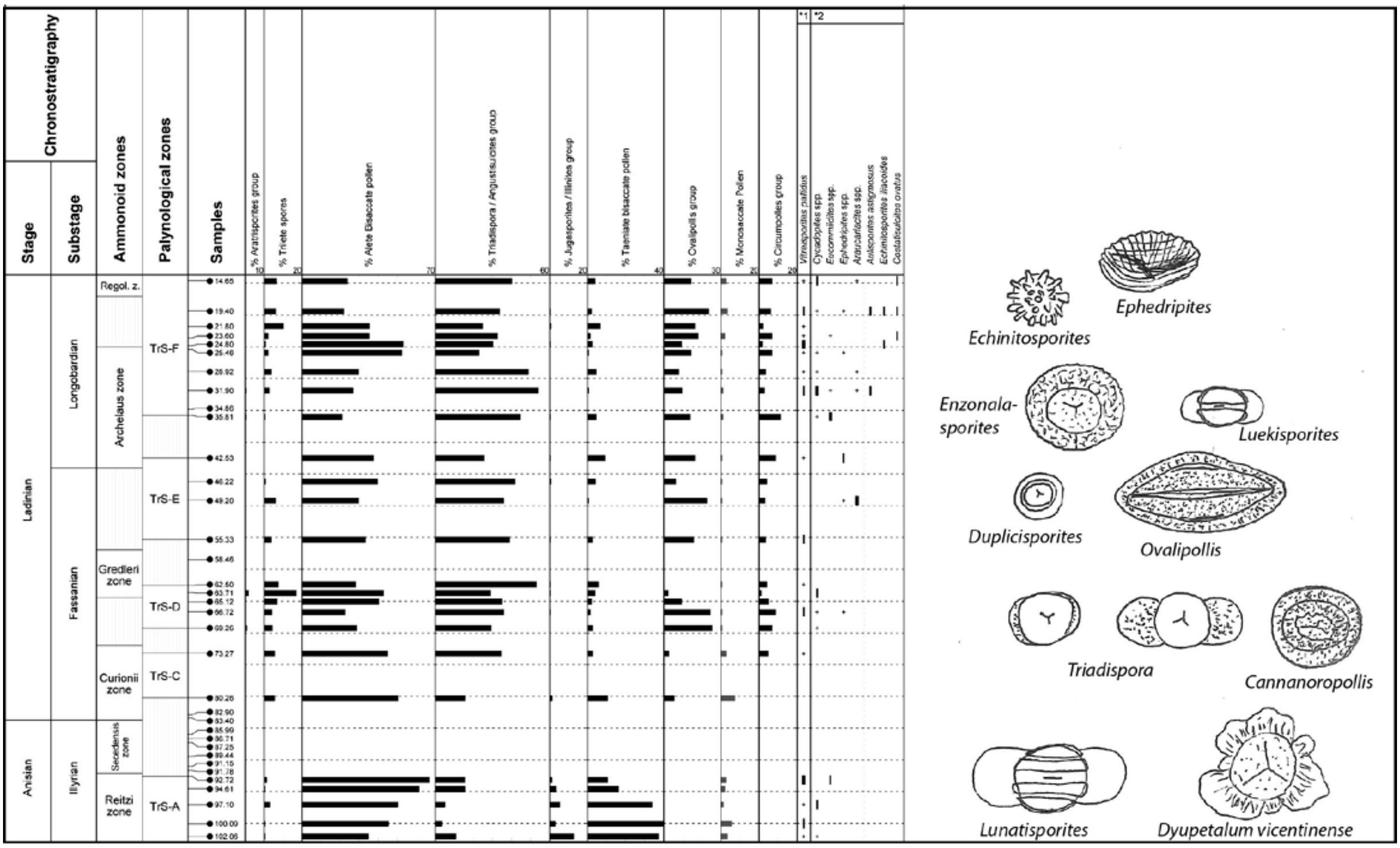

Fig. 27: Quantitative abundance of the most important pollen groups (from Hochuli et al., 2014, mod.).

Trilete spores: The trilete spores represent a heterogeneous entity, including lycopods, ferns, and sphenopsids. Relatively common and consistently represented are the smooth forms such as *Deltoidospora*, *Concavisporites* and *Todisporites* (ferns) as well as *Calamospora* (sphenophytes). Ornamented trilete spore appear as a highly diversified and heterogeneous group; they belong mostly to the ferns and lycophytes (e.g. *Kraeuselisporites*, *Uvaesporites*). Throughout the Seceda section trilete spores are rather uncommon, contrarily to the record of Van der Eem (1983) from the same area. These differences are possibly due to palaeogeographic or taphonomic differences or to preservational bias.

Alete bisaccate pollen: This heterogeneous group includes alete bisaccate pollen of various affinities (conifers and seed fern); in many cases the state of preservation precludes a clear differentiation between the alete bisaccates and possible representatives of the *Triadispora/Angustisulcites* group (see below).

Triadispora/Angustisulcites group: Apart from *Angustisulcites* and *Triadispora* also *Kuglerina* is part of this group, since it probably represents a monosaccate variant of the *Triadispora* group. Representatives of this group are abundant in most Middle Triassic assemblages. In the Seceda core 13 taxa were differentiated within this group including some important stratigraphic markers (e.g., *Angustisulcites* sp. A, *Triadispora verrucata* and *Kuglerina meieri*). This group is very common throughout the Seceda section, becoming more abundant in its upper part. The pollen grains of the *Triadispora/Angustisulcites* group can be attributed to conifers (Balme, 1995) and are regarded as xerophytic elements (Visscher & Van der Zwan, 1981; Van der Eem, 1983; Kürschner & Herngreen, 2010).

Jugasporites/Illinites group: Bisaccate pollen grains with monolete mark are attributed to this group. Representatives of *Jugasporites* are most common in the lowermost part of the Seceda section (zone TrS-A) and well presented in zone TrS-B. Representative of *Illinites* occur throughout the section. The quantitative distribution of this group is considered of biostratigraphic relevance.

Taeniate bisaccate pollen: This group includes several genera (e.g., *Lunatisporites, Striatoabieites, Striatopodocarpites*), all characterised by taeniae (striae) covering their central body. Taeniate bisaccate pollen grains are common and diverse throughout the studied sections, but are most abundant in the lower part of the Seceda core. This group includes some important markers such as *Strotersporites tozeri* or the representatives of the genus *Infernopollenites*. Generally this group is associated with the seed ferns, and considered to represent xerophytic elements (Visscher & Van der Swan, 1981; Van der Eem, 1983).

Ovalipollis group: Beside the genus *Ovalipollis* also *Staurosaccites* is included within this group since in poorly preserved material it might be difficult to differentiate the individual taxa. This group shows a significant increase within the section, which is considered important for the biostratigraphic interpretation. *O. pseudoalatus* is used as an important marker species (e.g. Van der Eem, 1983; Brugman, 1986; Brugman et al., 1994; Hochuli, 1998; Kürschner & Herngreen, 2010; Stockar et al., 2012).

Table 1: Characteristics of the proposed palynological zones TrS-A–TrS-F. Note, all taxa mentioned as FAD in zone TrS-A are first observations; **recalibrated records from Van der Eem (1983) (From Hochuli et al., 2014).

Interval	**Zone**	**FADs**	**LADs and other specific features**
Seceda: 14.86 – 35.81m	TrS-F	*A. astigmosus* (sporadic), *Costatisulcites ovatus, Doubingerispora filamentosa* (sporadic), *Enzonalasporites vigens, Patinasporites* spp. (sporadic), *Reticulatisporites dolomiticus*	Increase in diversity and abundance of the Circumpolles group
Seceda: 42.53 – 55.33m	TrS-E	*Anapiculatisporites spiniger***, *Annulispora* spp. (sporadic), *Araucaricites* spp., *Convolutispora* sp. B**, *Corbulispora* sp. A and sp. B**, *Infernopollenites rieberi* (sporadic), *Lueckisporites* cf. *singhii*	
Seceda: 62.50 – 69.26m	TrS-D	*Bianulisporites badius* (sporadic) **, *Circumstriatites* spp. **, *Duplicisporites verrucosus*, *Echinitosporites iliacoides* ** *Enzonalasporites* spp., *Heliosaccus dimorphus* **, *Infernopollenites parvus* **, *Podosporites amicus* (sporadic), *Triadispora verrucata*	*Cannanoropollis scheuringii* *Cannanoropollis* spp. *Dyupetalum vicentinense* *J. conmilvinus*
Seceda: 73.27 – 80.26m	TrS-C	*Bocciaspora blackstonensis* **, *Duplicisporites granulatus, Kyrtomisporis ervii* **, *S. rugoverrucata* **	
Val Gola - Margon	TrS-B	*Camerosporites secatus* **, *Foveosporites visscheri*, *Lycopodiacidites kokenii*, *Ovalisporites pseudoalatus* (common) **, *Paracirculina* spp., *Porcellispora longdonensis*, *Sellaspora* spp. and *S. foveorugulata*, *Uvaesporites* sp. A**	*Stellapollenites thiergartii,* *Staropollenites* spp. *St. antonescui* *Jugasporites conmilvinus*
Seceda 92.70 -102.06m	TrS-A	*Cannanoropollis scheuringii, Dyupetalum vicentinense, Kuglerina meieri, Staropollenites antonescui, Stellapollenites thiergartii, Concentricisporites plurianulatus* **, *Duplicisporites tenebrosus* **, *Ovalipollis pseudoalatus* ** (rare), *Palaeospongisporis europaeus***, *Partitisporites novimundanus***, *Staurosaccites quadrifidus* ** (sporadic)	*Strotersporites tozeri* *Stellapollenites* sp. 1 Taeniate bisaccates (common) *Jugasporites / Illinites* group, (common)

Monosaccate pollen: This group includes various monosaccate and also some pollen grains, which are certainly of heterogeneous botanical origin. Some taxa of this group have restricted ranges and are of biostratigraphic significance (e.g. *Stellapollenites thiergartii, Dyupetalum vicentinense, Cannanoropollis* spp., *Staropollenites* spp.).

Circumpolles group: Rare representatives of this group appear in the lower part of the section. The first appearance of relatively rare specimens and the subsequent onset of continuous or common representation of this group are considered of stratigraphic significance. They are common in zone TrS-C and above. The Circumpolles group is attributed to the conifer Cheirolepidiaceae and represents a distinct xerophytic element (Visscher and Van der Swan, 1981; Van der Eem, 1983).

Vitreisporites: *Vitreisporites* represents a bisaccate grain of seed fern affinity (Balme, 1995) and has been separated from other bisaccate taxa. In the present material this long-ranging form is rather rare.

Miscellaneous gymnosperm pollen: This group includes pollen grains of various morphologies and of heterogeneous botanical affinities. Quantitatively they are insignificant but some of them are important stratigraphic markers (e.g. *Echinitosporites iliacoides, Aulisporites astigmosus* and possibly *Araucariacites*); others are long ranging (e.g., *Ephedripites* and *Cycadopites*).

5. The Geology of Falzarego Pass and palaeobotany and palynology of the Heiligkreuz Formation

The sections of Falzarego Pass and Rifugio Dibona are located west of Cortina d'Ampezzo, on the orographic right side of the Boite Valley. The successions cropping out in this area are Late Triassic in age: the Cassian platforms and the coeval basinal successions (St. Cassian Formation), the shallow-marine Heiligkreuz (ex Dürrenstein) Formation, the argillaceous Travenanzes (ex Raibl) Formation and the thick peritidal Hauptdolomit/Dolomia Principale platform. The seismic-scale outcrops around Falzarego Pass (2105 m) allow for a detailed reconstruction of the facies stacking pattern and the spatial relations between platform top, slopes and basins of the late Triassic platforms. After the demise of the rimmed platforms, giving way to terrigenous carbonate ramps, the sediments record the flattening-out of the palaeogeography (Heiligkreuz Formation) and the onset of the widespread peritidal facies of the Hauptdolomit/Dolomia Principale.

Geology

The area of the Falzarego Pass records a complex framework of rimmed carbonate platforms and basins. The lowermost Lower Triassic platform is the Cassian Dolomite. This formation consists of light-coloured crystalline dolomites, showing indistinct or massive bedding. Here, the platform-top succession is thicker than in the Sella Group, and is characterized by tens of metres of well-bedded, finely crystalline dolostones, with birdseye structures, stromatolites and pisoids, indicating a deposition in very shallow-water tropical environments, including tidal flats. The slope deposits are characterized by thick-bedded, clinostratified slope breccias, interfingering with basinal sediments. The slope angle changed through time from 35-30° to 15-10°, as the basin shallowed upwards.

The coeval basinal St. Cassian/San Cassiano Formation predominantly consists of brown to yellowish marls alternating with carbonate turbidites, resedimented bioclastic wackstones and micrites, and siliciclastic sandstones. At the toe of the palaeo-slope, large olistoliths and isolated boulders are commonly present, entombed within much finer grained deposits.

In the excursion area, two different platforms, the Nuvolau and Lagazuoi Platforms, are visible in close proximity (Bosellini et al., 1982), most of the original intervening basinal area has been removed by a major Alpine overthrust. The latest

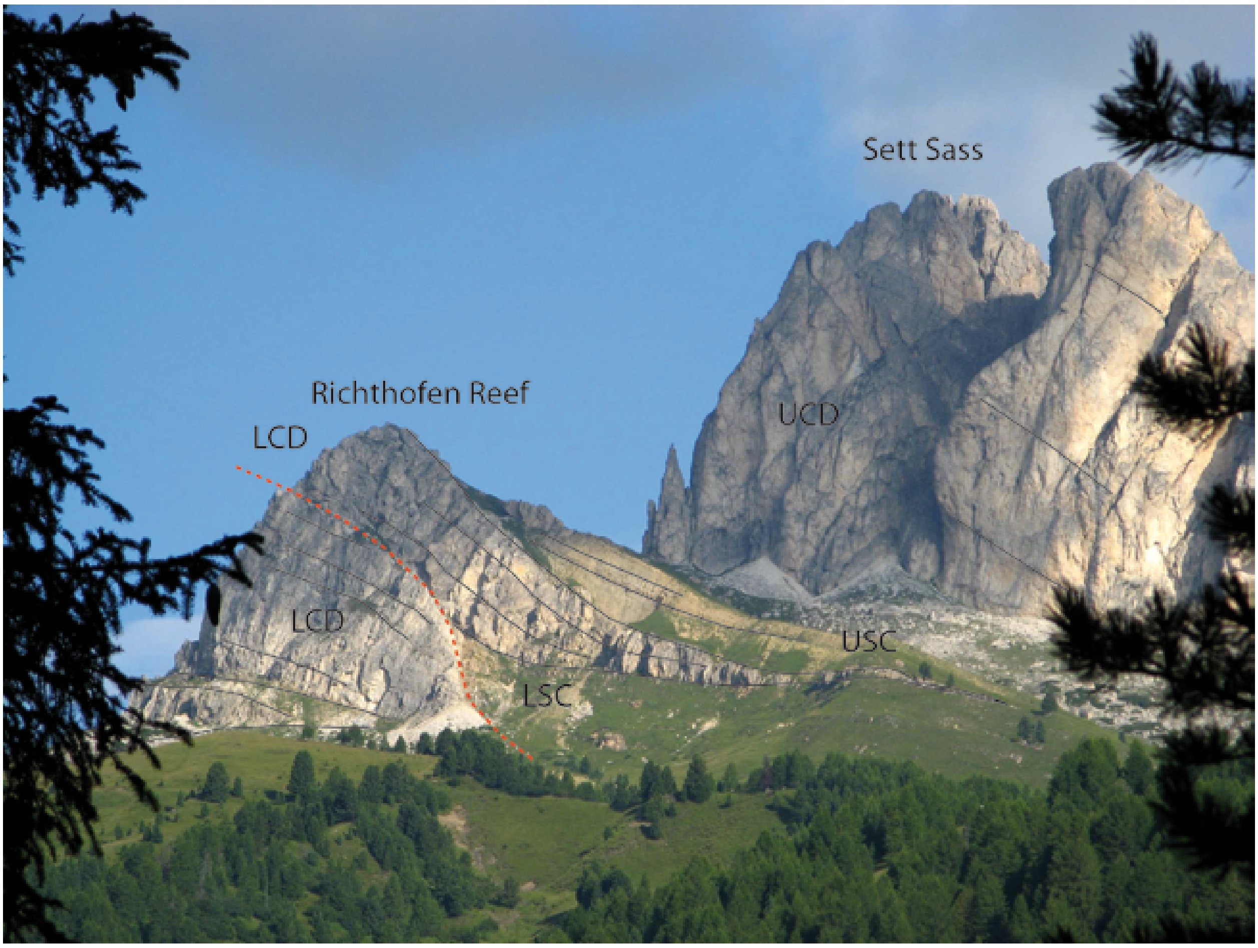

Fig. 29: Richthofen Reef and Set Sass: Lower Cassian Dolomite (LCD) and Lower St. Cassian/San Cassiano Formation (LSC) in the Richthofen Reef and Upper St. Cassian/San Cassiano Formation (USC) and Upper Cassian Dolomite (UCD) testifying two third order Carnian cycles. Lower and Upper Cassian Dolomite represent the highstand phases prograding into the basin of the St. Cassian/San Cassiano. Upper St. Cassian/San Cassiano (USC) onlaps the slope of the Lower Cassian Dolomites.

Ladinian–early Carnian age of these units has been inferred from ammonoids, conodonts and palynomorphs (e.g. Urlichs, 1974, 1994; Mastrandrea et al., 1997; Gianolla et al., 1998a, 1998b; Keim et al., 2001; Neri et al., 2007; Breda et al., 2009; Roghi et al., 2010). These rimmed platforms record two superimposed aggradation/progradation phases, separated by an interval of negligible carbonate export with basinal shale onlapping onto the slopes, probably recording a third-order depositional cyclicity (Fig. 29; Fois & Gaetani, 1982; De Zanche et al., 1993, Neri & Stefani, 1998; Gianolla et al., 1998a).

The Heiligkreuz (ex Dürrenstein) Formation records the flattening-out of the complex early Carnian topography and a period of anomalously abundant coarse siliciclastic supply (Pisa et al., 1980; De Zanche et al., 1993; Neri & Stefani, 1998; Bosellini et al., 2003; Preto & Hinnov, 2003; Neri et al., 2007; Breda et al., 2009; Stefani et al., 2010; Gattolin et al., 2013). The 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 with strong terrigenous input. The Heiligkreuz Formation lies on both, the Cassian Dolomite and on the basinal shales and limestones of the St. Cassian/San Cassiano Formation, and is in turn unconformably overlain by the sabkha and paralic facies of the Travenanzes Formation (Neri et al., 2007). The age of the latter is constrained by ammonoids and palynomorphs to a short stratigraphic interval close to the Julian–Tuvalian boundary (Gianolla et al., 1998a; De Zanche et al., 2000; Breda et al., 2009). The Heiligkreuz Formation is a roughly isochronous unit, representing a complete third-order depositional sequence (Russo et al., 1991; De Zanche et al., 1993; Gianolla et al., 1998a; Preto & Hinnov, 2003), here named Car3, according to the sequence stratigraphic framework of Gianolla et al. (1998a). The formation can be subdivided into several informal members (see description of the Dibona section below). In the northern shelf areas unreached by siliciclastics, the Heiligkreuz Formation is mainly made up of well-stratified shallow-water carbonates (Dürrenstein dolomite, sensu scripto), organized in metre-scale peritidal cycles, with peloidal and stromatolitic dolostones, and rare marly and varicoloured argillaceous layers, particularly abundant in its lower portion. In the Dibona area, monotonous alternations of fine-grained, light-coloured dolostones and red, green and grey marls and shales, with minor, decimetre-thick sandstone intercalations, dominate the Travenanzes Formation. These facies probably accumulated on wide coastal mud flats and in lagoons (Breda & Preto, 2011). Arid to semi-arid climatic conditions are inferred on the basis of the occurrence of calcrete palaeosols and sulphate evaporites, well developed in the Cortina valley, a few kilometres eastward of the visited sections. At the very base of the unit, metre-thick quartzose conglomerates and sandstones may occur (i.e. Falzarego Pass). The coarse siliciclastics increase in thickness and frequency to the south, to dominate all other lithofacies at the southern border of the Dolomites. This terrigenous facies association shows metre-thick cross-bedded sandstone bodies, with evidence of lateral accretion and erosional downcutting into reddish and grey claystones, in turn characterized by mud cracks and scattered tetrapod footprints. This facies association clearly indicates a fluvial depositional setting, gradually merging into a coastal sabkha/lagoonal environment. The levels of thin coarse siliciclastics, documented as far north as the Falzarego Pass, may record the feather-edge of a fluvial system.

The impressive well-stratified cliffs of the Hauptdolomit/Dolomia Principale forming the spectacular landscape of the Dolomites are mainly made up of a vertical stack of shallowing-upward peritidal cycles. This widespread Upper Triassic Formation records a gigantic carbonate tidal flat of a rimmed platform, whose margins were located in the eastern and northeastern Dolomites (Bosellini & Hardie, 1988; De Zanche et al., 2000; Gianolla et al., 2003). The change in thickness (250-2000 m) records laterally extremely variable subsidence rates. In the visited area, this unit forms the high wall of the Tofane Mountains, showing a stratigraphic thickness in the order of one kilometre.

Fig. 29: The well-displayed peritidal sedimentary cycles are capped by subaerial exposure surfaces associated with tepee structures. Marine pisoids are commonly found in tepee cavities and intra-tepee pools. A thinning-upward trend in the thickness of the sedimentary cycles indicates a progressive decrease in accommodation space over time.

Stop 1 – The upper part of the Cassian Dolomite (Lower Carnian) at Passo Falzarego

Along the main road to Passo Falzarego, coming from Cordevole Valley, the particularly well-exposed top of the Cassian Dolomite is visible. This outcrop, called Dürrenstein Dolomite by Bosellini et al. (1982) and Neri & Stefani (1998) corresponds partly to the platform interior of the Cassian Dolomite (Fig. 29).

Fig. 30: Pisoids at the top of the Cassian platform below the Falzarego Pass.

Calcisols characterized by irregular micritic glaebules, pisoids with micritic core (Fig. 30) and thin micritic-sparitic coating, and laminated carbonate crusts occur towards the top of the succession (Baccelle & Grandesso, 1989). The uppermost portion of the Carnian platform-top succession showing peritidal levels is unconformably overlain by reddish argillaceous dolostones evolving into mixed terrigenous carbonate successions (Heilig-kreuz Fm) (Stefani et al., 2010).

Sedimentation started again with the deposition of the Dibona Sandstones member (HKS2 Heiligkreuz Formation), which is, however, poorly exposed. At Passo Falzarego the upper Heiligkreuz Formation is represented by arenites with planar bedding, and cross bedding including herringbone cross-bedding, indicative of a shoreface environment with strong influence of tidal currents (Bosellini et al., 1978, 1982). This siliciclastic body is limited to the Passo Falzarego and its surroundings (Preto & Hinnow, 2003; Neri et al., 2007) and correlates to the massive dolomites of the Lagazuoi member, clearly visible at the Rifugio Lagazuoi on top of the wall north of the pass.

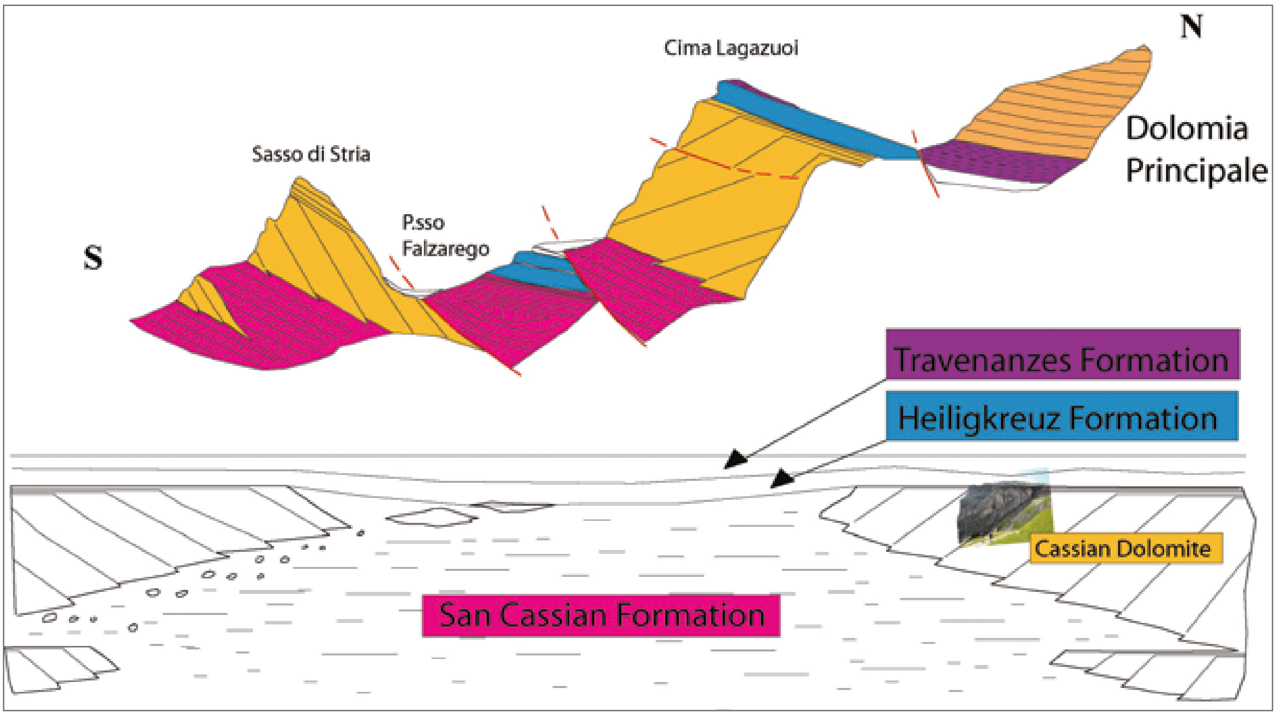

Fig. 31: above: cross section at Passo Falzarego from South to North. Below a paleotopographic reconstruction of platform and basin.

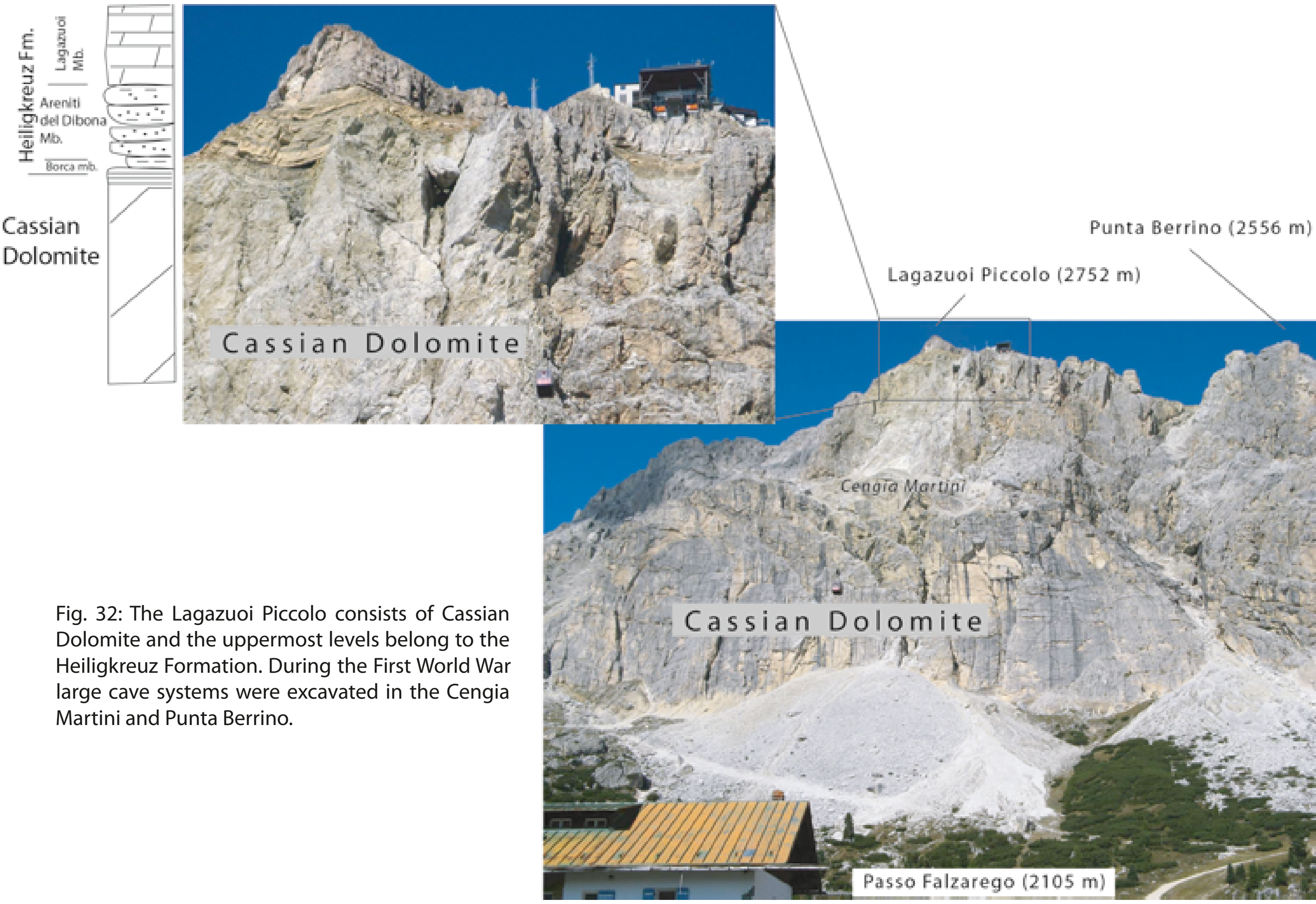

Fig. 32: The Lagazuoi Piccolo consists of Cassian Dolomite and the uppermost levels belong to the Heiligkreuz Formation. During the First World War large cave systems were excavated in the Cengia Martini and Punta Berrino.

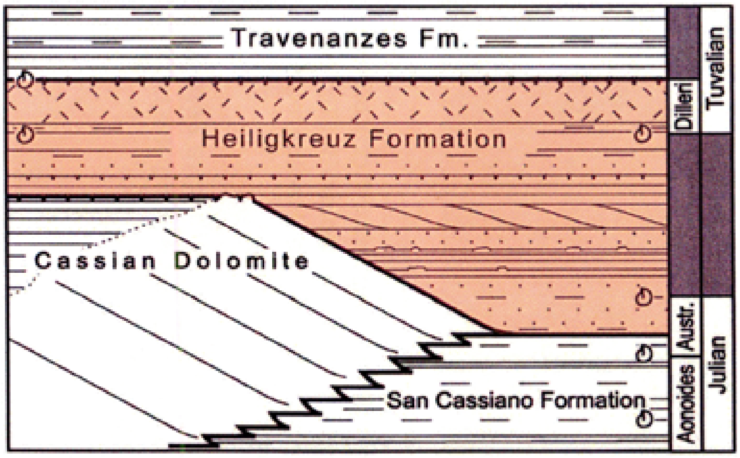

Fig. 33: Simplified stratigraphic setting of the Heiligkreuz Formation (pink shading) in the Cortina area. The infilling of the inherited lower Carnian basin is completed already with the prograding shoal barrier and lagoon at the top of the Borca member (from Preto & Hinnov, 2003, modified).

Passo Falzarego is located between a steep wall to the north (Cima Lagazuoi) and a relatively gently dipping slope to the south (toward Croda Negra-Punta Gallina; Fig. 31), a structurally controlled morphological arrangement. In the area bedding dips uniformly to the north, but the succession is dislocated by a major south-vergent Alpine thrust that uplifted the north block (hanging wall) for about 700 m. Thus, the stratigraphic succession cropping out at the pass (2105 m asl) is repeated - with some significant variations at the Rifugio Lagazuoi (2750 m asl) near the terminal of the cabin lift.

Thus, 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, is now pinched along a thrusting plain bifurcation (Fig. 32-33).

Stop 2 – The Rifugio Dibona section: an overview

The Rifugio Dibona section (Cortina d'Ampezzo, Belluno) presents the most complete stratigraphic record of the region due to its position above the basinal setting where the St. Cassian/San Cassiano Formation was deposited. This implies that sediments deposited immediately after the demise of the lower Carnian Cassian platform that bypassed the platform top and slopes, i.e. the lower and middle Borca member of the Heiligkreuz Formation, are preserved here. The Rifugio Dibona succession is a key section for the Carnian stratigraphy displaying an almost complete section of the Heiligkreuz Formation, the whole Travenanzes Formation (here almost 200 m thick), and the Hauptdolomit/Dolomia Principale (Fig. 34, 35). Thanks to the fairly continuous record of paleosols from the middle Heiligkreuz Formation upwards, the Rifugio Dibona section is ideal for the study of paleoclimatic trends and their relationship with sedimentation. The Heiligkreuz Formation crops out on the south faces of rock towers separated by narrow incisions (Fig. 35). Each incision corresponds to a nearly vertical fault uplifting the western block. The lowest part of the series is thus found to the west (left, facing the mountainside) while the uppermost part is more accessible to the east (i.e. right). Above, the Travenanzes Formation breaks the slope ("via ferrata Cengia Astaldi"), and the Hauptdolomit/Dolomia Principale constitutes the walls of Punta Anna (2731 m asl; Fig. 34).

In the Dibona section the Heiligkreuz Formation can be subdivided into several members (Neri et al., 2007). The Borca Member consists of a mixed carbonate–terrigenous facies, comprising skeletal grains, calcarenites, oolitic–bioclastic packstone/grainstones and hybrid arenites. In this member, metre-scale patch reefs can be found, with spectacularly preserved faunas, rich in corals (cf. Member A in Russo et al., 1991). The upper part of this member shows a distinct lithological pattern organized in peritidal cycles, several metres thick, characterized by stromatolitic dolostones, marly limestones with plant roots, and claystones rich in plant debris and amber; it is topped by a well-defined palaeosol, which can be traced over several kilometres (Preto & Hinnov, 2003). The

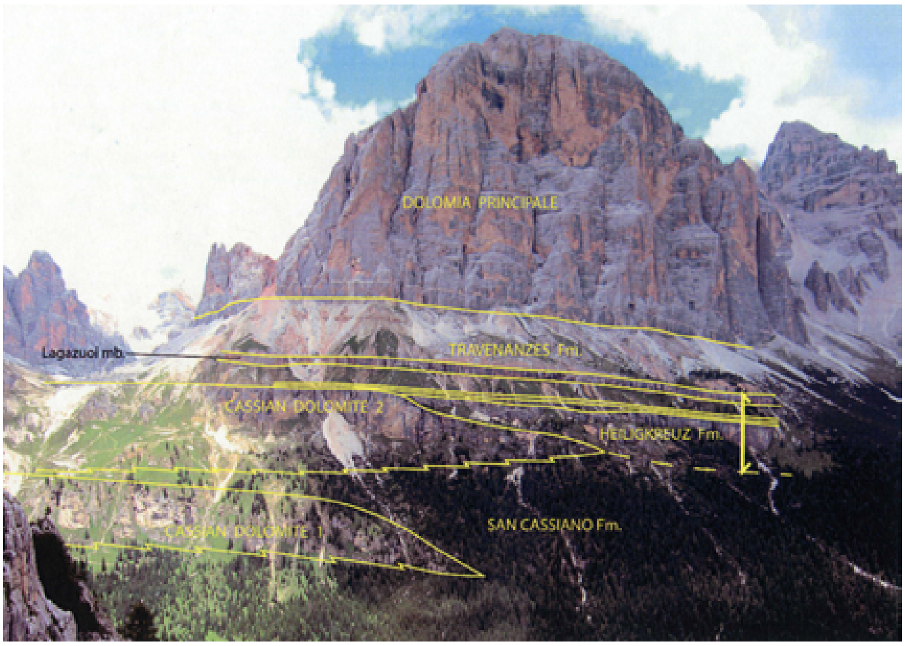

Fig. 34: Panorama of the field trip area from the Rifugio Scoiattoli sowing the rimmed platform geometry of the lower Carnian platforms versus the ramp geometry of the upper Carnian sediments.
From the southern side of the Falzarego valley, a panoramic view of the field trip area will be visible in afternoon light, showing the dramatic change in the depositional style that occurred during the Carnian time. The lower Carnian buildups show a flat top and steep slopes, with typical rimmed platform geometry. Two generations of carbonate platforms can be identified (Cassian Dolomite 1 and 2), a pattern recognised throughout the Dolomites. In contrast to that the (mostly) upper Carnian Heiligkreuz Formation is formed by a wedge of carbonate-clastic sediments, recording the strongly reduced topographic gradients of a mixed terrigenous-carbonate ramp depositional system (Preto & Hinnov, 2003; Breda et al., 2009; Gianolla et al., 2010).

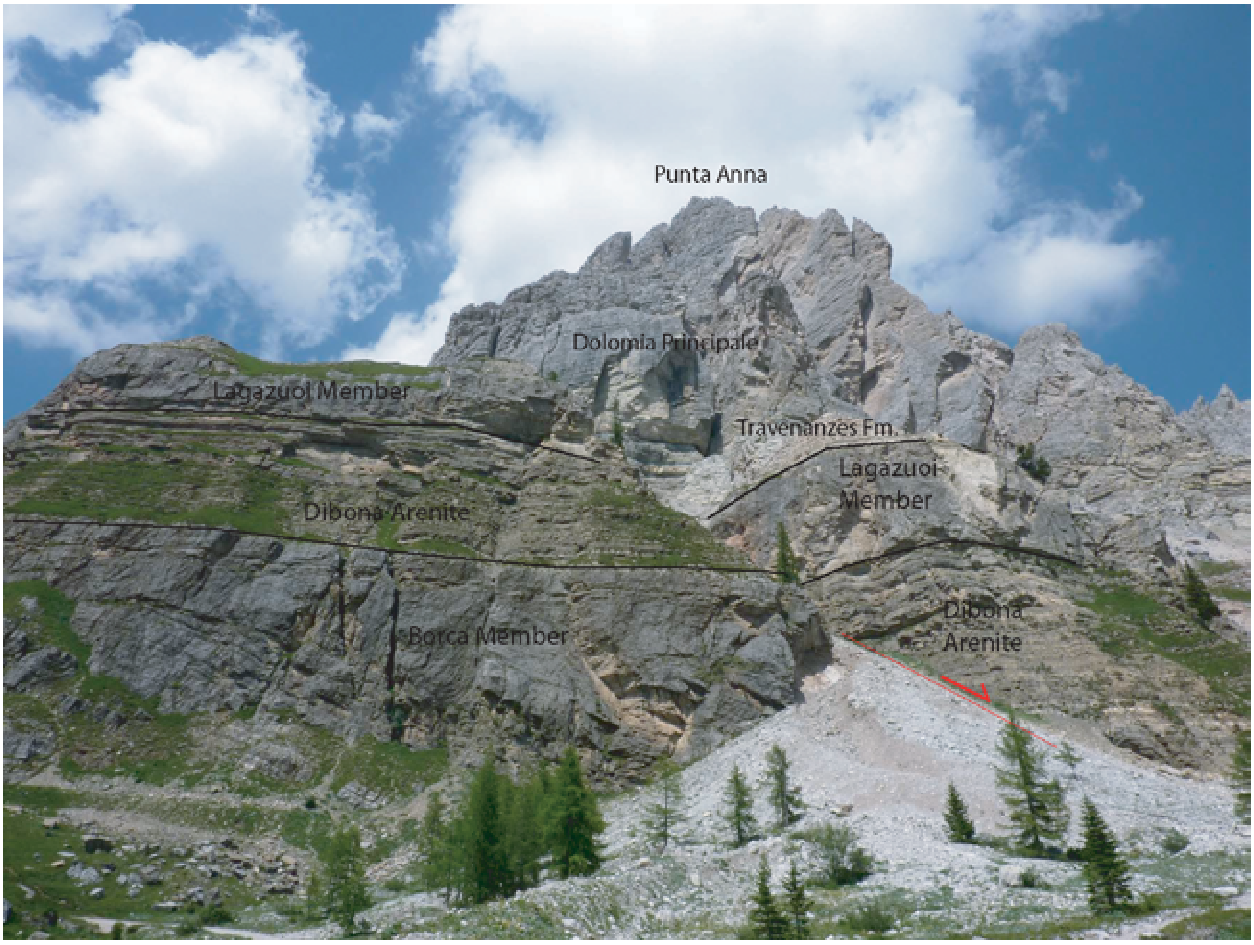

Fig. 35: The outcrop at Rifugio Dibona.

Dibona Member (cf. Bosellini et al., 1982) consists of mixed siliciclastic–carbonate lithologies; it is characterized by a progressive upward decrease in siliciclastics, indicating a deepening trend (for more details see Preto & Hinnov, 2003). This unit ends with nodular, bioturbated marly limestones, with *Chondrites* sp. and locally abundant pelagic fossils, condensed on the maximum flooding surface. The following Lagazuoi Member consists of dolostones with herring-bone cross-bedding, calcareous sandstones and massive dolostones. It forms an easily recognizable 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 the Falzarego Sandstone Member, (Bosellini et al., 1978; Neri et al., 2007; Breda et al., 2009; Gattolin et al, 2013) showing spectacular current lamination and tide-related structures.

Stop 3 – The Travenanzes Formation at the Dibona section

From the Rifugio Dibona , the Travenanzes Formation (Fig. 36) is visible immediately above the Lagazuoi Member of the Heiligkreuz Formation and below the Dolomia Principale (Norian-Rhaetian). The lower boundary with the Lagazuoi Member is sharp and erosive and with regional extent. The upper boundary with the Dolomia Principale is gradual and time-transgressive due to a constant decrease of the terrigenous input. The complete disappearance of the fine-clastic layers can be used to define the boundary between the two formations. The Travenanzes Formation is characterized by three carbonate-siliciclastic cycles corresponding to three transgressive-regressive sequences (Breda et al., 2006) showing an overall transgressive pattern. An upward tailing of the clastic intervals is observed, up to their complete disappearance at the onset of the Dolomia Principale.

Fig. 36: Panoramic view of the Travenanzes Formation above the Rifugio Dibona. Note the three carbonate/siliciclastic sequences and the upward tailing off the siliciclastic intervals (From Breda et al., 2009, modif.).

The regressive siliciclastic intervals are mainly made up of multicoloured flood-basin mudstones. The flood basin is a low-lying coastal mudflat representing a transition between terrestrial and marine deposition. Scattered shallow ephemeral stream conglomerates and sheetflood quartzarenites are interpreted as more distal tails of a terminal-fan fluvial system. Few decimeter thick, tabular dolomicritic layers characterized by a rich marine fauna (bivalves and gastropods) or flat pebble breccias (on top of convoluted algal laminations) are interpreted as tempestites. Due to the dominantly arid climate a coastal sabkha developed locally, characterized by nodular/chicken-wire anhydrite encased in red mudstones and organized in saline soil profiles. Evaporites and calcic paleosols are usually located on top of the regressive intervals; the better developed paleosols mark the top of higher-order sequences.

Organic carbon-isotope record

Organic carbon-isotope analysis of biomarkers and bulk organic matter of stratigraphic sections in the Dolomites show significant changes that can be put in relationship with the major climatic and environmental changes that occurred during the Carnian. A late Ladinian–early Carnian ~3‰ positive $\delta^{13}C$ shift is evidenced by bulk organic matter, higher plant *n*-alkanes, fossil wood and leaves (Fig. 36; Dal Corso et al., 2011, 2012). The positive trend is also recorded by $\delta^{13}C$ of brachiopod calcite (Korte et al., 2005) and testifies a global change of the isotope composition of the reservoirs of the exchangeable carbon (atmosphere–land–ocean system). This Middle–early Late Triassic long-term $\delta^{13}C$ positive shift has been attributed to the recovery of the land plants after the end-Permian mass extinction marked by the re-appearance of coal deposits in the geological record (Korte et al., 2005). Since higher plants during the photosynthesis fractionate ^{13}C, the development of large coal deposits would have resulted in an enhanced sequestration of ^{12}C from the reservoirs of the active carbon cycle, shifting the $\delta^{13}C$ of the atmosphere and the ocean towards more positive values, i.e. towards a ^{13}C-enriched $\delta^{13}C$ signature.

The positive trend is interrupted by a 4-2‰ negative carbon isotope excursion (CIE) at the boundary between the *Trachyceras* and *Austrotrachyceras* ammonoid zones that corresponds approximately to the boundary between the *Concentricisporites bianulatus* and the *Aulisporites astigmosus* sporomorph assemblages (Fig. 37).

The CIE is recorded by marine and terrestrial biomarkers and bulk organic matter and thus testifies to a global abrupt negative $\delta^{13}C$ shift triggered by the introduction of ^{13}C-depleted CO_2 into the atmosphere-ocean system (Dal Corso et al., 2012). At Milieres-Dibona, the negative CIE occurs at the onset of the Carnian Pluvial Event (CPE), a major climatic change from arid-semiarid to humid conditions that interrupted the monsoonal Late Triassic climate coupled to a biotic turnover among marine and terrestrial biota (Simms & Ruffell, 1989; Furin et al., 2006; Preto et al., 2010). At Milieres-Dibona the CPE is evidenced within the Heiligkreuz Formation by the arrival of coarse siliciclastic material into the basin (Preto & Hinnov 2003), the formation of paleosols that today develop in tropical humid climates with a short or without a dry season (Breda et al., 2009) and the occurrence of amber deposits (Roghi et al., 2006) (Fig. 37).

The negative CIE and the subsequent CPE could have been triggered by the coeval eruption of Wrangellia Large Igneous Province (LIP; Furin et al., 2006; Dal Corso et al., 2012), an oceanic plateau that was emplaced between the late Ladinian and late Carnian and today crops out in north-western North America (Greene et al., 2010; Xu et al., 2014). In the geological record the eruption of LIPs is often closely linked to major climate changes and biotic turnovers (e.g. end-Permian and end-Triassic mass extinctions). The CPE could be yet another example of negative CIE, climate change and biotic turnover associated to LIP eruption.

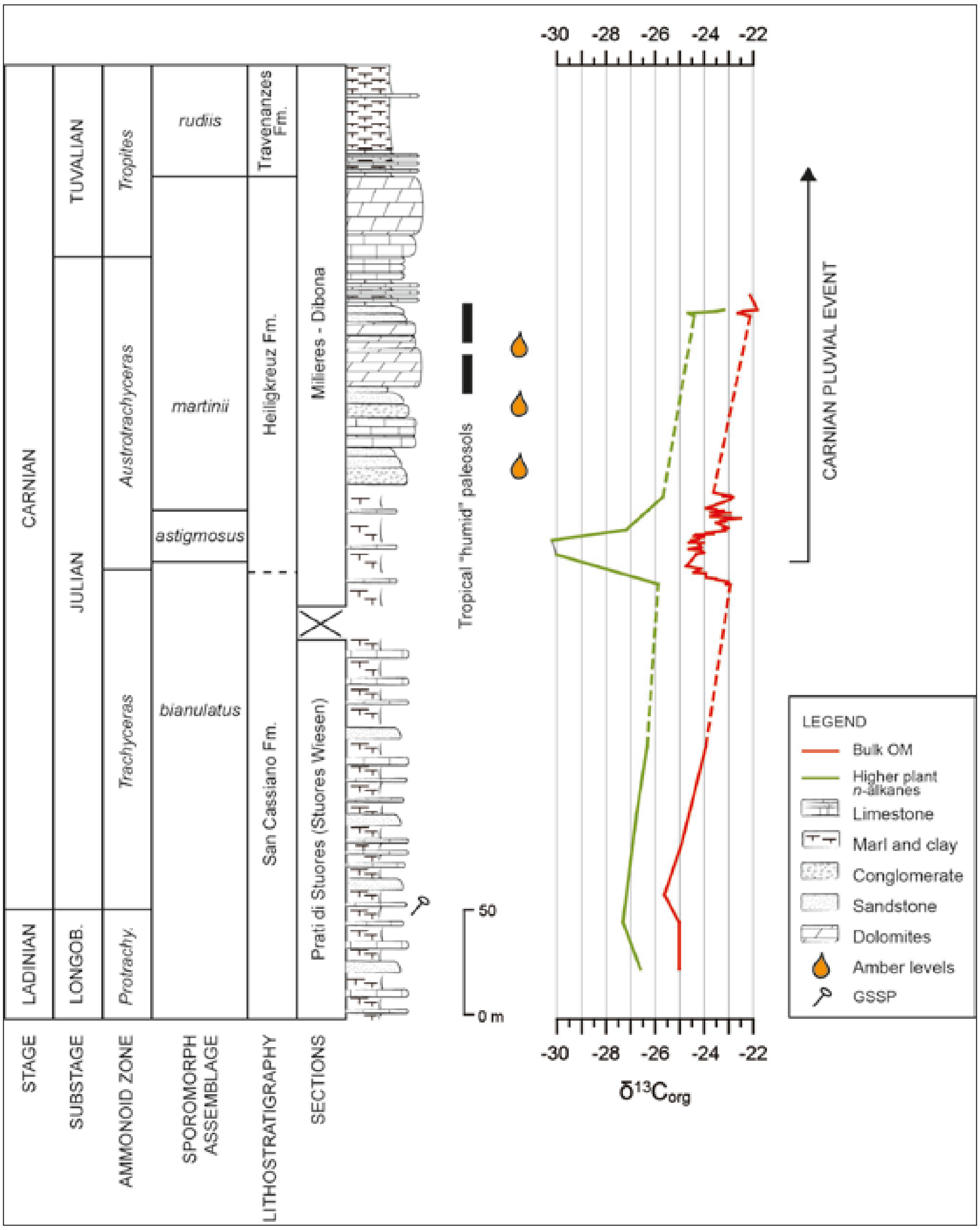

Fig. 37: Higher plant *n*-alkanes and bulk organic matter carbon isotope curves from the early Carnian of the Dolomites. A long-term 3‰ early Carnian positive $\delta^{13}C$ trend is suddenly interrupted by a 4-2‰ negative carbon isotope excursion (CIE). This negative CIE marks the onset of the Carnian Pluvial Event at Milieres-Dibona section that is characterized by coarse siliciclastic sedimentation, the development of palaeosols typical of tropical humid climates and the occurrence of large amber deposits. Carbon-isotope data are after Dal Corso et al. (2012). Higher plant *n*-alkanes $\delta^{13}C$ is re-calculated as mean weighted $\delta^{13}C$ of odd *n*-C25 – *n*-C31 alkanes.

The microflora

Qualitative and quantitative analyses of the Upper Triassic Heiligkreuz Formation provide information on palynostratigraphy and palaeoclimate during the last part of the Carnian Pluvial Event (CPE). A rich and diversified palynological association was found in the Dibona Sandstones member (Fig. 38) whereas the most interesting palynological assemblages of the Travenanzes Formation comes from the lowermost levels of this formation, few meters above the Lagazuoi member (Fig. 39). These associations contain the typical Late Triassic elements. The lower part of the Travenanzes Formation is composed of *Concavisporites* sp., *Todisporites* sp., *Baculatisporites* sp. 1, *Aulisporites astigmosus* Leschik, 1956, *Vallasporites ignacii* Leschik, 1956, *Enzonalasporites vigens* Leschik, 1956, *Ovalipollis* spp., *Camerosporites secatus* (Leschik, 1956) Scheuring 1978, *Granuloperculatipollis* sp., *Granuloperculatipollis rudis* (Venkatachala et Góczán, 1964) Mostler et al., 1978, *Riccisporites* sp. cf. *R. tuberculatus* Lundblad, 1954. The palynoflora of the Heiligkreuz Formation is comparable with the *Aulisporites astigmosus* and *Lagenella martini* assemblages of Roghi et al. (2010), whereas the one at the base of the Travenanzes can be attributed to the *Granuloperculatipollis rudis* assemblage (Roghi, 2004; Roghi et al., 2010). Both associations fall into the *densus-maljawkinae* phase of Brugman (1983) and Van der Eem (1983).

The upper part of the Heiligkreuz Formation is characterized by trilete, levigate and ornamentated spores, monosaccate and bisaccate pollen grains and Circumpolles. A clear predominance of conifers (51 %) is observed, followed by seed ferns (18 %), lycopsids, ferns and horsetails (18 %) (Fig. 40). In the paleosols the high percentage of seed ferns and conifers corresponds to abundant, well preserved cuticule of the latter group (Fig. 41) and to abundant amber droplets (see below). The Travenanzes Formation is characterized by high percentages of Circumpolles (43%; with *Camerosporites secatus* alone costituting 31%), *Ovalipollis* spp. (11%), lycopsids, ferns and horsetails (16%) and *Cycadopites* (6 %). The analyses of the hygrophytic and xerophytic elements from the Heiligkreuz Formation up to the lower part of the Travenanzes Formation show a general increase in the xerophytic elements (main increase in the Circumpolles group; from 8% to 42%) and a decrease of monosaccites (from 47% to 8%). Hygrophytic Azonotriletes maintain constant abundance and indicate the local persistence of humid conditions in the lowermost part of the Travenanzes Formation.

The same trend was observed in coeval levels of the Julian Alps (Cave del Predil, De Zanche et al., 2000, Roghi, 2004) and Austria (Lunz area, Roghi et al., 2010). In all sections a decrease of monosaccate and bisaccate pollen grains is related to a rapid increase of Circumpolles. The presence of Circumpolles could correspond to the final phase of the humid pulse, well testified both in the Dolomites, Julian Alps and Austria.

The amber

The Upper Triassic strata of the Heiligkreuz Formation preserve, like a precious treasure, the most ancient and quantitatively substantial amber deposits of the world (Fig. 42). The amber of the Heiligkreuz Formation was found both in sandstone, with marine pelecypods and plant debris suggesting that the amber was transported and redeposited, and associated in palaeosols with plant remains indicating an autochthonous origin. In the palaeosol a considerable abundance of isolated leaves with exceptionally preserved cuticles allowed the correlation of the amber-producing species to the family Cheirolepidiaceae, a group of conifers growing on the nearby emerged land, as indicated also by palynological analysis (Roghi et al., 2006a). The fossil resin drops found in the palaeosol show typical globe-shaped forms with a little stem and a main diameter of 2-3 mm; some of the outer drop surfaces show characteristic reticular structures suggesting fast desiccation (Fig. 42).

Fossil resin was first reported by Koken (1913) in his famous posthumous work on the mollusk and vertebrate fauna of Heiligkreuz. Later it was mentioned by Zardini (1973) and Wendt & Fürsich (1980), but only recently this amber was extensively studied not only with respect to its physicochemical properties, but also with the purpose to understand its palaeobotanical origin (Gianolla et

Tab. 2: Palynological association from the Heiligkreuz Formation in the Dibona section.

Species	**Botanical affinity**	**%**
Levigate and orrnamentated spores, genus *Calamospora, Todisporites, Concavisporites, Retusotriletes* and *Uvaesporites*	Lycopsids, ferns, Horsetails	13
Spiritisporites spirabilis Scheuring, 1970	?Ferns	< 1
Vallasporites ignacii Leschik in Kräusel and Leschik, 1956	Conifers	8
Enzonalasporites vigens Leschik in Kräusel and Leschik, 1956	Conifers	10
Patinasporites cf. *densus* (Leschik, 1956) Scheuring, 1970	Conifers	2
Patinasporites densus (Leschik, 1956) Scheuring, 1970	Conifers	1
Pseudoenzonalasporites summus Scheuring, 1970	Conifers	1
Samaropollenites speciosus Goubin, 1965	Conifers or seed ferns	1
Ovalipollis pseudoalatus (Thiergart, 1949) Schuurman, 1976	?Cycadales, ?seed ferns, ?conifers	8
Lunatisporites acutus Leschik in Kräusel and Leschik, 1956	Seed ferns (Peltaspermales), ?conifers, ?Podocarpaceae	4
Infernopollenites parvus Scheuring, 1970	Seed ferns (Peltaspermales), ?conifers	<1
Triadispora spp.	Conifers (Voltziales)	8
Lueckisporites sp.	Conifers (Majonicaceae)	3
alete bisaccate	Seed ferns (Peltaspermales), conifers	29
Duplicisporites continuus Praehauser-Enzenberg, 1970	Conifers (Cheirolepidiaceae)	1
Paracirculina maljawkinae Klaus, 1960	Conifers (Cheirolepidiaceae)	3
Duplicisporites verrucosus (Leschik, 1956) Scheuring, 1970	Conifers (Cheirolepidiaceae)	1
Duplicisporites granulatus (Leschik, 1956) Scheuring, 1970	Conifers (Cheirolepidiaceae)	6
Camerosporites secatus Leschik in Kräusel and Leschik, 1956	Conifers (Cheirolepidiaceae), ?seed ferns	<1

al., 1998b; Roghi et al., 2006a, 2006b; Ragazzi et al., 2003; Dal Corso et al., 2011). The Triassic amber of the Dolomites comes only from the Heiligkreuz Formation, corresponding to a time interval between the early and late Carnian. In coeval strata amber was found also in a wide area including the Schilfsandstein (Switzerland), the Raiblerschichten and Lunzerschichten (Austria), the Barnag member of the Sándorhegy Formation (Hungary) and the Chinle Formation (Arizona; Fig. 43). These findings suggests that resin exudation from the ancient trees could have been influenced by some kind of palaeopathology probably caused by palaeoclimatic fluctuations (namely during the Carnial Pluvial Event).

The fingerprint of the Triassic amber of the Dolomites was obtained through physico-chemical studies (Ragazzi et al., 2003; Roghi et al., 2006b) such as infrared spectrophotometry (FTIR), nuclear magnetic resonance (NMR), thermogravimetry (TG), differential thermogravimetry (DTG), and automated elemental analysis. The infrared spectrum of the Triassic amber is typical of fossil resins but presents a peculiar pattern.

Moreover, inside this amber a rich microbiological world was discovered (Fig. 44), and studied in collaboration with Alexander Schmidt (University of Göttingen) and Olimpia Coppellotti (University of Padova) (Schmidt et al., 2006). According to these studies, bacteria are the most abundant microbes in the amber from the Dolomites, together with anamorphic fungi, algae, ciliate protozoans and testate amoebae, showing an amazing similarity to extant taxa (in particular, to algae of the genus *Cosmarium*, and to protozoa of the genera *Coleps* and *Centropyxis*).

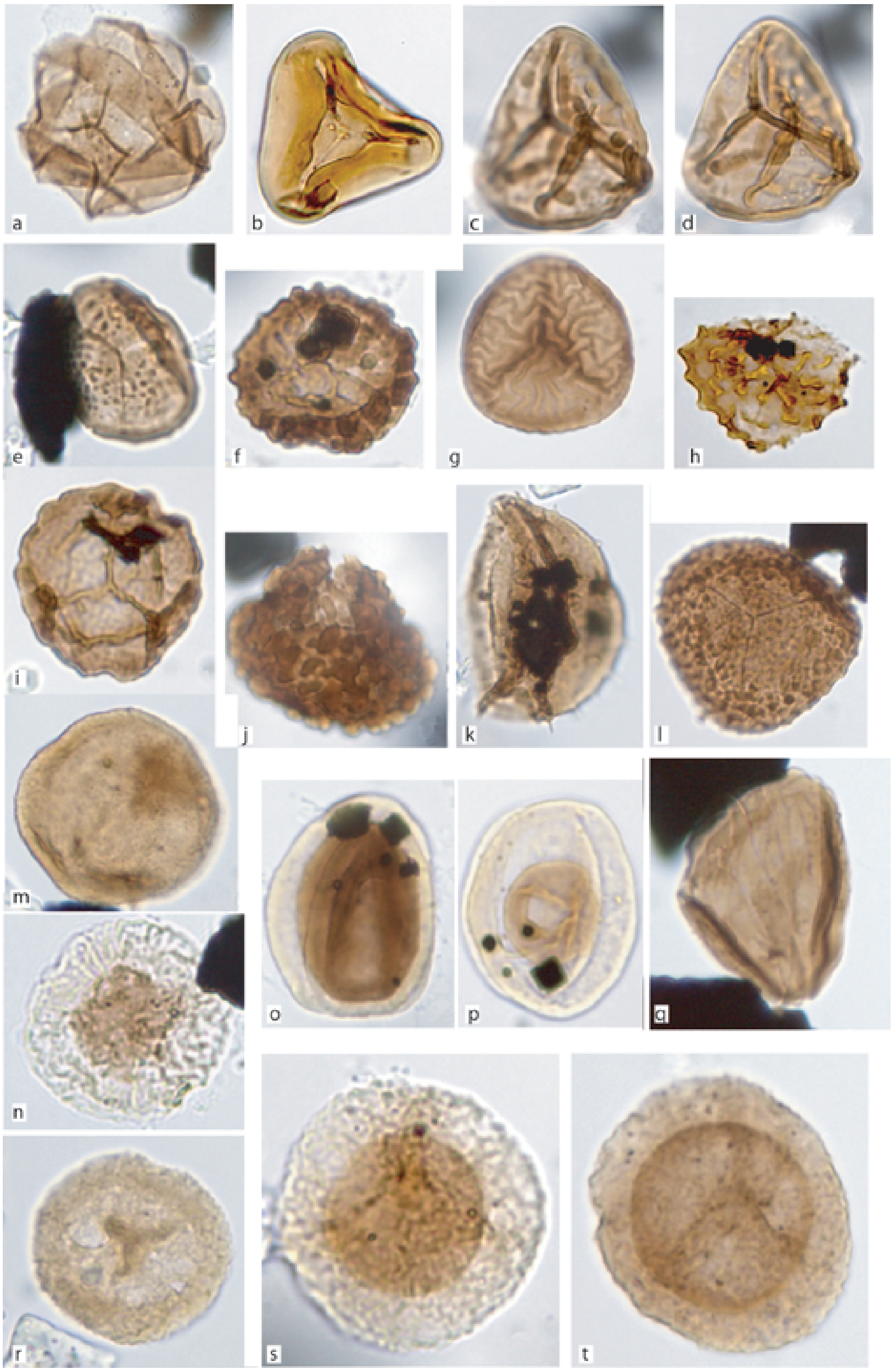

Fig. 38: Palynological association from the Heiligkreuz Formation: A) *Calamospora lunzensis*, (39 µm); B) *Concavisporites* sp. (50 µm); C, D) *Leptolepidites* sp. cf. *L. verrucatus* (30 µm); E) *Nevesisporites vallatus* (30 µm); F) *Uvaesporites gadensis* (25 µm); G) *Lycopodiacidites keupperi* (37 µm); H) *Gibeosporites hirsutus* (25 µm); I) *Anapiculatisporites telephorus* (30 µm); J) *Combaculatisporites mesozoicus* (38 µm); K) *Aratrisporites parvispinosus* (41 µm high); L) *Converrucosisporites tumulosus* (40 µm); M) *Pseudoenzonalasporites summus* (37µm); N) *Patinasporites* sp. cf. *P. densus* (30 µm); O) *Paracirculina maljawkinae* (30 µm); P) *Duplicisporites continus* (35 µm); Q) *Equisetosporites chinleanus* (34 µm height); R) *Vallasporites ignacii* (30 µm); S, T) *Tulesporites* sp. (S, 42 µm, T, 37 µm).

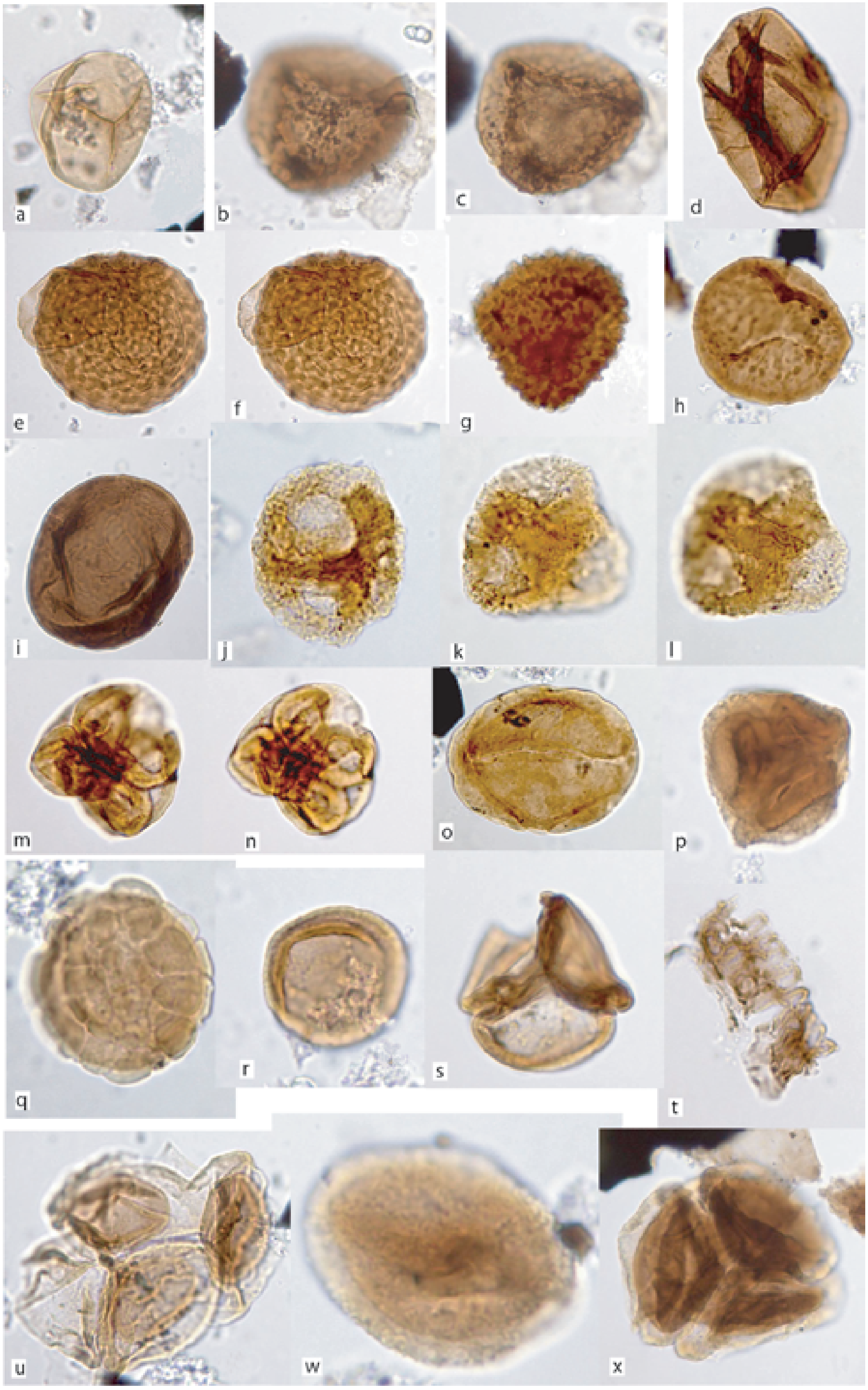

Fig. 39: Palynological association from the Travenanzes Formation: A) *Todisporites* sp. (46 µm); B, C) *Converrucosisporites* sp. (50 µm); D) *Laricoidites intragranulosus* (56 µm long); E, F) *Verrucosisporites* sp. (62 µm); G) *Combaculatisporites* sp. (48 µm); H) *Carnisporites ornatus* (36 µm); I) *Laricoidites intragranulosus* (56 µm long); J, K, L) *Vallasporites* sp. (J, 37 µm, K, L, 32 µm); M, N) *Riccisporites* cf. *R.tuberculatus* (35 µm); O) *Ovalipollis ovalis* (64 µm long); P) *Granuloperculatipollis* sp., tetrads (32 µm); Q) *Camerosporites secatus* (31µm); R) *Granuloperculatipollis* sp. (27 µm); S) *Riccisporites* cf. *R. tuberculatus* (27 µm);T) spirally plant fragments (20 µm large); U) cavate forms, tetrads (40 µm); W) *Aratrisporites* sp. (32 µm); X) *Granuloperculatipollis rudis* (40 µm).

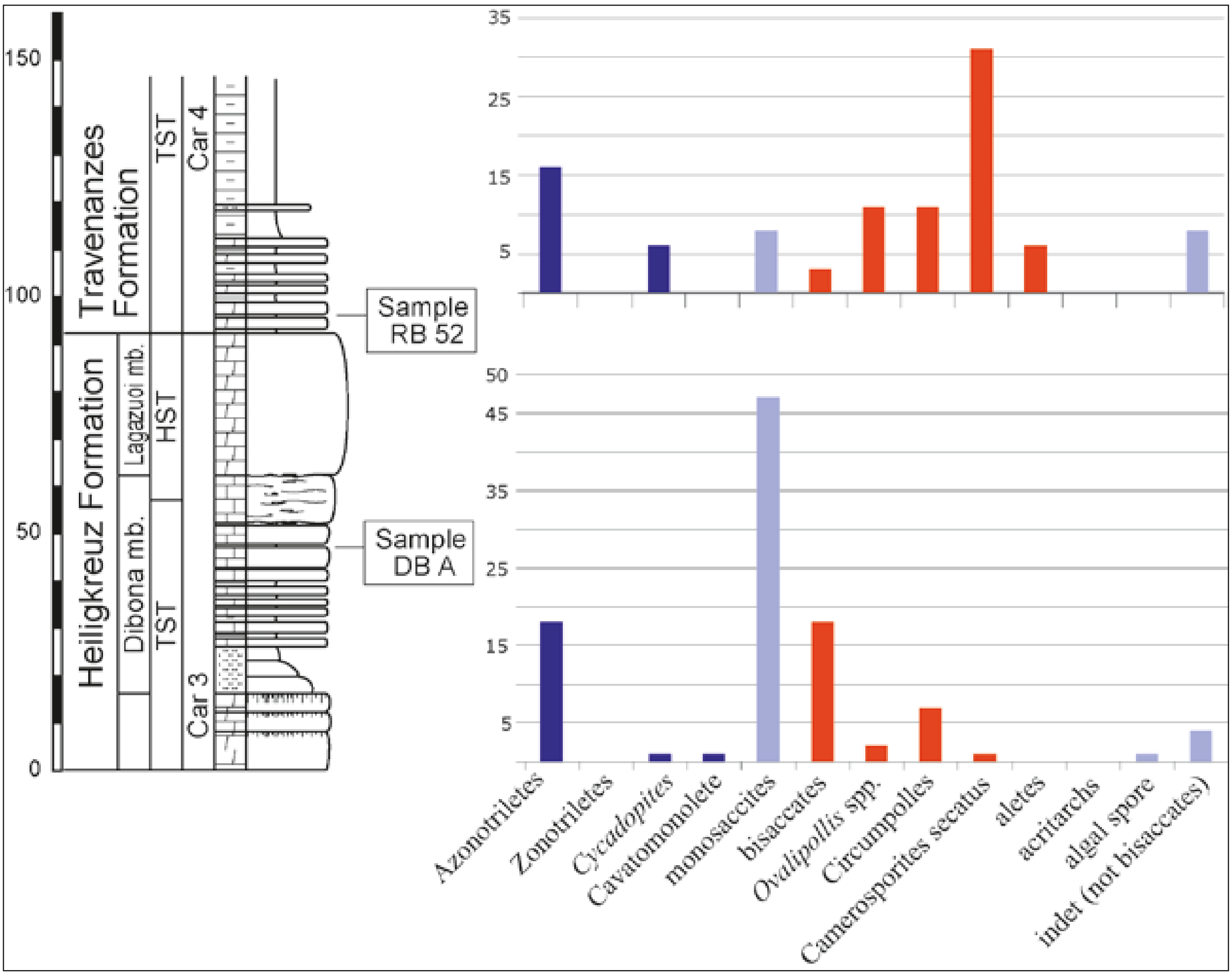

Fig. 40: Quantitative distribution of the main palynomorph groups in the upper part of the Heiligkreuz Formation (sample DBA) and in the lowermost part of the Travenanzes Formation (sample RB 52) (From Breda et al., 2009).

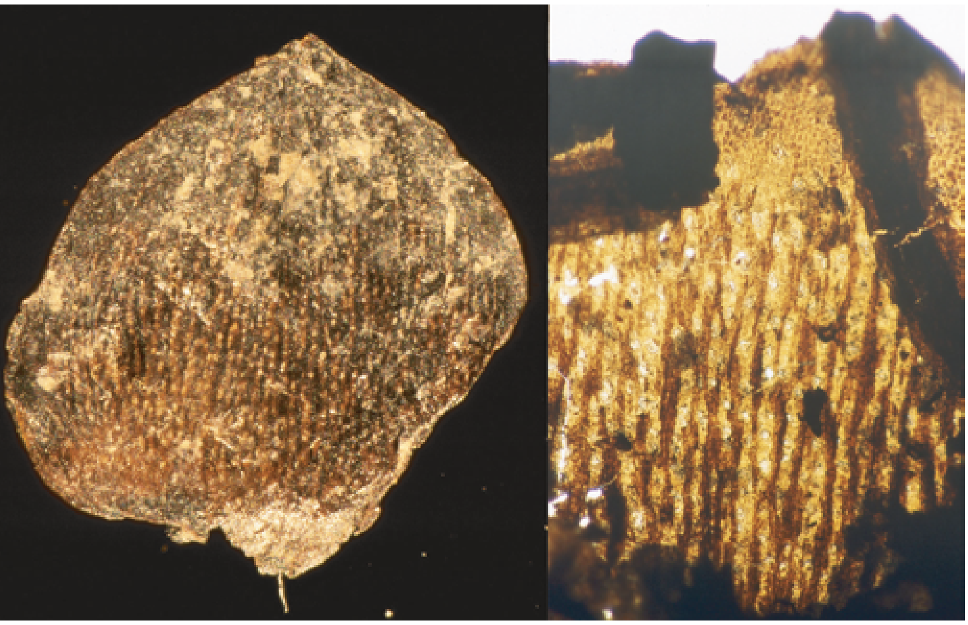

Fig. 41: Fossil leaves of conifer affinity from the paleosol richest in amber of the Dibona section (upper part of the Dibona Sandstones member, Heiligkreuz Formation).

Representatives of all trophic levels of a terrestrial microbiocoenosis were found exceptionally preserved: bacteria, and phototrophic algae as producers, protozoans as consumers, and fungi as decomposers. Bacteria represent the food source of testate amoebae and some ciliates. Ciliates, on the other hand, feed on microalgae, other ciliates, flagellates and on small metazoans. These findings give new insights in the evolution and palaeoecology of early Mesozoic microorganisms, suggesting that the basal levels of food webs of terrestrial biocoenoses have undergone virtually little or no morphological change from the Triassic to today (Schmidt et al., 2006).

During the ongoing investigations, involving so far about 70,000 droplets, three arthropods were discovered and described (Schmidt et al., 2012): a partly preserved nematoceran fly (Diptera) and two highly divergent species of eriophyoid mites, attributed to the new species *Triasacarus fedelei* and *Ampezzoa triassica* (Fig. 45). Their main features, comparable with present-day species, are a long (vermiform or fusiform) segmented body, peculiar feather claws and mouthparts, but only two pairs of legs instead of the usual four in mites. They were described as the oldest *bona fide* fossils of the Eriophyoidea superfamily (Schmidt et al., 2012), which includes the present-day gall mites and with at least 3,500 extant species represents one of the most specialized lineages of phytophagous arthropods. The ancient mites fed probably on amber-producing conifers of the extinct Cheirolepidiaceae, prior to the appearance and diffusion of flowering plants. Today, 97% of gall mites feed on angiosperms, and only 3% live on conifers, suggesting that these mites changed their feeding habits; therefore conifer feeding appears as an ancestral trait (Schmidt et al., 2012). This feeding habit might also have contributed to the resin production from plants, although the anomalous pre-Cretaceous abundance of amber found in the Carnian, most probably suggests a palaeoclimatic-related event (Carnian Pluvial Event: Roghi et al., 2006b, Dal Corso et al., 2012). Most recently, two new genera and

Fig. 42: Amber drops found in the paleosols of the Heiligkreuz Formation, Dolomites.

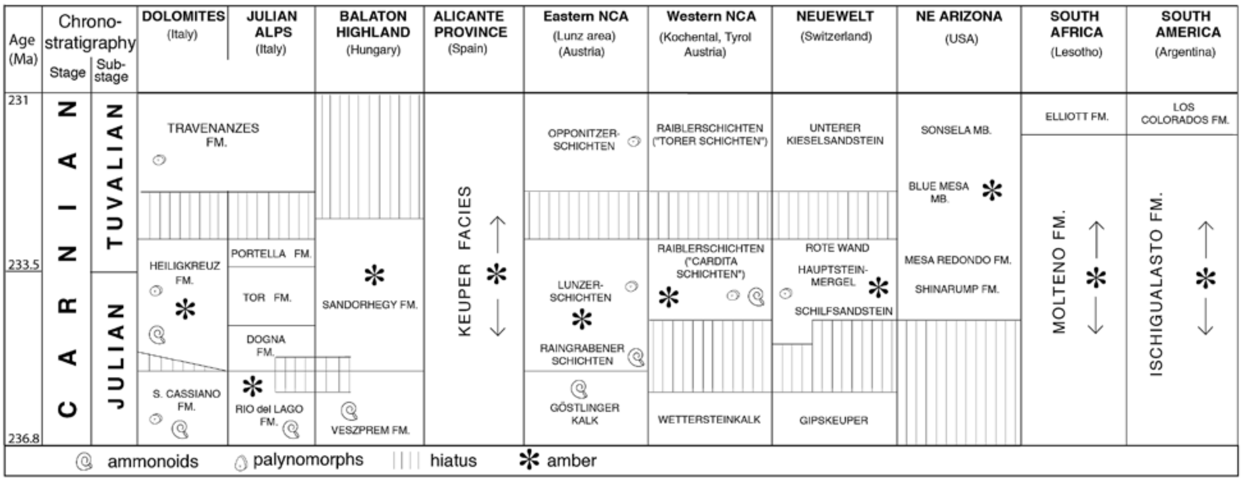

Fig. 43: Localities of Late Triassic fossil resin.

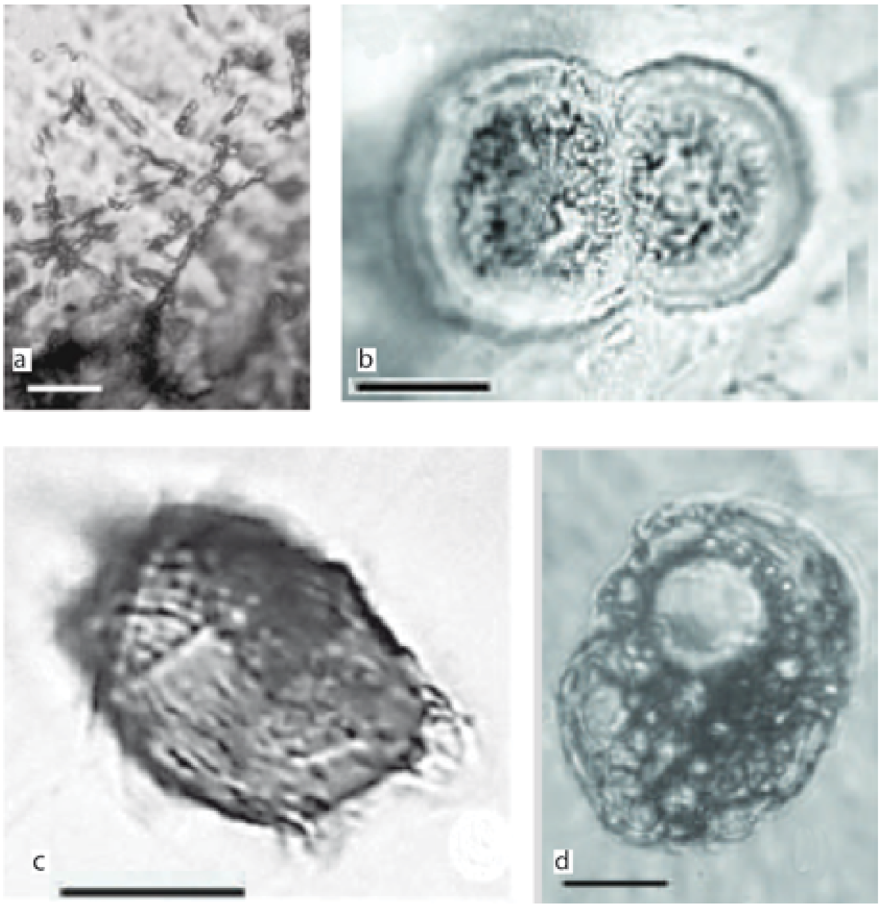

Fig. 44: Microinclusions in the Triassic amber from the Dolomites rod-shaped bacteria (A; scale bar 10 µm); algae of the genus *Cosmarium,* (B; scale bar 10 µm); protozoa of the genera *Coleps* (C; scale bar 5 µm) and Centropyxis (D, scale bar 10 µm). From Schmidt et al. (2006).

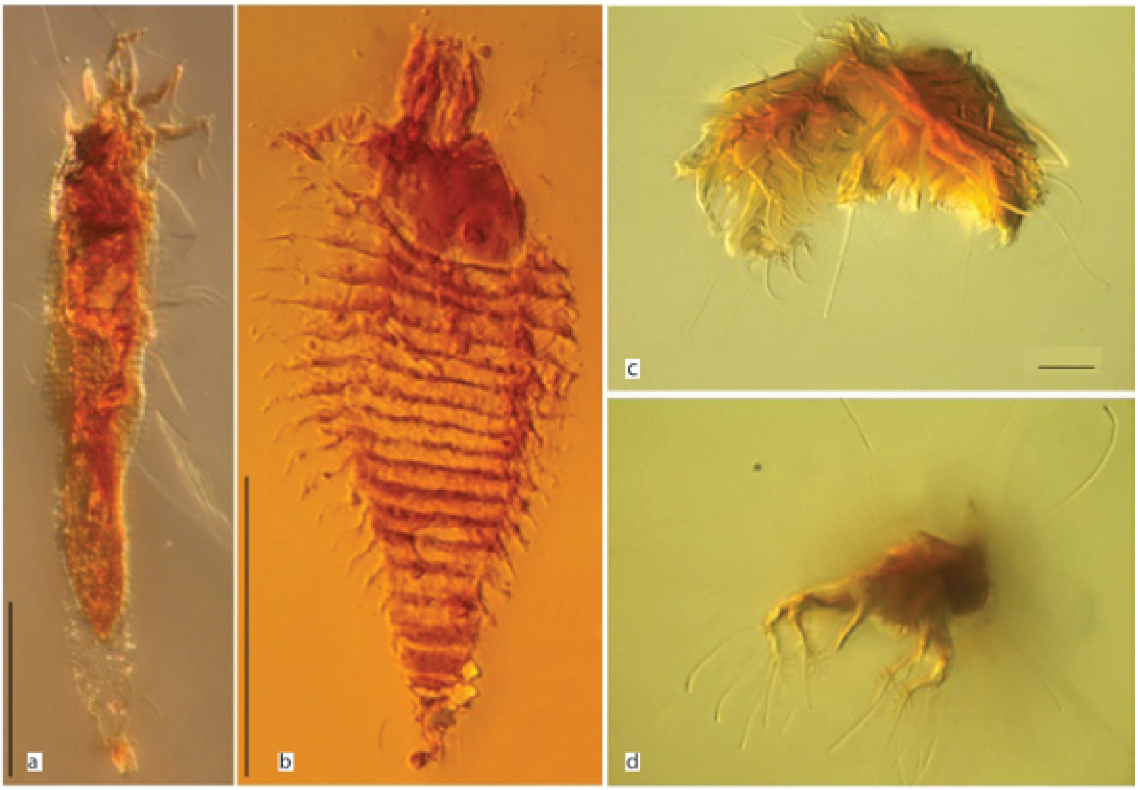

Fig. 45: The mites described in Triassic amber: A: *Triasacarus fedelei,* B: *Ampezzoa triassica,* C: *Minyacarus aderces;* D: *Cheirolepidotus dolomiticus* (Schmidt et al., 2012, Sidorchuk et al., 2014).

species of mites were discovered in Triassic amber of the Dolomites, *Minyacarus aderces* and *Cheirolepidop-tus dolomiticus* Fig. 46 (Sidorchuk et al., 2014). The new superfamily Triasacaroidea was instituted accommodating the four Triassic taxa, as already in those remote times highly specialized, four-legged, phytophagous mites, probably representing a precursor group that gave rise to present-day Eriophyoidea mites. From a closer investigation of the bodies and mouthparts of the Triassic mites, it was possible to suggest different feeding strategies in adapting to specialize on the same host plant of the Cheirolepidiaceae. In particular, the cheliceral stylets of *Triasacaroidea* are generally blunt, indicating that, unlike the extant *Eriophyoidea*, they were less able to pierce surface plant cells, but most probably they may have fed on mesophyll cells by access through leaf stomata (Sidorchuk et al., 2014), whose size appears to be appropriate for this kind of feeding. The overall of these data suggests that Triassic amber of the Dolomites is a unique kind of fossil resin with great potentials in outlining evolution steps and palaeoenvironmental characteristics.

The macroflora

The Heiligkreuz Formation yielded also several plant remains. These are mostly dispersed leaves with exceptionally well preserved cuticles. Articulated plant remains are very rare and comprise few equisetalean stem fragments and conifer shoots (Fig. 46). The most complete plant fossils are about 20 cm long and 1 cm wide shoots and branches. Often the shoot fragments are partly covered by amber, i.e. between the leaves the fossil resin is observed inside the resin canals of the wood. The dispersed leaves (Fig. 41) have been found in the same horizon as the amber drops. They are widely triangular to rhomboidal in shape, with an obtuse apex (4.5-8 x 3-10 mm). The cuticle shows stomata arranged in short rows and are characterized by a circle of 4-6 subsidiary cells (Kustatscher et al., 2011; Sidorchuk et al., 2014). The epidermal cells are polygonal, 20-30 mm in diameter with thick anticlinal and synclinal walls. The leaves are of the *Brachyphyllum* type and have been putatively assigned to the extinct gymnosperm family Cheirolepidiaceae (see Schmidt et al., 2012), a characteristic family of Jurassic and Cretaceous floras, found mostly in coastal and deltaic environments.

The Carnian floras of the eastern Southern Alps are generally composed of few taxa and dominated by conifer remains. The flora of Dogna in the Julian Alps (northeastern Italy), collected from a thick succession of subtidal clays, marls and bioturbated to nodular wackestone-packstones of the Rio del Lago Formation (early Carnian) is composed mostly of conifer shoots (*Brachyphyllum*, *Voltzia*) and seed fern fronds (*Ptilozamites*), while ferns (*Danaeopsis*) and horsetails are rare (Roghi et al., 2006a). The plant assemblage from Heiligkreuz (Dolomites; late Julian-early Tuvalian) contains conifer shoots and horsetail shoots, while the one from the Stuores Wiesen (Dolomites) yielded only conifers. The only diversified flora of Carnian age of the eastern Southern Alps is the one from Raibl/Cave del Predil, attributed lately to the Predil Limestone. The flora is well known since the 19th century (e.g., Bronn, 1858; Schenk, 1866-67, Stur, 1868, 1885; Dobruskina et al., 2001). It yields horsetails (*Equisetites arenaceus* (Jaeger) Schenk, 1864; *Calamites raiblensis* Schenk, 1865), ferns (*Neuropteridium grandifolium* (Schimper et Mougeot) Compter, 1883, *Neuropteridium elegans* (Brongniart) Schimper, 1869, *Chiropteris lacerata* (Quenstedt) Rühle von Lilienstern, 1931, *Cladophlebis ruetimeyeri* (Heer) Leonardi, 1953), ?*Cladophlebis leuthardtii* Leonardi, 1953), seed ferns (*Ptilozamites sandbergeri* (Schenk) Kustatscher et Van Konijnenburg-van Cittert, 2007). Some of the most important components of the Raibl flora are the cycadophytes (*Sphenozamites bronnii* (Schenk) Passoni et Van Konijnenburg-van Cittert, 2003, *Pterophyllum giganteum* Schenk, 1865, *Pterophyllum longifolium* Stur, 1885, *Macrotaeniopteris* vel *Bjuvia*). The conifers are also abundant and well diversified (*Voltzia haueri* Stur, 1885, *Voltzia raiblensis* Stur, 1885, *Cephalotaxites raiblensis* Stur, 1885, *Pelourdea vogesiaca* (Schimper et Mougeot) Seward, 1917. For more details see Roghi et al. (2006a) and Kustatscher et al. (2011).

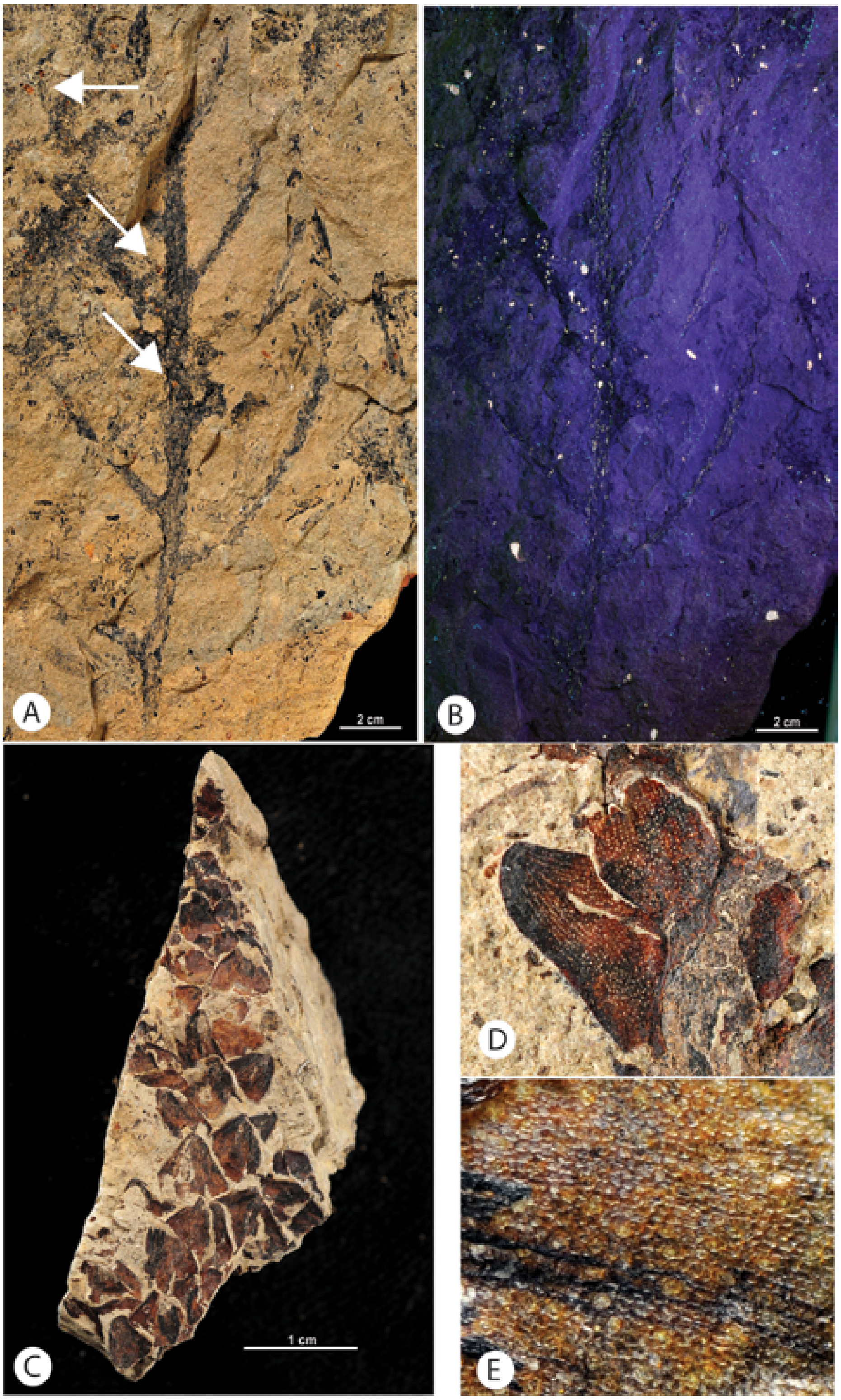

Fig 46: A: shoot fragments covered by amber drops (arrows), and containing also resin inside the resin canals of the wood; B: same sample in A, under UV light, which makes amber better visible. C and D: articulated plant remains with triangular to rhomboidal leaves attributed to *Brachyphyllum* type. E: cuticle with stomata arranged in short rows, characterized by a circle of 4-6 subsidiary cells and with polygonal epidermal cells (20-30 mm in diameter) presenting thick anticlinal and synclinal walls.

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