Field trip 2

Late Paleozoic and Mesozoic terrestrial environments in the Dolomites and surrounding areas

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1 Topics and highlights of the excursion

The Southern Alps represent one of the classical areas for the study of Late Paleozoic to Early Mesozoic stratigraphy. Spectacular outcrops allow exceptional insights into the genesis of the Permian continental-marine succession, Middle–Upper Triassic carbonate platforms and Jurassic shallow-marine to coastal successions. This area played an important role in the history of geology: in the 18th century Giovanni Arduino introduced in the Venetian and Recoaro Alps the subdivisions that now identify the four Erathems (Primary to Quaternary). Déodat de Dolomieu collected in the Etschtal/Valle dell'Adige the carbonate rock called in 1792 *Dolomie* by Nicolas de Saussure (Zenger et al., 1994; Mckenzie & Vasconcelos, 2009). The granitoid intrusions that metamorphosed the Middle Triassic limestone rocks in the area of Predazzo and Passo San Pellegrino played a major role in the demise, in the early 19th century, of the Neptunist Theory. Furthermore, since the late 19th century the Southern Alps and the Northern Calcareous Alps have been used to define the global 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). Since 1970, the number of studies in petrology, stratigraphy, sedimentology and palaeontology conducted in the area has increased substantially (Gianolla et al., 2009–2010; Roghi et al., 2014, and references therein) and the integration of numerous well-correlated sections has resulted in a reliable biostratigraphic framework (ammonoids, bivalves, conodonts, sporomorphs) tied to radioisotope age data and magnetic reversals (especially for the PT-boundary, and the Anisian–Ladinian and the Ladinian–Carnian boundary intervals; see Roghi et al., 2014 and references therein). At the same time, several studies based on discoveries made in the area allowed deriving new palaeoecological and palaeobiological models, which gave new insight of broad evolutionary interest (e.g. Schmidt et al., 2006; Posenato et al., 2014; Bernardi et al., 2015). Last but not least, since 2009 the Dolomites are included in UNESCO natural world heritage list which explecitely acknowledges the "spectacular landscapes, which reflect the complex geological architecture of the region" (Gianolla et al., 2009).

Although famous for its Triassic marine basinal and platform successions, the Dolomites include also important non-marine successions. The Athesian Volcanic Group represents the largest and best outcropping lower Permian volcanic area in Europe. Volcanic rocks are locally intercalated with sedimentary successions marking periods of volcanic inactivity. This alternation between radiometrically dated volcanic rocks and fluvio-lacustrine sedimentary successions gives the latter an exceptional time constrain. The early Permian Athesian Volcanic Group is covered by the late Permian fluvial Gröden/Val Gardena Sandstones. During the Triassic non-marine successions are rare. Terrestrial sediments can be found locally in the coastal Early Triassic Werfen Formation, the middle Anisian Piz da Peres Formation and Richthofen Conglomerate, subaerial settings of the middle Ladinian magmatic event and the middle–late Carnian paralic Travenanzes Formation. During the Early Jurassic the typical shallow-water limestones of the Calcari Grigi Group locally developed coastal facies that record terrestrial biota.

This excursion will take us to some of the most interesting outcrops of non-marine environments in the Dolomites and surrounding areas. This includes the late Permian Gröden/Val Gardena Sandstone of the Bletterbach gorge, the Middle and Late Triassic successions of the Etschtal/Valle dell'Adige and Nonstal/Val di Non (Bad Gfrill/Bagni di Caprile, Gampenpass/Passo Palade, Mt. Roen) and the Lower Jurassic successions of the famous Lavini di Marco dinosaur tracksite, near Rovereto. These sections, most of which intensively restudied in the last years by the authors of this guide, yielded well preserved plant remains, diverse tetrapod footprints as well as insect traces giving important insights into the paleoenvironmental and climatic conditions at the paleotropics during the late Palaeozoic and Mesozoic.
This field trip guide has been compiled by the authors based on personal data and observations but is largely based on several key publications of the same authors plus co-authors, namely: Avanzini et al. (1997, 2002a, 2013), Gennaro (2007), Petti et al. (2013), Roghi et al. (2014).

2 Geological and environmental settings

The stratigraphic framework of the Dolomites includes Permian to Cretaceous formations (for a more detailed overview see Gianolla et al., 2009), although the area is mostly famous for its Triassic successions, making the region a classical study area for the stratigraphy of this period (see Roghi et al., 2014). The stratigraphic basement is composed of lower Palaeozoic rocks, deformed and metamorphosed by the Carboniferous Variscan Orogeny (Brixen Quarzphyllite), covered by the first erosive event, the Waidbruck Conglomerate (Avanzini et al., 2007, 2012, 2013). An early Permian (trans-)tensional rifting resulted in an important volcanic activity that accumulated massive volcanic successions (Athesian Volcanic Group); during the periods of quiescence fluvio-lacustrine sediments deposited in small, local basins (Avanzini et al., 2007, 2013; Morelli et al., 2007; Marchetti et al., 2015). The middle Permian is missing due to an important unconformity, while the late Permian is mostly represented by fluvial red beds of the Gröden/Val Gardena Sandstone (Massari & Neri, 1997). A marine transgression from the East covered the area and triggered the accumulation of shallow marine evaporites and carbonates (Bellerophon Formation). The end-Permian mass extinction and its aftermath (Benton & Twitchett, 2003) are represented by the storm-dominated, shallow marine carbonate and terrigenous deposits of the basalmost Werfen Formation (e.g., Farabegoli et al., 2007). The strong tectonic activity of the Anisian basins (especially to the east) and emerged areas (especially to the west) (Bosellini, 1968), subjected the area to several emersion episodes and a differential subsidence (De Zanche et al., 1992, 1993; Gianolla et al., 1998a). These sequences are marked by subaerial unconformities, and formed by continental conglomerates, shallow-water terrigenous-carbonate deposits and finally deep-water sediments or prograding carbonate platforms. During the early Ladinian, the subsidence slowed down and the isolated nuclei expanded to large, up to thousand meters thick, platforms (Schlern/Sciliar Dolomite, Bosellini, 1984) while in the basins tens of metres of nodular-cherty limestones formed (Buchenstein/Livinallongo Formation). During the middle

Ladinian a violent massive intrusive and effusive magmatic activity in the Predazzo and Monzoni area formed locally subaerial areas, huge heterogeneous megabreccia bodies (Caotico Eterogeneo), pillow lavas and hyaloclastites. After the magmatic activity, the carbonate production restarted with a widespread progradation (Cassian Dolomite) and a high basinal sedimentation rate (St. Cassian/San Cassiano Formation). Later, the basins were filled by mixed terrigenous-carbonate deposits (Heiligkreuz Formation) that register several moist phases and yielded some of the oldest known amber with inclusions of microorganisms (e.g., Gianolla et al., 1998b; Schmidt et al., 2006). The return to aridity is registered in the middle-late Carnian by alternations of continental, paralic and shallow-marine mixed sediments (Travenanzes Formation). The decrease in siliciclastic input lead to the formation of a carbonate peritidal platform of regional extension (Hauptdolomit/Dolomia Principale; Bosellini & Hardie, 1988). In the Early Jurassic, shallow water limestones formed (Calcari Grigi Group; Masetti & Bottoni, 1978; Sauro et al., 1995; Avanzini et al., 2007), while soon after the region drowned due to the passive margin evolution of the Adria microplate giving origin to pelagic successions with encrinites and condensed nodular limestones (Rosso Ammonitico; Masetti & Bottoni, 1978). Finally, during the Cretaceous, the deposition of deep-water clay, marls and micrites (Marne del Puez) was interrupted by the onset of turbiditic sand input (Flysh di Ra Stua), recording the early stages of the Alpine deformation (Sauro et al., 1995).

3 Overview of Excursion route and stops

This three-day fieldtrip starts from the Bletterbach gorge (Bozen/Bolzano Province), crosses the area of Nonstal/Val di Non and Etschtal/Valle dell'Adige and ends in the Lavini di Marco dinosaur tracksite (Rovereto, Trento Province) (Fig. 1). The fieldtrip illustrates the early Permian to Early Jurassic tectono-stratigraphic evolution of a distinctive sector of the Southern Alps. The first day mainly concerns the Permian period. In the Bletterbach Gorge we will follow the evolution of this sector of the Alps from the uppermost portion of the Athesian Volcanic Group (Auer/Ora Formation; early Permian) to the Gröden/Val Gardena Sandstone (late Permian) fluvial deposits. During the second day we will move up from the Permian formations (Lana neighbourhood) to the Middle Triassic of the Gampenpass/Passo Palade observing a nearly complete stratigraphic succession. During several stops on the road from Lana to the pass (S.S. 238) we will see the different members of the Induan-Olenekian marine Werfen Formation, the carbonate and terrigenous Anisian units (Lower Sarl/Serla Dolomite, Piz da Peres Conglomerate, Voltago Conglomerate and Richthofen Conglomerate), the following upward mixed carbonate/terrigenous units (Gracilis Formation, Giovo Formation) and the late Illyrian carbonate platforms deposits (Contrin Formation). In the afternoon we will climb up Mt. Roen and, nearby Rifugio Oltradige (Hütte), we will stop by a spectacular outcrop of the Carnian Travenanzes Formation. From here we will also have a dramatic view of the western and central Dolomites that will be the focus of a session dedicated to landscape/panoramic geology. The last day is devoted to the Lower Jurassic of the Calcari Grigi Group and particularly to the Hettangian-late Sinemurian units (Monte Zugna Formation and basal portion of the Rotzo Formation). We will have a trip to the Lavini di Marco site, exploring its geology and popular dinosaur trackways, and have the chance to talk about historical and present day reseach on the fossil plants of the Rotzo Formation.

Day 1: The late Permian (Lopingian) flora and fauna of the Bletterbach

The Bletterbach Gorge is located southeast of Bozen/Bolzano and is, since 2009, part of the Dolomites UNESCO. The beauty of the landscape, the colors of the rocks – especially on a late summer or autumn evenings – are exquisite and have given the gorge the nickname of "Gran Canyon of South Tyrol". The Bletterbach is easily visible through walking paths that are used from spring to autumn (extimated 60.000 visitors each year); events and guided tours are coordinated by the visitor center of the Geoparc Bletterbach. The

Fig. 1: Excursion route of the field trip with the main stops of the three days.

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.

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

At the bottom of the Bletterbach Gorge is exposed the upper part of the Auer/Ora Formation (Fig. 2), the youngest volcanic unit of the Athesian Volcanic Group, earlier termed "Bozner Quarzporphyr". The top of 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 composed 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 matrix. Due to smaller phenocrysts and crystal fragments this groundmass appears heterogenous (Morelli et al., 2007). Fiamme formed of dark aphanitic or juvenile porphyric inclusions occur frequently. A regular network of subvertical joints and 8–10 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

Fig. 2: The lower sector of the Bletterbach showing the narrow valley with the steep slopes incised in the rhyolitic ignimbrites of the Auer/Ora Formation of the Athesian Volcanic Group.

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/Val Gadena Sandstone is exposed along the main gorge between the descent trail from the visitor centre and the waterfall (Fig. 3). By optic levelling of the top rhyolite between the main gorge and its tributaries, an upfilled palaeorelief of about 30 m can be reconstructed.

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

The lowermost part of the Gröden/Val Gadena Sandstone represents a ~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 made 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

Fig. 3: Boundary (unconformity) between the Auer/Ora Formation and the Gröden/Val Gardena Sandstone.

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 (for more details see Roghi et al., 2014) 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 features are up to 3 m thick petrogypsic and 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 of 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. 4). 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. 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, calcisols or vertisols, respectively. 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

Fig. 4: Example of outcrop with mature gypsisols (from Roghi et al., 2014). (A) Gypsisol with few and scattered nodules at the base. To the top gypsum nodules become common, coalesce and form a massive petrogypsic horizon. (B) Prominent gypsisol showing pseudo-anticlinal structures (gilgai relief) highlighted by secondary gypsum veins. The lower part comprises gypsum nodules of a petrogypsic horizon. (from Roghi et al., 2014)

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 shows a lateral-accretion macroform (LA) sensu Miall (1985). The lateral accreting sand body is interpreted as point bar sheets that 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).

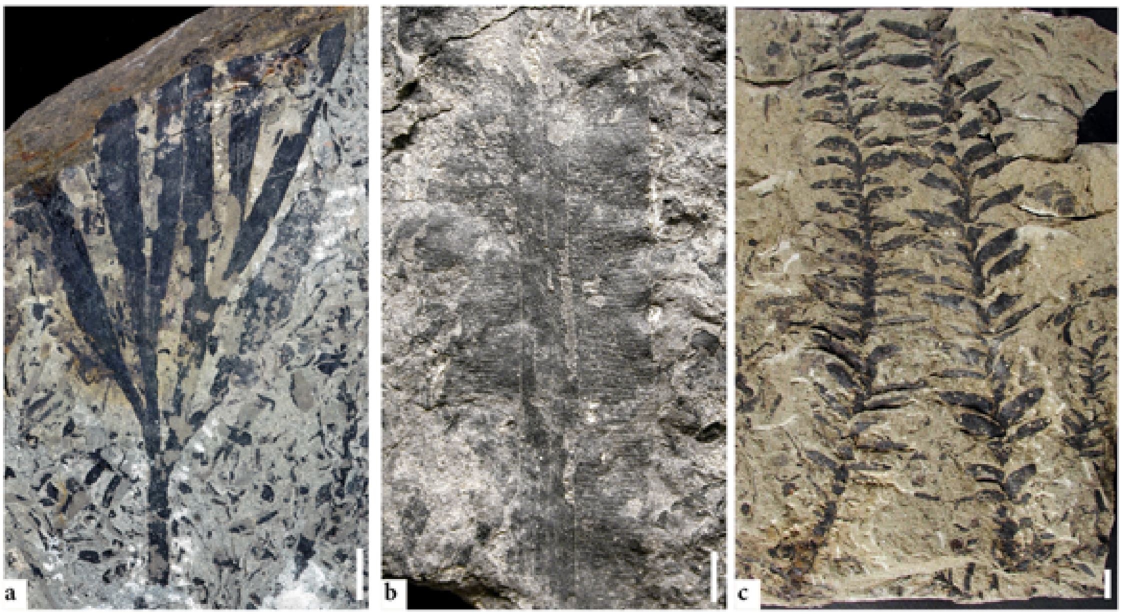
The short-term ingression evidenced by the Cephalopod Bank shifted this channel-floodplain system towards the West, and the Bletterbach area was transformed into a coastal-deltaic area. At the waterfall a ~3 m thick intercalation of thin silty sandstones and dark grey to black clays is exposed below the Cephalopod Bank (Fig. 5). 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 remains (the so called "cuticle horizon" of Clement-Westerhof, 1984, 1986, 1987; Poort & Kerp, 1990) suggest deposition under subaquatic conditions. The vertical succession of lithofacies can be best explained within a fluvio-deltaic setting. The succession around the waterfall is considered to represent the transition from a floodplain to an interdistributary bay and to a delta plain back to floodplain (for more details see Roghi et al., 2014).

Stop 5, Plant fossils around the Cephalopod bank

The first mention of plant fossils from the Bletterbach Gorge was by Perwanger (1946), who cited a "*Lepidodendron*-Stengel". Later, Leonardi (1948, 1968) figured "*Lepidodendron* cf. *sternbergi* Lindley et Hutton, *Schizolepis permensis* Heer, *Lepidodendron* cf. *veltheinianum* Sternberg, *Lepidodendron* sp., *Lebachia* (=*Walchia* auct.) *laxifolia* Florin and *Lebachia* (?) sp." (Leonardi, 1948); most fragments were badly preserved. Researchers from Utrecht University started a detailed study in the area finding horizons yielding plant fragments with exceptionally preserved cuticles attribuited to several conifer and seed fern taxa: *Ortiseia leonardii* Florin, 1964, *O. jonkeri* Clement-Westerhof, 1984, *O. visscheri* Clement-Westerhof, 1984, *Dolomitia cittertiae* Clement-Westerhof, 1987, *Majonica alpina* Clement-Westerhof, 1987, *Pseudovoltzia liebeana* (Geinitz) Florin, 1927, *P. sjerpii* Clement-Westerhof, 1987 and *Peltaspermum martinsii* (Germar) Poort et Kerp, 1990. Bulk macerations revealed a flora dominated by conifers with seed ferns and ginkgophytes as additional elements (Kerp & Kustatscher, 2005) with a high percentuage of gymnosperms, related to taphonomic selection. Several hundreds of better preserved plant remains were collected between 2003 and 2011 during a project of the Museum of Nature South Tyrol and the Geoparc Bletterbach. The plant fossils were assigned to 33 distinct fossil taxa, including foliage, stem fragments, fructifications, and dispersed seeds of sphenophytes, seed ferns, taeniopterids, ginkgophytes and conifers (Fig. 6) (Kustatscher et al., 2012, 2014a; Bauer et al., 2014; Roghi et al., 2014). Ginkgophyte leaf fragments are the dominant element (51%) including *Baiera digitata* (Brongniart) Heer, 1876, *Sphenobaiera* sp., putative *O-ha-tsuki*- type fertile leaves, seeds, and several leaves of uncertain affinities (Fischer et al., 2010; Bauer et al., 2014). The conifers represent the second most common plant group (~40% of the flora) with *Ortiseia leonardii* Florin, 1964, *Ortiseia visscheri* Clement-Westerhof, 1984, *Quadrocladus* sp. and *Pseudovoltzia* sp. The seed fern are rare in the flora (*Sphenopteris suessii* Geinitz, 1869, *Sphenopteris* sp., *Germaropteris martinsii* (Germar in Kurtze, 1839) Kustatscher et al., 2014 (Poort & Kerp, 1990; Kustatscher et al., 2014a) as are taeniopterid leaf fragments (< 1.5%) and horsetails (0.2%). The plant remains show also indications of plant-animal interactions (Roghi et al., 2014), although with a low frequeny of insect damage patterns.

Fig. 5:
The Cephalopod Bank in the Bletterbach Gorge.

Fig. 6:
(a) Leaf of *Baiera digitata*;
(b) Leaf fragment of *Taeniopteris* sp. B.
(c) Shoot fragment of *Ortiseia leonardii*;



Stop 6, The tetrapod footprints of the Bletterbach Gorge

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 (e.g., Leonardi 1951, 1953, 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 Loapingian tetrapod association (just to cite a few international fieldtrips run in this locality see Conti et al., 1986, Pittau et al., 2005; Gianolla et al., 2010; Roghi et al., 2014).

Thirtheen footprint-bearing horizons were recognized 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 hundred meters upstream the waterfall. To date, only footprints document the presence of tetrapod vertebrates, since no skeletal remains have been found. The ichnoassemblage is however abundant and shows a high diversity allowing a detailed reconstruction of the 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).

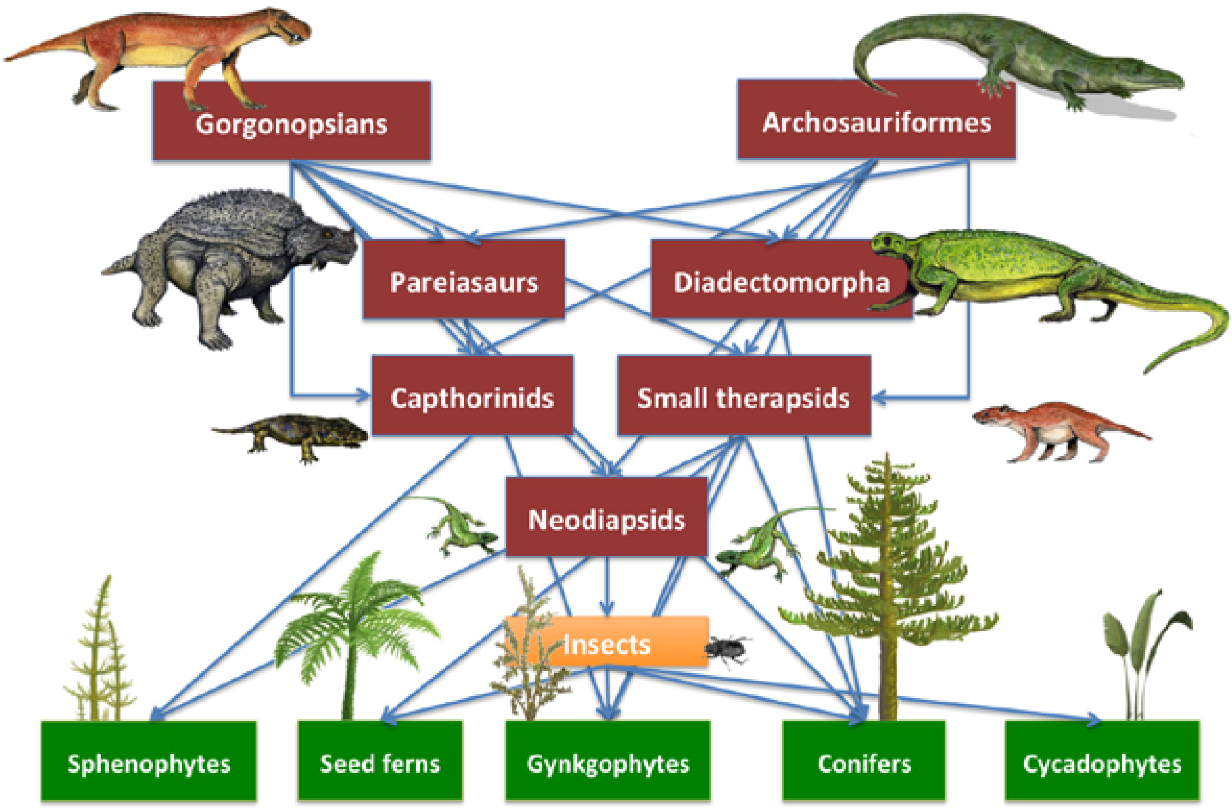


Fig. 7: The Gröden/Val Gardena Sandstone trophic network as derived from the study of vertebrate ichnoassociation, fossil plants and plant-arthropod interaction (from Roghi et al., 2014)

The ichnofauna counts thirteen ichnotaxa belonging to various groups of synapsid (therapsids), parareptiles (pareiasaurs), eureptiles (capthorinids and neodiapsids as younginiformes), and archosauriformes (see Conti et al., 2000; Avanzini et al., 2011; Bernardi et al., 2015). The Bletterbach ecosystem was characterised 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. 7) (Bernardi et al., 2014).

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). *Pachypes* is the only known footprint convincingly referred to pareiasaurs (Valentini et al. 2009). About 40 specimens (tracks and trackways) are known to date from this site, all preserved as natural casts (Fig. 8). The other exceptional features of the Gröden/Val Gardena Sandstone outcropping in this area are

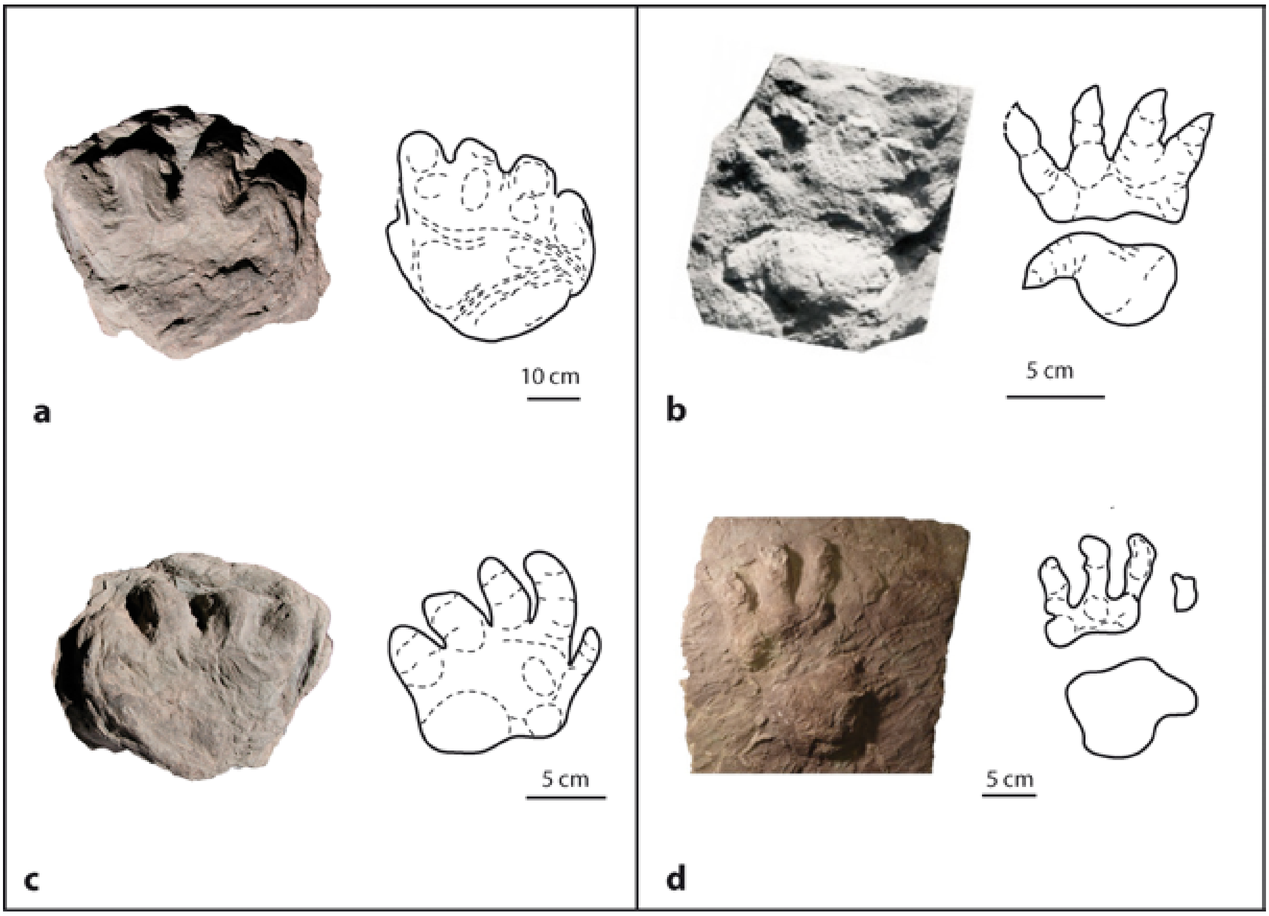


Fig. 8: Two key features of the Bletterbach ichnofauna. a, c: The well preserved pareiasaur tracks *Pachypes dolomiticus* Leonardi et al., 1975, abundant in the Gröden/Val Gardena Sandstone succession. b, d: Two chirotheriid footprints attributed to archosaurian trackmakers, from Leonardi et al. (1975); Conti et al. (1977); Valentini et al. (2009); Bernardi et al. (2015).

chirotheriid footprints (Conti et al., 1977; Wopfner, 1999; Bernardi et al., 2015). These tracks, assigned to "Chirotheriid indet." or to cf. *Protochirotherium*, can be confidently attributed to archosauriform trackmakers (Bernardi et al., 2015). Archosauriforms radiated from the Lower Triassic, but the occurrence of chirotheriid tracks in the upper Permian (Lopingian) of the Dolomites indicates that derived archosauriforms were already present before the PT-boundary. Together with the occurrence of the recently discovered fragmentary archosauriform *Eorasaurus* from the upper 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, 2015), further highlighting the scientific relevance of the Bletterbach palaeontological site worldwide.

Day 2 morning: The Triassic of the Nonstal/Val di Non area

The area crossed by the field trip on the second day is interested by a monoclinal, gently dipping towards Southwest (Fig. 9).

In this geographic sector volcanic and sedimentary units regularly overlap each other (Avanzini et al., 2001, 2007, 2012). An important tectonic lineament (Völlan/Foiana Line) borders to the west the Gallberg/Monte Gall-Shonegg/Macaion block bringing into contact the sedimentary units of the Etschtal/Valle dell'Adige with the volcanic Laugen Spitze/Monte Luco units (Fig. 10). Close to the Völlan/Foiana Line the monoclinal is characterised by a series of narrow folds with subvertical flanks and axis parallel or gently dipping (en-echelon) with respect to the master fault. A low-angle fault set in the Middle Triassic clastic units cuts the summit portion of Gallberg/Monte Gall and is connected to the Völlan/Foiana Line along the Brandis creek. The Southern Alps succession of this sector includes units from the metamorphic basement of Variscan age up to the Middle Triassic sedimentary units (essentially marls and limestone). The Southern Alps basement, buried beneath the alluvial deposits of Adige River near Lana, is composed of quartz-phyllite intruded by lower Permian plutons and dykes (Monte Cross Granodiorite near Lana). The basement is covered by a thick lower Permian volcanic succession (1500–2000 m), recently mapped as Athesian Volcanic Group, coheval and comagmatic with the above mentioned intrusions. The Permo-Mesozoic sedimentary cover has a relatively reduced thickness in comparison to the Western Dolomites and Venetian Prealps. Furthermore, they are characterised by several gaps, particularly in the Triassic (upper Ladinian–Carnian) with peculiar sedimentological features. The area between the Etschtal/Valle dell'Adige and the Giudicarie, of which the Mendel/Mendola–Schönegg/Macaion chain represents the northernmost sector, is interpreted as a relative structural high for the whole Mesozoic. The substrate is followed by a Pleistocene-Holocene cover articulated in a variety of diverse geological bodies mainly related to the glacial dynamics that during the Quaternary strongly controlled the geological evolution of this area. These deposits are well represented in the lateral valleys, where they establish complex heteropic and overlapping relationships (Avanzini et al., 2013).

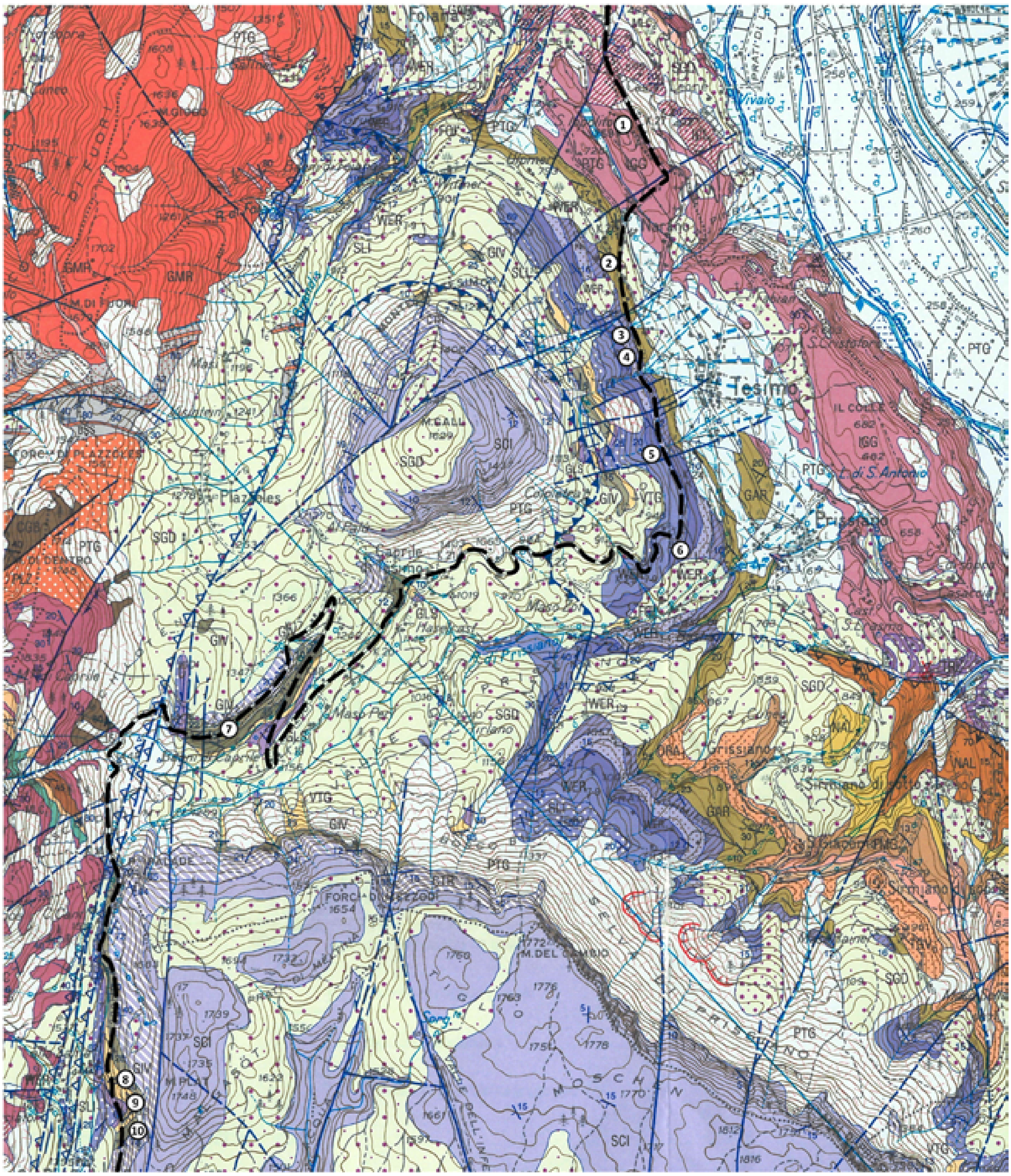


Fig. 9: The Nonstal/Val di Non and the excursion route. It mainly follows Avanzini et al. (2013).

Stop 1, The San Ippolito hill and the lower Permian volcanic rocks

The hill is modelled within the Gargazzone Formation and shows clearly the effect of the extensive glacial exaration related to the last Wurmian pleniglacial. The bump is constituted by a wide exposed surface of sheepback rocks. Volcanic rocks are represented by black to dark grey

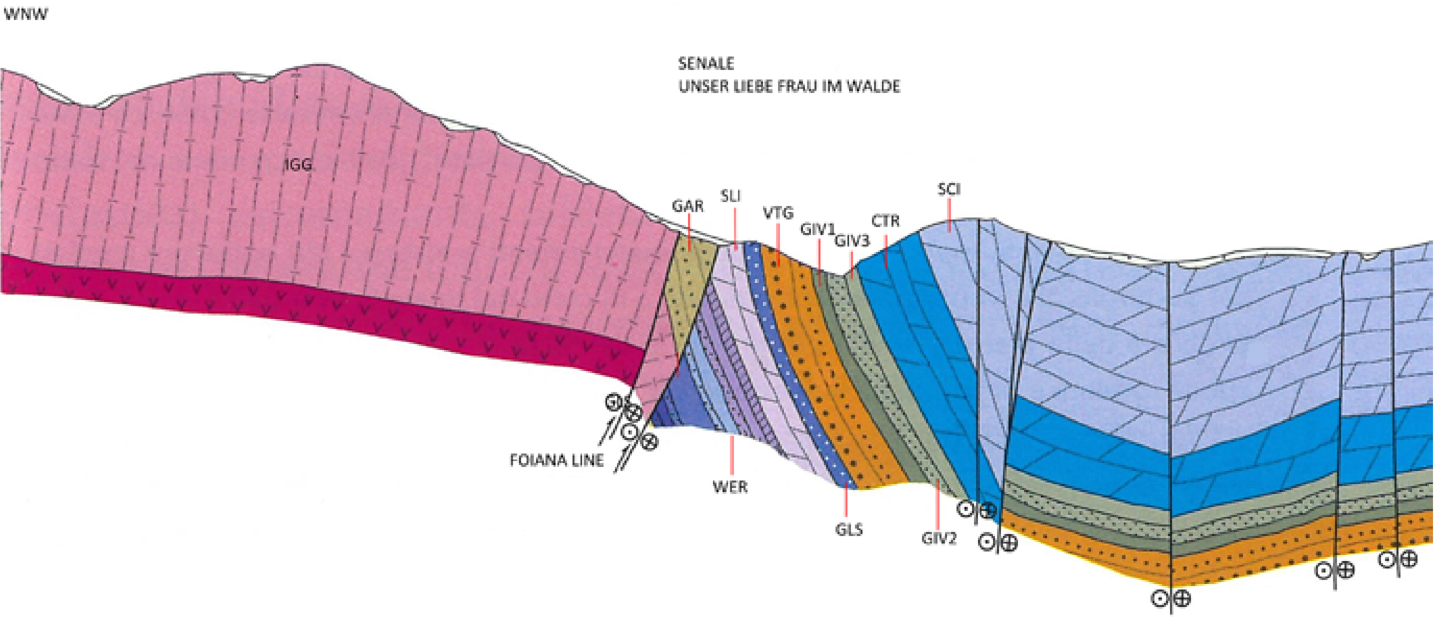


Fig. 10: Geological section across the Völlan/Foiana Line near the Gampenpass/Passo Palade.

Fig. 11:
The top of the Permian volcanites: The Gargazzone Formation at San Ippolito Hill.

Fig. 12: Outcrop at the base of the Gröden/Val Gardena Sandstone near Narano.

pyroclastic ignimbrite with red-to-violet tones along the cracks due to its progressive oxidation. The surfaces exposed to subaerial weathering show colors varying from light grey to orange. From a stratigraphical point of view we are at the top of the lower Permian volcanites (Fig. 11). The wide plateau that extends toward S–SE, including the village of Tisens/Tesimo, marks the top of the volcanic succession, cropping out in the lower escarpments that overlook the Etschtal/Valle dell'Adige. The boundary between the volcanites and the upper sequences is marked by a regional erosional unconformity; the clastic deposits of the Gröden/Val Gardena Sandstone therefore cover different stratigraphic units of the Athesian Volcanic Group.

Stop 2, The lower portion of the Gröden/Val Gardena Sandstone

Here the typical lithofacies of the lower Gröden/Val Gardena Sandstone are characterised by grey-to-white sandstones intercalated with levels of coarser sandstone and microconglomerates (Fig. 12). Fining upward sequences of medium-to-coarse sandstone, with low-angle cross lamination can be recognized. They are organised into thin lenticular units marked by a sharp erosional base. In the basal portion these units show conglomerate lenses made by centimetre-sized quartz clasts. The depositional environment of this portion of the Gröden/Val Gardena Sandstone can be referred to a proximal fluvial system constituted by a net of shallow channels characterised by low sinuosity.

Stop 3, The top of the Gröden/Val Gardena Sandstone and the base of the Werfen Formation

The top of the Gröden/Val Gardena Sandstone, between the Etschtal/Valle dell'Adige and the Giudicarie, is characterised by red, grey and whitish sandstone alternating with red or grey siltites organised in sandy bars and channel-fill sandstone bodies (Fig. 13). The topmost 3–3.5 metres of the formation are made by an alternation of black sandstone and arenaceous dolostone with mm- to cm-sized interlayers of silty marls. Above the last sandy bank lies a succession of finely stratified reddish pelites (< 1m). Carbonate intraclasts and nodules ("caliche"), related to the occurrence of paleosols at the top of the unit, are clearly visible within this pelitic succession. A sandy-to-silty unit with ripple marks covers the top of the formation. This unit is 1 m thick and is constituted by a dense alternation of pelites and fine sandstone; the dominant sedimentary structures are current- and wave-generated ripples. Bioturbation is represented by vertical burrows. This shallow water unit is followed, through an erosional surface, by sandy deposits and finally by the oolitic layers of the basal Werfen Formation (Tesero Member; Induan *p.p.*). This interval replaces the Bellerophon Formation along the northwestern Etschtal/Valle dell'Adige (Cassinis et al., 1993).

Fig. 13: The upper part of the Gröden/Val Gardena Sandstone.

Stop 4, The base of the Werfen Formation

The base of the Werfen Formation (late Changsingian–Olenekian *p.p.*) is represented by the Tesero Member (Induan *p.p.*), grey-yellowish to brown coarse-grained dolostone with a clear oolitic texture (Fig. 14). At the base, the banks are massive and up to 50–60 m thick, showing an internal subdivision in thinner layers welded by stilolitic joints. The depositional environment of the Tesero Member is shallow marine (subtidal) allowing the development of oolitic bodies and their reworking by the wave. Temporary changes in the hydraulic regime toward milder hydrodynamic conditions allowed the settling of the finer horizons.

Above the massive banks, the Tesero Member gradually changes into an alternation of grey-yellowish marly limestone and marls. The marly limestone, organised in cm-thick laminae or more rarely into dm-thick layers, contain a small quartzitic-micaceous silty fraction, often bioturbated and with nodular structures. These layers are intercalated with marly limestones and marls with graded bioclastic lenses. In both lithotypes parallel lamination is frequent, while low-angle cross lamination is rare. These layers correspond to the Mazzin Member that reflects a different depositional environment with muddy seabeds and low hydrodynamic energy.

Stop 5, From the Andraz Horizon to the Campil Member (Werfen Formation)

In this stop the Andraz Horizon (Induan *p.p.*) is formed by a dense alternation of yellowish marly or marly-silty evaporitic dolostones and reddish siltstones. This horizon is approximately 7 m thick and completely devoid of fossil remains. The lower boundary is marked by sudden increase of the silty fraction. The dolostones are arenaceous

Fig. 14: The basal part of the Tesero Member within the Werfen Formation.

and granular. Vacuolar texture is common in all horizons and the surface beds are characterised by desiccation cracks (mud-cracks, small teepees). The depositional environment is reconstructed as an arid tidal flat with fluctuations of inter-supratidal conditions. This is the first peritidal episode of the Werfen Formation and marks the top of the first of four major sedimentary cycles with regressive trend documented within the formation itself. The overlying Seis/Siusi Member (Induan *p.p.*-Olenekian *p.p.*) is made of an alternation of grey and/or reddish marly and marly-silty limestones, sometimes bioturbated, with oolitic-bioclastic calcarenites ("*Gastropoden-Oolith*"). The calcarenites (grainstone and packstone) are made of oolites, bivalves and microgastropods; more rarely they are characterised by a high percentage of recrystallized peloids (packstone). The pelitic lithotypes constitute cm-sized laminae or more rarely they form massive banks about 1 m thick while calcarenites layers are cm to dm-sized. An evaporitic horizon occurs at the top of the unit, composed of some metres thick reddish to yellowish silty dolostones and siltstones. They represent the upper boundary of the unit that ends the second sedimentary cycle with a regressive trend documented within the formation. The depositional environment is a shallow marine seabed, characterised by high wave and recurrent storm events that allowed the deposition of bioclastic sandstone.

Above is the Gastropods Oolith (Olenekian *p.p.*), made up of reddish oolithic-bioclastic calcareous sandstones rich in bivalves and small gastropods. Strata are few cm to 10 cm thick and are intercalated with gray marls and breccia horizons ("*Koken-conglomerat*"). Bioturbation is frequent. Total thickness of the member is 20–25 meters.

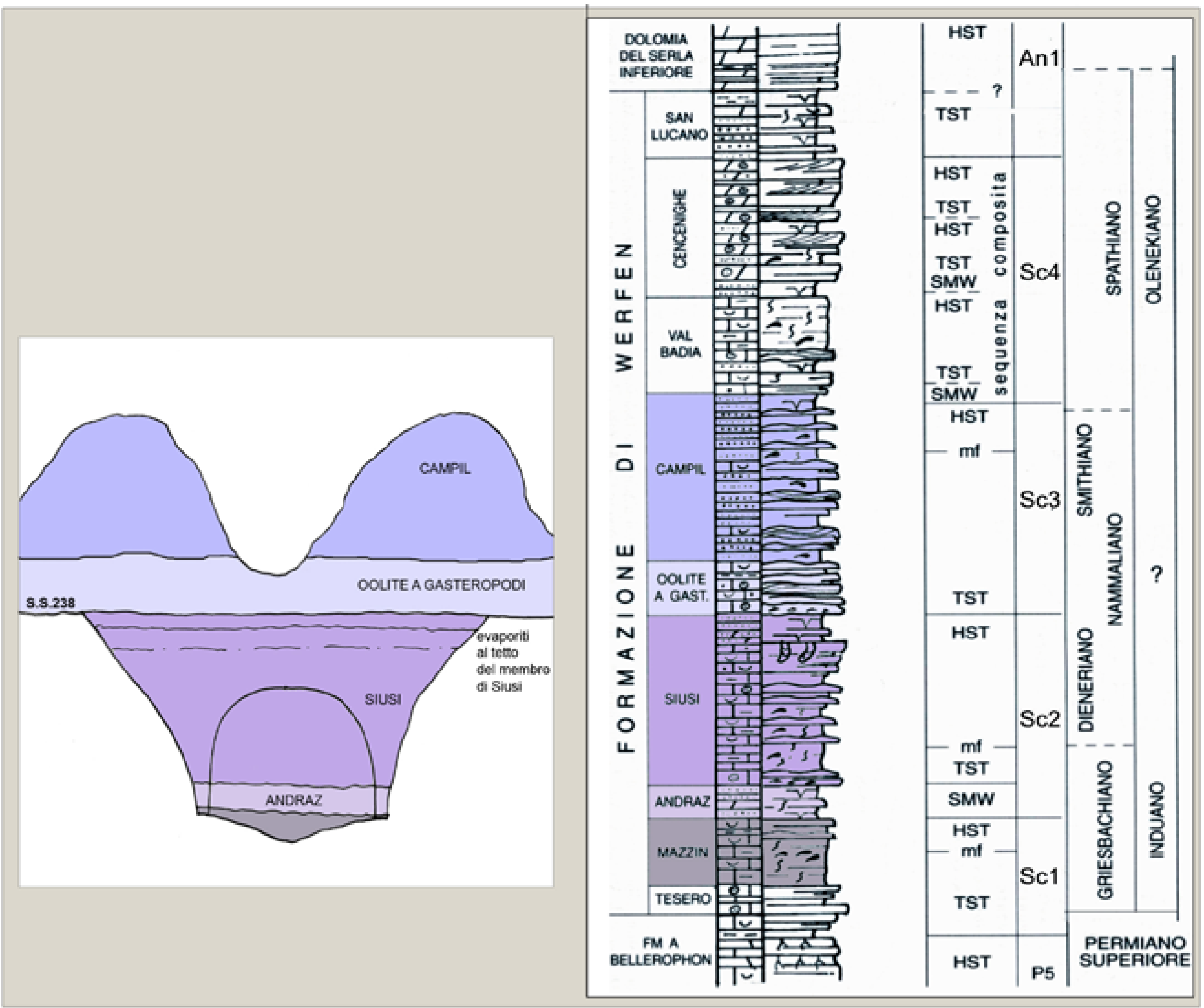


Fig. 15: Part of the Werfen Formation outcropping at the bridge at km. 24 of the S.S. 238.

The depositional environement is reconstructed as a shallow sea, above wave base. In the upper part of the succession a gradual transition to the Campil Member (Olenekian *p.p.*) crops out. It is marked by an alternation of decimetric red sandstones and reddish siltstones or silty marls. The latter are organised in cm-sized layers. The sedimentary structures encompass different types of cross- and parallel-lamination, and load structures (ball-and-pillows). The depositional environment is a muddy seabed, below the wave base level but always less deep than the underlying members (Fig. 15).

Stop 6, The Anisian successions

The Anisian succession is constituted by terrigenous and terrigenous-carbonate units essentially deposited in basinal, lagoonal, peritidal and continental environments. Three terrigenous, mainly conglomeratic, units of subsequent ages (Piz da Peres Conglomerate, Voltago Conglomerate and Richthofen Conglomerate, each representing the base of a third-order sequence) are followed upward by some mixed carbonate/terrigenous units (i.e. Gracilis Formation, Giovo Formation) and by carbonate platforms deposits (Contrin Formation) (Figs. 16, 17).

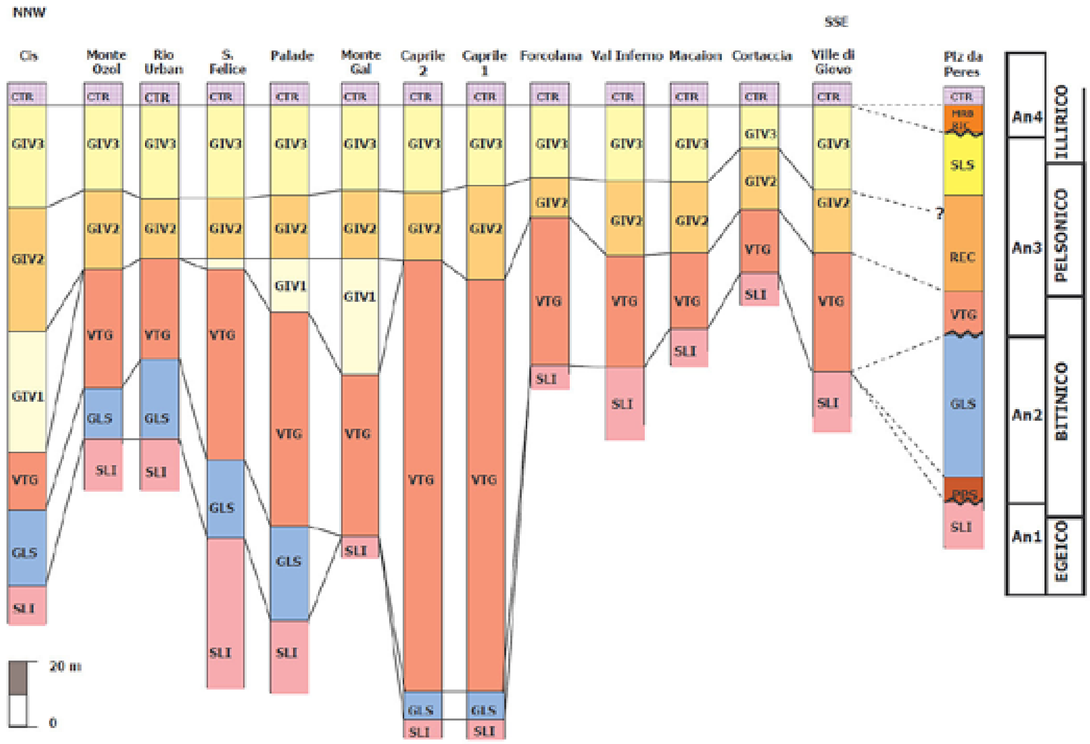


Fig. 16: Stratigrafic section of the sedimentary units of Anisian age between Nonstal/Val di Non and Etschtal/Valle dell'Adige and their correlation with those of the northeastern Dolomites. SLI – Lower Sarl/Serla Dolomite; PPS, Piz da Peres Conglomerate; GLS – Gracilis Formation; VTG – Voltago Conglomerate; GIV1 – Gampenpass/Passo Palade Member of the Giovo Formation; GIV2, Kurtatsch/Cortaccia Member of the Giovo Formation; GIV3 – Monte Ozol Member of the Giovo Formation; REC – Recoaro Limestone; SLS – Upper Sarl/Serla Dolomite; RIC – Richthofen Conglomerate; MRB – Morbiac Limestone; CTR – Contrin Formation.

The Lower Sarl/Serla Dolomite (late Olenekian-early Anisian) is composed of stratified light-grey dolostones (10–30 cm thick) with stylolites. The dolostones are intercalated with marly horizons following the cyclicity in a peritidal environment, with inter-supertidal horizons marked by reddish surfaces. The depositional environement is a shallow tidal flat. The boundary with the overlying Gracilis Formation (Bitinian–early Pelsonian) is marked by an erosional surface (paraconformity); the Gracilis Formation is a carbonate-terrigenous sequence made by intercalations of calcareous-marly dolostones and slightly nodular bioclastic calcareous sandstones. Its upper part (ca. 40 meters) is made of grey-yellow silty limestones. The boundary with the Lower Sarl/Serla Dolomite is sharp and easily recognisable, being marked by also by colour change from white dolostones below to the grey lithofacies above. The Piz da Peres Conglomerate of the eastern Dolomites is missing. The Gracilis Formation documents a depositional environment with tidal flats and small carbonatic platforms near coastal environments with predominantly terrigenous sedimentation (Fig. 17).

The middle Anisian (Pelsonian) palaeogeographic and stratigraphic setting of the Southern Alps is complex. The sedimentary units show a great variability in thickness and facies associations (Fig. 18). Along the Etschtal/Valle dell'Adige, the Pelsonian units show a wide lateral continuity and thickness, the base of which is constituted by Voltago Conglomerate (?Bithynian–earliest Pelsonian), which can be up to 130 m thick and finally the Giovo Formation.

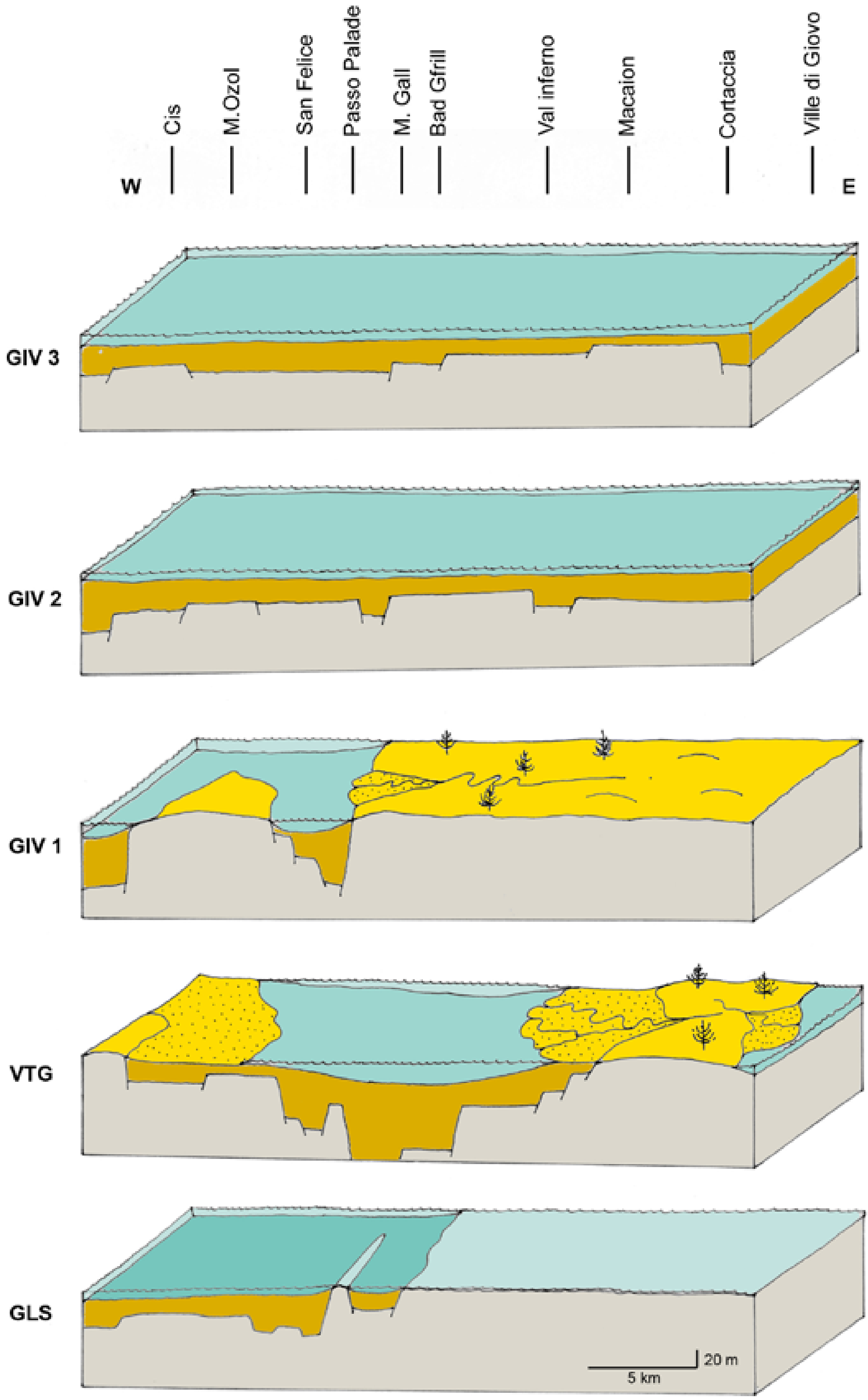


Fig. 17: Early–middle Anisian paleogeographic evolution of the Nonstal/Val di Non and Etschtal/Valle dell'Adige.

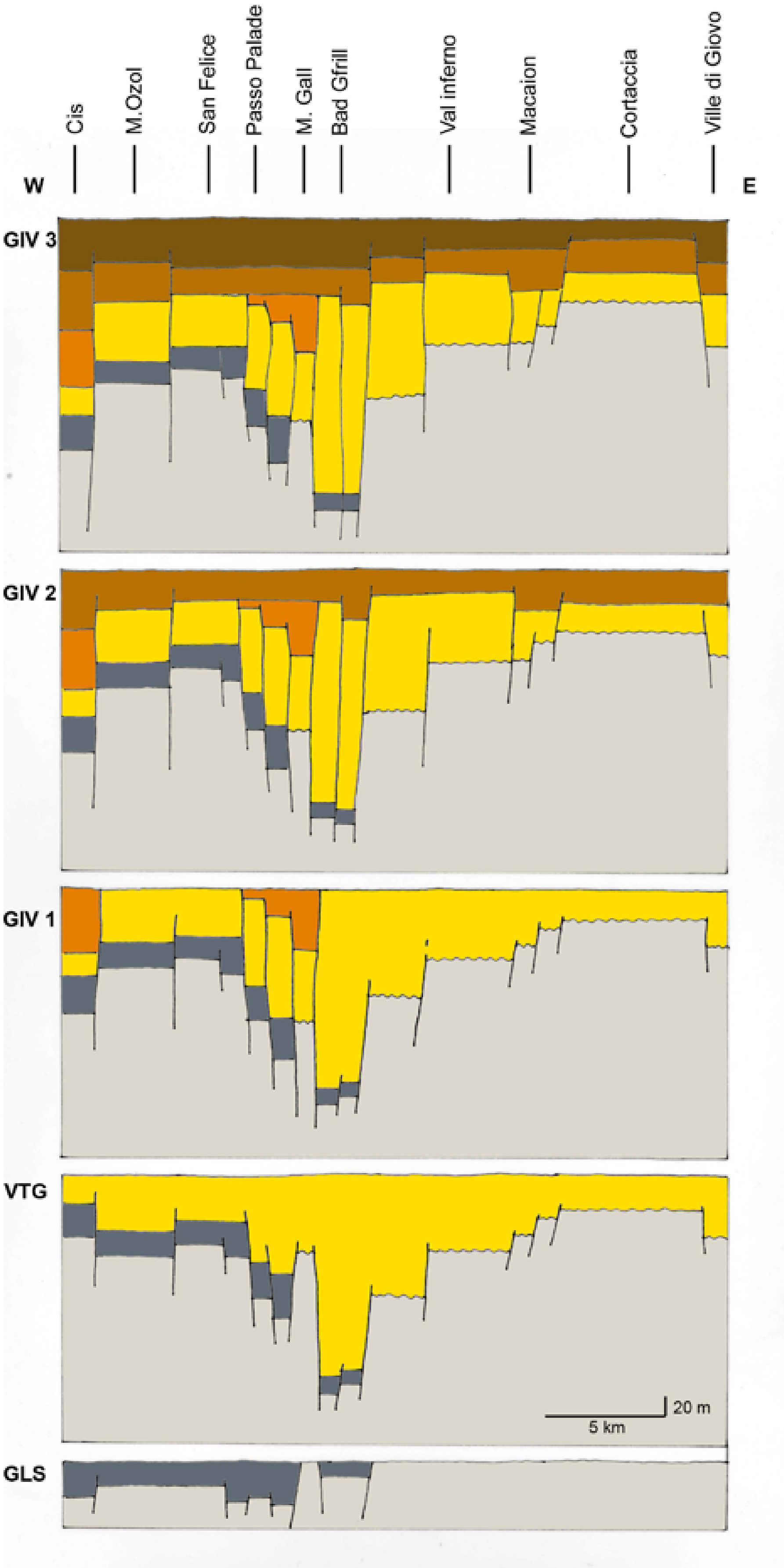


Fig. 18:
Correlation scheme between the formations of the lower–middle Anisian and the sinsedimentary evolution of Nonstal/Val di Non and Etschtal/Valle dell'Adige.

The last Anisian carbonate platform is constituted by the Contrin Formation (late Illyrian). In the Etschtal/Valle dell'Adige and surrounding areas the Pelsonian sedimentary units are thick and laterally extended while the Illyrian terrigenous successions are represented only locally and by thin and immature conglomerates. The great carbonate platforms of the Dolomites are almost completely absent.

Stop 7, The Giovo Formation

The Giovo Formation is a composite formation of up to 140 m thickness, typical of the Etschtal/Valle dell'Adige. It can be distinguished in three members: Gampenpass/Passo Palade Member (GIV1), Kortatsch/Cortaccia Member (GIV2), Monte Ozol Member (GIV3).

The Gampenpass/Passo Palade Member (GIV1) represents, locally, the base of the formation. It is made of yellow to gray sandstones with carbonate cement and graded conglomerates with cross lamination. Fossil content, although discontinuous, comprises abundant plant remains and crinoids (*Encrinus liliiformis*, *Dadocrinus gracilis*). The clasts, made of a variety of carbonates, evaporitic dolostones and clastic units derive from the top of the underlying Voltago Conglomerate (Fig. 19). Sandstone horizons can be alternated with grey pelites, often bioturbated and rich in plant remains. Cross lamination at different scale can be recognized together with slumpings. Thickness varies from 0 to 50 m. The depositional environment is marginal marine (foreshore) with high terrigenous imput from the emergent land.

The Kortatsch/Cortaccia Member (GIV2) overlaps or locally replaces the Gampenpass/Passo Palade Member. In the lower portion it is composed of siltstones and grey marls that are rich in plant remains. Above there is an alternation of peritidal limestones and silty-sandstones, similar to the "Calcari scuri del Torrente Framont" (Agordo Formation) described by Pisa et al. (1979). Strata have variable thickness (5–20 cm) and are often heavily bioturbated, resulting in the general nodularity of

Fig. 19: Typical aspect to the Gampenpass/Passo Palade Member at Unsere Liebe Frau im Walde/Senale.

the interval. Above, subtidal limestones are more frequent. They can be represented by bioturbated (nodular) calcareous sandstones, rich in ostracods, crinoids and brachiopods, or by encrinets (e.g., Gallberg/Monte Gall Tunnel, along S.S. 238) (Fig. 20). Thickness of the member ranges from 20 to 50 m. The lowermost horizons are rich in plant remains, invertebrate traces (*Rhizocorallium*) and vertebrate tracks (*Rhynchosauroides, Synaptichnium, Chirotherium*). Calcareous algae (*Diplopora* sp.) and forams (*Glomospira* sp.) are often associated with ostracods, brachiopods (*Tetractinella trigonella, Rhynchonella decurtata, Coenothyis vulgaris*), corals (*Montlivaltia, Thamnasteria* cf. *silesiaca*) and crinoids (*Encrinus liliiformis*, *Dadocrinus gracilis*). The depositional environment can be related with a complex setting of lagoons and shallow seaways with frequent emersion phases that were gradually replaced laterally by an open sea with carbonate sedimentation typical of a subtidal platform.

Fig. 20: Kurtatsch/Cortaccia Member at the tunnel at km 15.9 of the S.S. 238.

Fig. 21: Dark dolomites at the base of the Monte Ozol Member near Gampenpass/Passo Palade.

Fig. 22: *Encrinus liliiformis* fragments in the outcrop near the tunnel of km 15.9 of the S.S. 238.

Fig. 23: Carbonate lithofacies of the Gracilis Formation near the tunnel at km 15.9 of the S.S. 238.

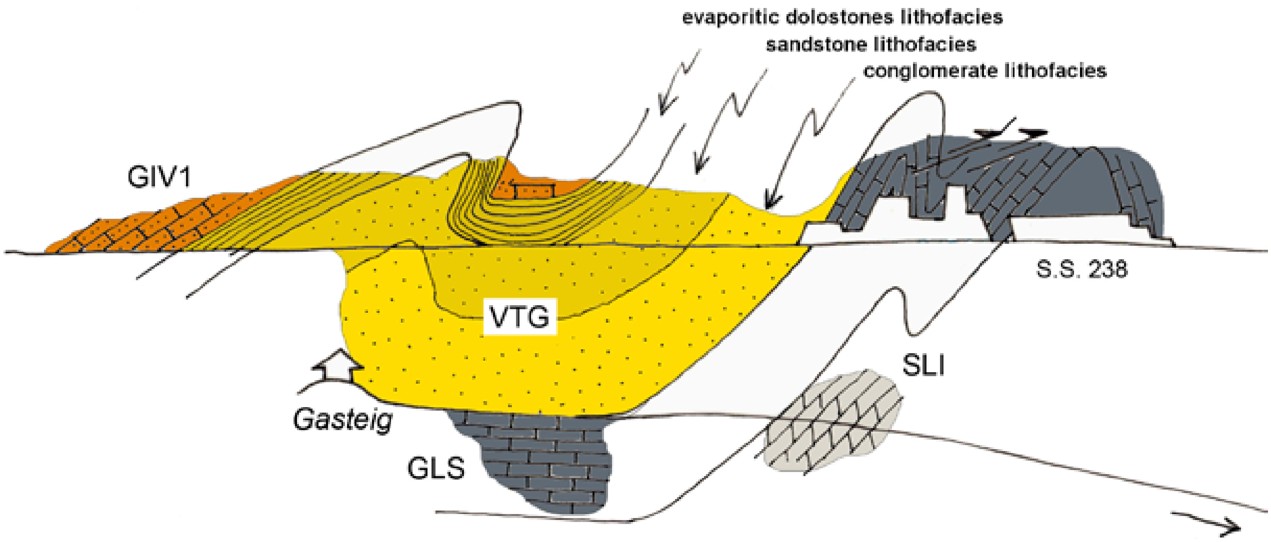


Fig. 24: Scheme of the Anisian outcrops along the S.S. 238 near Sankt Felix/San Felice.

The Monte Ozol Member (GIV3) was considered the base of the Mendel-Dolomit by Richthofen (1874). It is made of dolostones, dark gray bioclastic limestones and calcareous sandstones. They are organized in 10 cm thick strata, moderately bioturbated and are replaced upward by subtidal grey dolostones (Fig. 21). Bioclasts are mostly crinoid fragments, forming locally entire horizons of encrinites. The thickness of the member varies from 10 to 40 m. The boundary with the overlying Contrin Formation can be marked by an erosional surface (e.g., Shonegg/Macaion) and few cm of volcanic clay. These strata can be correlated with the Richthofen Conglomerate that was not deposited in this area. This interval crops out along the road just before the tunnel, where a wide outcrop of white dolostones can be observed.

The Giovo Formation crops out near the tunnel, where a sub-vertical transpressive fault puts into contact the Kurtatsch/Cortaccia Member of the Giovo Formation (in which the tunnel was dug) with its underlying Gampenpass/Passo Palade Member (just above the tunnel). Outside the tunnel the Kurtatsch/Cortaccia Member can be observed with its typical disarticulated crinoid remains (*Encrinus liliiformis*) (Fig. 22).

About 200 meters uphill a second sub-vertical fault borders a sequence of sub-vertical strata dipping eastward. At this outcrop the boundary between the Gracilis Formation (Fig. 23) and the underlying Lower Sarl/Serla Dolomite can be observed. This is the last carbonate unit in the area, before crossing the Völlan/Foiana fault after which the lower Permian volcanites of Laugen Spitze/Monte Luco crops out.

Stop 8, The Voltago conglomerate and the base of the Giovo Formation

The Voltago conglomerate crops out in the high Nonstal/Val di Non and in the Etschtal/Valle dell'Adige along the Mendelkamm/Mendola mountain chain. It was first described by Kreis (1971) and corresponds to the "Mittlere Peresschichten" of Bechstädt & Brandner (1971) (for more details see Avanzini et al., 2001, 2007). The Voltago Conglomerate (Pelsonian *p.p.*) is characterised by discontinuous conglomeratic horizons of up to 2 m thickness. These intervals are chaotic near the base, while towards the top they show gradation and cross lamination. The lowermost portion is composed of white dolomitic clasts (Lower Sarl/Serla Dolomite) in a whitish-yellow matrix. Silty limestones and grey or reddish arenaceous dolostones follow. Upward follows a bioturbated red-grey sandstones that near the top is replaced by an intercalation of stromatolitic dolostones and arenaceous evaporitic dolostones alternated with green or red siltstones with a thickness of ca. 10 cm. Within these horizons thin smectites document the original deposition of volcanic ashes. Parallel (or low angle) laminations, ripples and mud craks are the main sedimentary structures of the unit. Bioturbation is abundant. The conglomerate reaches up to 130 m in thickness. (Fig. 24)

This site yielded an abundant association of tetrapod tracks with *Parasynaptichnium gracilis*, *Synaptichnium pseudosuchoides, Isochirotherium delicatum* and *Rhyncosauroides tirolicus* (Avanzini, 2000, 2002b). Plant remains belong to conifer shoots of the genus *Voltzia*. The depositional environment is terrestrial to marginal marine. In the lower portion of the formation it documents the development of a deltaic system and vegetated swamps, which may evolve in lagoons. In the upper part the environment shifts to a carbonate tidal flat influenced by strong evaporation.

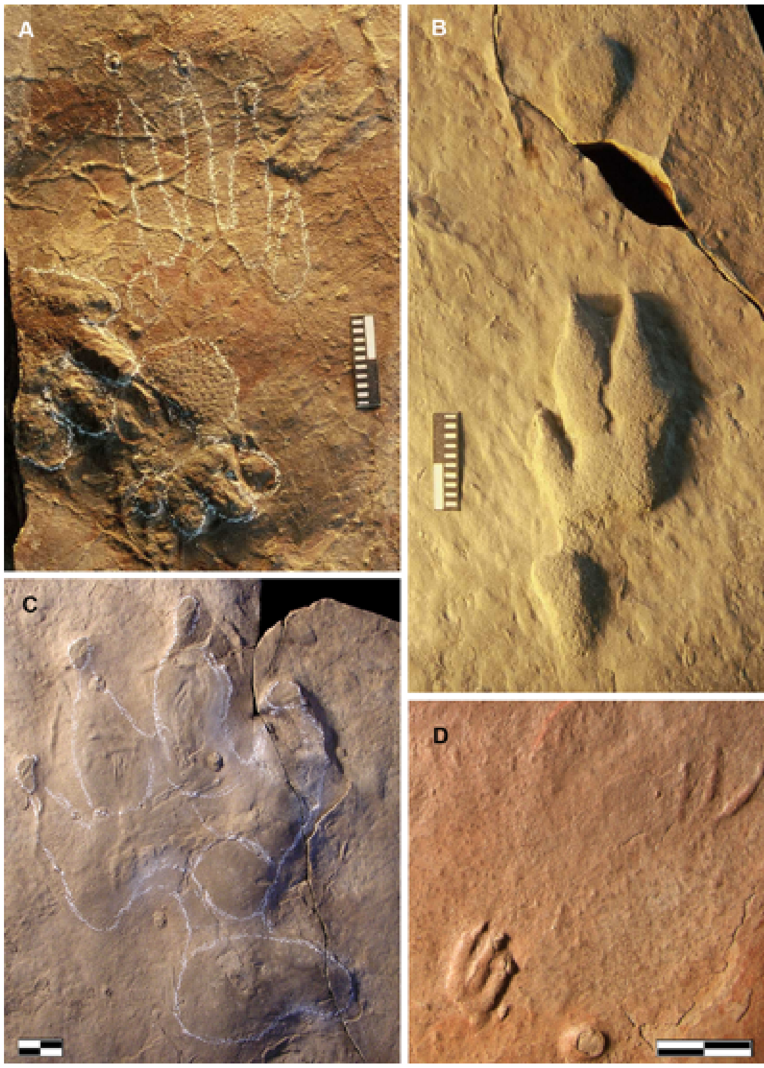
The Voltago Conglomerate is separated from the Giovo Formation (Gampenpass/Passo Palade Member) by an evaporitic lithozone (Fig. 25). The lower portion of the Gampenpass/Passo Palade Member is here visible and represented by cross-laminated yellow-grey sandstones with carbonate cement. Some micro-conglomerates show clasts of evaporitic dolostones which source is the top of the Voltago Conglomerate. The depositional environment is a marginal marine foreshore with a high terrigenous supply from the emergent lands.

Stop 9, The Anisian fauna of Nonstal/Val di Non - Roen

The Anisian formations of the Nonstal/Val di Non and the Mendelkamm/Mendola-Roen mountain chain yielded a well-preserved vertebrate ichno–association that documents the presence of a rich variety of reptile taxa (Avanzini & Neri, 1998; Avanzini, 2000, 2002b; Valdiserri & Avanzini, 2007) (Fig. 26). The footprints found in the Voltago Conglomerate of the northermost sector of Nonstal/Val di Non and Tisens/Tesimo Valley (Gampenpass/Passo Palade, Bad Gfrill/Bagni di Caprile, Unsere liebe Frau in Walde/Senale) can be mostly referred to lepidosauromorph and archosaurian producers. The most abundant morphs can be assigned to the wideaspread ichnogenus *Rhyncosauroides* and most frequently to the species *R. tirolicus* (Avanzini & Renesto, 2002). These document the presence of lepidosauromorph reptiles from 10–60 cm in lenght. Less common, but in all well represented, are medium- to large-sized tracks assigend to the chirotheriid ichnogenera *Synaptichnium, Chirotherium,* cfr. *Brachychirotherium* and *Isochirotherium* (Avanzini & Lockley, 2002; Avanzini & Mietto, 2008a,b). These tracks can be attributed to archosaur producers and document the presence of whole communities of

Fig. 25: Change from red sandstones (on the left) to evaporitic dolomites (on the right) along the S.S. 238.

Fig. 26: Some of the tetrapod footprints of the Voltago Conglomerate: A - *Synaptichnium* sp. with impressions of the skin and *Brachychirotherium* sp. (Unsere Liebe Frau im Walde/Senale); B - *Isochirotherium delicatum* (Unsere Liebe Frau im Walde/Senale); C - *Chirotherium barthi* (Bad Gfrill/Bagni di Caprile); D - *Rotodactylus* sp. (bottom left) and *Rhyncosauroides tirolicus* (top right) (Bad Gfrill/Bagni di Caprile). Scale bar = 2 cm.



trakmakers, distributed along age classes. Reconstruction of the population structure for the trackmaker of *I. delicatum*, for example, was made possible by the discovery, in the Gampenpass/Passo Palade are of hundreds of slabs with exceptionally preserved fossil specimens (Avanzini & Lockley, 2002). Exceptionally, fine anatomical details of the tracks (e.g., skin/scales) were also preserved at times (Avanzini, 1999).

Just few kilometers southeast, in the deep Höllental/Val di Inferno that cuts the eastern flank of Monte Roen, near the village of Tramin/Termeno, other chirotheroid tracks have been described by Avanzini & Leonardi (2002). The unique morphological features allowed the erection of a new ichnospecies: *Isochirotherium infernii*. The track-bearing horizons, of Illirian age, were originally considered to be part of the Morbiac Limestone but are now attributed to the Giovo Formation (Petti et al., 2013). The abundance of these findings and the tight correlation between marine and continental associations allowed developing a tetrapod biochronology scheme for the Anisian in this area (Avanzini & Mietto, 2008a).

All these findings have special ecological interest given the paucity of skeletal remains of Anisian age discovered in the Dolomites are so far. With the exception of few isolated fragmentary remains (see Petti et al., 2013), the record of continental tetrapods is in fact only represented by a well-preserved lepidosauromorph, *Megachirella wachtleri* (Renesto & Posenato, 2003; Renesto & Bernardi, 2014).

Stop 10, The Anisian flora of Nonstal/Val di Non

The oldest flora appearing in the fossil record of the Triassic of the Dolomites shows a highly diversified vegetation dominated by ferns, cycadophytes and conifers. The floras of the Dolomites and Recoaro areas consist of typical Middle Triassic elements such as the osmundaceous ferns (*Neuropteridium*, *Anomopteris*, *Gordonopteris*), herbaceous and subarborescent lycophytes (*Lepacyclotes*, *Lycopia*, *Isoetites*) and conifers (*Voltzia*, *Albertia*, *Pelourdea*; e.g., Broglio Loriga et al., 2002). Seedferns (*Scytophyllum*, *Peltaspermum*, *Sagenopteris*) and cycadophytes (*Bjuvia*, *Nilssonia*, *Dioonitocarpidium*) are common, while horsetails are rare (*Equisetites*; e.g., Broglio Loriga et al., 2002; Kustatscher et al., 2014a).

In the Nonstal/Val di Non the plant remains are represented by stem and strobili fragments of horsetails (*Equisetites conicus* Sternberg, 1833), frond fragments of ferns (*Neuropteridium elegans* (Brongniart) Schimper, 1879, *Gordonopteris lorigae* van Konijnenburg-van Cittert et al., 2006), reproductive organs of cycads (*Dioonitocarpidium*

sp. cf. *Dioonitocarpidium pennaeformis* (Schenk) Rühle von Lilienstern, 1928) and shoot fragments of conifers (*Voltzia walchiaeformis* Fliche, 1908, *Voltzia recubariensis* Schenk, 1868) (Fig. 27).
Although the plant fossils from the Nonstal/Val di Non are very fragmentary and not very well preserved, they however contain some of the typical Anisian elements from the Southern Alps such as the ferns *Gordonopteris lorigae*, *Neuropteridium elegans* and the conifers *Voltzia recubariensis* and *Voltzia walchiaeformis*. It is worth to mention the conifer *Voltzia recubariensis* occurrence, which a typical element of the Anisian floras of the whole Southern Alps (Brack & Kustatscher, 2013). The cycadophyte megasporophyll *Dioonitocarpidium* is also common in the Anisian of the Southern Alps while it appears in the German Basin only with the Ladinian (e.g., Kustatscher et al., 2013). *Equisetites conicus* was so far the first record from the Anisian; this taxon is generally known from the Ladinian of the German Basin and the Carnian of the Alpine area (Kustatscher et al., 2013).

Day 2 afternoon: The Late Triassic of the Roen succession

The Mt. Roen outcrop is located west of the village of Tramin/Termeno (Bozen/Bolzano Province) in the uppermost Höllental/Val di Inferno, at an altitude of 2000 m a.s.l.
The outcrop can be referred to the Travenanzes Formation (=upper portion of the "Raibl Beds" Auct.; Neri et al., 2005). The Travenanzes Formation shows a strong lateral variation in this area, as typical of transitional and coastal environment with interfingering between terminal fan/flood plain and a shallow lagoonal environment with periodic input of continental detritic sediments (D'Orazi Porchetti et al., 2008) (Fig. 28).

Samples of black and grey shales from the lowermost part of the Travenanzes Formation have yielded a remarkable amount of organic matter, mainly composed of amorphous material and sporomorphs (Gennaro, 2007). According to Roghi (2004), the palynological association belongs to the *Granuloperculatipollis rudis* assemblage, characterised by Circumpolles *Partitisporites*

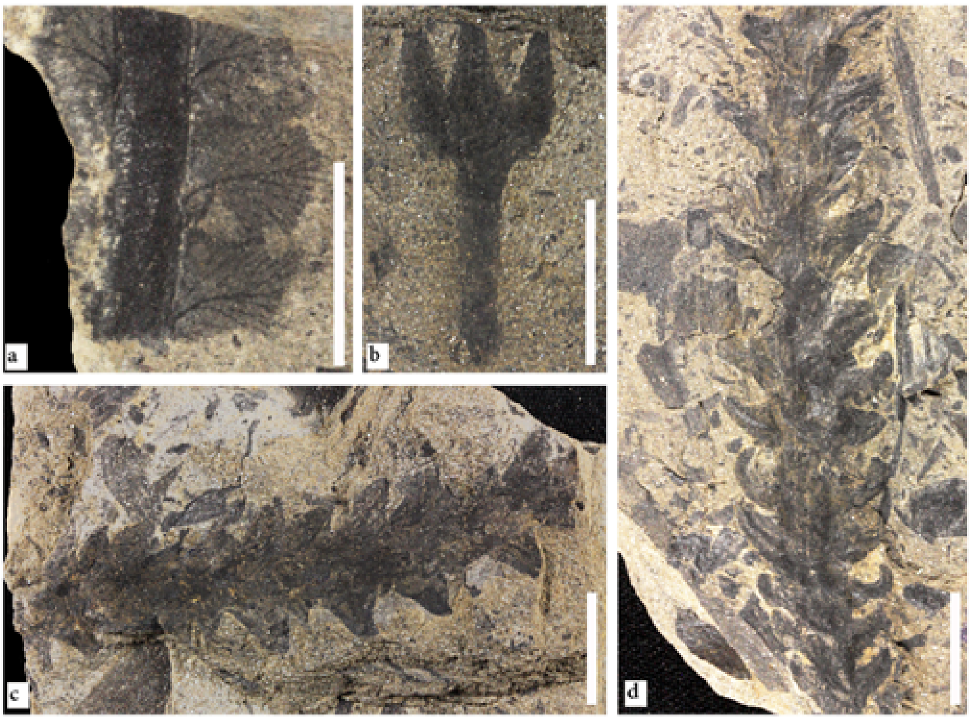


Fig. 27:
Some constituents of the Anisian flora found in this area. a) *Neuropteridium* sp.; b) ovuliferous cone scale; c, d) *Voltzia recubariensis*.
Schenk, 1868

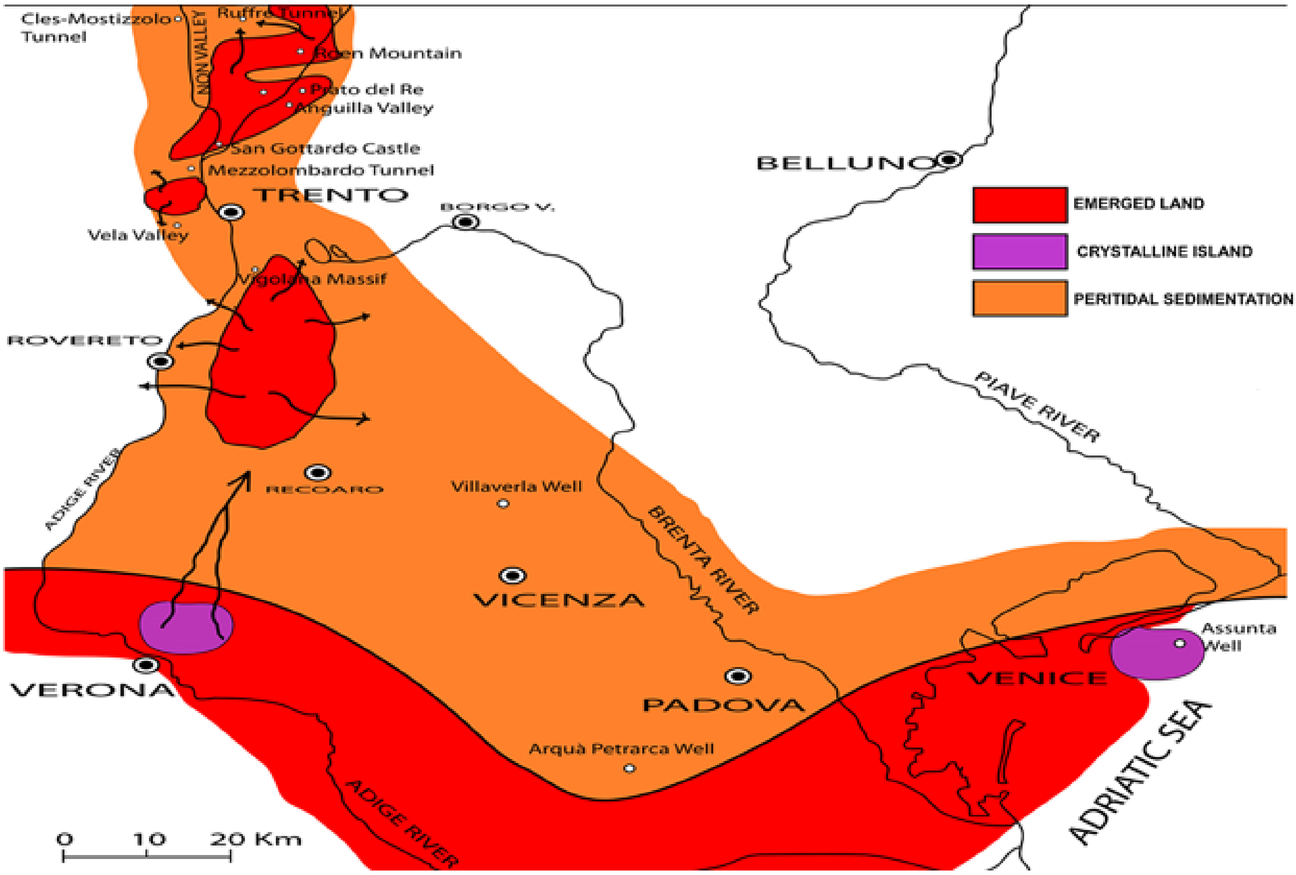


Fig. 28: Palaeogeographic reconstruction of the region during the deposition of the Travenanzes Formation (from Gennaro, 2007).

quadruplicis and *Granuloperculatipollis rudis*. This latter species always occurs with the "long range" elements *Enzonalasporites vigens*, *Pseudoenzonalasporites summus*, *Camerosporites secatus* and *Duplicisporites verrucosus* (Roghi, 2004). Apart from *Partitisporites quadruplicis* all other five species have been found in the collected samples, often in association with *Ricciisporites tuberculatus*. This association indicates a Tuvalian age.

Stop 1, The Travenanzes Formation at Monte Roen

In the Roen area the Travenanzes Formation mainly consists of interbedded white-gray aphanitic to silty dolostones and reddish or greenish shales, with subordinate sandstone to conglomerate intercalations (Fig. 29). This mixed siliciclastic-carbonate succession has been interpreted as representing a marginal marine environment with supplies of terrigenous or fully marine sediments, albeit shallow.

Facies alternations suggest interfingering between alluvial-plain, carbonate tidal flat and shallow-lagoon deposits (Avanzini et al., 2010, 2012; Breda & Preto, 2011). The upper portion of the Travenanzes is organized into meter-scale, and is constituted of shallowing-upward peritidal cycles, not easily distinguishable from those of the overlying Hauptdolomit/Dolomia Principale (Breda & Preto, 2011). In the classical central/eastern Dolomites sections the Travenanzes Formation lies on the Heiligkreuz Formation (lower Carnian) while in other areas as those crossed by this field trip (i.e., Nonstal/Val di Non, Etschtal/Valle dell'Adige) it lies directly on the Schlern/Sciliar Dolomite (upper Anisian–upper Ladinian) or on volcanics (upper Ladinian), with a sharp and erosional contact. In the Monte Roen sector the Travenanzes Formation is constituted by terrigenous, carbonate and evaporitic units deposited in fluvial, lagoonal and peritidal environments.

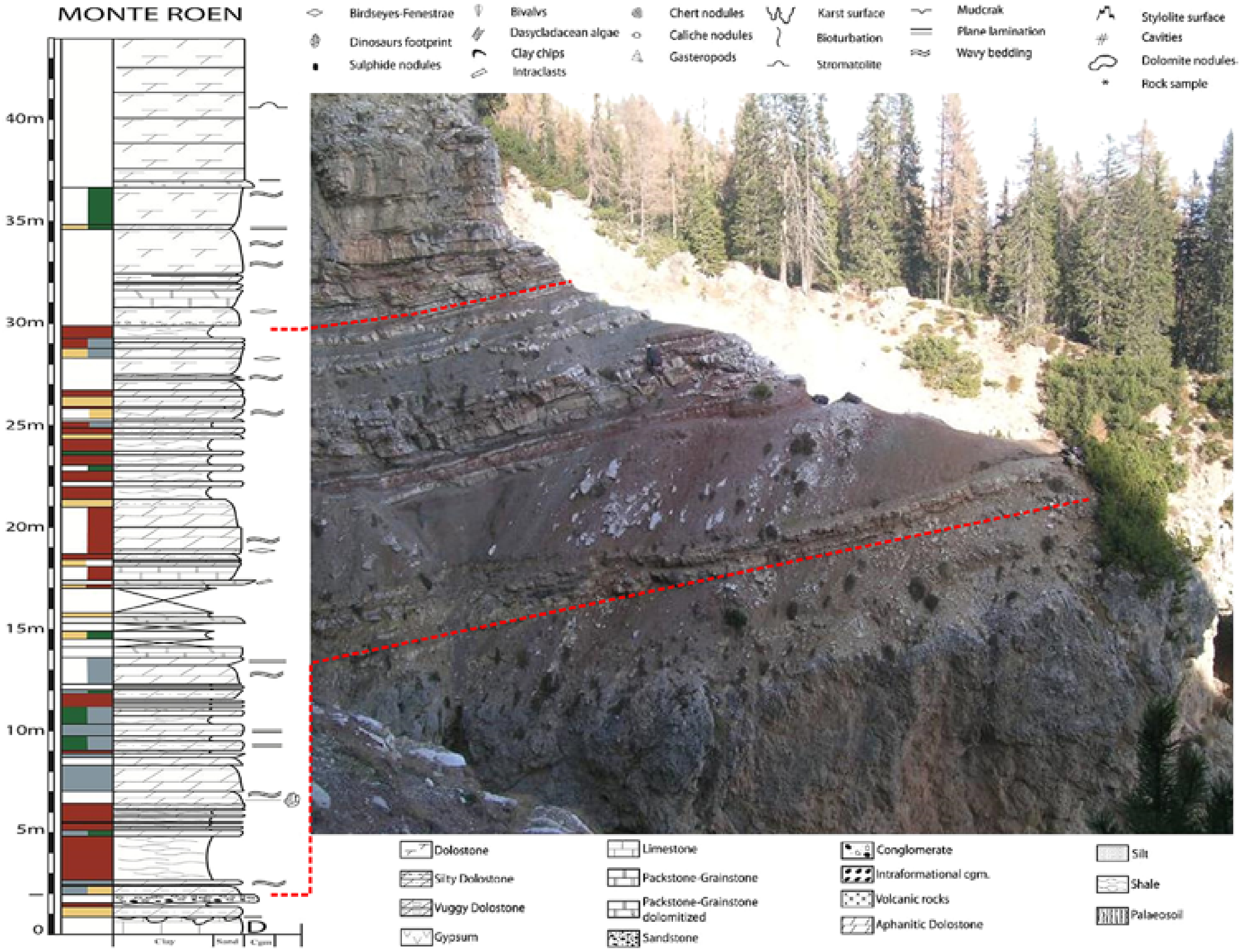


Fig. 29: The Monte Roen section (from Gennaro, 2007).

Stop 2, The Travenanzes Formation ichnoassociation

The Travenanzes ichnoassociation is very diversified, and is dominated by medium-to-large archosaur tracks (*Brachychirotherium*, *Evazoum*, cf. *Atreipus*, *Grallator*) (Fig. 30). The related faunal association is well diversified including aetosaurs, crocodile-like archosaurs, dinosauromorpha and dinosaurs (D'Orazi Porchetti et al., 2008; Avanzini et al., 2010; Bernardi et al., 2010, 2013). In the Roen section two dinosaur footprints have been found about 6 m above the base of the Travenanzes Formation. The track-bearing layer lies within an interval of 50 cm, characterised by whitish aphanitic dolostones separated by thin levels of red and green shales (Gennaro, 2007).

The tracks can be confidently attributed to theropod dinosaur trackmakers with an estimated body length of about 5 m, and a body mass value approximately of 200 kg. This size is not known from dinosaur skeletal remains of Carnian age found worldwide (Benton, 2006; Brusatte et al., 2010) and is approximated only by the Norian theropod dinosaur *Liliensternus* (Cuny & Galton, 1993; Lucas et al., 2006). These specimens are part of a diverse Carnian ichnofauna discovered in the area, as in

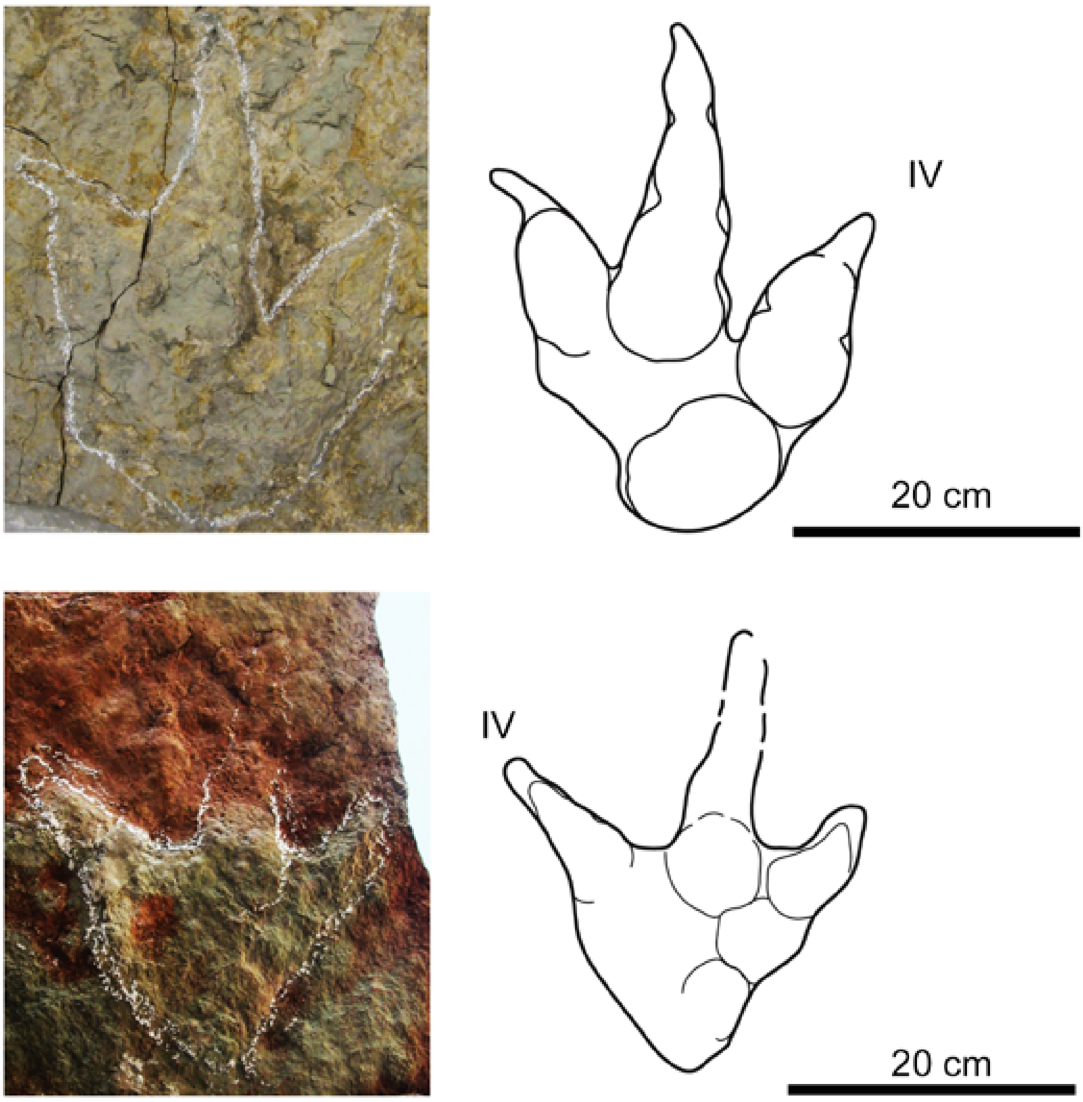


Fig. 30: A - Theropod pedal imprint from the Monte Roen site. B – the finding is confirmed by a similar specimen found in the Mostizzolo site, just few km south. Both tracks were found in the Travenanzes Formation (from Bernardi et al., 2013.

the Mostizzolo (near Cles village, about few km south west from Monte Roen; Bernardi et al., 2010) and San Gottardo outcrops (D'Orazi Porchetti et al., 2008). The Travenanzes faunal assemblage of Southern Alps has thus been considered one of the most diversified for the Tuvalian interval worldwide (Bernardi et al., 2013) and documents one of the earliest forms of evidence of dinosaurs in northern Pangea, and the co-occurrence with dinosauriforms and crurotarsal archosaurs provides support to the non-abrupt replacement of the archaic fauna by a dinosaurian one (Bernardi et al., 2013).

Stop 3, The Travenanzes Formation flora

The Carnian flora is generally rich and diversified, a typical example being the Lunz flora in Austria. This flora experiences generally the first sure occurrence of bennettitalean together with the horsetails, ferns, cycads, seedferns and conifers. In the Travenanzes and San Cassian Formation plant remains are poorly preserved and generally restricted to horsetail stem fragments (e.g. *Equisetites*), fern frond fragments (e.g., *Danaeopsis*) and conifer shoot fragments. Recently discovered floras of Carnian age from the Julian Alps (Dogna) and the Dolomites (Rifugio Dibona) yield some conifer shoots possibly attributed to the Cheirolepidiaceae while the cuticles of other conifer shoots resemble the Permian conifers (see Roghi et al., 2006). In general, the dominant group are the conifers (*Voltzia*, *Brachyphyllum*).

Day 3: The Early Jurassic: the Lavini di Marco ichnosite and the flora of the Rotzo Formation

The Lavini di Marco tracksite is located few kilometers south of Rovereto (Trento Province) and represents one of the most important European dinosaur footprint-bearing outcrops. It has been studied thoroughly by several authors that, since 1990s, carried out extensive ichnological, sedimentological and palynological research (Lanzinger & Leonardi, 1992; Leonardi & Avanzini, 1994; Avanzini et al., 1997; Leonardi & Mietto, 2000; Avanzini et al., 2001, 2002a, 2003; Piubelli et al., 2005; Avanzini et al., 2006).

Stop 1, The Lavini landslide

Few natural phenomena in the Alps have been the subject such controversial geologic, historic, philological and literary interpretations as the Lavini di Marco (Venzo, 2000). The descriptions of the Lavini are mostly confined to the interpretation of the causes of the event or to the debate on the probable mention of it in Dante's Divina Comedia (1314). The name Lavini or Slavini comes from the late Latin word labina which means "landslide" (Fig. 35).

Geological studies started in the XIX century and focused on attempts to date and identify the origin of the event. The accumulation was considered to be the result of multiple, different events and according to some authors, it would have destroyed the village of Lagaris or Lagare (Venzo, 2000). Orombelli & Sauro (1988) identify at least two events: The main one, which took place in 883 A.D., and another much older landslide, that

Fig. 31: The Lavini di Marco site and its landslide

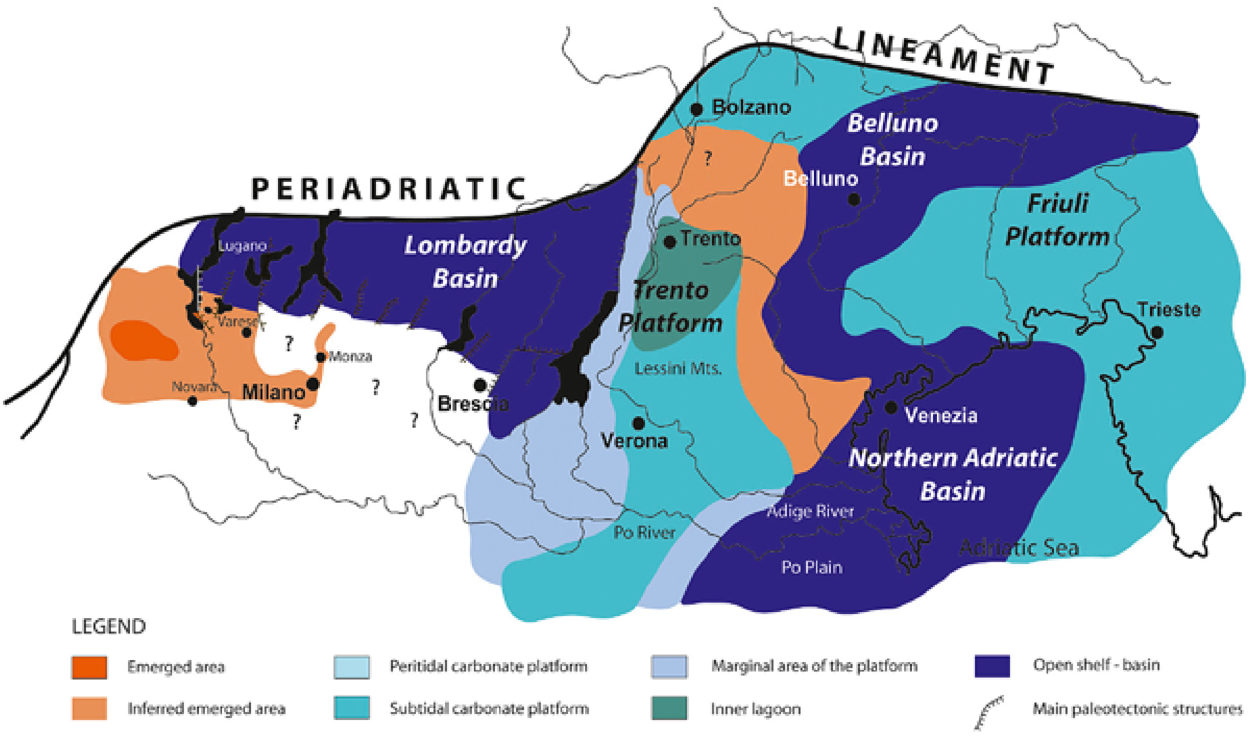


Fig. 32: Palaeogeographic restoration of the central-eastern sector of Southern Alps during the Early Jurassic (From Petti et al., 2011c).

occurred more than 4000 years ago. The dinosaur footprints are preserved on the wide bed surfaces ("*laste*") exposed by the falling of the overlaying strata (Fig. 31).

Stop 2, Geology and palaeogeography: The Calcari Grigi Group and the Trento Platform

The Lavini di Marco trampled horizons have been ascribed to the middle-upper part of the Monte Zugna Formation (Hettangian–Sinemurian *p.p.*) "Middle Peritidal Unit" *sensu* Avanzini et al. (2006) within the Calcari Grigi Group (Bosellini & Loriga, 1971) and cover approximately 300.000 m^2 of monoclinal surfaces (Piubelli et al., 2005). From a palaeogeographic point of view, the Calcari Grigi Group belong to the Trento carbonate Platform, now extending north–south from Verona to Bozen/Bolzano (NE Italy) and that during the Mesozoic covered an area of approximately 20.000 km^2 (Fig. 32).

This domain was characterised by shallow-water carbonate sedimentation through all the Early Jurassic and was bounded on the east by the Belluno pelagic basin and on the west by the Lombard pelagic basin through the so-called "Garda escarpment", a normal fault system active during the Jurassic and the Cretaceous (Castellarin et al., 1993, 2005). As suggested by palynological analysis of some track-bearing horizons (Avanzini et al., 2006), the climate during the Early Jurassic varied from arid to humid conditions. The discovery in 1989 of the Lavini di Marco tracksite gave rise to an extensive search of other dinosaur tracks-bearing outcrops in the Calcari Grigi Group. As a result to date twelwe dinosaur tracksites were discovered to different formations of the Calcari Grigi Group (Fig. 33) (see Avanzini & Petti, 2008 for a review).

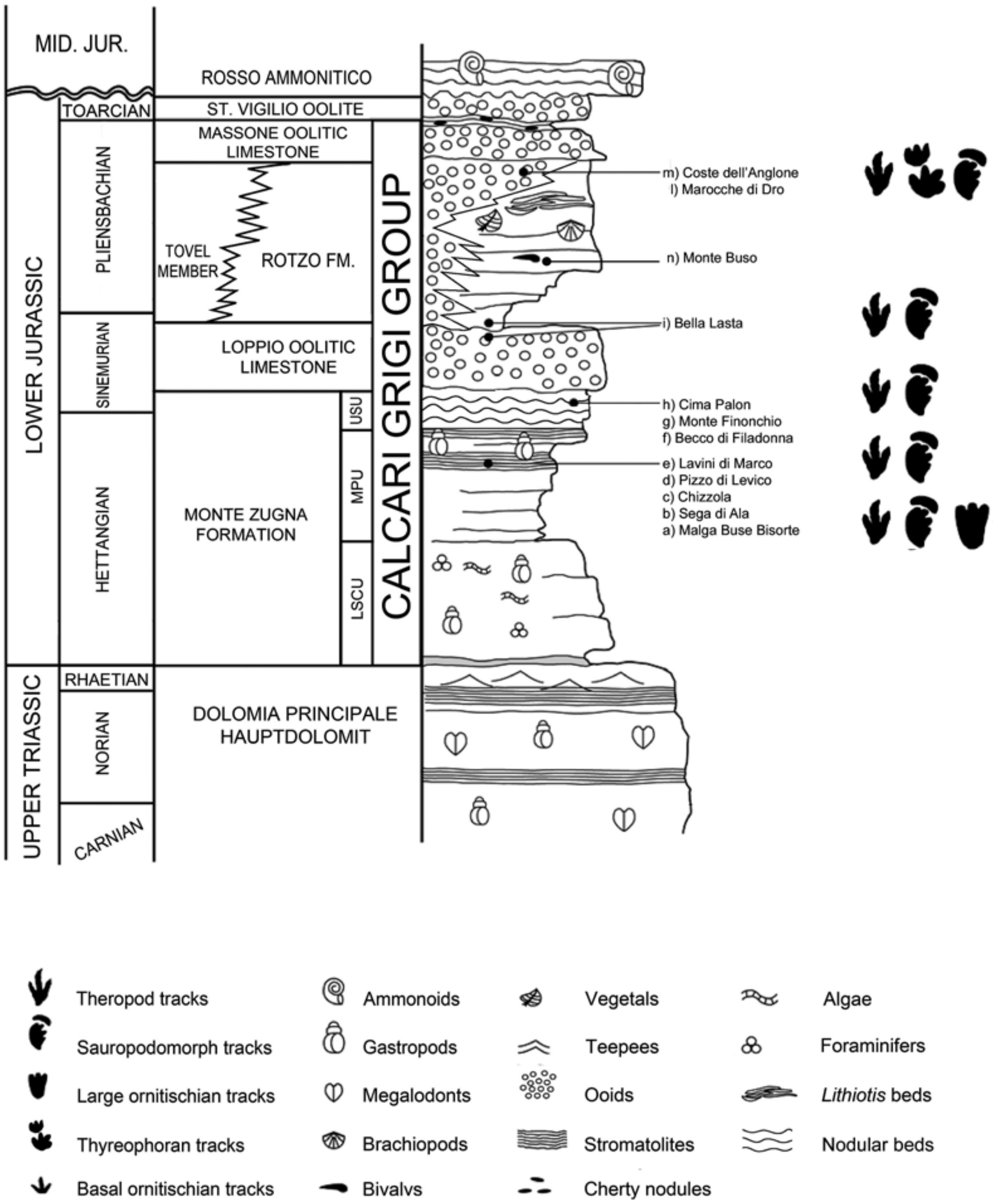


Fig. 33: Lithostratigraphic successions of the Lower Jurassic Calcari Grigi Group, showing the stratigraphic positions of the different dinosaur tracksites.

Stop 3, Sedimentology of the track-bearing strata

The lowermost part of the Monte Zugna Fm. is made of alterntions of subtidal limestones in metric beds and levels of green clay, without evidence of tidal deposits. By contrast, peritidal cycles with structures typical of the tidal environment characterise the upper part of the member where the dinosaur footprints are found. The subtidal facies, representing the lower 2/3 of the cycle, are mainly made up of homogeneous micritic, peloidal-fossiliferous limestones, completely reworked by bioturbation. Sometimes accumulations of large bivalves are present. There are both storm layers and colonies with individuals in life position (*Gervillia buchii*).

The supratidal facies are characterised by peculiar sedimentary structures such as storm-bacterial lamination (stromatolites), mud cracks, teepees, birdseyes, flat pebble breccias etc. (Masetti, 2000). The fossils in this member are rare. Brachiopods at the base of the Monte Zugna Formation are represented by *"Terebratula" dubiosa* Haas and *Pisirhynchia uhligi* Haas. Small foraminifers (Textulariidae, Ataxophragmiidae, *Mancyna* cf. *termieri*) are found at various levels. The most important microfossil from a chronostratigraphical point of view is the alga *Palaeodasycladus mediterraneus* (Pia), which is an Early Jurassic marker. Together with the early Sinemurian ammonoid *Charmasseiceras* in the uppermost underlying Loppio Formation it constrains the age of the track-bearing layers to the Hettangian (Avanzini et al., 2006).

In the Lavini di Marco ichnosite, seven dinoturbated levels have been recognized in a 7 meter-thick succession (Avanzini et al., 2002a). The richest footprint levels are numbered 104, 105 and 106. Layer 104 refers to the upper 10–15 cm of a 70 cm thick subtidal bed. It is a bioclastic packstone to rudstone, which grades upwards to a peloidal wackestone containing ostracods. Locally, the topmost surface shows small-scale depressions, from a few mm to 100 mm deep, separated by hillocks. The depressions are commonly filled by laminated, ostracod-bearing mudstone and wackestone, which are capped by dolomitic crust, clay, and iron oxides. The "ridges" consist of typical, subtidal bioclastic packstone and grainstone. These microtopographic features seem indicative of lateral karstification by analogy with observations on modern tropical carbonate islands (Borrouhil-Le Jean, 1993). The influence of freshwater is indicated by the stable isotope trend and, in particular, by $\delta^{18}O$ values below -2‰ (Land, 1986). At the top of layer 104 there are few trackways exhibiting excellently preserved theropod footprints.

Layer 105 consists of alternating stromatolitic laminae and light gray peloidal mudstones, dark gray bioclastic wackestones and reddish mudstones. The lower boundary is marked by a light brown, laminated mudstone which smooths the irregular surface topography of layer 104. A continuous layer of dark-gray wackestone, about 10 mm thick, containing *Thaumatoporella parvovesiculifera* is intercalated within the inter-supratidal stromatolitic bindstones. This continuous layer, probably a storm layer, grades into hazel-colored mudstone spotted by iron oxides, and then it is capped by a fine grained breccia or by a laminated mudstone-wackestone with evidences of pedogenetic rubefaction. This rubefacted horizon is characterised by iron-rich glaebules (Bain & Foos, 1993), clotted micrite and circumgranular cracking, all features indicative of supratidal conditions. SEM observations and EDAX analyses revealed that the red, pedogenetic horizons consist of a mixture of dolomite, limestone, clay and iron oxides. Smaller theropod footprints are common where layer 105 is thinner. Larger, deeper theropod and sauropod tracks, occur in thicker parts.

Layer 106 (100–120 mm thick; Fig. 34) exhibits lateral facies variations in the various sectors of the outcrop. The boundary with layer 105 is marked by dark gray stromatolitic bindstone and fenestral mudstone with iron oxides concentrated between cyanobacterial laminae. The top of the stromatolitic layer is pervasively dolomitized in the northern sectors of the outcrop. Study of the upper part of layer 106 allows the identification of a series of microenvironmental belts. At the Colatoio Chemini fine-grained, mud-supported breccias with disrupted laminated mudstone clasts, black pebbles, and light-brown subtidal lithoclasts crop out. Eastward, these breccias grade in to mudcracked mudstones which are locally affected by strong rubefaction. Further

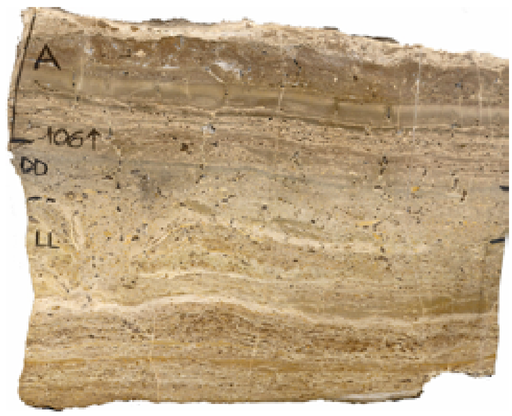


Fig. 34: A polished section across layer 106, which preserves the majority of fossil footprints.

east and southeast, fenestral mudstones pass to coarser sediments which exhibit wave ripples. The mudcracked, rubefacted sediments limit the occurrence of pervasive dolomitization and establish a boundary between two environments characterised by different footprints. The dolomitized sector exhibits deep sauropod footprints and tracks that cut across the entire layer 106 and part of layer 105. Exceptionally, some footprints extend down to the top of layer 104.

Stop 4, The ichnosassociation of Colatoio Chemini and Laste Alte

This is the most havily trampled area of the whole ichnosite and is dedicated to the memory of Luciano Chemini, who discovered in 1989 the first dinosaur footprints of the site (Fig. 35).

The ichnoassemblage is very rich and comprises predominantly tridactyl footprints of small- to medium- sized theropod dinosaurs that fall in the ichnogenera *Kayentapus* isp. Welles, 1971, *Grallator* isp. Hitchcock, 1858 and *Eubrontes* isp. Hitchcock, 1845. *Kayentapus* isp. is the most common morph. Some of the tridactyl footprints assigned to the ichnogenus *Anomoepus* isp. Hitchcock, 1848 have been attributed to basal ornithischians that had functionally tridactyl and clawed, theropod-like feet (Avanzini et al., 2001) but the interpretation remains uncertain. Some of the tridactyl tracks are elongate, displaying the whole or partial impressions of the metatarsus indicating a crouching posture of the dinosaur (Avanzini et al., 2001). In addition to tridactyl tracks there are many narrow-gauge trackways of medium-sized quadrupeds that document the presence of sauropodomorphs. Most of these trackways closely resemble those of *Parabrontopodus* Lockley, Farlow et Meyer, 1994 from the Upper Jurassic of Colorado (USA) and *Breviparopus* Dutuit et Ouazzou, 1980 from the Upper Jurassic–Lower Cretaceous of Morocco, both attributed to sauropodomorphs. Among the quadrupedal trackways, it is worth to mention the ichnotaxon *Lavinipes cheminii* Avanzini, Leonardi et Mietto, 2003 (Fig. 36) which was erected based on the unique morphologies shown by some large-sized tracks. *L. cheminii* has been attributed to basal sauropods (Avanzini et al., 2003).

Fig. 35: Several sauropod trackways can be seen along Colatoio Chemini.

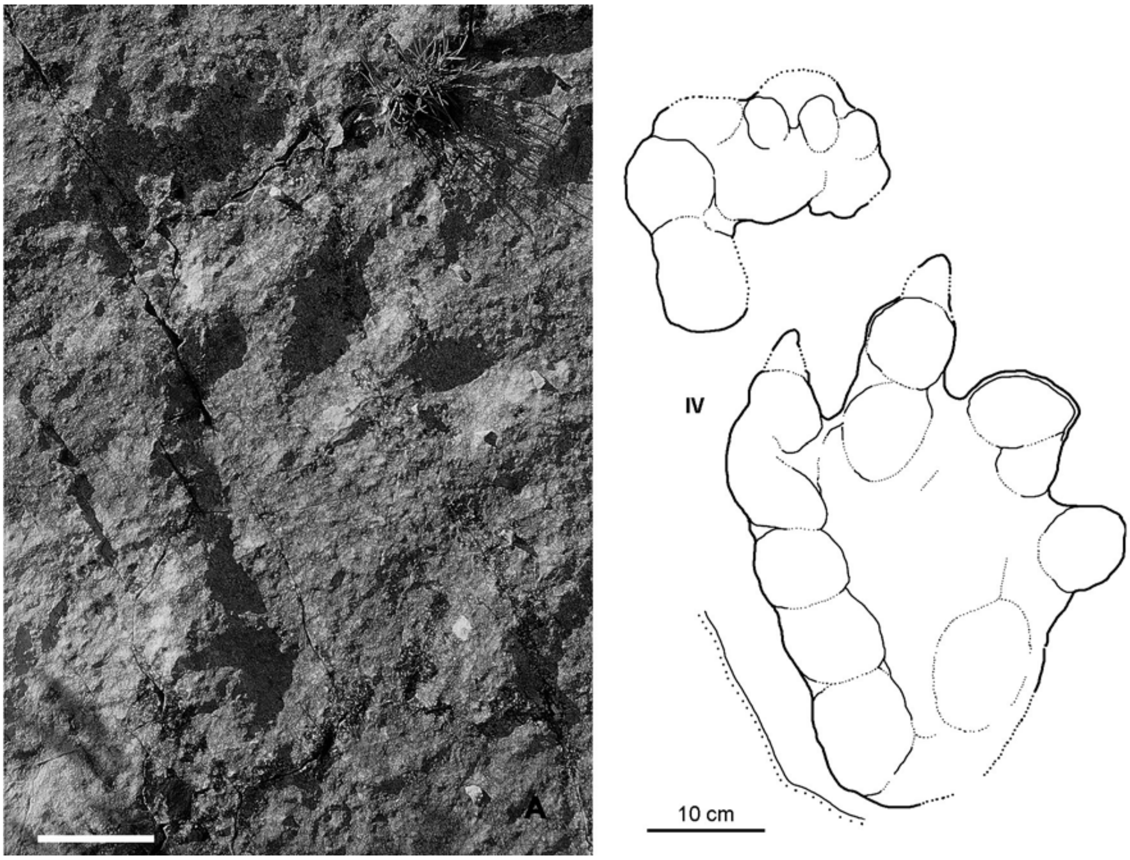


Fig. 36: *Lavinipes cheminii* Avanzini, Leonardi et Mietto, 2003 (from Avanzini et al., 2003).

Stop 5, The Rotzo Formation and its exceptionally preserved flora

The Rotzo formation is characterised by a heterogeneous lithological composition (ooidal, peloidal, bioclastic and intraclastic limestones, marls, and clays), arranged into asymmetrical thickening and shallowing-upward meter-scale sequences (Masetti et al., 1998). This formation has been generally referred to a subtidal environment and can be subdivided into two main lithofacies: the lower is mainly represented by limestone-marl alternations, whereas the upper is characterized by the so-called *Lithiotis* beds or mounds (Masetti et al., 1998; Posenato & Avanzini, 2006). The lower lithofacies is essentially characterized by bioturbate mudstones-wackestones which are locally interbedded with microlaminated wackestones-packstones dark gray in color, slightly marly, strongly fissile, and with a high concentration of organic matter (Masetti et al., 1998; Bassi et al., 2008).

These black shale deposits are characterized by a well-preserved paucispecific and oligohaline fauna of small thin-shelled bivalves (*Eomiodon*, ?*Myrene*, and rare isognomids; Bassi et al., 2005), ostracodes (*Phraterfabanella*, *Klieana*, *Limnocythere*; Boomer et al., 2001), as well as fossil testate amoebae (*Difflugia*, *Pontigulasia*, *Centropyxis*; Bassi et al., 2008). Dinosaur tracks as well as vertebrate remains (crocodyloform teeth and semionotid fish scales) have also been documented from these levels (Petti et al., 2011a, 2011b, 2013; M. Bernardi, F. M. Petti, and M. Avanzini, unpublished data). In addition, these black shales contain abundant macrofloral remains (cuticle, charcoal) and rhizoliths in life position, suggesting the presence of a well-developed flora, including woody plants (Avanzini, 1998; Masetti et al., 1998). The palynological assemblage is dominated by Circumpollen (56%), usually attributed to a xerophytic vegetation of subtropical, warm, and rather arid climate. *Azonotriletes* (40%; ferns) indicate warm swamp or marsh vegetation, typical of a humid climate and freshwater influence. *Chasmatosporites* (2%; Cycadales) is typical of subtropical zones with warm-humid climates (see also Avanzini et al., 2006).

The flora of Rotzo is the most famous Jurassic flora of Italy. It has been studied since the XVIII century (e.g., Del Pozzo, 1764; Massalongo, 1851, 1853a, b, 1856, 1859). It was studied in detail by Barone Achille De Zigno (e.g., 1850, 1856–68, 1873–85, 1878) who described a total of 326 species (82 new species). Grandori (1913a, b, 1915) and Wesley (1956, 1958, 1966, 1974) reviewed the flora and identified several taxa of horsetails, ferns, seed ferns, cycadophytes and conifers. Horsetails are represented by *Equisetites* and *Phyllotheca*. The ferns are represented by *Gleichenites*, *Dictyophyllum*, *Protorhipis*, *Hymenophyllites*, *Coniopteris*, *Phlebopteris*, *Matonidium*, seed ferns by *Sagenopteris*, *Pseudosagenopteris*, *Cycadopteris* and *Dichopteris* while ginkgophytes are absent. *Sphenozamites*, *Otozamites*, *Zamites*, *Pterophyllum*, *Ptilophyllum*, *Weltrichia*, *Wielandiella* and *Blastolepis* are the cycadophyte genera in the flora. The conifers are represented by the genera *Brachyphyllum*, *Pagiophyllum*, *Elatocladus*, *Desmiophyllum*, *Pityophyllum* and *Dactylethrophyllum*. The flora is dominated by bennettitaleans and small-leaved conifers (e.g., Wesley, 1974; Barale, 1982; Kustatscher et al., 2014b) (Fig. 36). The reconstructed habitat corresponds to a brackish–swampy environment characterised by plants with coriaceous leaves, while conifers occupied the hinterland. The ferns also grew in areas that were not influenced by the brackish water. The climate was interpreted as semi-arid (Wesley, 1966).

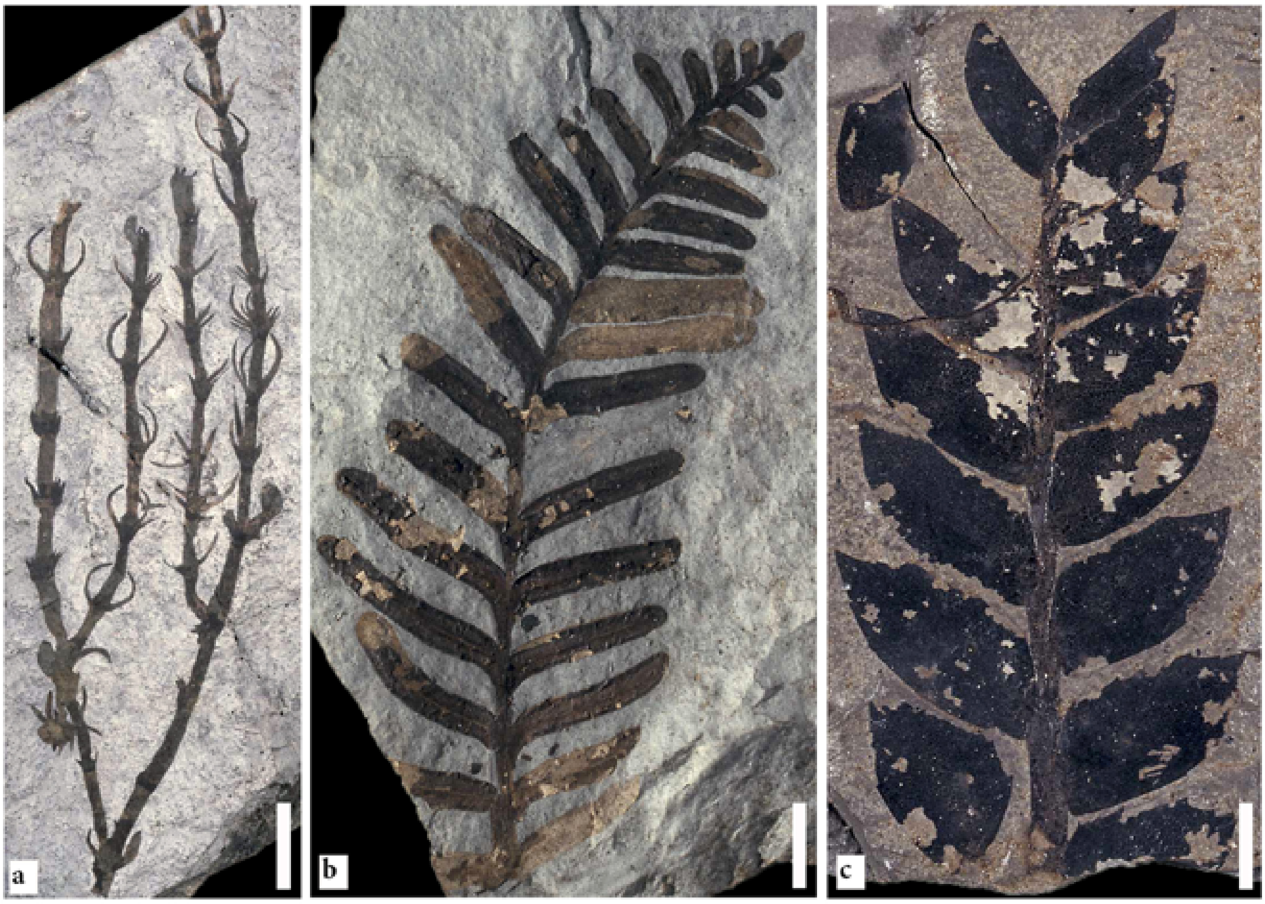


Fig. 37: Some constituents of the Jurassic Rotzo flora. a) Phyllotheca sp.; b) Dichopteris sp.; c) Sphenozamites roessertii (from Kustatscher et al., 2014b).

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Zeitschrift/Journal: Geo.Alp

Jahr/Year: 2016

Band/Volume: 013

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Artikel/Article: Field trip 2 Late Paleozoic and Mesozoic terrestrial environments in the Dolomites and surrounding areas 71-116