TRIASSIC MACRO- AND MICROFLORAS OF THE EASTERN SOUTHERN ALPS

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ABSTRACT

In this paper, we provide an overview of the historically known Triassic floras from the Eastern Southern Alps (e.g., Raibl and Recoaro), as well as the newer macro- and micro-plant assemblages that have been recorded during the 20th and 21st centuries. This includes some specimens stored in various European museums. The plant assemblages are presented here in chronostratigraphic order, starting with the Early Triassic, an interval of which only very few plant fragments are known from the area, whereas palynological data are available. In contrast to the Early Triassic, the Anisian floras (e.g., Kühwiesenkopf/Monte Prà della Vacca) are quite diverse, in both macrofloras – including *in situ* spores – and palynological assemblages. Similarly, the Ladinian of the Eastern Southern Alps is well known from the flora of Monte Agnello, which is outstanding in terms of both diversity and in total number of specimens, with additional information being derived from a large number of smaller macrofloral collections. The Carnian flora of the Eastern Southern Alps is also represented by a wide range of plant fossils, in contrast to the Norian/Rhaetian floras, which are represented only by a low number of macroremains and dispersed pollen and spores findings. A special subject of interest is the presence of amber in some of the Triassic sediments of the Southern Alps. Between the Wengen/La Valle and Heiligkreuz formations, the Dolomites represent the largest Triassic amber deposit known to date.

In addition to macrofossil collections, the palynological data from many localities permits the reconstruction of environmental conditions during the various stages of the Triassic in the Southern Alps. They provide evidence for at least three shifts from xerophytic to hygrophytic palynoassemblages. Moreover, (chrono-)stratigraphic revision of the various localities enables a better understanding of the geographic and temporal distribution of the various taxa.

Focusing on the overview picture of Triassic flora in the Eastern Southern Alps, only one necessary systematic aspect is highlighted herein. We transfer the material described as *Sphenozamites wengensis* to the genus *Macropterygium* as *Macropterygium wengensis* (Wachtler et Van Konijnenburg-van Cittert, 2000) Kustatscher et Van Konijnenburg-van Cittert comb. nov. The genus *Macropterygium* has been redefined for species with pinnate leaves with wedge-shaped segments that do not yield any cuticles and, thus, cannot be assigned to either the Cycadales or the Bennettitales, thereby distinguishing it from *Apoldia* and *Sphenozamites*.

KEY WORDS

Dolomites, fossil plants, palynomorphs, Werfen Formation, Dont Formation, Wengen Formation, Dolomia di Forni, Anisian, Ladinian, Carnian, Norian

1. INTRODUCTION

The Triassic successions of the Southern Alps are historically famous for two plant fossil sites. Both were well-known already in the 19th century; these were found at Raibl (now Cave del Predil) in the Julian Alps and at Recoaro in the Venetian Prealps (e.g., Schauroth, 1855; Bronn, 1858; De Zigno, 1862; Schenk, 1866–67; Stur, 1868a, 1868b; Schenk, 1868; Gümbel, 1879). Plant and fish fossils from the Carnian Predil Limestone of Raibl/Cave del Predil, stored today mostly in Vienna at the Natural History Museum and the Geological Survey of Austria, were donated or sold by local miners (e.g., Bronn, 1858; Schenk, 1866–67). The historical fossil plant collection of Recoaro comes from the Anisian successions cropping out in the area around Recoaro (Catullo, 1846; Massalongo, 1857; De Zigno, 1862) and is today stored mainly in the palaeontological collections of the natural history museums of Verona, Padova and Venice. Several important plant collections were recovered from the Dolomites (mostly 20th and 21st century) and the Carnic and Julian Alps (20th–21st century). From the Western Southern Alps, only a few floras are known so far, such as the Carnian flora from Monte Pora in the Bergamasc Alps and the Ladinian plants from the UNESCO World heritage site Monte San Giorgio (e.g., Passoni, 1996, 1999; Passoni & Van Konijnenburg-van Cittert, 2003;

Stockar & Kustatscher, 2010). There are also isolated historical reports about plant fossils from the Ladinian sediments of Besano, Brembana Valley, Seriana Valley, Valsassina and the surroundings of Lake Como (Schenk, 1889; Sordelli, 1896).
More recent studies include palynological analyses. Their results show that palynomorph assemblages reflect the climatic fluctuations that affected the main floristic groups during the Triassic, when the area of the Southern Alps was positioned in low northern latitudes, at about 20–35° N, on the north-western coast of Pangaea. They evidence a series of shifts to more humid climatic conditions that were partly of regional (late Anisian, late Longobardian) and partly of worldwide scale (e.g., Carnian Pluvial Episode). Furthermore, palynological analyses led to one of the most detailed biostratigraphic scales for this region, with biostratigraphic zones and distinct palynological assemblages based on the appearance of characteristic taxa, correlated with the ammonoid biozonation (e.g., Visscher & Brugman, 1981; Van der Eem, 1983; Brugman, 1986; Jadoul et al., 1994; Roghi, 1995; Carulli et al., 1998; Hochuli et al., 2015).
The aim of this paper is an integrative overview on the historically known Triassic floras in the frame of current (chrono-)stratigraphy, combined with new data that have been recorded during the 20th and 21st century. This also includes some single fossil specimens and small collections stored in various European museums.

2. MATERIALS AND METHODS

The Southern Alps as considered herein correspond to the part of the Eastern Alps lying south of the Periadriatic Seam. They are mainly located in Northern Italy and adjacent areas of Austria and Slovenia. In contrast to the austroalpine nappes in the Central Alps, the sediments of the Southern Alps document the history of the southern Tethys and the microcontinent Adria (e.g., Schmid et al., 2008). To the south, the Southern Alpine successions are overlain discordantly by the sediments of the Po Basin. The outcropping successions comprise mainly Permian to Cretaceous sediments, with limestones and dolomites being the most prominent types. This paper discusses the Eastern Southern Alps, i.e., East of the Giudicarie Line, including the Dolomites, the Venetian Prealps, the Julian Alps and Prealps and the Carnic Alps. This area is where almost all plant fossil localities of Triassic age in the Alps are located (Figs. 1, 9, 12) and can be considered in a coherent stratigraphic context (Figs. 2, 3, 5).
The fossils discussed here are stored in the palaeontological collections of several local and international museums and universities (Appendix 1). These include the Museum of Nature South Tyrol in Bozen/Bolzano (collection number prefix "NMS PAL"), the Museum de Gherdëina (prefix "MDG"), the Museo delle Regole of Cortina d'Ampezzo (prefix "MDR"), the Museo

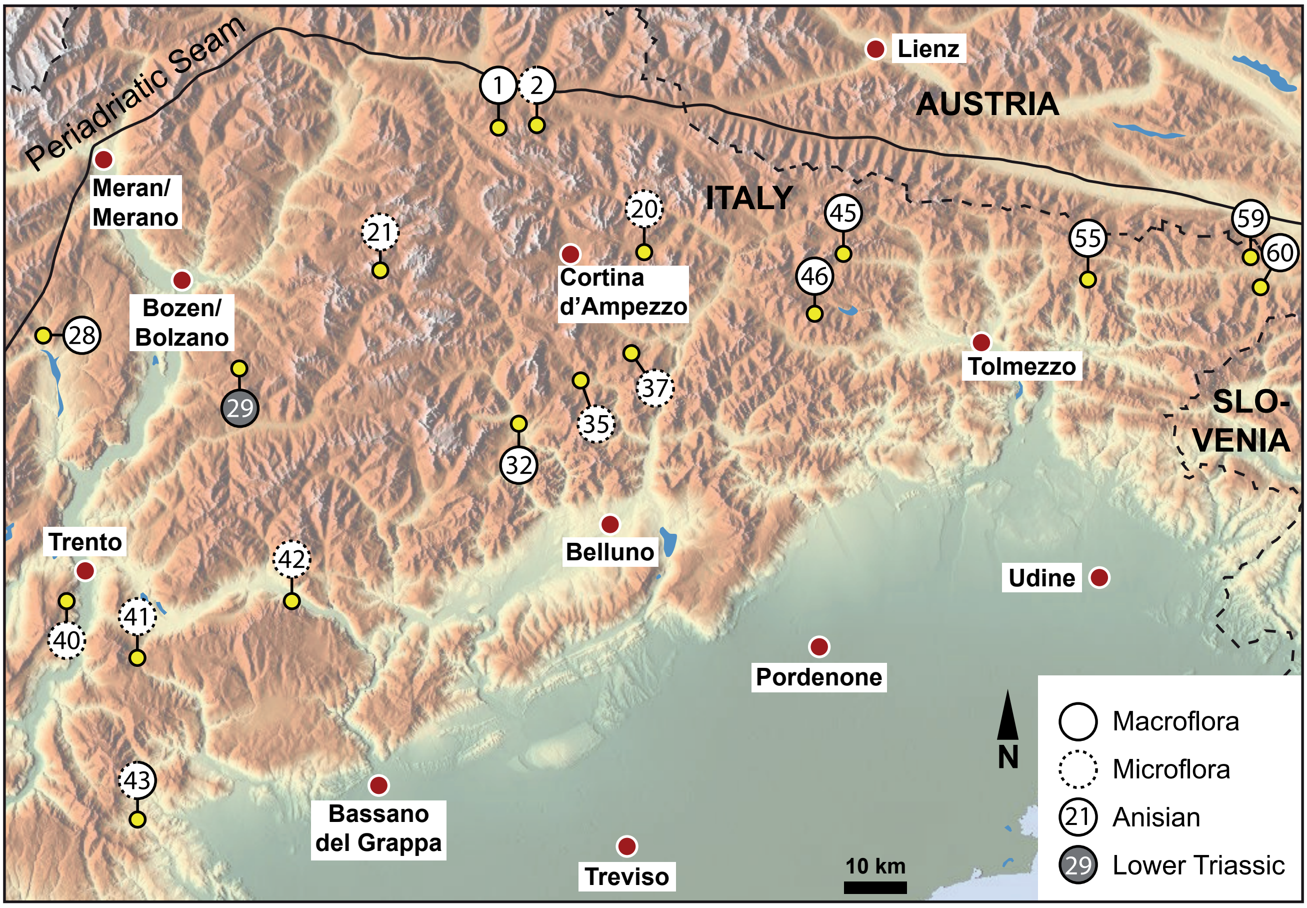

Figure 1: Map of the Eastern Southern Alps with the localities from which Lower Triassic and Anisian plant macrofossils and/or microfossil assemblages have been reported. **1.** Piz da Peres; **2.** Kühwiesenkopf/Monte Prà della Vacca; **20.** Palus San Marco; **21.** Plattkofel/Sasso Piatto, Grohmannspitze/Punta Grohmann (Rif. S. Pertini, Rif. T. Demetz, Gabia), Val Duron; **28.** Val di Non; **29.** Bletterbach Gorge; **32.** Valle di San Lucano, Agordo; **35.** Valle di Zoldo, Dont; **37.** Monte Rite; **40.** Val Gola, Margon; **41.** Val di Centa; **42.** Rio dei Carrari; **43.** Recoaro Terme, Monte Rove; **45.** Culzei, Prato Carnico, Val Pesarina; **46.** Monte Bìvera; **55.** Val Aupa (Moggio Udinese); **59.** Rio Tschofen, Tarvisio; **60.** Canale Prasnig, Rio Freddo/Kaltwasser.

Ladino Fodom (prefix "PL"), the Museo Geologico delle Dolomiti of Predazzo (prefix "MPP"), the Museo Friulano di Storia Naturale of Udine (prefix "MFSNgp"), the Museo di Storia Naturale of Venice (prefix "MSNV"), the Museo Civico di Storia Naturale, Verona (prefix "MCSNV"), the Museum für Naturkunde Berlin (prefix "MB.Pb"), the Natural History Museum of Vienna (prefix "NHMW"), the Goldfuss Museum Bonn (prefix "STIPB-PB"), the Staatliche Sammlung für Naturkunde Dresden (prefix "ItTr"), the Staatliches Museum für Naturkunde Stuttgart (prefix "SMNS"), the National Museum Prague (NMP), the Bayerische Staatssammlung für Geologie und Paläontologie (prefix "BSPG"), the Geologisches Landesamt München (prefix "GLA"), the palaeontological collections of the universities of Ferrara (prefix "MPL"), Padova (prefix "MPP"), Göttingen (prefix "GZG"), Halle-Wittenberg (prefix "MLU"), Innsbruck (prefix "GII"), Utrecht (prefix "UU") and Tübingen (prefix "GPIT"), as well as the botanical institute of the University of Innsbruck (prefix "BII"). Additional specimens described in the 19th and early 20th centuries are partly lost (e.g., Schauroth, 1855; Catullo 1846; Massalongo, 1857; Bronn, 1858; De Zigno, 1862; Schenk, 1866–67, 1868; Stur, 1868a, 1868b; Gümbel, 1879; Mojsisovics, 1879; Arthaber, 1903; Ogilvie Gordon, 1927, 1934; Mutschlechner, 1932). For the sake of overview, localities are grouped in the geographic maps (Figs. 1, 9, 12) and tables (1, 3, 4). Details on individual localities are provided in Appendix 1.

3. THE EARLY TRIASSIC FLORAS OF THE EASTERN SOUTHERN ALPS

3.1. THE EARLY TRIASSIC MACROFLORA OF THE EASTERN SOUTHERN ALPS

There are so far no identified plant remains from the Early Triassic successions of the Eastern Southern Alps, although several small fragments were collected, e.g., in the Bletterbach Gorge ([29] in Figs. 1, 2, pers. observ. EK and HN). This scarcity in plant fossils may be related to the fact that the depositional environment of the Early Triassic Werfen Formation with its coastal sand-, silt- and limestones was not favorable for plant preservation.

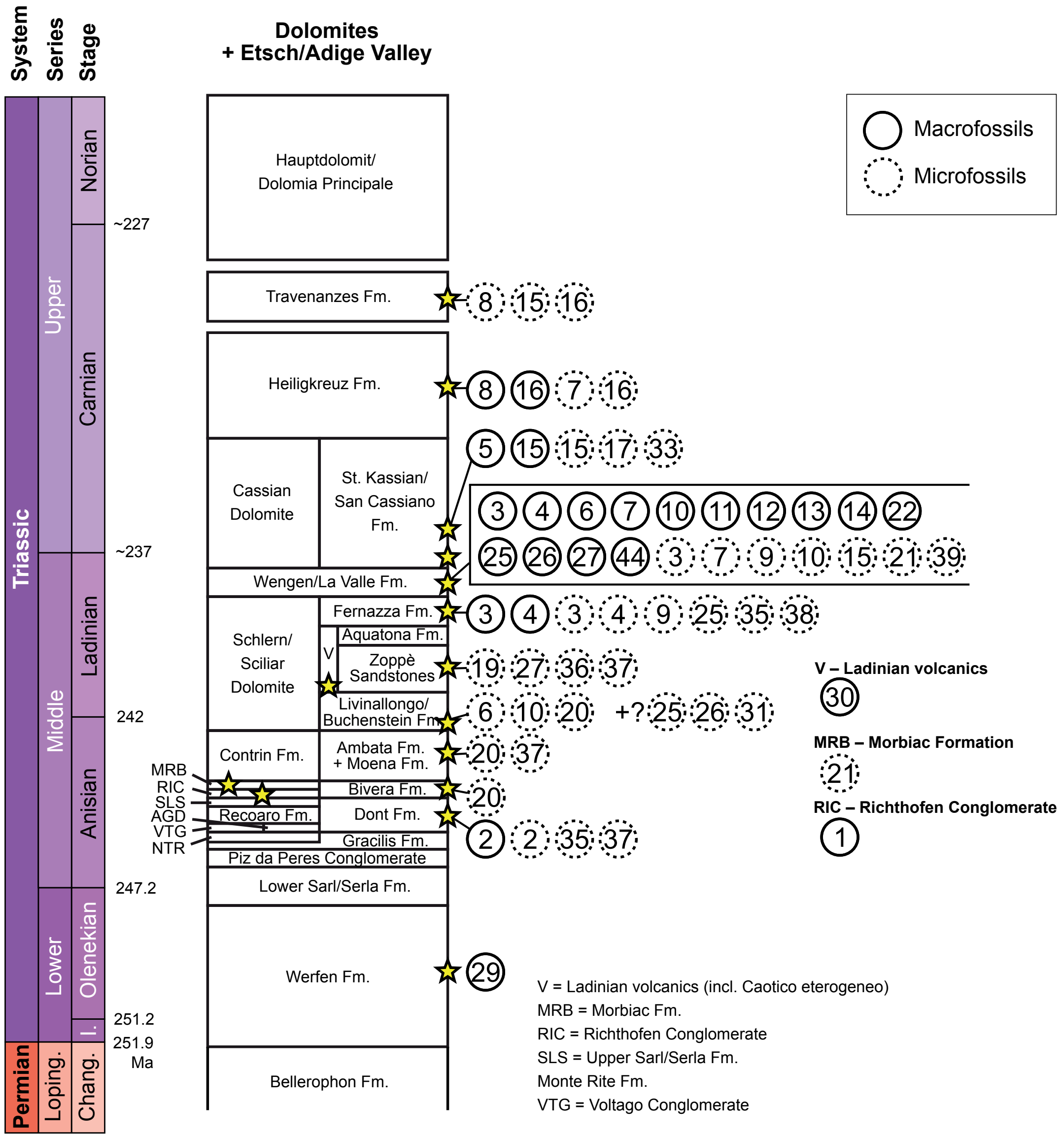

Figure 2: Stratigraphic distribution of plant macro- and microfossil assemblages in the Dolomites and the Etsch/Adige Valley. Encircled numbers refer to the localities in Figs. 1, 9, 12. Loping. = Lopingian; Chang. = Changhsingian; I. = Induan.

3.2. THE EARLY TRIASSIC MICROFLORA OF THE EASTERN SOUTHERN ALPS

The palynological record of the Early Triassic sediments gives better insights into the floral composition of this time interval. Several palynological analyses of the Permian–Triassic boundary (PTB) have been carried out in recent years (e.g., Cirilli et al., 1998; Looy et al., 2005; Spina et al., 2015; Nowak et al., 2019). The studied sections are mainly located in the Dolomites, such as Seres (Cirilli et al., 1998), Tesero (Spina et al., 2015), Tramin (Looy et al., 2005; Bernardi et al., 2018) and the Laurinswand in the Rosengarten/Catinaccio Massif (Nowak et al., 2019). The Early Triassic biotic recovery flora after the Permian–Triassic crisis is characterized by quantitatively poor palynological assemblages, with bisaccate pollen typical of Permian sediments, as well as trilete and monolete spores (cingulate and zonate). The spores show a notable increase in relative abundance and in the frequency of spore tetrads around the PTB (Looy et al., 2005; Nowak et al., 2019), probably correlative to the so-called "spore spike" that has been reported elsewhere from this interval.

A mass occurrence of *Reduviasporonites* (al. *Tympanicysta*, *Chordecystia*) has also been observed close to the PTB in the Southern Alps, most pronounced in the Tesero Member (Werfen Formation) at the Tesero section (Eshet et al., 1995; Visscher et al., 1996; Foster et al., 2002). Similar observations have been made in other parts of the world in approximately coeval strata (e.g., Eshet et al., 1995; Steiner et al., 2003; Sandler et al., 2006; Rampino & Eshet, 2018; Hochuli, 2016). This phenomenon has been called a "fungal spike" and led to theories about the role that this taxon might have played in the end-Permian mass extinction as a saprophyte or pathogen. This phenomenon is, however, not restricted to the disaster level as previously supposed. In the Laurinswand section, *Reduviasporonites* is present in almost all palynological assemblages from the upper Bellerophon and lowermost Werfen formations, but with the highest relative abundance in the lower Mazzin Member of the Werfen Formation (Nowak et al., 2019). The "fungal spike" normally pre-dates the spore spike, whereas at the Laurinswand section, the peak in abundance of *Reduviasporonites* lies stratigraphically above the onset of the spore spike (Nowak et al., 2019).

Palynological associations of Olenekian age (Val Badia and Cencenighe members, Werfen Formation) are characterized by abundant lycophyte spores and acritarchs (Visscher, 1974). The sudden spread of gymnosperms, evidenced in Hungary at the end of the Spathian and corresponding to the restoration of the equatorial semi-arid conifer forests in Europe, has also been recorded in the Recoaro area (Aegean–Bithynian) with an important increase in bisaccate pollen grains (alete, monolete, trilete), especially of the *Triadispora* group (Brugman, 1986; Looy et al., 1999 and references therein).

The Lower Triassic of the Alpine Realm is palynostratigraphically divided into an unnamed interval and two phases (Fig. 4); the nejburgii-heteromorphus phase and the heteromorphus-conmilvinus phase (Kustatscher & Roghi, 2014). The older phase ranges from the upper part of the Induan to the lower part of the Spathian, the younger one corresponds to the middle-upper Spathian (Brugman, 1986; Visscher & Brugman, 1986; Nowak et al., 2018). The nejburgii-heteromorphus phase is characterized by the first occurrence of *Voltziaceaesporites heteromorphus* and is subdivided into the late Dienerian-Smithian heteromorphus-papillatus subphase (Brugman, 1986) and the early Spathian heteromorphus-leschikii subphase. The heteromorphus-papillatus subphase shows a dominance in *Densoisporites nejburgii* and abundant *Endosporites papillatus* and *Punctatisporites* spp. The heteromorphus-leschikii subphase is dominated by *D. nejburgii* and, in the upper part, by abundant grains of *V. heteromorphus* and *E. papillatus.* Taeniate pollen grains are rare. Acritarchs are dominant in both subphases (Brugman, 1986).

The heteromorphus-conmilvinus phase starts with the first occurrence of *Jugasporites conmilvinus*. *Densoisporites nejburgii* continues to be dominant in the conmilvinus-cymbatus subphase, in correspondence with abundant *Voltziaceaesporites heteromorphus*, *J. conmilvinus* and trilete spores. The *Cyclotriletes-Convolutispora* complex has its first occurrence in this subphase. The conmilvinus-noviaulensis subphase corresponds to a decrease in abundance of *D. nejburgii* in conjunction with a dominance of bisaccate pollen grains such as *V. heteromorphus* and *J. conmilvinus* (Brugman, 1986).

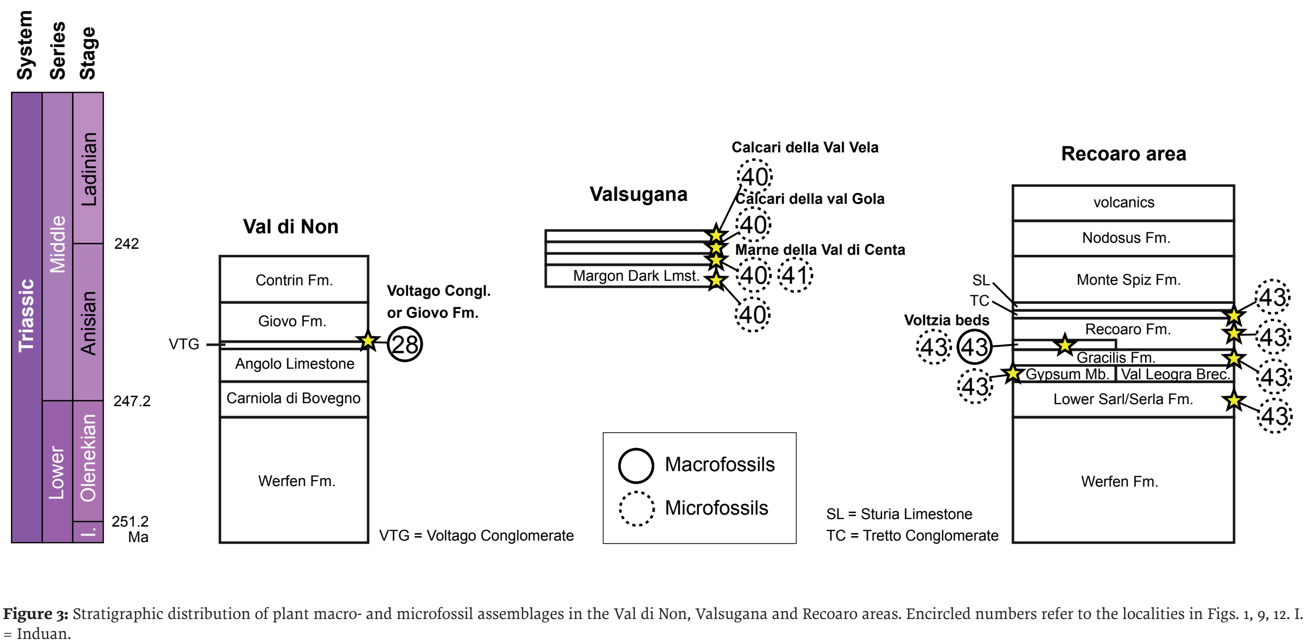

Figure 3: Stratigraphic distribution of plant macro- and microfossil assemblages in the Val di Non, Valsugana and Recoaro areas. Encircled numbers refer to the localities in Figs. 1, 9, 12. I. = Induan.

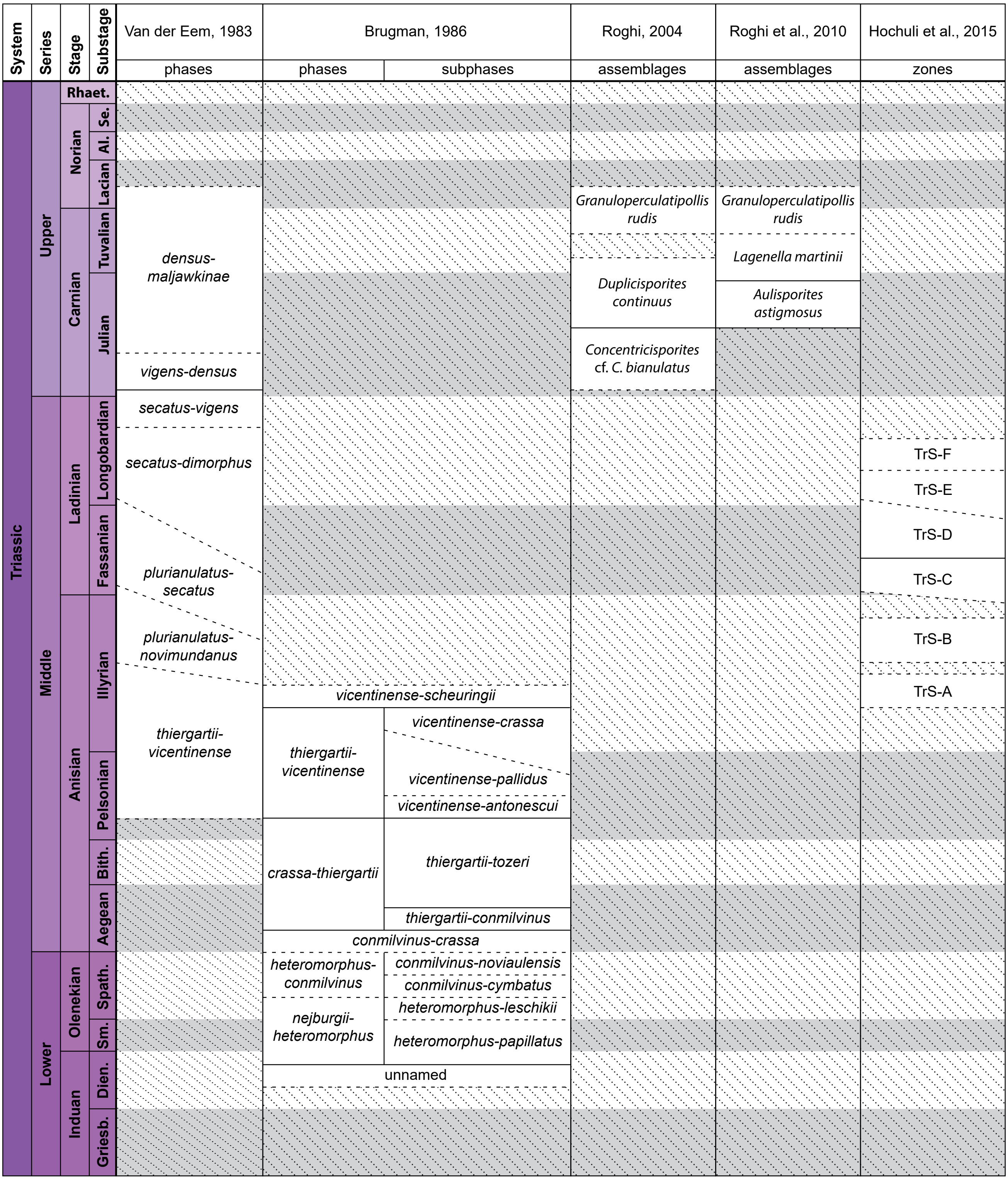

Figure 4: Palynostratigraphic schemes for the Triassic of the Southern Alps. Griesb. = Griesbachian; Dien. = Dienerian; Sm. = Smithian; Spath. = Spathian; Bith = Bithynian; Al. = Alaunian; Se. = Sevatian; Rhaet. = Rhaetian.

4. THE ANISIAN FLORAS OF THE EASTERN SOUTHERN ALPS

4.1. THE ANISIAN MACROFLORA OF THE EASTERN SOUTHERN ALPS

The most abundant, diverse and best-preserved plant assemblages of the Southern Alps come from Middle Triassic sediments (Fig. 1, 2, 3, 5). Grauvogel-Stamm & Ash (2005) described the Anisian flora (lower Middle Triassic) of the Northern Dolomites as one of the oldest examples of a full recovery of the ecosystems after the end-Permian crisis. The Anisian flora of the Eastern Southern Alps represents a highly diverse vegetation dominated by ferns, cycadophytes and conifers, while seed ferns and lycophytes are common and sphenophytes are rare. The diversity of the local assemblages may, however, vary noticeably. The most diverse and abundant Anisian plant assemblage comes from Kühwiesenkopf/Monte Prà della Vacca near Olang/Valdaora ([2] in Figs. 1, 2) in the Northern Dolomites (Broglio Loriga et al., 2002; Van Konijnenburg-van Cittert et al., 2006; Kustatscher et al., 2007, 2009, 2010a, 2010b). Less rich plant assemblages come from Piz da Peres ([1] in Figs. 1, 2; near Enneberg/Marebbe, also Northern Dolomites; Todesco et al., 2008), Agordo ([32] in Figs. 1, 2; Kustatscher et al., 2011b; Testa et al., 2013), Recoaro ([43] in Figs. 1, 2; e.g., Catullo, 1846; Schauroth, 1855; Massalongo, 1857; De Zigno, 1862; Schenk, 1868; Gümbel, 1879) and the Val di Non ([28] in Figs. 1, 3; Kustatscher et al., 2012a). Isolated plant fossil findings were collected from the surroundings of Rio Freddo/Kaltwasser ([60] in Figs. 1, 5; between Raibl/Cave del Predil and Tarvisio), Val Aupa ([55] in Figs. 1, 2; Moggio Udinese), Prato Carnico ([45] in Figs. 1, 5) and Tarvisio in the Udine Province ([59] in Figs. 1, 5; collection of the Museo Friulano di Storia Naturale).
Our knowledge of the Anisian flora of the Eastern Southern Alps is, thus, strongly influenced by the plant assemblage of Kühwiesenkopf/Monte Prà della Vacca that was subjected to less taphonomic and preservation bias than other Anisian plant fossil localities, which show a more limited number of taxa (see Tab. 1). Lycophytes are represented by both herbaceous and sub-arborescent taxa (Broglio Loriga et al., 2002; Kustatscher, 2004; Kustatscher et al., 2010a, 2010b). *Lycopia dezanchei*, the most common form, is characterised by a dichotomising creeping prostrate rhizome (representing the primary shoot axis) from which arise aerial axes, apically bifurcated and covered with bundles of long microphylls. Isoetales are represented by two taxa. *Isoetites brandneri*, the more abundant form, is characterised by a short stem and long, helically inserted microphylls. *Lepacyclotes bechstaedtii* has a quadrilobed corm with proximally inserted macrosporophylls and distal microphylls that arise in a narrow spiral. Selaginellales are rare in the flora, with *Selaginellites leonardii* characterised by a strobilus yielding both micro- and megaspores, and some sterile fragments that have never been found in organic connection. Sphenophytes are represented by stem fragments, strobili and isolated sporangiophore heads of *Equisetites mougeotii*, as well as a few specimens of *Equisetites* sp. (Fig. 6A), *Neocalamites* sp. and *Echinostachys* sp. (Broglio Loriga et al., 2002; Kustatscher et al., 2007).
The ferns are a very diverse plant group represented, e.g., by several osmundaceous taxa, such as *Neuropteridium voltzii*, *N. elegans* and *N. grandifolium*, and their respective fertile fronds *Scolopendrites scolopendrioides* (fertile fronds of *N. voltzii*) and *S. grauvogelii* (fertile fronds of *N. elegans*). Another typical Anisian fern in European floras is *Anomopteris mougeotii* (Fig. 6B), whereas *Gordonopteris lorigae* is known so far only from the Southern Alps. The two marattialean taxa ?*Marattiopsis* sp. and *Danaeopsis* sp. are represented by small fragments (Van Konijnenburg-van Cittert et al., 2006; Kustatscher et al., 2012b). *Sphenopteris schoenleiniana*, *Cladophlebis remota*, *Cladophlebis* sp. and a fern described under gen. indet. sp. indet. by Van Konijnenburg-van Cittert et al. (2006) that resembles the specimens described as *Neuropteridium curvinerve* by Wang & Wang (1990) are of unknown botanical affinity. Some enigmatic fertile structures (*Lugardonia paradoxa*) consisting of an up to 20 cm long axis with helically arranged short stalks each carrying a cluster of 3–4 elongated microsporangia may also belong to the ferns or seed ferns (Kustatscher et al., 2009).
Seed ferns include the peltasperm foliage type *Scytophyllum bergeri* with sun and shade leaves and the associated reproductive organs *Peltaspermum bornemannii* (Kustatscher et al., 2007). Leaf fragments assignable to *Sagenopteris* sp. and *Ptilozamites* sp. are rare in the flora (Broglio Loriga et al., 2002; Kustatscher & Van Konijnenburg-van Cittert, 2007; Kustatscher et al., 2007, 2010a); these might each represent the oldest occurrence of their respective genera. Cycadophytes are well represented in this flora (Broglio Loriga et al., 2002; Kustatscher, 2004; Kustatscher et al., 2010a). *Bjuvia* sp. is characterized by large entire leaves (up to 50 cm long and 20 cm wide) with thin and brittle cuticles. *Taeniopteris* sp. has smaller leaves with an entire margin and parallel, undivided veins. Some dissected leaves with strap-like, regular or irregular leaf segments resemble *Pterophyllum robustum* from the Middle Triassic of Apolda (Germany; Kelber & Hansch, 1995). Moreover, several dispersed macrosporophylls and cones also belong to the cycadophytes. Each macrosporophyll has a finely pinnate apical part and carries two rows of seeds typical of the genus *Dioonitocarpidium* (Fig. 6C; Broglio Loriga et al., 2002; Kustatscher, 2004; Kustatscher et al., 2010a).
At least five different conifer taxa have been distinguished (Broglio Loriga et al., 2002; Kustatscher, 2004; Kustatscher et al., 2010a). *Voltzia recubariensis* has robust, triangular, helically arranged leaves arising almost perpendicularly from the axis and male cones have been found as well (Fig. 6E). *Voltzia walchiaeformis* has fine, falcate needles inserted spirally on the shoots. The secondary shoots arise in one plane from the primary shoot. A third voltzialean taxon has heterophyllous leaves, ranging from short and falcate (1 cm long; Fig. 6D) with a pointed apex to long and strap-like (3–4 cm long) with a rounded apex, similar to those of *V. heterophylla* Brongniart. However, the female cones belonging to this conifer have ovuliferous scales divided into several lobes that are only slightly fused at the base, similar to *Pseudovoltzia*, a late Permian conifer (Clement-Westerhof, 1987). *Albertia* has multiply branched shoots, covered with spirally attached, elliptic leaves, whereas the leaves of *Pelourdea vogesiaca* are up to 25–30 cm long and lanceolate, slightly restricted at the base and with parallel veins.
Additional taxa have been recorded in less rich Anisian plant assemblages, including the sphenophytes *Equisetites arenaceus* and *E. conicus*, the fern *Cladophlebis leuthardtii* and the cycad macrosporophyll *Dioonitocarpidium pennaeformis* (Kustatscher et al., 2011b, 2012a). The conifer taxa *Aethophyllum foetterlianum*, *Araucarites massalongii*, *Araucarites pachyphyllus*, *Taxites massalongii*, *T. vincentinus* and *Taxodites saxolimpiae* were described from the flora of Recoaro (Tab. 1; De Zigno, 1862; Gümbel, 1879; Schenk, 1868), some were even mentioned only on labels in museum collections (e.g., *Araucarites agordicus* Anger, *Araucarites albuctenoides* Mass.). However, this taxonomy is partly outdated and needs a detailed revision with a modern approach. These taxa will therefore not be considered further on.

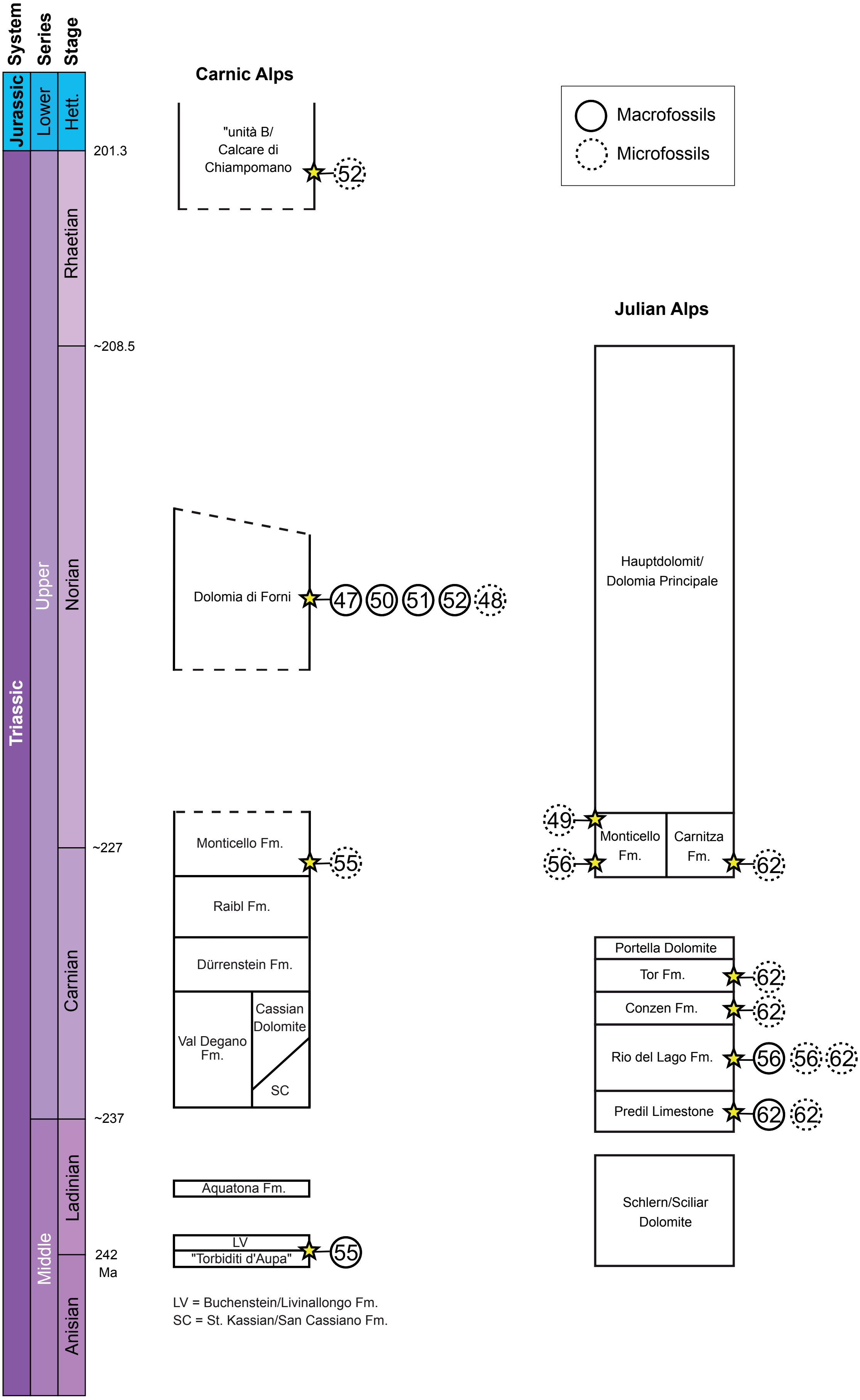

Figure 5: Stratigraphic distribution of plant macro- and microfossil assemblages in the Carnic and Julian Alps. Encircled numbers refer to the localities in Figs. 1, 9, 12. Hett. = Hettangian.

Anisian		Kühwiesenkopf	Piz da Peres	Recoaro	Agordo	Val di Non	Prato Carnico	Rio Freddo/Kaltwasser	Moggio Udinese	Tarvisio	Monte Bivera
Lycophytes	*Isoetites brandneri*	x									
	Lepacyclotes bechstaedtii	x									
	Lepacyclotes sp.						x				
	Lycopia dezanchei	x									
	Selaginellites leonardii	x									
Horsetails	*Echinostachys* sp.	x		x							
	Equisetites arenaceus			x					x		
	Equisetites conicus					x					
	Equisetites mougeotii	x	?								
	Equisetites sp.			x	?		?		x		
	Neocalamites sp.	x				x					
Ferns	*Anomopteris mougeotii*	x	x		x				x		
	Cladophlebis leuthardtii		x								
	Cladophlebis remota	x			x						
	Cladophlebis sp.	x									
	Danaeopsis angustifolia	?	?								
	Gordonopteris lorigae	x	x			x					
	Marattiopsis sp.	?									
	Neuropteridium elegans	x	x			x					
	Neuropteridium grandifolium	x									
	Neuropteridium voltzii	x	x		x			x			
	Pteridophyta incertis sedis	x									
	Scolopendrites grauvogelii	x									
	Scolopendrites scolopendrioides	x									
	Scolopendrites sp.		x		x						
	Sphenopteris schoenleiniana	x									
	Symopteris sp.									x	
Seed ferns	*Peltaspermum bornemannii*	x	x								
	Peltaspermum sp.				x		x				
	Ptilozamites sp.	?									
	Sagenopteris sp.	x									
	Scytophyllum bergeri	x	x								
Cycads	*Bjuvia dolomitica*	x	x								
	Dioonitocarpidium pennaeformis					?					
	Dioonitocarpidium sp.	x	x								
	Nilssonia sp.	x									
Conifers	*"Aethophyllum foetterlianum"*			x							
	Albertia sp.	x		x	x		x				
	"Araucarites agordicus"			x							
	"Araucarites albuctenoides"			x							
	"Araucarites massalongii"			x							
	"Araucarites pachyphyllus"			x							
	Elatocladus sp.	x									
	Pagiophyllum sp.			x							
	Pelourdea vogesiaca	x					x				
	Pseudovoltzia sp.	?									
	"Taxites massalongii"			x							
	"Taxites vincentinus"			x							
	"Taxodites saxolimpiae"			x							
	"Voltzia heterophylla"	x		x			x				
	Voltzia recubariensis	x	x	x	x	x	x				
	Voltzia walchiaeformis	x				?					
	Voltzia sp.	x		x	x		x				x
Incertae sedis	*Carpolithes* sp.	x					x				
	Lugardonia paradoxa	x									
	Taeniopteris sp.	x	x		x						

Table 1: Occurrences of Anisian plant macrofossil taxa at the various localities in the Eastern Southern Alps.

Figure 6: Plant macrofossils from the Anisian of the Eastern Southern Alps. Scale bars = 10 mm. **A.** stem fragment with vascular bundles of *Equisetites* sp., NMS PAL 808; **B.** Frond fragment of *Anomopteris mougeotii* Brongniart, 1828, NMS PAL 241; **C.** *Dioonitocarpidium* sp. from Kühwiesenkopf/Monte Prà della Vacca, NMS PAL 1669; **D.** shoot of *Voltzia* sp., NMS PAL 671; **E.** male cone of *Voltzia recubariensis* (De Zigno) Schenk, 1868, MPP.

4.2. THE ANISIAN IN *SITU* SPORES AND POLLEN OF THE EASTERN SOUTHERN ALPS

In situ spores have been isolated from the fertile organs of several macrofossil taxa of the Kühwiesenkopf/Monte Prà della Vacca plant fossil assemblage (Tab. 2). These include isospores of osmundaceous ferns (*Scolopendrites scolopendrioides*, *S. grauvogelii*, *Gordonopteris lorigae*; Van Konijnenburg-van Cittert et al., 2006) and microspores of the sphenophyte *Equisetites mougeotii* (Kustatscher et al., 2007), as well as both micro- and megaspores of selaginellalean (*Selaginellites leonardii*) and isoetalean (*Isoetites brandneri*) lycophytes (Kustatscher et al., 2010b; Zavialova et al., 2010). In addition, the problematic *Lugardonia paradoxa* has yielded *in situ* palynomorphs that may be either spores or pre-pollen (Kustatscher et al., 2009) (Fig. 7D).
So far, only the *in situ* spores of *Isoetites brandneri* and *Selaginellites leonardii* have been compared to dispersed sporomorph taxa. Kustatscher et al. (2010b) suggested that the possibly monolete microspores of *I. brandneri* (Fig. 7H) might relate to *Aratrisporites*. However, *Aratrisporites* is cavate, whereas the spores of *I. brandneri* have only one discernable wall layer. Considering also their lack of ornamentation and round to reniform shape, they correspond rather to *Laevigatosporites*, if they are monolete. The megaspores probably relate to *Verrutriletes* (Fig. 3G; Kustatscher et al., 2010b). The morphology and ultrastructure of both the micro- and megaspores of *S. leonardii* has been studied in detail by Zavialova et al. (2010). The microspores (Fig. 7J) were found to conform to *Uvaesporites* in ultrastructure, while no conclusion was reached on the correspondance of a dispersed taxon for the megaspores (Fig. 7I).
The spores of *Scolopendrites scolopendrioides* and *S. grauvogelii* (Fig. 7A, 7B) are both described as "trilete, circular in equatorial outline, with a diameter of 35–45 µm", and with a "scabrate to granulate" exospore (Van Konijnenburg-van Cittert et al., 2006, pp. 952–953). They could conceivably represent slightly immature versions of *Osmundacidites*. The exospore may also appear psilate with only pits around the proximal pole, thereby resembling *Todisporites*. Van Konijnenburg-van Cittert et al. (2006, p. 956) wrote about the spores of *Gordonopteris lorigae* (Fig. 7C) that they were "globose, trilete, 43–62 µm in diameter, with a finely punctate exospore". They can thus be compared to the dispersed genus *Punctatisporites*. The microspores of *Equisetites mougeotii* (Fig. 7E, 7F) have been briefly described as "slightly immature trilete spores, 30–45 µm in diameter" (Kustatscher et al., 2007, p. 1279). To this may be added that they show a dense, scabrate to verrucate ornamentation and that the laesurae can reach the equator.

Plant group	Macrofossil taxon	*In situ sporomorphs*				First description of *in situ* sporomorphs		
		Type	Short description	Corresponding dispersed taxa	Figure(s), this work	Reference	Page(s)	Figure(s)
Pteridophyta, Filicales, ?Osmundaceae	*Scolopendrites scolopendrioides*	isospores	trilete, circular in equatorial outline, diameter 35–45 µm, exospore psilate or scabrate to verrucate	*?Osmundacidites, Todisporites*	3A	Van Konijnenburg-van Cittert et al. 2006	952	pl. 1, figs. 1, 5–6
	Scolopendrites grauvogelii	isospores	trilete, circular in equatorial outline, diameter 35–45 µm, exospore psilate or scabrate to verrucate	*?Osmundacidites, Todisporites*	3B		952–953	pl. 1, figs. 4, 7
	Gordonopteris lorigae	isospores	trilete, globose, diameter ca. 45–60 µm, exospore finely punctate	*Punctatisporites*	3C		955–956	pl. 3, figs. 1–2
Sphenophyta, Equisetales, Equisetaceae	*Equisetites mougeotii*	immature spores	trilete, circular, scabrate to verrucate, diameter 30–45 µm, laesurae can reach equator	?	3E, F	Kustatscher et al. 2007	1279	pl. 1, figs. 6–7
incertae sedis	*Lugardonia paradoxa*	spores or pre-pollen	trilete, more or less circular, smooth inner wall, granulate-verrucate outer wall, diameter ~100 µm, laesurae 3/4 to 7/8 radius, no margo	?	3D	Kustatscher et al. 2009	91	pl. 2, figs. 3–10; pl. 3, figs. 1–11; text Fig. 1
Lycophyta, Selaginellales, Selaginellaceae	*Selaginellites leonardii*	microspores	trilete, diameter 42.5–50 µm, proximally punctate/?granulate or psilate and distally rugulate	*Uvaesporites*	3H	Kustatscher et al. 2010	597	pl. 1, figs. 6–8
		megaspores	trilete (aperture delicate or undeveloped, rare plicae), oval to circular, diameter 270–340 x 300–410 µm, spore wall 10 µm thick and psilate to punctate	?	3G		597	pl. 1, figs. 5, 9
Lycophyta, Isoetales, Isoetaceae	*Isoetites brandneri*	immature microspores	reniform (?monolete), longest diameter up to 35–40 µm, psilate, single wall layer	*?Laevigatosporites*	3J		602	pl. 2, fig. 4
		megaspores	trilete (aperture delicate, rare plicae), diameter 270–300 µm, thick spore wall, convolute to verrucate with proximally reduced ornamentation	*?Verrutriletes*	3I		602	pl. 2, fig. 5

Table 2: Overview on *in situ* palynomorphs from the Dont Formation (Anisian) from the Kühwiesenkopf/Prà della Vacca section.

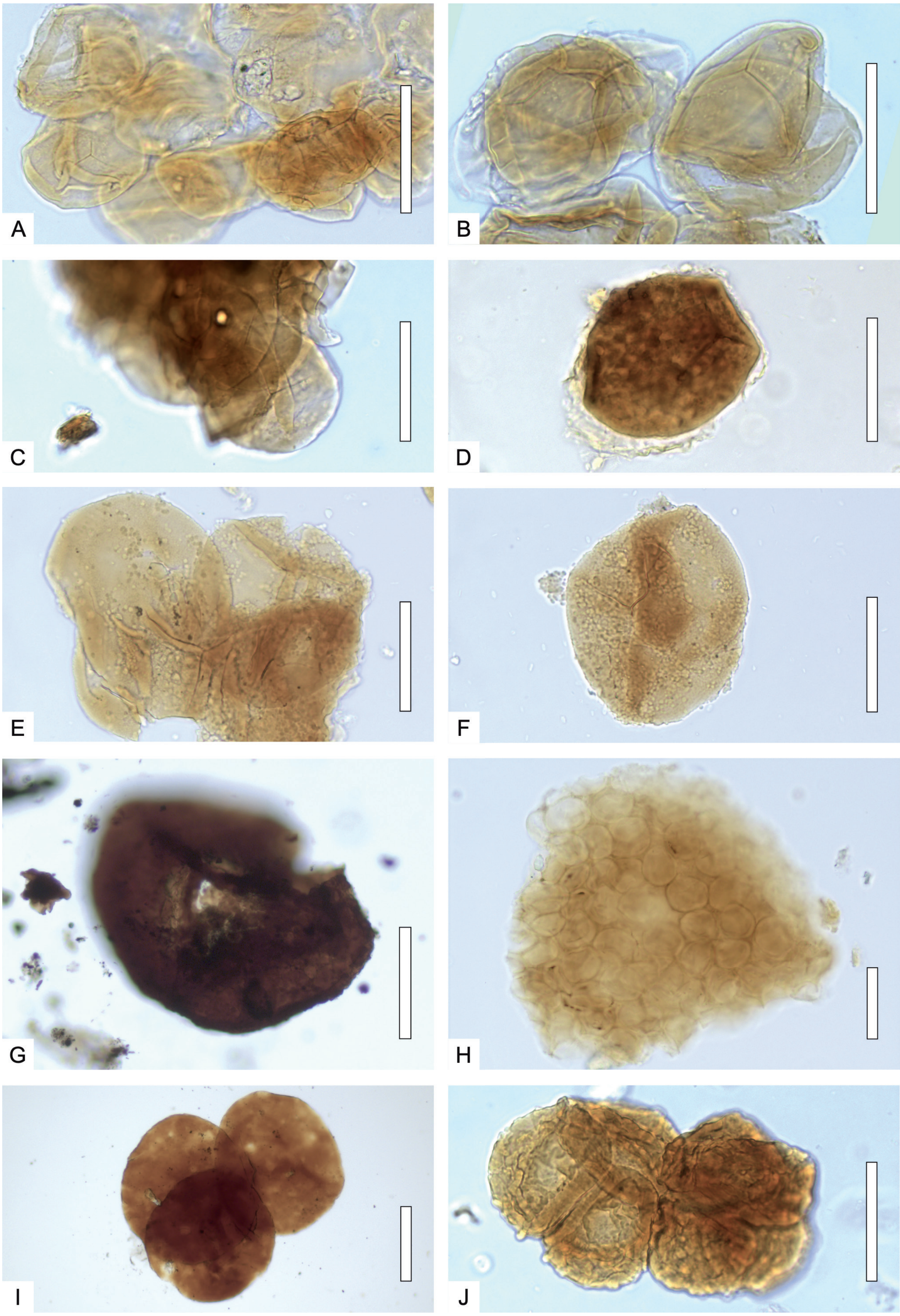

Figure 7: *In situ* palynomorphs from the Dont Formation (Anisian) at the Kühwiesenkopf/Monte Prà della Vacca section. Scale bars A–D, F, H, J = 50 µm; E, G = 100 µm; I = 200 µm. **A.** Spores of *Scolopendrites scolopendrioides* (Brongniart) Van Konijnenburg-van Cittert et al., 2006, NMS KÜH 204; **B.** Spores of *Scolopendrites grauvogelii* Van Konijnenburg-van Cittert et al., 2006, NMS PAL 379; **C.** Spores of *Gordonopteris lorigae* Van Konijnenburg-van Cittert et al., 2006, NMS PAL 259; **D.** Spores or prepollen of *Lugardonia paradoxa* Kustatscher et al., 2009, NMS PAL 1105; **E, F.** Spores of *Equisetites mougeotii* (Brongniart) Wills, 1910, NMS PAL 561; **G.** Megaspore of *Isoetites brandneri* Kustatscher et al., 2010, NMS PAL 1126; **H.** Cluster of microspores of *I. brandneri*, NMS PAL 1136; **I.** Megaspores of *Selaginellites leonardii* Kustatscher et al., 2010, NMS PAL 536; **J**. Two tetrads of microspores of *S. leonardii*, NMS PAL 536.

4.3. THE ANISIAN MICROFLORA OF THE EASTERN SOUTHERN ALPS

The palynofloras diversify noticeably during the Anisian. They contain a large abundance of different lycophytes, horsetails and fern spores, as well as seed fern, cycadophyte and conifer pollen (Fig. 8).

Biostratigraphically (Fig. 4), the Anisian has been divided by Brugman (1986) into at least four phases and five suphases: i) the conmilvinus-crassa phase, ii) the crassa-thiergartii phase (with the thiergartii-conmilvinus and the thiergartii-tozeri subphases), iii) the thiergartii-vicentinense phase (with the vicentinense-antonescui, the vicentinense-pallidus and the

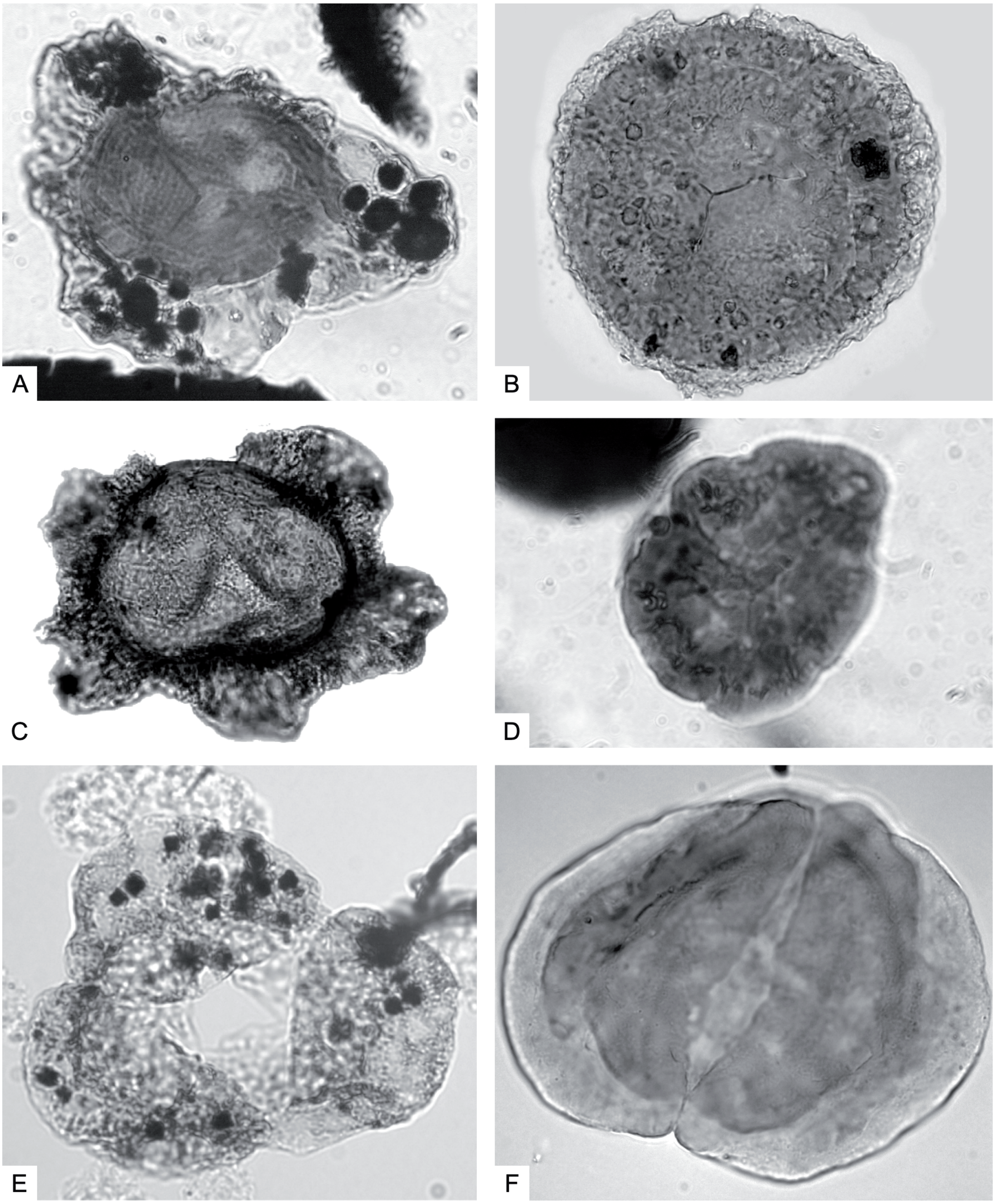

Figure 8: Palynomorphs of the Anisian of the Eastern Southern Alps. **A.** *Cristianisporites triangulatus*, 93 µm; **B.** *Cannanoropollis scheuringii*, 90 µm; **C.** *Dyupetalum vicentinense*, 160 µm; **D.** *Densoisporites variomarginatus*, 100 x 30 µm; **E.** *Stellapollenites thiergartii*, 70 µm; **F.** *Jugasporites conmilvinus*, 50 µm.

vicentinense-crassa subphases) and iv) the vicentinense-scheuringii phase. Previously, Van der Eem (1983) had distinguished the Fassanian (Early Ladinian) into the thiergartii-vicentinense (vicentinense-scheuringii phase in Brugman, 1986) and plurianulatus-novimundanus phases. In an unpublished PhD thesis, Roghi (1995) restudied the Middle Triassic of the Dolomites and distinguished at least three phases and eleven zones that are currently being revised. In all three studies, phases and zones are characterized by first and last occurrences of selected pollen taxa, while the subphases are generally referring to quantitative differences within the phase, thus representing primarily environmental and/or climatic signals that may be strongly diachronous (Van der Eem, 1983; Brugman, 1986; Roghi, 1995, 1997). The time calibration of these phases need revision after the definition of the GSSP for the base of the Ladinian (Brack et al., 2005). They are now considered to be of middle-upper Illyrian age (Hochuli et al., 2015). Finally, Hochuli et al. (2015) defined a succession of Anisian–Ladinian palynozones (TrS-A to TrS-F) from the Seceda drill core, of which the first two zones belong to the Anisian (TrS-A and TrS-B), specifically the Illyrian substage. The TrS-A zone corresponds to the thiergartii-vincentinense phase of Van der Eem (1983) and to the vicentinense-scheuringii phase of Brugman (1986).

Between the Early and Middle Triassic, a strong shift in dominance from trilete and monolete spores to bisaccate pollen with and without aperture is observed, although the initially common pollen species *Voltziaceaesporites heteromorphus* and *Jugasporites conmilvinus* (Fig. 8F) also decrease noticeably (Brugman, 1986; Kustatscher & Roghi, 2006; Kustatscher et al., 2006a, 2010a). The spore *Cristianisporites triangulatus* (Fig. 8A) and *Densoisporites variomarginatus* (Fig. 8D) and pollen monosaccate *Dyupetalum vicentinense* (Fig. 8C) and *Stellapollenites thiergartii* (Fig. 8E) are characteristic for the Anisian whereas monosaccate *Cannanoropollis scheuringii* (Fig. 8B) appear in the upper Anisian. Of particular importance is also the radiation and increase in abundance of the *Triadispora* group. An increase in and/or dominance of trilete spores is observed in the middle Pelsonian vicentinense-pallidus subphase of the thiergartii-vicentinense phase, especially with the genera *Concavisporites*, *Punctatisporites*, *Cyclotriletes*, *Verrucosisporites*, *Convolutispora* and *Uvaesporites*. *Vitreisporites* is also abundant in some levels. This shift from hygrophytic to xerophytic elements has been observed in several quantitative palynological analyses of the Southern Alps (Brugman, 1986; Kustatscher et al., 2010a; Dal Corso et al., 2015). These palynological data are further supported by changes in the associated abundant macroflora and indicate a warm and humid climate (e.g., Kühwiesenkopf/Monte Prá della Vacca; Kustatscher & Roghi, 2006; Kustatscher et al., 2006a), especially since they do not seem to be linked to specific depositional sequences and systems tracts (Dal Corso et al., 2015). This change in floral composition and precipitation regime is recognizable in other sections in the northwestern Tethys (e.g., Hungary, Recoaro; Brugman, 1986). The climatic change cannot be explained with a northward drift of the continents (Mangerud & Rømuld, 1991), since such a change in palaeolatitude would have caused a long-term trend rather than an episodic and short-term humid phase. Additionally, the Southern Alps were placed within the arid tropical belt (10–30°N) during the Middle Triassic and entered the humid climate belt (>30°N) only in the latest Triassic (Muttoni et al., 2013). The vicentinense-scheuringii phase is again dominated by xeromorphic elements (mainly bisaccate pollen grains) with a low percentage of hygromorphic elements (Dal Corso et al., 2015).

5. THE LADINIAN FLORAS OF THE EASTERN SOUTHERN ALPS

5.1. THE LADINIAN MACROFLORA OF THE EASTERN SOUTHERN ALPS

Many Ladinian localities throughout the Dolomites yielded small amounts of plant remains, often limited to a few taxa only (Tab. 3). The first record of plant fossils in the Dolomites belongs to these rare accounts of fossil plant remains; a fern frond fragment, probably *Cladophlebis leuthardtii*, figured by Wissman & Münster (1841). Other authors occasionally mentioned and figured plant fossils from the so-called "Buchensteiner Schichten" and "Wengener Schichten" of various areas in the Dolomites (Fig. 2, 9; Mojsisovics, 1879; Arthaber, 1903; Ogilvie Gordon, 1927, 1934; Mutschlechner, 1932; Leonardi, 1953, 1968; Calligaris, 1982–83, 1986; Jung et al., 1995) and from Sappada ([44] in Fig. 2, 9; Leonardi, 1964). Thus, by the end of the 20th century, a reasonably high number of different plant remains had been described from the Dolomites. Most of these remains, at least those that are accessible in public collections, come from the Wengen or Fernazza formations, the old "Wengener Schichten". So far, only one fragment belonging with certainty to the Buchenstein Formation has been identified (in the Zürich collection, pers. observ. EK).

Most plant fossil sites are situated in the South Tyrol area of the Dolomites, such as Seewald and Innerkohlbach near Prags/Braies ([3] in Fig. 2, 9), several localities in the Gadertal/Val Badia (Ritberg, Wengen/La Valle, [4] in Fig. 2, 9; St. Leonhard in Abtei/S. Leonardo in Badia, [7] in Fig. 2, 9; near Corvara, [13] in Fig. 2, 9; St. Kassian/San Cassiano, [14] in Fig. 2, 9; Grödner Joch/Passo Gardena, [12] in Fig. 2, 9) and the area of Gröden/Val Gardena and Seiser Alm/Alpe di Siusi (Pufels/Bulla, Puflatsch/Bullaccia, [10] in Fig. 2, 9; Schgaguler Schwaige/Malga Schgaguler, [11] in Fig. 2, 9; e.g., Kustatscher & Van Konijnenburg-van Cittert, 2005; Kustatscher et al., 2014). One of the richest and most diverse plant assemblages comes from Monte Agnello (near Pampeago, [30] in Fig. 2, 9) in the Trento Province (Kustatscher et al., 2014). Additional localities, in the Friuli-Venezia-Giulia region are Arabba, [24] in Fig. 2, 9; Forcella Giau and Corvo Alto/Monte Mondeval (Croda da Lago Group, [27] in Fig. 2, 9), Laste and Monte Sief (Livinallongo area, [26] in Fig. 2, 9); Cercenà ([22] in Fig. 2, 9), Spitz Zuel/Col d'Agnelessa (near Dont, [44] in Fig. 2, 9), Sappada ([10] in Fig. 2, 9), Val Aupa (Moggio Udinese, [55] in Fig. 5, 9), Monte Nebria (Malborghetto Valbruna, [58] in Fig. 2, 9), and Dierico ([54] in Fig. 2, 9; Kustatscher & Van Konijnenburg-van Cittert, 2005; Kustatscher et al., 2014; see also the collection database of the Museo Friulano di Storia Naturale, Udine).

The late Ladinian flora of the Southern Alps has always been considered to be gymnosperm-dominated, due to the abundance and diversity of this group. However, the discovery of a (par-) autochtonous flora at Monte Agnello allows new insight into the composition of this flora, since the latter plant assemblage yielded a number of different fern taxa (see below) including some of the earliest representatives of the Matoniaceae and perhaps Dipteridaceae (Kustatscher et al., 2014).

Thus, the Ladinian flora of the Eastern Southern Alps, as presently known, is composed of representatives of almost all plant groups (Tab. 3). The lycophytes and sphenophytes are

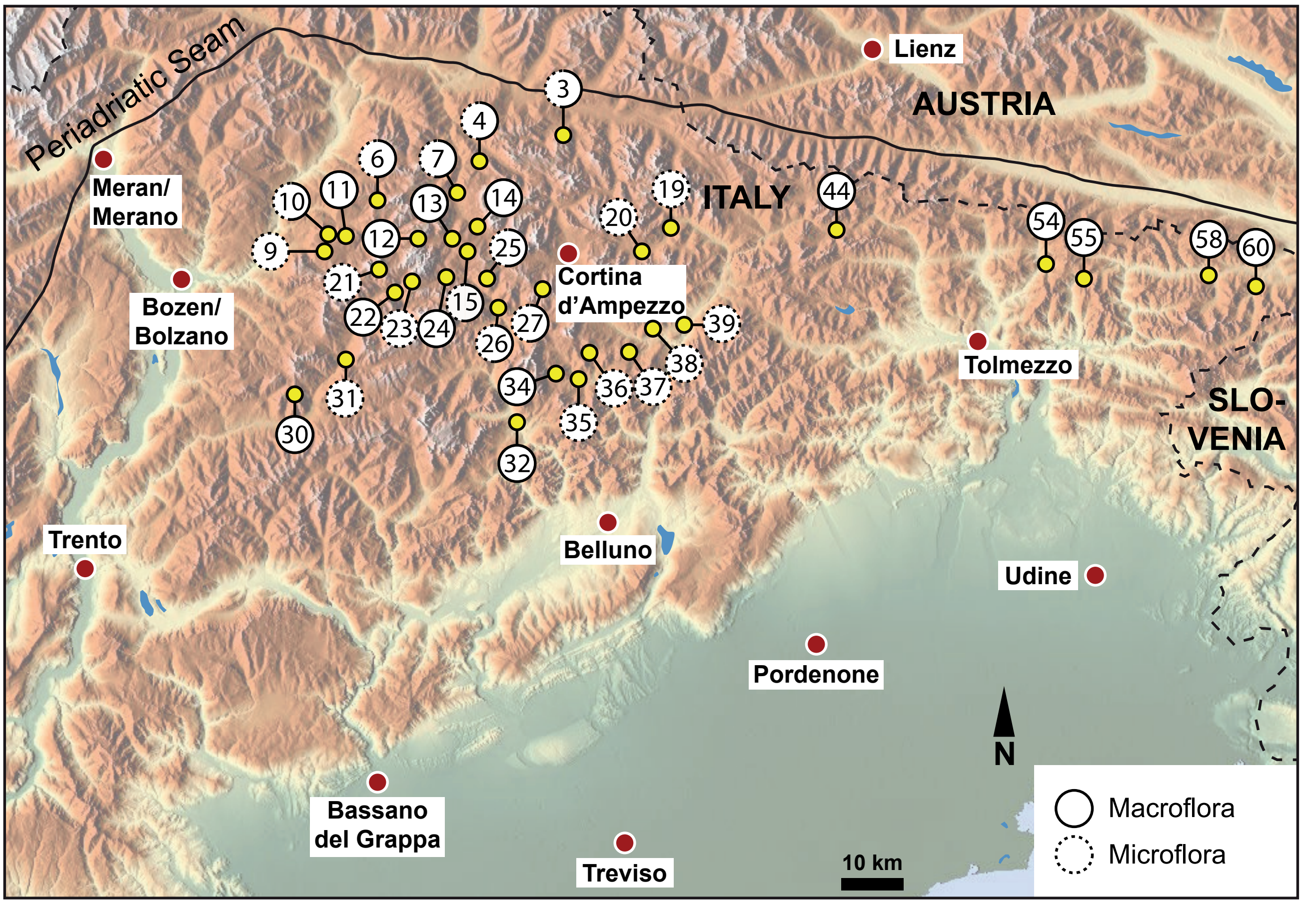

Figure 9: Map of the Eastern Southern Alps with the localities from which Ladinian plant macrofossils and/or microfossil assemblages have been reported. **3.** Prags/Braies (Seewald, Innerkohlbach); **4**. Ritjoch (Wengen/La Valle); **6.** Seceda (incl. Forcella di Pana/Panascharte, Aschkler Alpe/Alpe di Mastlé); **7.** St. Leonhard i. Abteital/San Leonardo in Badia; **9.** Seis/Siusi, Frommbach, Frötschbach; **10.** Pufels/Bulla, Puflatsch/Bullaccia; **11.** Schgaguler Schwaige/Malga Schgaguler; **12.** Grödner Joch; **13.** Col Alto, Corvara; **14.** St. Kassian/San Cassiano; **15.** Stuores Wiesen/Prati di Stuores; **19.** Val Ansiei, Cosderuoibe; **20.** Palus San Marco; **21.** Plattkofel/Sasso Piatto, Grohmannspitze/Punta Grohmann, Rif. S. Pertini, Rif. T. Demetz, Gabia, Val Duron; **22.** Cercenà; **23.** Pordoi, Pordoijoch/Passo Pordoi; **24.** Arabba; **25.** Livinallongo, Monte Sief, Col di Lana; **26.** Laste di Sopra, Caprile; **27.** Croda da Lago Group, Corvo Alto, Lastoni di Formin, Forcella Giau; **30.** Monte Agnello; **31.** Moena; **32.** Valle di San Lucano, Agordo; **34.** Spiz Zuel, Col d'Agnelessa; **35.** Valle di Zoldo, Dont; **36.** Zoppè di Cadore; **37.** Monte Rite; **38.** Vallesina di Sopra; **39.** Val Giaule, Pieve di Cadore; **44.** Sappada; **54.** Dierico; **55.** Val Aupa, Moggio Udinese; **58.** Monte Nebria, Malborghetto Valbruna; **60.** Canale Prasnig, Rio Freddo.

rare, with only a few sporophylls of *Lepacyclotes zeilleri* and some stem fragments of *Equisetites arenaceous* (Fig. 10A). The most abundant and diverse fern family is the Osmundaceae, with *Cladophlebis ladinica*, *C. leuthardtii*, *C. ruetimeyeri*, *Cladophlebis* sp., *Neuropteridium elegans*, *Scolopendrites* sp. and *Gordonopteris lorigae* (Kustatscher et al., 2004, 2014; Kustatscher & Van Konijnenburg-van Cittert, 2005). The Marattiales are represented by *Danaeopsis marantacea*, the Matoniaceae by frond fragments of *Phlebopteris fiemmensis*. Some frond pinna fragments resembling *Thaumatopteris* probably belong to the Dipteridaceae because of their typical venation (Kustatscher et al., 2014). The affinity of *Chiropteris monteagnellii* remains unclear, as well as the affinity of the whole genus *Chiropteris*. However, considering the leaf morphology and venation pattern, *Chiropteris* spp. might have belonged to the Dipteridaceae (Kustatscher & Van Konijnenburg-van Cittert, 2013; Kustatscher et al., 2014).

The seed fern group is dominated by *Ptilozamites sandbergeri* (Kustatscher & Van Konijnenburg-van Cittert, 2005), both leaf fragments and putative fertile structures and seeds are known. Peltaspermalean leaf fragments, such as *Scytophyllum bergeri*, are less common in this flora (Kustatscher et al., 2006b, 2007, 2014). The leaves of cycadophytes are assigned to the entire-margined *Bjuvia dolomitica* and *Taeniopteris* sp., the macrosporophylls to *Dioonitocarpidium moroderi* (Fig. 10B; Wachtler & Van Konijnenburg-van Cittert, 2000; Kustatscher et al., 2004, 2014; Kustatscher & Van Konijnenburg-van Cittert, 2005). The dissected leaves, previously assigned to *Pterophyllum*, yielded typical cycadalean cuticles and cannot be assigned to *Pterophyllum* anymore. They are here assigned to their corresponding fossil-taxon *Nilssonia* sp. (Fig. 10C) for these parallel-margined dissected leaves (Pott, 2013). *Sphenozamites wengensis* and *Sphenozamites* sp. cf. *S. bronnii* – the forms with club-shaped segments – are here assigned to a different genus (*Macropterygium*, see section 9) as no cuticles have been found so far, and *Sphenozamites* is nowadays reserved for bennettitalean leaves only (Zijlstra et al., 2013). The isolated macrosporophylls with a distal pinnate form and proximal two rows of seeds belong to the species *Dioonitocarpidium moroderi*. The genus *Voltzia* is dominant among the conifers with *Voltzia dolomitica* (Fig. 10D), *V. heterophylla*, *V. ladinica*, *V. pragsensis*, *V. zoldana* and *Voltzia* sp. Additional conifers are *Albertia* sp., *Pelourdea vogesiaca* (Fig. 10E) und *Elatocladus* sp. (Fig. 10F; Wachtler & Van Konijnenburg-van Cittert, 2000; Kustatscher et al., 2004; Kustatscher & Van Konijnenburg-van Cittert, 2005).

Ladinian		Wengen/La Valle	Monte Agnello	Prags/Braies	Seiser Alm/Alpe di Siusi	Gröden/Val Gardena	Hochabteital/alta Val Badia	Croda da Lago Group	Livinallongo	Col d'Agnelessa	Arabba	Cercenà	Sappada	Moggio Udinese	Malborghetto Valbruna	Dierico
Lycophytes	*Lepacyclotes zeilleri*	x														
Horsetails	*Equisetites arenaceus*	x											x			
	Equisetites sp.	?					?		?			?	?	?	x	
Ferns	*Anomopteris mougeotii*						x							x		
	Chiropteris monteagnellii		x													
	Cladophlebis ladinica		x													
	Cladophlebis leuthardtii	x		x	x	x	x	x	x			x	x			
	Cladophlebis ruetimeyeri				x		x					x				
	Cladophlebis sp.		x													
	Danaeopsis angustifolia			?												
	Danaeopsis marantacea						?									
	Gordonopteris lorigae	x						?				x	x			
	Neuropteridium elegans	x	x					x					x			
	Phlebopteris fiemmensis		x													
	Scolopendrites sp.						x									
	Thaumatopteris sp.		x													
	Dipteridaceae indet.		x													
Seed ferns	*Ptilozamites sandbergeri*	x		x	x	x		x								
	Scytophyllum bergeri		x				x									
Cycadophytes	*Bjuvia dolomitica*	x			x	x	x	x								
	Bjuvia sp.		?		?		?		?				?			
	Dioonitocarpidium moroderi				x											
	Macrotaeniopteris sp.		x													
	Nilssonia sp.		x						x							
	"Pterophyllum filicoides"						x					x				
	„Pterophyllum" sp.			x	x		x									
	„Zamites sp."						x									
Conifers	*Albertia* sp.															x
	Elatocladus sp.				x											
	Pelourdea vogesiaca	x		x	x											
	Pelourdea sp.		x	x	?							?				
	Voltzia dolomitica	x		x	x								x	?		
	"Voltzia heterophylla"															x
	Voltzia ladinica	x		x	x	x								x		
	Voltzia pragsensis	x		x	x											
	Voltzia zoldana											x				
	Voltzia sp.	x	x	x	x	x						x	x	x	x	x
Incertae sedis	*Carpolithes* sp.	x											x	x		
	Macropterygium bronnii						?		?							
	Macropterygium wengensis	x		x												
	Macropterygium sp.		x													
	Taeniopteris sp.		x	x		x	x					x	x			

Table 3: Occurrences of Ladinian plant macrofossil taxa at the various localities in the Eastern Southern Alps.

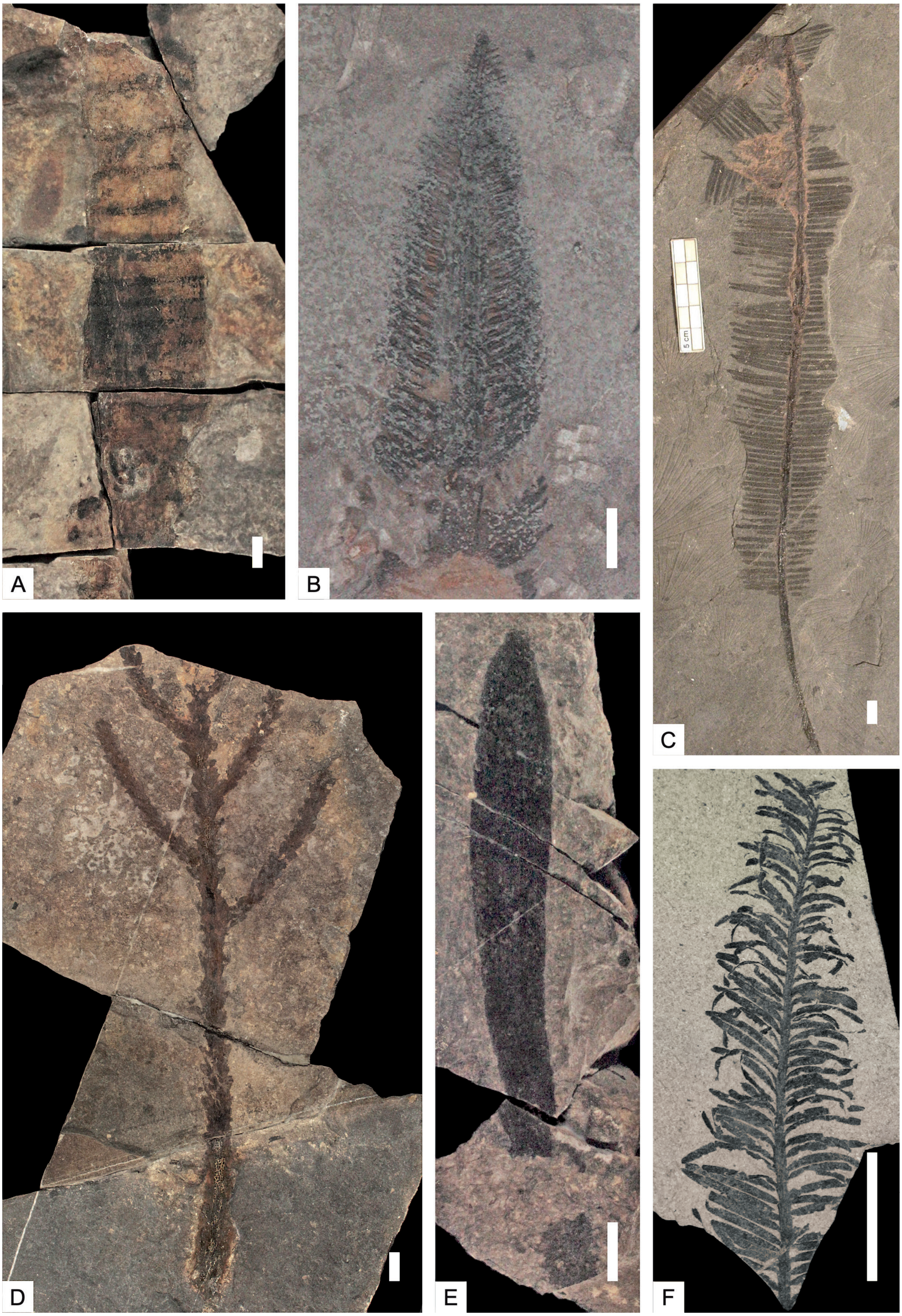

Figure 10: Plant macrofossils from the Ladinian of the Eastern Southern Alps. Scale bars = 1 cm. **A.** stem fragment of *Equisetites arenaceus* (Jaeger) Schenk, 1864 (Brongniart) Wills, 1910, NMS PAL 003; **B.** Megasporophyll of *Dioonitocarpidium moroderi* (Leonardi) Kustatscher et al., 2004, MDG M22; **C.** *Nilssonia* sp., GII P3775; **D.** shoot of *Voltzia dolomitica*, NMS PAL 032; **E.** *Pelourdea vogesiaca*, NMS PAL 556; **F.** *Elatocladus* sp., 1868, MDG 02.

5.2. THE LADINIAN MICROFLORA OF THE EASTERN SOUTHERN ALPS

Several palynological studies have been carried out on Ladinian successions in the Dolomites during the last 25 years (Cros & Doubinger, 1982; Van der Eem, 1982, 1983; Blendinger, 1988; Roghi, 1995, 1997; Broglio Loriga et al., 1999; see also Fig. 2, 9). Palynological data were mostly used for biostratigraphy (Fig. 4; Blendinger, 1988; Roghi, 1995, 1997; Broglio Loriga et al., 1999). In several studies (i.e. Van der Eem, 1983; Kustatscher & Van Konijnenburg-van Cittert, 2005; Hochuli et al., 2014), the

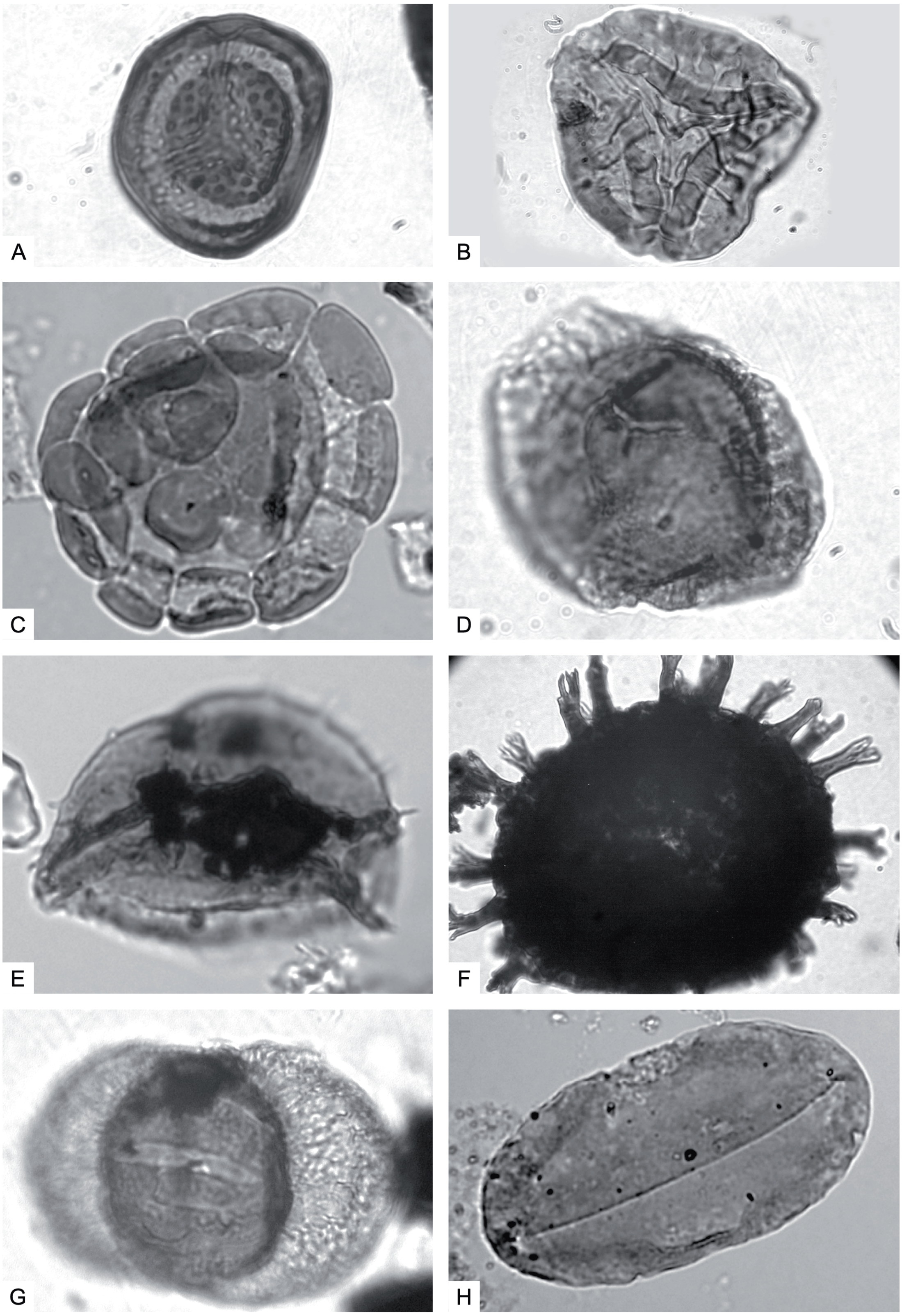

Figure 11: Palynomorphs of the Ladinian of the Eastern Southern Alps. **A.** *Gordonispora fossulata*, Ritberg section, 30 µm; **B.** *Kyrtomisporis ervii*, Ritberg section, 54 µm; **C.** *Camerosporites* secatus, 44 µm; **D**. *Triadispora* sp., Ritberg section, 40µm; **E.** *Aratrisporites* sp., 55µm; **F.** *Keuperisporites baculatus*, Ritberg section, 80µm; **G.** *Lunatisporites acutus*, Ritberg section, 70 µm; **H** *Ovalipollis pseudoalatus*, 71 µm.

palynomorphs are also considered as a source for paleoclimatic and paleoenvironmental data.Striate and taeniate bisaccate pollen (*Lunatisporites acutus* (Fig. 11G) decline gradually during the Ladinian, contemporaneous to a marked increase in bisaccate pollen such as *Triadispora* (Fig. 11D) and *Ovalipollis pseudoalatus* (Fig. 11H) (Van der Eem, 1983; Brugman, 1986; Roghi, 1995, 1997). The cavatomonolete *Aratrisporites* (Fig. 11E) is well represented during the Ladinian and Circumpolles (*Duplicisporites* spp.; *Camerosporites* secatus (Fig. 11C) and monosaccate pollen appear. The Ladinian Circumpolles from the Southern Alps were identified as ancestors of the "true" Circumpolles from the Late Triassic, which belong to the Hirmeriellaceae (Zavialova & Roghi, 2005). Also present in the uppermost Ladinian are: *Concentricisporites* sp. cf. *C. bianulatus* *Enzonalasporites vigens*, *Kyrtomisporis ervii* (Fig. 11B), *Keuperisporites baculatus* (Fig. 11F) and *Gordonispora fossulata* (Fig. 11A), together with *Nevesisporites vallatus*, *Todisporites marginalis*, *Calamospora* sp. A, *Apiculatisporites parvispinosus* and *Densosporites* sp. cf. *D. variomarginatus* (Mietto et al., 2012).

Van der Eem (1983) defined a sequence of at least four palynomorph phases for the Ladinian of the Western Dolomites (Southern Alps), correlated to regional ammonoid zones of Krystyn (1983). This includes the plurianulatus-secatus phase (p.p.), the secatus-dimorphus phase and the secatus-vigens phase (p.p.). Roghi (1995) revised the sequence of phases of Van der Eem (1983) in combination with the work of Brugman (1986) and proposed the scheuringii-pseudoalatus phase (with 5 zones, of which 3 belong to the Ladinian and one belongs partly also to the Anisian) and the pseudoalatus-baculatus phase (with 4 zones) based on different stratigraphic successions. These were correlated with ammonoid stratigraphy (Fig. 4). After the definition of the Ladinian GSSP (Brack et al., 2005), Hochuli et al. (2015) defined a succession of Anisian–Ladinian palynozones (TrS-A to TrS-F) from the Seceda drill core, of which the last four zones belong to the Ladinian (TrS-C to TrS-F).

Quantitative palynological analyses suggest that the Ladinian was generally dry and warm, but with a small humid event in the late Ladinian (e.g., Van der Eem, 1983; Kustatscher & Van Konijnenburg-van Cittert, 2005; Preto et al., 2010).

Megaspores have been reported from the Ladinian to Carnian at several localities in the Dolomites and have been assigned to the *Horstisporites selaginelloides* megaspore assemblage zone (Wierer, 1997; Marcinkiewicz et al., 2014).

6. THE CARNIAN FLORAS OF THE EASTERN SOUTHERN ALPS

6.1. THE CARNIAN MACROFLORA OF THE EASTERN SOUTHERN ALPS

One of the most important historical plant fossil collections comes from the Carnian flora of Cave del Predil/Raibl ([62] in Fig. 5, 12; Bronn, 1858; Schenk, 1866–67, Stur, 1868a, 1885; Dobruskina et al., 2001). Additional fossiliferous outcrops of Carnian age are Rifugio Dibona (Cortino d'Ampezzo area; [16] in Fig. 2, 12), Stuores/Pralongià (near Corvara, [15] in Fig. 2,

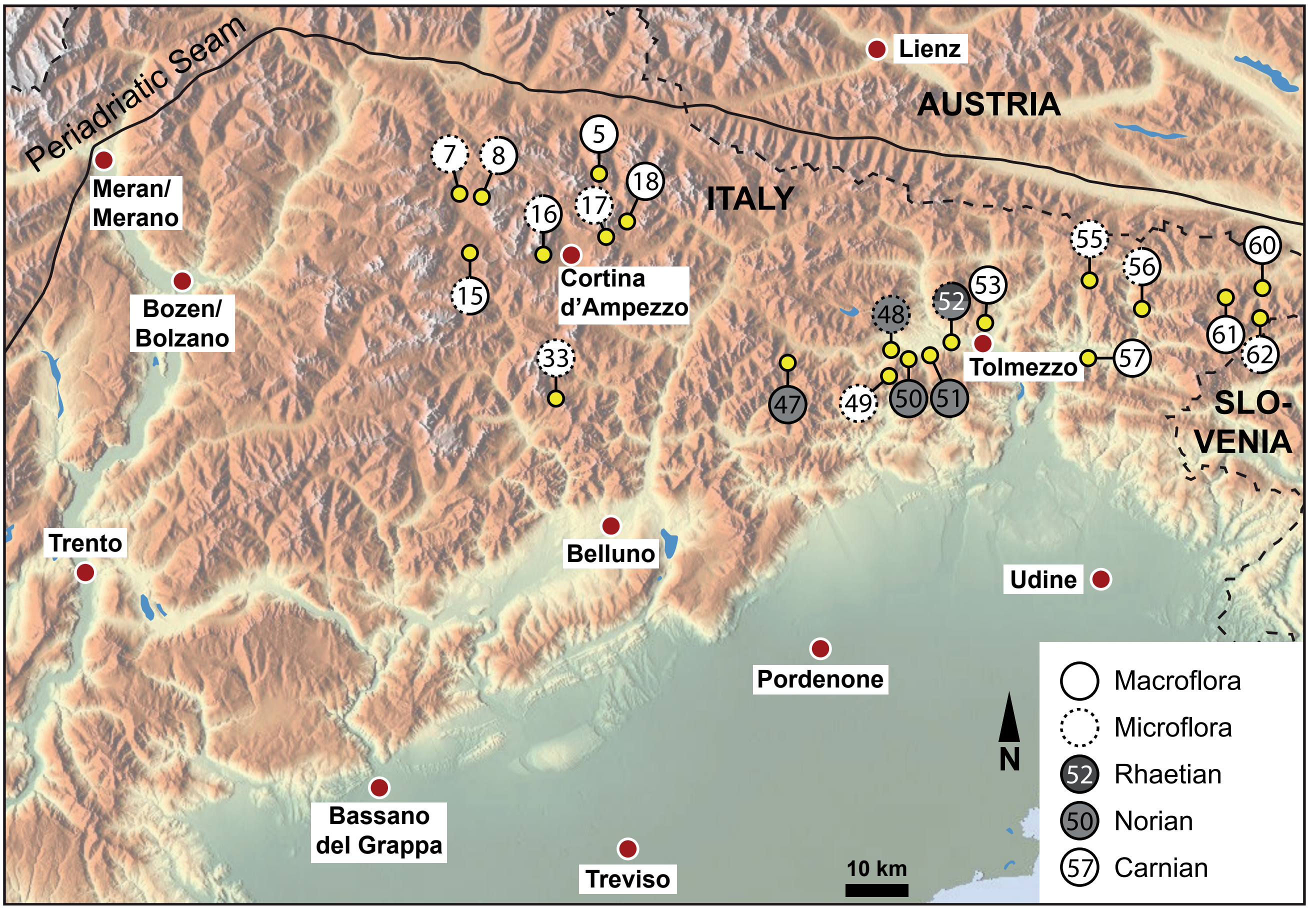

Figure 12: Map of the Eastern Southern Alps with the localities from which Upper Triassic plant macrofossils and/or microfossil assemblages have been reported. **5.** Seelandalpe, Plätzwiese/Prato Piazza; **7.** St. Leonhard im Abteital/San Leonardo in Badia; **8.** Heiligkreuz/Santa Croce; **15.** Stuores Wiesen/Prati di Stuores; **16.** Rifugio Dibona; **17.** Passo Tre Croci; **18.** Misurina; **33.** Passo Duran; **47.** Rio Rovadia; **48.** Priuso, Rio Canfoz; Caprizi, frana di Borta, Rio Molino; **49.** Monte Rest; **50.** Rio Torzulis, Socchieve; **51.** Preone, Rio Seazza, Valle di Preone, Enemonzo, Rio Spisulò; **52.** Villa Santina, Rio Plera, Rio Forchiàr, Rio Secco, **53.** Fusea, Cazzaso; **55.** Val Aupa, Moggio Udinese; **56.** Dogna, Val Dogna, Balador, Rio Pontuz; **57.** Rio Serai, Resiutta; **60.** Canale Prasnig, Rio Freddo/Kaltwasser; **61.** Val Saisera, Canale Placcia, Canale Klinken; **62.** Raibl/Cave del Predil, Rio dei Combattenti, Rio delle Cascate, Rio Conzen, Portella, Sella Ursic.

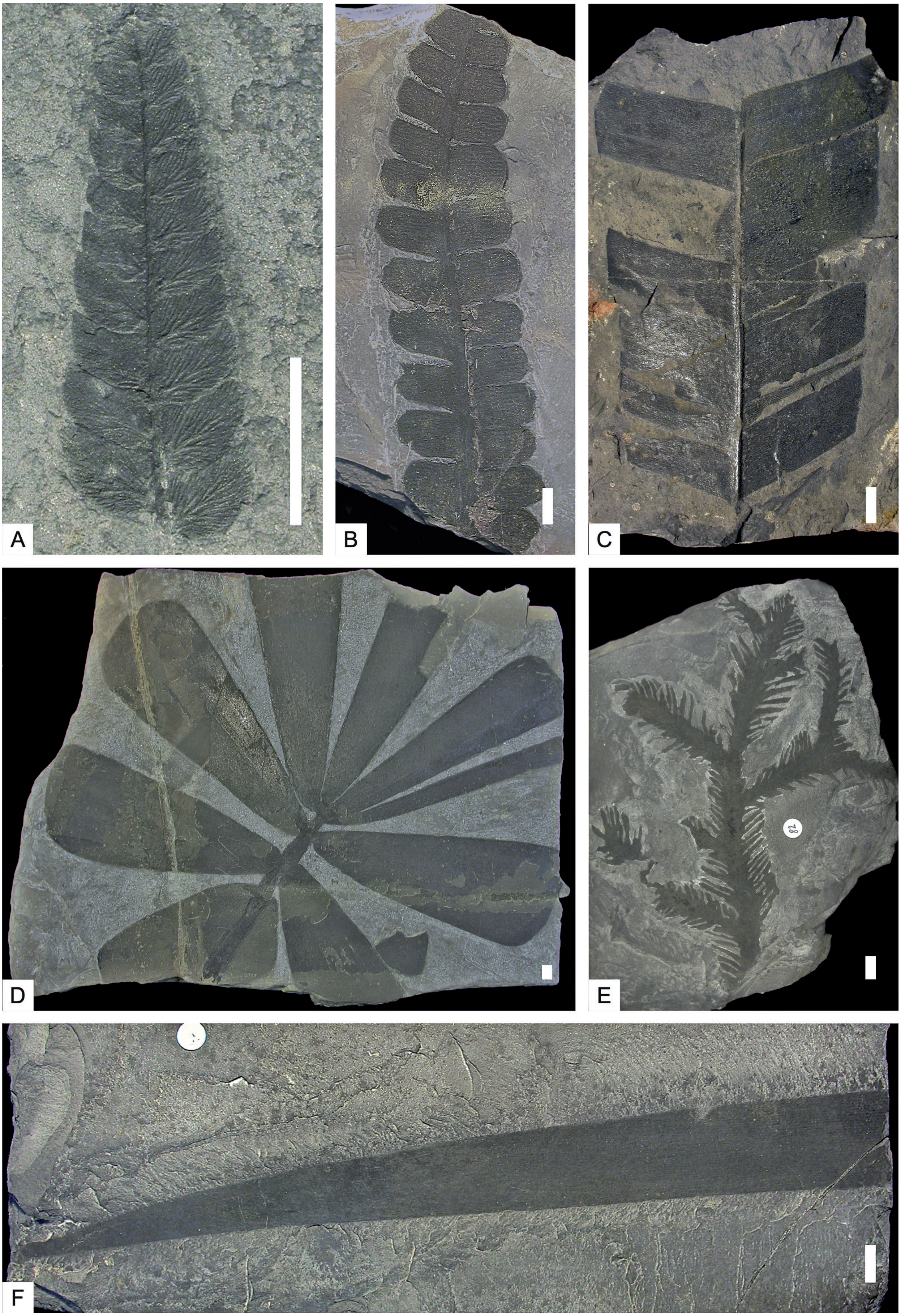

Figure 13: Plant fossils from the Carnian of the Eastern Southern Alps. Scale bars = 1 cm: **A.** frond fragment of *Cladophlebis leuthardtii* Leonardi, 1953, GBA 2007-072-0012; **B.** Leaf fragment of *Ptilozamites sandbergeri* (Schenk) Kustatscher et Van Konijnenburg-van Cittert, 2007, GBA 2005-0008-004; **C.** *Macrotaeniopteris* sp., GBA 2007-072-0070; **D.** *Macropterygium bronnii* (Schenk) Weber, 1996, GBA 2007-072-0053; **E.** *Voltzia haueri* Stur, 1885, GBA 1986-2-4; **F.** *Pelourdea vogesiaca* (Schimper et Mougeot) Seward, 1917, GBA 1986-2-128A.

12), Heiligkreuz/Santa Croce (near St. Leonhard im Abteital/S. Leonardo in Badia, [8] in Fig. 2, 12) and Misurina ([18] in Fig. 2, 12; Kustatscher et al., 2011a) in the Dolomites, as well as Dogna in the Julian Alps ([56] in Fig. 5, 12; Roghi et al., 2006a). Other plant remains of Carnian age come from the Friuli area; the most important plant fossil localities are Val Saisera and Canale Placcia (both Malborghetto Valbruna, [61] in Fig. 5, 12), Fusea (near Tolmezzo, [53] in Fig. 5, 12), Rio Serai (Resiutto, [57] in Fig. 5, 12), as well as Rio Freddo/Kaltwasser and Canale Prasnig in the Tarvisio area ([60] in Fig. 5, 12; collection database of the Museo Friulano di Storia Naturale, Udine).

The Carnian flora of the Eastern Southern Alps is composed of a wide range of plant fossils (Tab. 4). These include, among the sphenophytes, internal stem casts and stem fragments

Upper Triassic		**Carnian**										**Norian**		
		Hochabteital/ alta Val Badia	Dogna area	Seiser Alm/ Alpe di Siusi	Plätzwiese/ Prato Piazza	Raibl/ Cave del Predil	Misurina	Rifugio Dibona	Malborghetto Valbruna	Fusea	Rio Serai, Resiutto	Rio Seazza	Rio Forchiar	Rio Secco di Villa Santina
Horsetails	*Equisetites arenaceus*	x		x										
	Equisetites sp.	?	x			x		x				x		
Ferns	*„Asterotheca“* spp.													
	Chiropteris lacerata					x								
	„Camptopteris“ sp.													
	Cladophlebis leuthardtii					x								
	Cladophlebis ruetimeyeri					x								
	„Clathropteris“ spp.													
	Danaeopsis angustifolia		?											
	Danaeopsis marantacea					?								
	Danaeopsis sp.		x											
	“Laccopteris lunzensis”													
	Neuropteridium elegans					x								
	Neuropteridium grandifolium					x								
	„Oligocarpia“ sp.													
	*„Rhacopteris“*sp.					x								
	“Rhacopteris raiblensis”					x								
	Rhacophyllum crispatum					x								
	„Speirocarpus“ sp.					x								
Seed ferns	*Ptilozamites sandbergeri*	x	x			x								
	Sagenopteris sp.					x								
Cycads	*Apoldia tenera*					?								
	“Cycadites suessi”					x								
	“Dioonites pachyrrhachis”					x								
	Dioonitocarpidium sp.					x								
	Macrotaeniopteris sp.					x								
	Nilssonia sp.					x								
Bennettitales	*“Pterophyllum filicoides”*					x								
	Pterophyllum giganteum					x								
	Pterophyllum sp.					x								
Conifers	*Albertia* sp.											?		
	Brachyphyllum sp.		x									x	x	x
	“Cephalotaxites raiblensis”					x								
	Pagiophyllum sp.											x	x	
	Pelourdea vogesiaca					x						x		
	Pelourdea sp.		x			x						x	x	x
	„Podozamites“ sp.					?								
	„Thuites“ sp.					x								
	Voltzia foetterlei					x								
	Voltzia haueri		x			x								
	“Voltzia heterophylla”					x								
	“Voltzia pachyphylla”					x								
	Voltzia raiblensis					x								
	Voltzia sp.	x	x		x	x	x	x	x	x	x	x	x	x
	“walchian-like” conifer		?											
Incertae sedis	*Carpolithes* sp.	x												
	Macropterygium bronnii	?				x								
	Phylladelphia strigata					x								
	Taeniopteris sp.					x								

Table 4: Occurrences of Late Triassic plant macrofossil taxa at the various localities in the Eastern Southern Alps.

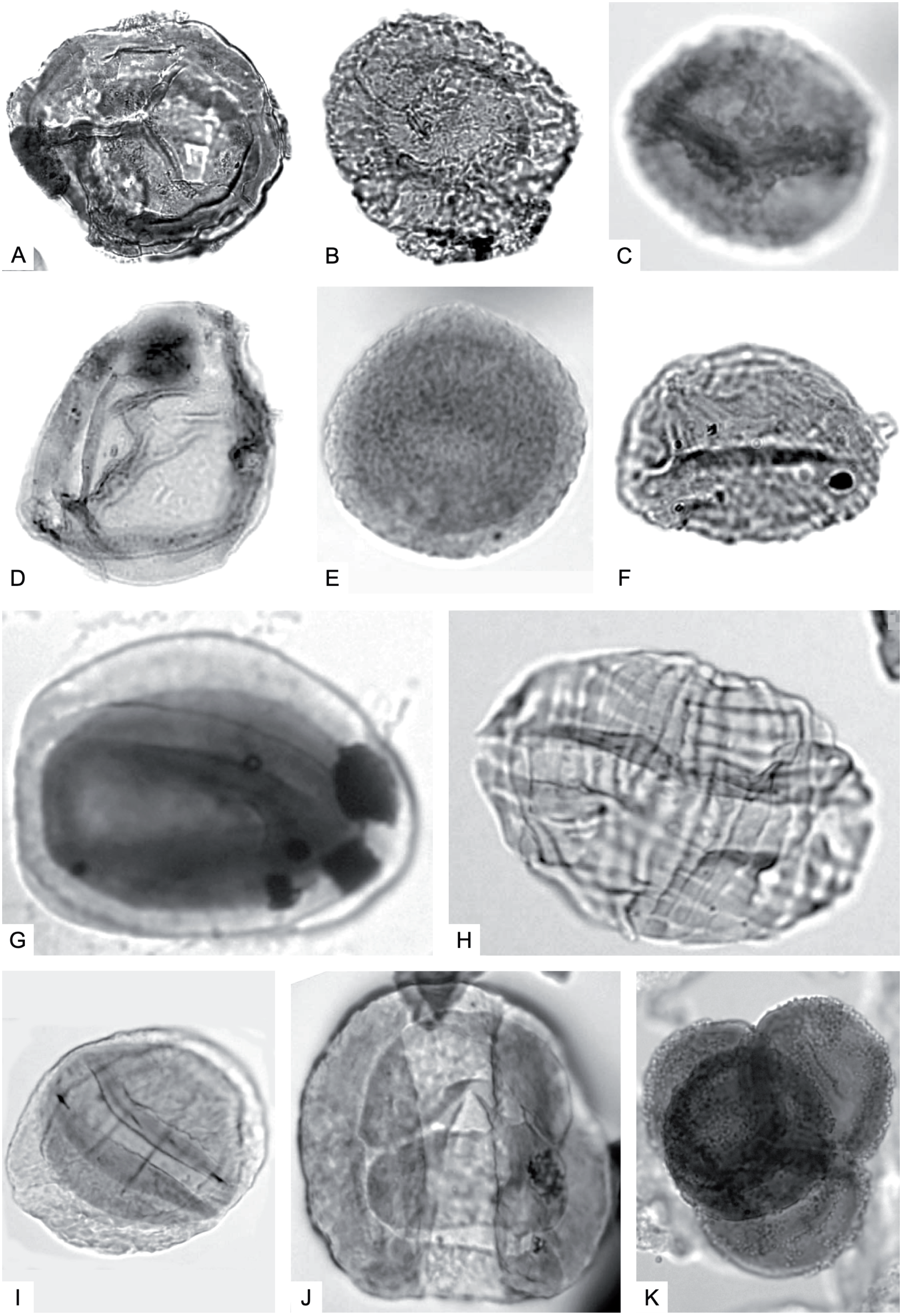

Figure 14: Palynomorphs of the Upper Triassic of the Eastern Southern Alps. **A.** *Concentricisporites* sp., 105 µm; **B.** *Patinasporites densus*, 62 µm; **C.** *Vallasporites ignacii*, 32 µm; **D.** *Aulisporites astigmosus*, 38 µm; **E.** *Enzonalasporites vigens*, 43 µm; **F.** *Lagenella martinii*, 35 µm; **G.** *Paracirculina* sp., 35 µm; **H.** *Equisetosporites chinleanus*, 50 µm; **I.** *Lueckisporites* cf. *L. parvus*, Rifugio Dibona, 65 µm; **J.** *Infernopollenites sulcatus*, 50 µm; **K.** *Granuloperculatipollis rudis*, 35 µm.

belonging to *Equisetites arenaceus* (Kustatscher et al., 2011a). The fern frond fragments belong to the Marattiales (*Danaeopsis lunzensis*, *D. angustifolia*, *Rhacophyllum crispatum*), Osmundaceae (*Cladophlebis leuthardtii*, (Fig. 13A), *C. ruetimeyeri*, *Neuropteridium elegans, N. grandifolium*), Matoniaceae (*Phlebopteris*), Dipteridaceae (*Clathropteris* sp.) and uncertain botanical affinity (*Chiropteris lacerata, Rhacopteris raiblensis, Rhacopteris* sp.). The seed ferns are dominated by simply pinnate leaves of *Ptilozamites sandbergeri* (Fig. 13B) and leaflets of *Sagenopteris* sp. The first undisputed Bennettitales (*Pterophyllum giganteum, Pt. longifolium*) appear in the fossil record of northern Italy during the Carnian. Historically mentioned are the cycadophyte leaves *Macropterygium bronnii* (Fig. 13D) and entire leaves belonging to *Macrotaeniopteris* sp. (Fig. 13C), as well as fragments of macrosporophylls assignable to *Dioonitocarpidium* sp. (e.g., Stur, 1885; Dobruskina et al., 2001; Kustatscher et al., 2012b).

Conifers are dominated by shoot fragments of *Voltzia*, such as *V. foetterlei*, *V. haueri* (Fig. 13E), *V. pachyphylla, V. raiblensis*. More rarely, *Brachyphyllum* sp. and *Cephalotaxites raiblensis* occur as well (Dobruskina et al., 2001). Long lanceolate leaves were historically assigned to the genus *Noeggerathia* but might belong to *Pelourdea vogesiaca* (Fig. 13F; Bronn, 1858). So far, leaf fragments with preserved cuticles were found only in Dibona, together with the amber drops that belong to the conifer family Hirmeriellaceae, and other conifers resembling the Permian walchian conifers (Roghi et al., 2006a, 2006b; for details see below). *Phylladelphia strigata* is of unknown botanical affinity (Kustatscher & Van Konijnenburg-van Cittert, 2008).

6.2. THE CARNIAN MICROFLORA OF THE EASTERN SOUTHERN ALPS

In the lowermost Carnian, several important types of vesicate and monosaccate pollen, (*Vallasporites ignacii* (Fig. 14C), *Patinasporites densus* (Fig. 14B), Circumpolles (*Duplicisporites verrucosus*, *Camerosporites secatus* (Fig. 11C), *C. pseudoverrucatus*), costate (*Weylandites magmus*) and bisaccate (*Samaropollenites speciosus*) pollen have their first occurrence (Mietto et al., 2012). Bisaccate pollen decline during the Carnian, whereas monosaccate, vesicate and the circumpollen forms show a noticeable diversification. Azonotrilete and monolete spores indicate the presence of ferns and cycads in cycadalean-dominated hygrophytic plant communities reflecting riverine, swamp or marsh environments (Roghi, 2004; Roghi et al., 2010; Kustatscher & Roghi, 2014).

In younger deposits, pollen of Bennettitales (*Aulisporites astigmosus*, Fig. 14D), as well as monolete (*Cycadopites* spp.) and costate forms (e.g., *Equisetosporites* (Fig. 14H), *Lagenella* (Fig. 14F) increase in abundance, indicating a flood plain vegetation characterized by moist soil conditions in a humid environment (Roghi, 2004; Roghi et al., 2010). This local humid event corresponds to the so-called "Carnian Pluvial Episode", a globally recorded climatic change (e.g., Simms & Ruffell, 1989; Gianolla et al., 1998; Roghi, 2004; Roghi et al., 2006b, 2010; Preto et al., 2010; Dal Corso et al., 2012, 2018). The abundant presence of cavatomonolete spores (*Aratrisporites* spp.) indicates mangrove-like ecosystems. The presence of bisaccate pollen (*Lunatisporites* spp., *Lueckisporites* cf. *L. parvus*; Fig. 14I) indicates influx of hinterland elements (Brugman et al., 1994). Circumpollen and monosaccate pollen represent xerophytic coastal pioneer vegetation, probably from saline mudflats.

Three main assemblages covering the Carnian Pluvial Episode in the Southern and Northern Calcareous Alps have been defined; the *Aulisporites astigmosus*, *Lagenella martinii* and *Granuloperculatipollis rudis* assemblages (Roghi et al., 2010). The *Aulisporites astigmosus* assemblage is late Julian in age and is found in the upper Conzen and lower Tor formations (Julian Alps), as well as in the lower Heiligkreuz Formation (Dolomites). It is characterized by the presence of *Calamospora lunzensis, Kraeuselisporites cooksonae, Distalanulasporites punctus, Leschikisporis aduncus*, *Tigrisporites halleinis, Duplexisporites* sp. 1, *Aulisporites astigmosus* and *Aratrisporites* spp.

The *Lagenella martinii* assemblage (Fig. 4) covers the middle–upper Tor and upper Heiligkreuz formations (late Julian to lower Tuvalian). Characteristic for this assemblage are spores such as *Conbaculatisporites mesozoicus, Leschikisporites aduncus, Raistrickia alpina, Baculatisporites comaumensis* and *Camarozonosporites*, as well as pollen grains such as *Lagenella martinii* (Fig. 14F), *Equisetosporites chinleanus* (Fig. 14H), *Araucariacites* spp., *Enzonalasporites vigens* (Fig. 14E), *Camerosporites secatus, C. pseudoverrucatus*, *Ovalipollis pseudoalatus* (Fig. 11H), *Duplicisporites* spp., *Patinasporites* spp., *Vallasporites ignacii*, *Cycadopites* spp. and *Doubingerispora filamentosa*.

The *Granuloperculatipollis rudis* assemblage has been found in the Carnitza Formation and in the Hauptdolomit/Dolomia Principale of the Julian Alps. It spans across the Carnian–Norian boundary and is characterized by the presence of *Infernopollenites sulcatus* (Fig. 14J), cf. *Brodispora* sp., *Granuloperculatipollis rudis* (Fig. 14K) and *Paracirculina quadruplicis* (Fig. 14G).

7. THE NORIAN FLORAS OF THE EASTERN SOUTHERN ALPS

7.1. THE NORIAN MACROFLORA OF THE EASTERN SOUTHERN ALPS

The Norian of the Eastern Southern Alps is generally rare in plant fossils. Almost all records so far came from the Dolomia di Forni in the Carnic Prealps (Figs. 5, 12; Dalla Vecchia, 2000, 2012). The most productive outcrops lie in the valley of the Rio Seazza near Preone ([51] in Figs. 5, 12). Other reported outcrops yielding plant fossils are Rio Rovadia and Rio Torzulis (both Socchieve; [50] in Fig. 5, 12), Rio Canfoz (Priuso; [48] in Figs. 5, 12), Rio Spisulò (Enemonzo; [51] in Fig. 5, 12), Rio Plera and Rio Forchiar (both Villa Santina, [52] in Figs. 5, 12; Dalla Vecchia, 2012). A few plant fossils from other localities in the same area, also belonging to the Dolomia di Forni, are listed in the collection database of the Museo Friulano di Storia Naturale. Most of the plant remains are conifer shoots, primarily shoot fragments assignable to the genera *Voltzia, Brachyphyllum* (Fig. 15E) or *Pagiophyllum* (Fig. 15B) and dispersed ovuliferous scales (Fig. 15C, 15D). Leaves and leaf fragments of *Pelourdea*, perhaps *Pelourdea vogesiaca* (Fig. 15A, 15F) are also present. Dalla Vecchia (2000) mentioned fragments of Bennettitales, whereas lycophytes, sphenophytes, ferns and seed ferns have so far not been observed.

Apart from the Dolomia di Forni, Dalla Vecchia (2000) also reported the presence of *Brachyphyllum* from a "bituminous" intercalation in the Dolomia Principale/Hauptdolomit at the Rio Serai near Resiutta in the collection of the Museo Friulano di Storia Naturale.

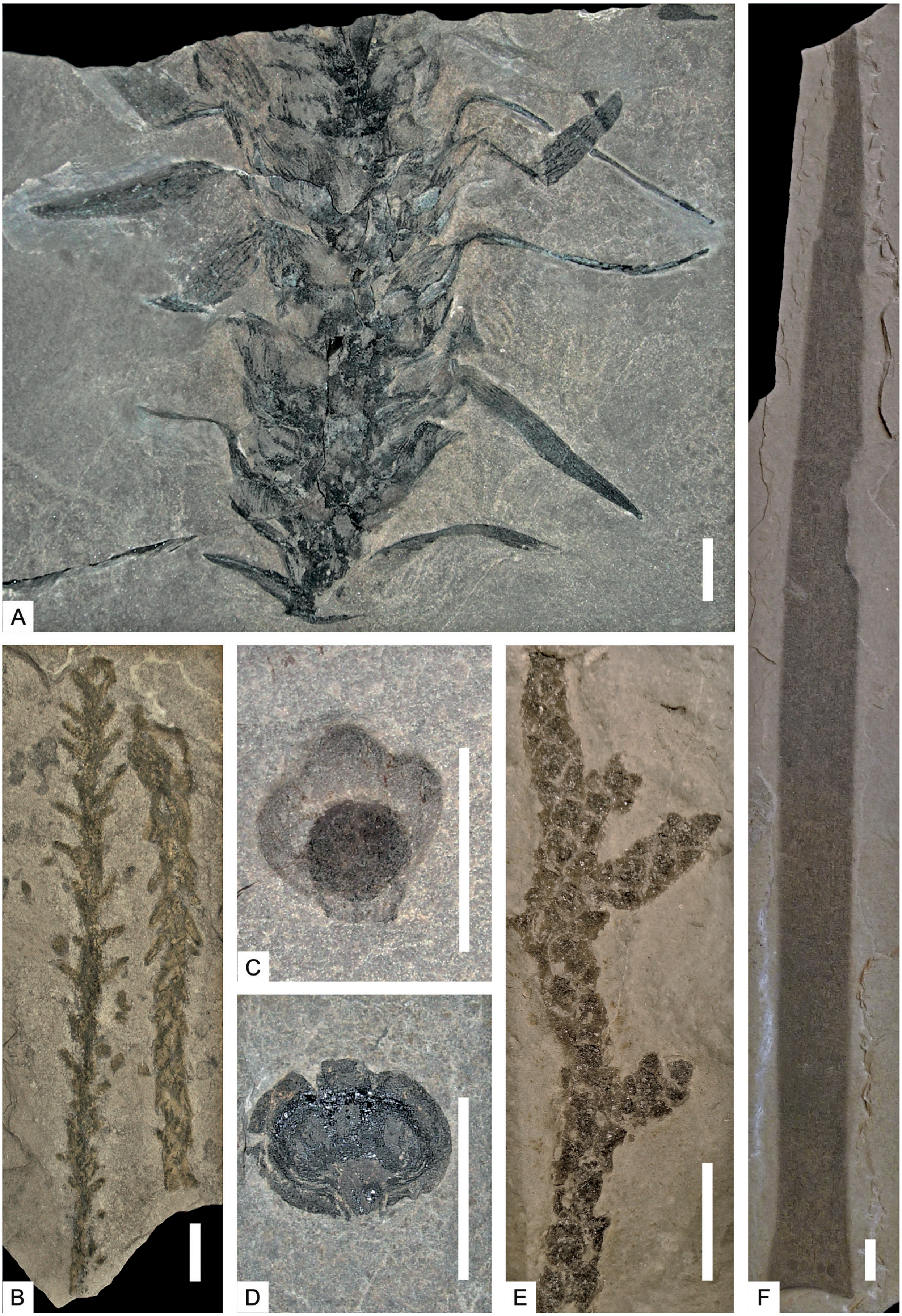

Figure 15: Plant fossils from the Norian of the Eastern Southern Alps. Scale bars = 10 mm: **A.** putative stem fragment of *Pelourdea vogesiaca* (Schimper et Mougeot) Seward, 1917, MFSN 40305; **B.** shoot fragments of *Pagiophyllum* sp., MFSNgp 40292; **C.** female scale of unknown affinity, MFSNgp 44397; **D.** female scale bar of cheirolepidaceous affinity, MFSNgp 44429; **E.** shoot fragments of *Brachyphyllum* sp., MFSNgp 50365; **F.** *Pelourdea vogesiaca* (Schimper et Mougeot) Seward, 1917, MFSNgp 1826.

7.2. THE NORIAN-RHAETIAN MICROFLORA OF THE EASTERN SOUTHERN ALPS

The Monticello Formation, Dolomia di Forni and Chiampomagno Limestone yielded abundant Norian and Rhaetian palynological associations in the Carnic and Julian Alps (Figs. 5, 12). They represent sediments of the intraplatform basins heteropic to the Dolomia Principale/Hauptdolomit and Dachstein Limestone (Dalla Vecchia, 2012; Carulli et al., 1998). These assemblages are dominated by trilete spores, monosaccate and bisaccate pollen and Circumpolles typical for the middle part of the Norian. During the late Norian, an increase in trilete spores and Circumpolles, along with a decrease of bisaccate pollen can be observed (Kustatscher & Roghi, 2014). The Rhaetian associations are characterized by trilete spores with fern, sphenophyte and lycophyte affinities and pollen grains belonging to the Circumpolles (*Corollina*), as well as pollen of uncertain botanical affinity, such as *Rhaetipollis germanicus* (Carulli et al., 1998).

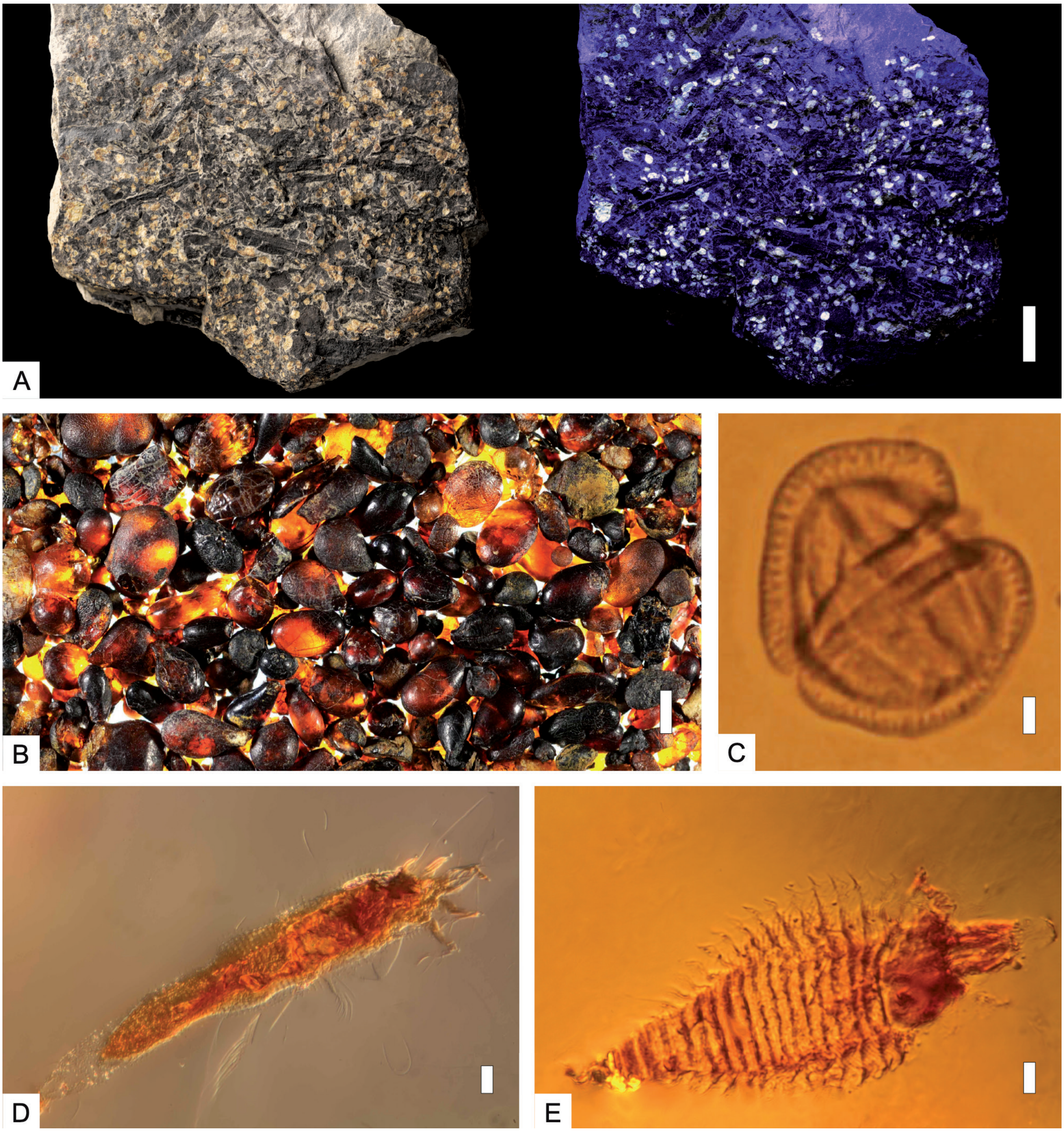

Figure 16: Triassic amber from the Dolomites. **A.** Sandstone with amber drops, fossil wood and charcoal (Heiligkreuz Fm., Dibona Section). The right image shows the sample under UV light, scale bar = 2 cm; **B.** Amber drops from the main palesols (Heiligkreuz Fm., Dibona section), scale bar = 5mm; **C.** Bisaccate taeniate pollen grain (*Lunatisporites* sp.) inside fossil resin, scale bar = 10µm; **D.** Plant-feeding mite inside Triassic amber: *Triasacarus fedelei* Lindquist et Grimaldi in Schmidt et al., 2012, scale bar = 10µm; **E.** Plant-feeding mite inside Triassic amber: *Ampezzoa triassica* Lindquist et Grimaldi in Schmidt et al., 2012, scale bar = 10µm.

8. THE AMBER

Triassic amber (Fig. 16) is very rare and occurs concentrated in a specific time interval in the Upper Triassic. Koken (1913) was the first to mention amber from the Triassic of the Southern Alps, specifically from the Heiligkreuz Formation around Cortina d'Ampezzo. This fossil resin is associated with conifer shoots and cuticle fragments, partly in palaeosoils. It was rediscovered almost 100 years later near the Rifugio Dibona (Fig. 16A, 16B) and subjected to a detailed study that also reported various inclusions (Fig. 16C–E); Roghi et al., 2006b, Schmidt et al., 2012, Sidorchuk et al., 2015; Seyfullah et al., 2018). More findings of amber together with plant fossils came from the Carnian of Dogna in the Julian Alps (Roghi et al., 2006a). Carnian amber is found in many different localities in Europe, North America and Southern Africa (Schmidt et al., 2012) and is linked to stressed conditions triggered by the Carnian Pluvial Episode (Gianolla et al., 1998; Roghi et al., 2006b). The Dolomites represent the largest Triassic amber deposit known to date.

Older Triassic amber was found in only one sample each from the Anisian in the Recoaro area and from putatively Ladinian sediments in the Dolomites (Roghi et al., 2017). The Anisian amber was found in a small collection of fossils, originally belonging to the botanist Abramo Massalongo (who lived from 1824 to 1860), which is presently housed at the Museum of Natural History of Venice. It pertains to the so-called "*Voltzia* beds" (lower Anisian) of the Recoaro area. Palynologically, these beds correspond to the vicentinense-antonescui subphase of the thiergartii-vicentinense phase (Fig. 4), which is characterized by the dominance of conifer pollen (Brugman, 1986). The amber was found in association with a conifer shoot fragment that was identified by Massalongo as "*Araucarites athrotanoides* Msslg" (*nomen in schedis*), which nowadays would correspond to *Voltzia recubariensis*. The Ladinian amber is associated with a shoot of *Voltzia ladinica* that was found, according to its label at the Museum of Natural History of Vienna, in the "Wengener Schichten" of Wengen/La Valle (Gadertal/Badia Valley). Based on the lithology, the sample corresponds to the uppermost part of the Wengen/La Valle Formation (latest Ladinian; Roghi et al., 2017). The Carnian amber of the Southern Alps has been mainly recovered from the Heiligkreuz Formation in the eastern Dolomites and in (marginal) marine sediments of the Rio del Lago Formation in the Julian Alps (Koken, 1913; Zardini, 1973; Gianolla et al., 1998; Roghi et al., 2006a, 2006b). In all cases, the amber was associated or in physical connection with conifer shoots and/or leaves, which permits the assignment to their respective resin-producing plant species. The Anisian and Ladinian amber of Northern Italy was produced by representatives of the Voltziales (*Voltzia recubariensis* and *V. ladinica*, respectively).

Although rare, the presence of the fossil resin in the Recoaro area and in the Wengen/La Valle area suggests it may be coeval with two Triassic humid shifts detected during the Bithynian/Pelsonian and Longobardian, respectively (Preto et al., 2010; Stefani et al., 2010). A transgressive phase could also have created stressed conditions for the forest habitat, leading to increased resin production while at the same time creating favorable conditions for the preservation of fossil plants and resin.

9. TAXONOMIC REMARKS

Genus *Macropterygium* Schimper, 1870
Type: Macropterygium bronnii (Schenk) Schimper, 1870

Remarks. Schimper (1870) attributed leaves to his new genus *Macropterygium* that had previously been assigned to *Pterophyllum bronnii* by Schenk (1866–67). *Macropterygium* was originally a junior synonym of *Sphenozamites* Brongniart, 1849. Wesley (1958) reserved the name *Sphenozamites* for leaves of bennettitalean affinity, and erected the new genus *Apoldia* Wesley, 1958 for macromorphologically similar leaves with a cycad affinity. The species *Sphenozamites tener* Compter, 1883 was assigned to *Apoldia* because of its cycadalean cuticle (Linnell, 1932, p. 251). However, that combination was invalid, since it lacked a full and direct reference to the basionym of the type species (Zijlstra et al., 2009). Moreover, the new combination was not in general use and new species with oblanceolate to spatulate segments were still assigned to the genus *Sphenozamites*.

During a revision of various *Pterophyllum* and *Zamites* species, Weber (1996) re-discussed *Macropterygium* and proposed *M. bronnii* (Schenk) Schimper, 1870 as type species and the specimen figured by Bronn (1858, pl. 4, fig. 1) as holotype of the species. Within the genus, he proposed three new subgenera – *Macropterygium* (Schimper) Arber, 1907, *Glandulozamites* (Bock) Weber, 1996 and *Indozamites* Weber, 1996 – and assigned *M. bronnii* to the first subgenus. The author suggested also to assign *Macropterygium* putatively to the Bennettitales, based on the finding of a syndetocheilic stoma apparatus in *Macropterygium rogersianum* (Fontaine) Weber, 1996. However, no cuticles have been described for the type species.

Zijlstra et al. (2009, 2013) proposed the conservation of the genus *Sphenozamites* for fossil bennettitalean leaves only. As a consequence, the genus *Macropterygium* Schimper, 1870 in its original diagnosis by Schimper is not considered a junior synonym of *Sphenozamites* anymore, since the former genus was created to include leaf fragments belonging to *Pterophyllum bronnii* Schenk, 1866–67, for which so far no cuticle has been described and which can, therefore, not be assigned with certainty to any plant group. Here we propose to use *Sphenozamites* (Brongniart) Miquel, 1851 for leaves with a clear affinity with the Bennettitales, *Apoldia* Wesley, 1958 for leaves clearly belonging to the cycads and *Macropterygium* Schimper, 1870 for those with unknown botanical affinity.

Macropterygium wengensis (Wachtler et Van Konijnenburg-van Cittert, 2000) Kustatscher et Van Konijnenburg-van Cittert comb. nov.
Basionym: Sphenozamites wengensis Wachtler et Van Konijnenburg-van Cittert, 2000, The fossil flora of the Wengen Formation (Ladinian) in the Dolomites (Italy), pp. 109–110, pl. 3, fig. 1–2.

Holotype: The specimen figured by Wachtler et Van Konijnenburg-van Cittert, 2000, pl. 3, fig. 1.

References

2000 *Sphenozamites wengensis* Wachtler et Van Konijnenburg-van Cittert, p. 109–110, pl. 4, fig. 1–3, pl. 5, fig. 1–5.
2004 *Sphenozamites wengensis* Wachtler et Van Konijnenburg-van Cittert – Kustatscher, p. 36.
2013 *Sphenozamites wengensis* Wachtler et Van Konijnenburg-van Cittert – Petti et al., p. 465.

Description. The rachis of the leaf fragments is thick (2–6 mm), the segments are inserted (sub-)oppositely and slightly to the upper side of the stout rachis, without covering it significantly. The segments are oblanceolate, slightly asymmetric with the posterior margin longer than the anterior margin, a slightly restricted base and a rounded apex. The segments are 30–45 mm long with a maximum width of 11–15 mm. The veins originate from the attachment area, fork in the lower and middle part of the segments and reach the outer margin at a concentration of 16/cm.

Remarks. The epidermis of *Macropterygium wengensis* has not been found preserved so far. Petti et al. (2013) suggested that the leaf fragments of *Sphenozamites wengensis* Wachtler et Van Konijnenburg-van Cittert, 2000 should be considered as cycadalean and thus transferred to the genus *Apoldia*. However, the missing cuticles make it impossible to assign this taxon to any higher plant group; consequently, an assignment to the genus *Macropterygium* Schimper, 1870 is proposed here.

Geographic and stratigraphic distribution. The species is so far restricted to the Ladinian of the Dolomites.

10 STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF THE MACRO PLANT REMAINS

The Triassic flora of the Eastern Southern Alps is a diverse flora with at least 95 different taxa. However, the stratigraphic record of these taxa is still scattered. Some plant assemblages, such as those from the Kühwiesenkopf/Monte Prà della Vacca (37 taxa) and the Raibl/Cave del Predil area (34 taxa), are important not only in comparison with other localities from the Southern Alps, but are also among the most diverse and abundant of their respective time slices in Europe. Relatively abundant and diverse assemblages are Piz da Peres (14 taxa), Recoaro (12 taxa; this plant assemblage is in need of a modern revision), Wengen/La Valle (15 taxa), Monte Agnello (15 taxa), Seiser Alm/Alpe di Siusi (12 taxa), Prags/Braies (11 taxa), and Agordo (10 taxa). All other localities yielded less than 10 taxa each. As a general overview, considering each of the stages, the Anisian flora of the Southern Alps is composed of 52 taxa, the Ladinian one of 39 taxa, the Carnian of 35 taxa and the Norian of 7 taxa only (Tab. 1, 3, 4). This apparent decrease in taxa could be in part artificial and not reflect a general decrease in diversity throughout the Triassic, because it appears in comparison with the best-preserved, and therefore unusually diverse Anisian plant fossil assemblage from the Kühwiesenkopf/Monte Prà della Vacca and the Recoaro plant assemblage, which needs further taxonomic revision. The Carnian and Norian plant assemblages are also in need of a taxonomic revision and/or study of the available collections. This could noticeably change our understanding of the diversity within the various stages.

On a generic level and excluding the problematic eight genera of the Recoaro and Raibl/Cave del Predil plant assemblages, 45 different taxa can be distinguished in the Eastern Southern Alps (Tab. 5). Only few of them are long-ranging taxa present from the Anisian to the Norian, i.e., *Equisetites* among the horsetails and *Pelourdea* and *Voltzia* among the conifers (Tab. 5). The lycophytes are represented by four different genera (*Isoetites*, *Lycopia*, *Selaginellites* and *Lepacyclotes*), all of which are restricted to the Middle Triassic. With the exception of *Pleuromeia*, the

Group	Genus	Anisian	Ladinian	Carnian	Norian
Lycophytes	*Isoetites*	x			
	Lycopia	x			
	Selaginellites	x			
	Lepacyclotes	x	x		
Horsetails	*Echinostachys*	x			
	Neocalamites	x			
	Equisetites	x	x	x	x
Ferns	*Sphenopteris*	x			
	Anomopteris	x	x		
	Gordonopteris	x	x		
	Scolopendrites	x	x		
	Cladophlebis	x	x	x	
	Neuropteridium	x	x	x	
	Symopteris	?			
	Marattiopsis	?			
	Danaeopsis	?	?	x	
	Phlebopteris		x		
	Thaumatopteris		x		
	Chiropteris		x	x	
	Rhacophyllum			x	
Seed ferns	*Peltaspermum*	x			
	Scytophyllum	x	x		
	Sagenopteris	x		x	
	Ptilozamites	?	x	x	
Cycadophytes	*Bjuvia*	x	x	?	
	Nilssonia	x	x	x	
	Dioonitocarpidium	x	x	x	
	Macrotaeniopteris		x	x	
	Apoldia			?	
Conifers	*Pseudovoltzia*	?			
	Elatocladus	x	x		
	Albertia	x	x		?
	Pelourdea	x	x	x	x
	Voltzia	x	x	x	x
	Brachyphyllum			x	x
	Pagiophyllum				x
Incertae sedis	*Lugardonia*	x			
	Taeniopteris	x	x	x	
	Carpolithes	x	x	x	
	Macropterygium		x	x	
	Phylladelphia			x	

Table 5: Occurrences of plant macrofossil genera in the Anisian to Norian stages within the Eastern Southern Alps.

most characteristic Early Triassic lycophyte genus of Europe, all relevant Triassic lycophyte genera are thereby present in the Eastern Southern Alps. With the exception of *Schizoneura* and *Broomsgrovia*, all relevant European sphenophyte genera are present in the Eastern Southern Alps as well. The fern group is the most diverse plant group in the Triassic of the Eastern Southern Alps (14 genera) and shows an interesting stratigraphic pattern (Tab. 5). The Anisian and Ladinian plant assemblages are mainly dominated (both in abundance and diversity) by Osmundales; Marattiales occur already putatively in the Anisian assemblages (*Marattiopsis*, *Danaeopsis*) but are confirmed only in the Carnian (*Danaeopsis*; Kustatscher et al., 2012b). *Asterotheca*, a typical element of Ladinian and Carnian floras in Europe is conspicuously absent (e.g., Kustatscher & Van Konijnenburg-van Cittert, 2011; Pott et al., 2018). The Dipteridaceae and Matoniaceae appear within the Ladinian and/or Carnian of the Eastern Southern Alps, constituting some of the earliest representatives of these families in the fossil record (Kustatscher et al., 2014).

All seed fern genera in the Eastern Southern Alps are already present in Anisian plant assemblages, although the occurrence of *Ptilozamites* is still putative. These four genera (*Scytophyllum, Peltaspermum, Sagenopteris*, and *Ptilozamites*) are among the most important Triassic genera in Europe. Peculiarly, the first occurrences of all these genera are stratigraphically lower in the South Eastern Alps than in the Central European Basin (cf. Kustatscher & Van Konijnenburg-van Cittert, 2013). A similar pattern can be observed in the cycadophytes. The occurrences of *Bjuvia* and *Dioonitocarpidium* in the Anisian of the Kühwiesenkopf/Monte Prà della Vacca are the earliest occurrences of these two genera in Europe, although megasporophylls assigned to *Dioonitocarpidium* have even been described from the Permian of Texas (DiMichele et al., 2001). The genus *Pterophyllum* is currently considered part of the Ladinian flora, although cuticle analyses would be necessary in order to confirm the early presence of this bennettitalean.

The conifers are the second most abundant and diverse group within individual plant assemblages. With the exception of the long-ranging taxa *Pelourdea* and *Voltzia*, most genera are present in short time slices only. Confirmed findings of *Aethophyllum* and *Albertia* (the last with a putative record in the Norian) are restricted to the Middle Triassic of the Eastern Southern Alps. Both genera are well described from the Buntsandstein of the Germanic Basin, which is slightly older in age (e.g., Schimper & Mougeot, 1844; Fliche, 1910; Grauvogel-Stamm, 1978). Peculiar is the putative presence of *Pseudovoltzia* and conifer shoots with cuticles that resemble walchian-type conifers in the Carnian Dibona locality. Detailed studies will be necessary in order to confirm whether these two genera survived the end-Permian mass extinction. Five genera can so far not be assigned to any major plant group.

Only very few taxa are distributed throughout the entire Eastern Southern Alps, from the westernmost part (i.e., Val di Non, Monte Agnello), to the northernmost Dolomites (Kühwiesenkopf/Monte Prà della Vacca, Piz da Peres, Prags/Braies and Wengen/La Valle), to the Julian/Carnic Alps in the East (e.g., Dogna, Rio Serai, Raibl/Cave del Predil) and to the Venetian Alps in the South (Recoaro). In fact, only two genera are represented in all areas of the Eastern Southern Alps, i.e., the sphenophyte genus *Equisetites* and the conifer genus *Voltzia*, although *Equisetites* is missing in Monte Agnello. The conifer *Pelourdea*, on the other hand, is stratigraphically present through all stages in the Eastern Southern Alps, but is not present in the westernmost localities, in the Non Valley and at Recoaro (Tab. 1, 3, 4). Whether this is a collecting artefact or has a biogeographical reason, can so far not be determined.

The lycophytes in general do not only have stratigraphical constraints in the Dolomites but are also restricted to the Northern Dolomites and Sappada. Among the ferns, the geographically most widely distributed ones are the genera *Cladophlebis*, *Neuropteridium* and *Gordonopteris*. Among the seed ferns, *Scytophyllum* is restricted to the Dolomites, whereas *Ptilozamites* is present both in the Dolomites and in the Julian Alps. Cycadophytes are generally rare in specific plant assemblages but have a geographically wide distribution in the Dolomites and Julian Alps. Within the conifers, *Albertia* is also a widely distributed genus, missing only in the Non Valley and in the Julian Alps.

11. CONCLUSIONS

The presented overview of all the Triassic macro- and microplant assemblages from the Eastern Southern Alps, includes 62 main outcrop areas (Figs. 1, 9, 12). Some of these floras have been known for centuries (e.g., Raibl, Recoaro), but the majority has been discovered in the 20th and 21st century. Both historically famous plant fossil assemblages are in need of taxonomic revision, as they have not been studied in detail since the end of the 19th century. Consequently, some of the species and genera known from the historical papers have not been considered in the context of palaeogeography and stratigraphy.

The more recently collected floras (e.g., Kühwiesenkopf/Monte Prà della Vacca, Agordo, Piz da Peres, Monte Agnello) and/or revised museum collections (e.g., Val di Non) are well-documented and add a considerable amount of interesting data to our knowledge of the flora in the Eastern Southern Alps during the Triassic. Some of the newly discovered plant fossil assemblages are quite rich in specimens and diverse in taxonomic composition (e.g., the Anisian flora of Kühwiesenkopf/Monte Prà della Vacca and the Ladinian flora of Monte Agnello). These new collections allow new insights into the vegetation composition of the Western Tethys Realm during the Triassic. What previously seemed to be a mainly conifer-dominated flora is now recognized as more diverse, with a large number of fern and cycadophyte taxa.

In general, the Triassic flora of the Eastern Southern Alps is diverse, with at least 95 taxa (belonging to at least 45 genera) occurring within the Triassic System. However, the comprehensive compilation of data shows clearly that most of these taxa are described only from one or few localities, in general from the most abundant and diverse plant fossils assemblages indicated above. The only exceptions are the horsetail *Equisetites* and the conifer *Voltzia*, which are both diverse and very abundant through time and occur geographically over the entire Eastern Southern Alps. A general decrease in taxonomic diversity trough time can be observed. This is an artifact related to the increasing scarcity of diverse and abundant plant assemblages and the need for revision of some of the Late Triassic floras. Moreover, the fact that several genera seem to be restricted to certain areas of the Eastern Southern Alps may be related to the patchy record. We cannot exclude the possibility that a severe collecting bias is still influencing our understanding of the geographic and

stratigraphic distribution of the various taxa.
Palynological studies on the Triassic sequences of the Eastern Southern Alps have been in full swing since the 1980s and provided us with a large amount of data not only on specific assemblages, but also on palaeoecological and palaeoclimatological changes in the Eastern Southern Alps during the Triassic. These led to (chrono-)stratigraphic revisions of several plant fossil localities, permitting us to obtain a better correlation between the different plant assemblages. The biostratigraphic phases, zones or assemblages are calibrated with the aid of ammonoid, and rarely conodont, biozones, thus, enabling an exceptional temporal resolution. A detailed, high-resolution sampling of the Late Triassic and earliest Triassic will permit to extend and improve the biostratigraphic scale (Fig. 4), filling up some of the existing gaps in the Southern Eastern Alps.
Quantitative palynological analyses have evidenced several shifts (i.e., in the late Anisian, in the late Ladinian and in the middle Carnian), that are partly overlapping with regional and/or global shifts from xerophytic to hygrophytic plant communities, showing that the climate during the Triassic was not as uniform as sometimes presumed. These shifts in the climatic signal are coeval with amber findings in the Eastern Southern Alps. This includes the late Pelsonian shift with amber droplets on *Voltzia recubariensis* from Recoaro, the late Ladinian shift with amber from the Wengen Formation of Wengen/La Valle and the famous Carnian Pluvial Episode with abundant amber findings throughout the Dolomites, including major occurrences near Heiligkreuz, Rifugio Dibona and Dogna. At a first glance it may appear that the shifts correspond to the major occurrences in plant fossil assemblages, such as for example with Kühwiesenkopf/Monte Prà della Vacca and Recoaro. On the other hand, other important plant fossil outcrops, such as Monte Agnello or Raibl/Cave del Predil, do not correspond with the humid shifts but are slightly older. At Dogna and Rifugio Dibona, plant remains were found in great numbers, but the collected plant assemblages are not very diverse.
Almost 180 years after the first figure of a plant remain (small fern frond fragment) from the Eastern Southern Alps, the vegetation record has become well-stocked with a wide range of plant groups and taxa. The different taxa necessitated different habitats, nutrients, soil and water availability, occupying, thus, different types of environments. The Southern Alps were, during the Triassic, a dynamic and changing landscape due to tectonic movements, volcanic activities and sea-level changes. These provided a wide range of environmental settings that changed through time. The dynamic landscape is reflected in the different plant fossil assemblages that can be observed in the different plant fossil localities. Although the micro-and macroplant assemblages are distributed unevenly across the geographic area and the stratigraphic succession, they show a high potential for the reconstruction of these different environments due to the excellent biostratigraphic time constraints (combination of palynological and ammonoid zones). Moreover, the exceptional preservation and the possibility to study macro-plant remains, microfloral assemblages and *in situ* spores and pollen, permit to combine and improve both proxies.

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APPENDIX 1:

List of all macrofossil taxa discussed in this paper, their stratigraphic attribution, age constraints and collocation in the various national and international collections, or – in cases where the present location is unknown – references to the publications in which they have been described/figured. Taxa with names between quotation marks (" ") require revision.

LYCOPHYTES

***Isoetites brandneri* Kustatscher et al., 2010**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

***Lepacyclotes bechstaedtii* Kustatscher et al., 2010**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

***Lepacyclotes zeilleri* (Fliche) Retallack, 1997**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Wengen/La Valle (NHMW)

***Lepacyclotes* sp.**
Anisian: undifferentiated Anisian of Culzei (Prato Carnico, MFSNgp)

***Lycopia dezanchei* Kustatscher et al., 2010**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

***Selaginellites leonardii* Kustatscher et al., 2010**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

HORSETAILS

***Echinostachys* sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL)

***Equisetites arenaceus* (Jaeger) Schenk, 1864**
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MPP), "Torbiditi d'Aupa" (Illyrian) of Val Aupa (Moggio Udinese; MFSNgp)
Ladinian; upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Sappada (MPL)
Carnian: Heiligkreuz Formation (late Julian-early Tuvalian) of Heiligkreuz (Bosellini & Largaiolli, 1965), undifferentiated Carnian of Seiser Alm/Alpe di Siusi (GII)

***Equisetites conicus* Sternberg, 1833**
Anisian: Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG)

***Equisetites mougeotii* (Brongniart) Wills, 1910**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

?*Equisetites mougeotii* (Brongniart) Wills, 1910
Anisian: Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)

***Equisetites* sp.**
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MB.Pb, MPP) and "Torbiditi d'Aupa" (Illyrian) of Val Aupa (Moggio Udinese; MFSNgp)
Ladinian: undifferentiated Ladinian of Monte Nebria (Malborghetto Valbruna; MFSNgp)
Carnian: Rio del Lago Formation (Julian) of Dogna (MPP), Predil Limestone (Julian) of Raibl/Cave del Predil (MB.Pb, GBA, BII), Heiligkreuz Formation (Tuvalian) of Rifugio Dibona (MPP)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp)

?*Equisetites* sp.
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico; MFSNgp) and unspecified Prato Carnico (MFSNgp)
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Wengen/La Valle (NHMW), St. Kassian/San Cassiano (Hochabteiltal/alta Val Badia; NMP), Cercenà (Val Zoldana, MPP), Sappada (MPL), undifferentiated Ladinian of Monte Sief (Livinallongo, GII), Bevorchians (Moggio Udinese; MFSNgp)
Carnian: San Cassian Formation (Julian) of Stuores Wiesen/Pralongià (Hochabteiltal/alta Val Badia; ItTr; Bizzarini et al., 2001), Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW)

***Neocalamites* sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG)

FERNS

***Anomopteris mougeotii* Brongniart, 1828**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL), "Torbiditi d'Aupa" (Illyrian) of Val Aupa (Moggio Udinese; MFSNgp)

Ladinian: Wengen Formation (Longobardian) of Corvara (Hochabteiltal/alta Val Badia; GPIT), undifferentiated Ladinian of Bevorchians (Moggio Udinese; MFSNgp)

"*Asterotheca*" spp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

"*Camptopteris*" sp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)
***Chiropteris monteagnellii* Kustatscher et al., 2014**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

***Chiropteris lacerata* (Quenstedt) Rühle von Lilienstern, 1931**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Bronn, 1858)

***Cladophlebis ladinica* Kustatscher et al., 2014**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

***Cladophlebis leuthardtii* Leonardi, 1953**
Anisian: Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Corvara (Hochabteiltal/alta Val Badia; NHMW), Cercenà (Val Zoldana; MPL, MPP), Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; BSGP), Pufels/Bulla (Gröden/Val Gardena; MPL), Grödner Joch/Passo Gardena (Hochabteiltal/alta Val Badia; GLA), Corvo Alto (Croda da Lago Group; MDR) and Sappada (MPL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW)

***Cladophlebis remota* (Presl) Van Konijnenburg-van Cittert et al., 2006**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

***Cladophlebis ruetimeyeri* (Heer) Leonardi, 1953**
Ladinian: Wengen Formation (Longobardian) of Cercenà (Val Zoldana; MPP, MPL), Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; MPL) and Col Alto (Hochabteiltal/alta Val Badia; MDR)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

***Cladophlebis* sp.**
Anisian: Middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP), Wengen Formation (Longobardian) of Corvo Alto (MDR)

"*Clathropteris*" spp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

?*Danaeopsis angustifolia* (Schenk) Kustatscher et al. 2012
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Ladinian: upper part of the Fernazza Formation (Longobardian) of Innerkohlbach (Prags/Braies; NMS PAL)
Carnian: Rio del Lago Formation (Julian) of Dogna (MPP)

?*Danaeopsis marantacea* (Presl) Schimper, 1869
Ladinian: Wengen Formation (Longobardian) of Corvara (Hochabteiltal/alta Val Badia; Mojsisovics, 1879)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Schenk, 1866–7)

***Danaeopsis* sp.**
Carnian: Rio del Lago Formation (Julian) of Dogna (MPP)

***Gordonopteris lorigae* Van Konijnenburg-van Cittert et al., 2006**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL, GII), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL), Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG)
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Cercenà (Val Zoldana, MPP) and Sappada (MPL)

?*Gordonopteris lorigae* Van Konijnenburg-van Cittert et al., 2006
Ladinian: Wengen Formation (Longobardian) of Corvo Alto (MDR)

"*Laccopteris lunzensis* Stur, 1885"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

?*Marattiopsis* sp.
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

***Neuropteridium elegans* (Brogniart) Schimper, 1879**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL, GII), Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP), upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Forcella Giau (MDR), Monte Sief (Livinallongo; BSPG) and Sappada (MPL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

***Neuropteridium grandifolium* (Schimper et Mougeot) Compter, 1883**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

Neuropteridium voltzii **(Brogniart) Schimper, 1879**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL), undifferentiated Anisian of the Ponte di Rio Freddo/Kaltwasser (MFSNgp)

"*Oligocarpia*" sp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

Phlebopteris fiemmensis **Kustatscher et al., 2014**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

"*Rhacopteris*" sp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

"*Rhacopteris raiblensis* Stur, 1885"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

Rhacophyllum crispatum **(Münster in Sternberg) Kustatscher et Van Konijnenburg-van Cittert, 2011**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

Scolopendrites grauvogelii **Van Konijnenburg-van Cittert et al., 2006**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

Scolopendrites scolopendrioides **(Brogniart) Van Konijnenburg-van Cittert et al., 2006**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

Scolopendrites **sp.**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo; NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Ladinian: Wengen Formation (Longobardian) of St. Kassian/San Cassiano (Hochabteiltal/alta Val Badia; GII)

"*Speirocarpus*" sp.
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

Sphenopteris schoenleiniana **(Brongniart) Presl, 1838**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

Symopteris **sp.**
Anisian: undifferentiated Anisian of Rio Tschofen (Tarvisio, MFSNgp)

Thaumatopteris **sp.**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

Dipteridaceae indet.
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

Pteridophyta incertis sedis
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

SEED FERNS

Peltaspermum bornemannii **Kustatscher et al. 2007**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)

Peltaspermum **sp.**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico, MFSNgp)

Ptilozamites sandbergeri **(Schenk) Kustatscher et Van Konijnenburg-van Cittert, 2007**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL), St. Leonhard im Abteital/S. Leonardo in Badia (Hochabteiltal/alta Val Badia; NHMW), Seiser Alm/Alpe di Siusi (MDG), Wengen/La Valle (BSPG), Pufels/Bulla (Gröden/Val Gardena; BSPG) and Corvo Alto (Forcella Giau; MDR)
Carnian: Rio del Lago Formation (Julian) of Dogna (MPP), Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA, GII), undifferentiated Carnian of Canale Prasnig (Raibl/Cave del Predil; MFSNgp)

?*Ptilozamites* sp.
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

Sagenopteris **sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

Scytophyllum bergeri **Bornemann, 1856**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP), Wengen Formation (Longobardian) of Corvara (BGA)

CYCADOPHYTES

?*Apoldia tenera* (Compter) Wesley, 1958
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW)

***Bjuvia dolomitica* Wachtler et Van Konijnenburg-van Cittert, 2000**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL),
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL), Wengen Formation (Longobardian) of Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; BSPG), undefined Seiser Alm/Alpe di Siusi (MDG), Wengen/La Valle (NHMW), Corvara (Hochabteiltal/alta Val Badia; BSPG), Corvo Alto (Croda da Lago Group; MDR), Mondeval (Croda da Lago Group; MDR) and Gröden/Val Gardena (MDG)

?*Bjuvia* sp.
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP), Wengen Formation (Longobardian) of Livinallongo (PL), Grödner Joch/Passo Gardena (Hochabteiltal/alta Val Badia; GLA), Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; BSPG), Corvara (Hochabteiltal/alta Val Badia; NMS PAL), Sappada (MPL)

***Cycadites suessi* Stur, 1885**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (Stur, 1885)

***Dioonites pachyrrhachis* (Schenk) Stur, 1885**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA)

***Dioonitocarpidium moroderi* (Leonardi) Kustatscher et al., 2004**
Ladinian: Wengen Formation (Longobardian) of Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; MDG)

***?Dioonitocarpidium pennaeformis* (Schenk) Rühle von Lilienstern, 1928**
Anisian: Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG)

***Dioonitocarpidium* sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

***Macrotaeniopteris* sp.**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA, NHMW)

***Nilssonia* sp.**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

"*Pterophyllum filicoides* (Schlotheim) Zeiller, 1906"
Ladinian: Wengen Formation (Longobardian) of Livinallongo (PL), Corvara (Hochabteiltal/alta Val Badia; GII), Cercenà (Val Zoldana, MPP, MPL) and St. Kassian/San Cassiano (Hochabteiltal/alta Val Badia; MPL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA)

"*Pterophyllum giganteum* Schenk, 1865"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (UU)

"*Pterophyllum*" sp.
Ladinian: Wengen Formation (Longobardian) of Corvara (Hochabteiltal/alta Val Badia, SMNS), Seiser Alm/Alpe di Siusi (MDG), ?Laste/Monte Sief (Livinallongo; PL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA)

"*Zamites* sp."
Ladinian: Wengen Formation (Longobardian) of St. Kassian/San Cassiano (GPIT)

CONIFERS

"*Aethophyllum foetterlianum* Massalongo ex De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MSNV)

***Albertia* sp.**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MSNV, MPP), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico; MFSNgp) and undefined Prato Carnico (MFSNgp)
Ladinian: undifferentiated Ladinian of Dierico (MFSNgp)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp)

***?Albertia* sp.**
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp)

"*Araucarites agordicus* Anger, in schedis"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MSNV)

"*Araucarites albuctenoides* Mass., in schedis"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MCSNV)

"*Araucarites massalongii* De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MCSNV)

"*Araucarites pachyphyllus* De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MPP)

***Brachyphyllum* sp.**
Carnian: Rio del Lago Formation (early Carnian) of Dogna (MPP)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp), Rio Forchiar (MFSNgp) and Rio Secco (MFSNgp)

"*Cephalotaxites raiblensis* Stur, 1885"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

***Elatocladus* sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)
Ladinian: Wengen Formation (Longobardian) of Puflatsch / Bullaccia (MDG)

***Pagiophyllum* sp.**
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MCSNV)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp) and Rio Forchiar (MFSNgp)

***Pelourdea vogesiaca* (Schimper et Mougeot) Seward, 1917**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico; MFSNgp) and unspecified Prato Carnico (MFSNgp)
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL) and Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; MDG)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (MB. Pb, NMHW)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp)

***Pelourdea* sp.**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA), undifferentiated Carnian of Balador (Rio Lavaz, Dogna area; MFSNgp)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp), Rio Forchiar (MFSNgp), Rio Spisulò (MFSNgp)

?*Pelourdea* sp.
Ladinian: Wengen Formation (Longobardian) of Cercenà (Val Zoldana; MPP) and Seiser Alm/Alpe di Siusi (MPL)

"*Podozamites* sp."
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA, NHMW)

?*Pseudovoltzia* sp.
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

"*Taxites massalongii* De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MPP)

"*Taxites vincentinus* Massalongo ex De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MCSNV, MPP)

"*Taxodites saxolimpiae* Massalongo ex De Zigno, 1862"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MCSNV)

"*Thuites* sp."
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW)

***Voltzia dolomitica* Wachtler et Van Konijnenburg-van Cittert, 2000**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL), Wengen/La Valle (NHMW, GII), Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; MDG) and Sappada (MPL)

?*Voltzia dolomitica* Wachtler et Van Konijnenburg-van Cittert, 2000
Ladinian: Wengen Formation (Longobardian) of Wengen/La Valle (NHMW), undifferentiated Ladinian of Bevorchians (Moggio Udinese; MFSNgp)

"*Voltzia foetterlei* Stur, 1885"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (MB. Pb, NHMW, GBA, SMNS, NMP)

"*Voltzia haueri* Stur, 1885"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA, NMP, BII?), Rio del Lago Formation (Julian) of Dogna (MPP)

"*Voltzia heterophylla* (Brongniart) Schimper et Mougeot, 1844"
Anisian: "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MSNV), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), undifferentiated Anisian of Prato Carnico (MFSNgp)
Ladinian: undifferentiated Ladinian of Dierico (MFSNgp)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, ItTr)

***Voltzia ladinica* Wachtler et Van Konijnenburg-van Cittert, 2000**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL), Wengen/La Valle (NHMW), Seiser Alm/Alpe di Siusi (MDG), Gröden/Val Gardena (WDG), undifferentiated Ladinian of Bevorchians (Moggio Udinese; MFSNgp)

"*Voltzia pachyphylla* Schimper, 1869"
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA)

***Voltzia pragsensis* Wachtler et Van Konijnenburg-van Cittert, 2000**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL) and Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/Alpe di Siusi; MDG)

Voltzia raiblensis **Stur, 1885**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, UU, SMNS, NMP)

Voltzia recubariensis **(De Zigno) Schenk, 1868**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL), "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MB.Pb, MPL, MCSNV, MPP, GZG), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL, GII), Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico; MFSNgp)

Voltzia walchiaeformis **Fliche, 1910**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

?*Voltzia walchiaeformis* **Fliche, 1910**
Anisian: Voltago Limestone or Giovo Formation (Pelsonian) of Monte Avert (Val di Non; GZG)

Voltzia zoldana **Leonardi, 1953**
Ladinian: Wengen Formation (Longobardian) of Cercenà (Val Zoldana, MPP)

Voltzia **sp.**
Anisian: Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo; "Strati a Voltzia" (part of the Voltago Conglomerate, early Pelsonian) of Recoaro (MPL), middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), undifferentiated Anisian of the "Pragser Dolomiten" (BSPG), NMS PAL, MPP), Culzei (Prato Carnico; MFSNgp), unspecified Prato Carnico (MFSNgp) and Monte Bivera (MFSNgp)
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP), upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Innerkohlbach (Prags/Braies; NMS PAL), Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL), Wengen/La Valle (NHMW, GII), Aschkler Alpe/Malga Mastlè (Seceda, Gröden/Val Gardena; BSPG), Schgaguler Schwaige/Malga Schgaguler (Seiser Alm/ Alpe di Siusi; BSGP), Cercenà (Val Zoldana, MPP), and Sappada (MPL), undifferentiated Ladinian of Seiser Alm/Alpe di Siusi (SMNS), Pufels/Bulla (Gröden/Val Gardena; MPL), Bevorchians (Moggio Udinese; MFSNgp), Monte Nebria (Malborghetto Valbruna, MFSNgp) and Dierico (MFSNgp)
Carnian: Rio del Lago Formation (Julian) of Dogna (MPP), San Cassian Formation (Julian) of Stuores Wiesen/Pralongià (Hochabteiltal/alta Val Badia; Bizzarini et al., 2001), Misurina (NMS PAL) and Seelandalpe (Plätzwiese/Prato Piazza; BSPG), Predil Limestone (Julian) of Raibl/Cave del Predil (GPIT, STIPB-PB MPL, MFSNgp, GPIT/PL, NMP, GII, ItTr), Heiligkreuz Formation (Tuvalian) of Rifugio Dibona (MPP), undifferentiated Carnian of Balador (Rio Lavaz, Dogna area; MFSNgp), Canale Klinken (Malborghetto Valbruna; MFSNgp), Canale Placcia (Malborghetto Valbruna; MFSNgp), Canale Prasnig (Raibl/Cave del Predil; MFSNgp), Fusea (MFSNgp), Rio dei Combattenti (Raibl/Cave del Predil; MFSNgp), Rio Freddo/Kaltwasser (Raibl/ Cave del Predil; MFSNgp) and Rio Serai (MFSNgp)
Norian: Dolomia di Forni (Alaunian–Sevatian) of Rio Seazza (MFSNgp), Rio Forchiar (MFSNgp) and Rio Secco (MFSNgp)

?"walchian-like" conifer
Carnian: Rio del Lago Formation (early Carnian) of Dogna (MPP)

INCERTAE SEDIS

Carpolithes **sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL), undifferentiated Anisian of Culzei (Prato Carnico; MFSNgp)
Ladinian: Wengen Formation (Longobardian) of Seewald (Prags/ Braies; NMS PAL), undifferentiated Ladinian of Bevorchians (Moggio Udinese; MFSNgp), Wengen Formation (Longobardian) of Wengen/La Valle (NHMW) and Sappada (MPL)
Carnian: San Cassian Formation (Julian) of Stuores Wiesen/ Pralongià (Hochabteiltal/alta Val Badia; Bizzarini et al., 2001)

Lugardonia paradoxa **Kustatscher et al., 2009**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL)

Macropteridium bronnii **(Schenk) Schimper, 1870**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA, BSPG)

?*Macropteridium bronnii* **(Schenk) Schimper, 1870**
Ladinian: Wengen Formation (Longobardian) of St. Leonhard im Abteital/S. Leonardo in Badia (Hochabteiltal/alta Val Badia; NHMW), and Livinallongo (PL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (GBA, BSPG)

Macropteridium wengensis **(Wachtler et Van Konijnenburg-van Cittert, 2000) Kustatscher et Van Konijnenburg-van Cittert comb. nov.**
Ladinian: upper part of the Fernazza Formation (Longobardian) of Ritjoch/Forcela da Cians (Wengen/La Valle; NMS PAL) and Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL)

Macropteridium **sp.**
Ladinian: Pyroclastic layers (part of the Caotico Eterogeneo) of early Longobardian age of Monte Agnello (MGP)

Phylladelphia strigata **Bronn, 1858**
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW, GBA)

Taeniopteris **sp.**
Anisian: middle part of the Dont Formation (middle–late Pelsonian) of Kühwiesenkopf/Monte Prà della Vacca (NMS PAL, GII), Richthofen Conglomerate (Illyrian) of Piz da Peres (NMS PAL), Agordo Formation, Richthofen Conglomerate or Morbiac Limestone (Bithynian–Pelsonian) of Valle San Lucano, Agordo (NMS PAL)
Ladinian: Wengen Formation (Longobardian) of Seewald (Prags/Braies; NMS PAL), Pyroclastic layers (part of the Caotico

Eterogeneo) of early Longobardian age of Monte Agnello (MGP), Wengen Formation (Longobardian) of Cercenà (Val Zoldana, MPP), Corvara (Hochabteiltal/alta Val Badia; BSPG), Sappada (MPL), Gröden/Val Gardena (MPL), unspecified Gadertal/Val Badia (MPL)
Carnian: Predil Limestone (Julian) of Raibl/Cave del Predil (NHMW)

NEW LITHOSTRATIGRAPHIC TERMS USED IN THE GEOLOGICAL MAP OF THE WESTERN DOLOMITES.

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The Geological Map of the Western Dolomites is based on the new mapping and compilation of the entire sedimentary cover of the Autonomous Province of Bozen/Bolzano. It was carried out as part of the project "Geological Base Map of South Tyrol". In the course of this new mapping, new lithostratigraphic terms were introduced, or conventional ones redefined, across the boundaries of official map sheets. This was not always in line with the Italian national mapping programme CARG. New and newly defined lithostratigraphic terms are explained below. Their position is shown in the lithostratigraphic table (Fig. 1).

Werfen Formation: Von Lilienbach (1830) and Peters (1854) originally described the "strata of Werfen" or "Werfen schist" in the type region south of Salzburg. Later, this term was also

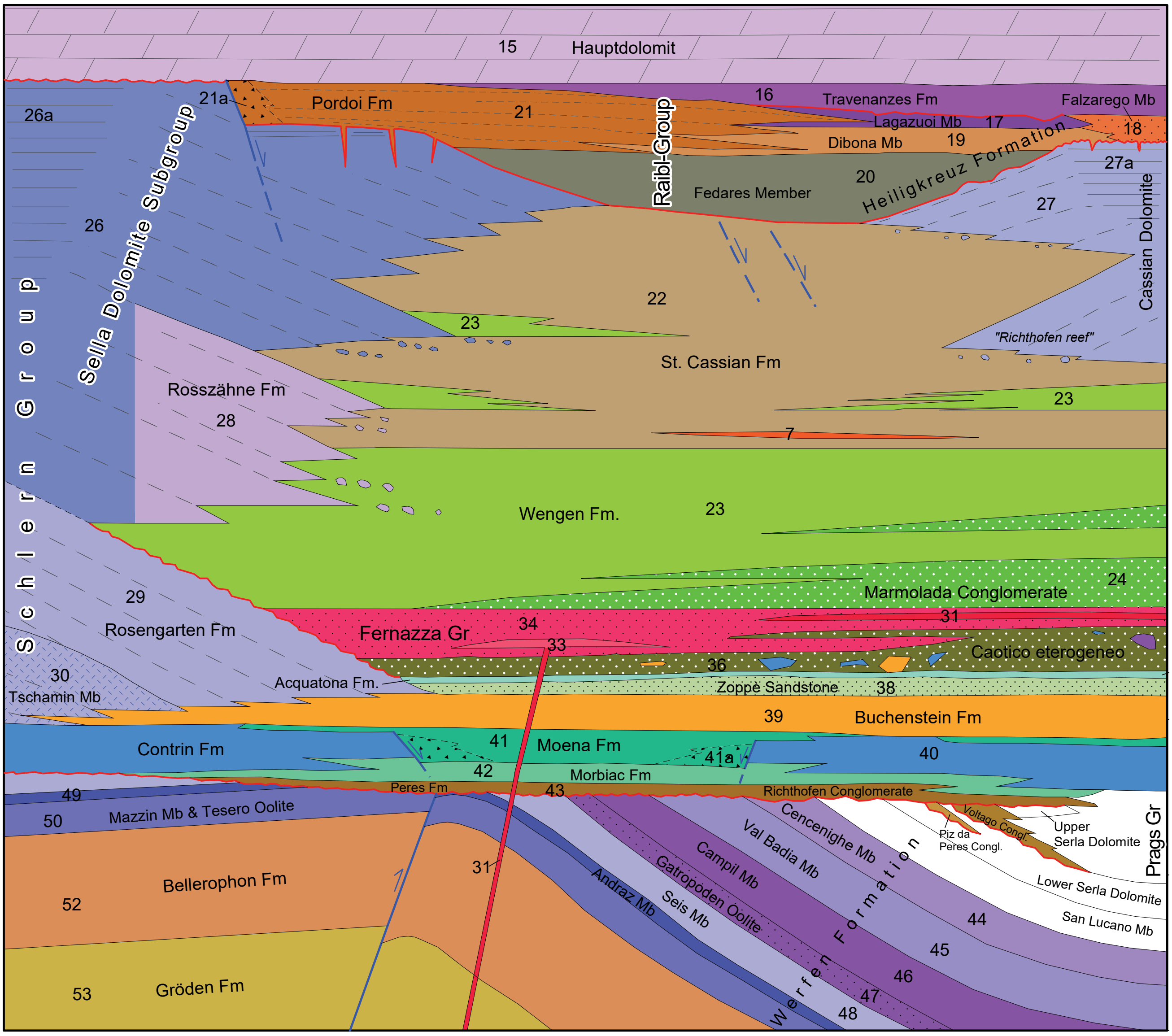

FIG. 1: Stratigraphic scheme of the Permian to Upper Triassic succession of the Western Dolomites. Geological Map of Südtirol/Alto Adige, Western Dolomites, 1:25.000 (2019).

transferred to the Dolomites and defined here by Bosellini (1968) and Broglio Loriga et al. (1983) as Werfen Formation, subdivided into subformations (members). However, the clearly different facial and lithological development in the type region in the Northern Calcareous Alps requires a new definition (see also Neri (2006). If the term "Werfen" is to be retained, it can only be used as in **"Werfen Group"**. This would have the advantage that comparable developments in the Werfen facies (mixed siliciclastic-carbonatic, cyclical sedimentation in shallow shelf environments with specific faunal developments) could be summarized by the term "Werfen Group". In wide areas of the western Tethys, developments in the Werfen facies presently carry different formation names in different countries. Use of the term Werfen Group would mean that units, which in the Dolomites are currently defined as members, would become formations (fig. 2). The possibility to map these units, which is a basic prerequisite for the term ‚formation', is given, and mapping has already been carried out on all new map sheets, albeit using the member classification. Unfortunately, the proposal for a new classification could not yet be introduced for the Geological Map of the Western Dolomites, as the editors of adjacent geological maps of the CARG project as well as the client (Geological Survey of South Tyrol) were afraid of a confusion of terms.

For mapping reasons, the **"Gastropod Oolith Member"** was assigned to the **Campil Member** (in anticipation of the future formation name) in certain areas, where separation between the two members in the field was not possible. The Gastropod Oolith Member is very variable in the Dolomites and adjacent areas (see e.g. Venturini et al., 2009, in the Carnic Alps) and is often difficult to identify in individual outcrops, in particular if the sequence is disturbed. An easily recognisable criterion for mapping in the field is the increase in the terrigenous siliciclastic content, which can be observed in the background sedimentation even in facially different sequences. Both the Gastropod Oolith and the Campil Members were distinguished from the Seis Member by the appearance of the first distinct layers of fine-grained sandstone.

Peres Formation: The term was introduced by Pia (1937) and extended by Bechstädt & Brandner (1970). It refers to terrigenous clastic deposits with silty, mostly red marls and intercalated lenses of conglomerates. In the basin area of the Prags/Braies Group, the Peres Formation occurs at three stratigraphic levels (Lower, Middle and Upper Peres Beds in Bechstädt & Brandner, 1970), which combine to one level on the adjacent Etsch-Gadertal/Adige-Val Badia platform and are no longer distinguishable here. The individual designation of the three horizons with their conglomerate intercalations (Piz da Peres Conglomerate, Voltago Conglomerate and Richthofen Conglomerate, according to De Zanche et al., 1992) does not appear useful for the mapping of the entire area and was therefore not applied. In the area of the western Etsch/Adige platform, it is not possible either to distinguish correctly between the various conglomerates. Therefore, the term "Peres Formation" was given preference here (Geological Base Map of the A.P.B., sedimentary cover, 2003, sheets Bozen/Bolzano, Eppan/Appiano, Mezzolombardo and Predazzo; unpublished).

Schlern Group: This is a collective term for the Upper Anisian to Lower Carnian carbonate platforms between the Contrin

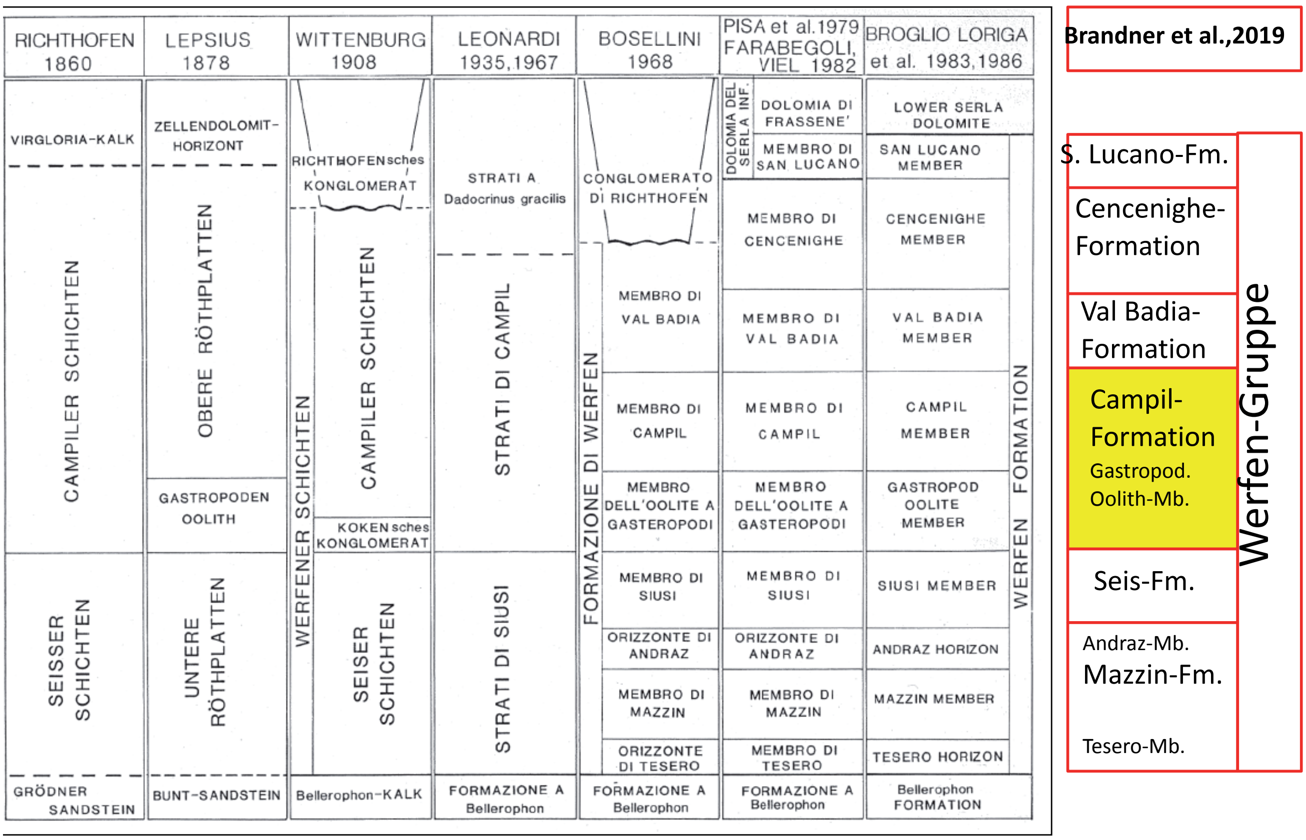

FIG. 2: Proposal for a new classification of the Werfen Formation in the Western Dolomites. The introduction of the new term „Werfen Group" is indicated to have the possibility to include the „Werfener Schichten" of the type locality in Salzburg with their quite different lithological habit.

Formation and the Raibl Group. The newly introduced term is appropriate in those areas where continuous carbonate platform developments are present without intercalation of carbonates interfingering with basinal sediments or volcanites. This is the case, for example, at the western edge of the Schlern/Sciliar massif or at the northern edge of the Dolomites (Toblach/Dobbiaco sheat). The "Sexten/Sesto Dolomite Group" on the geological map of the Sexten/Sesto Dolomites Nature Park 1:25,000 (2004) is equivalent to the Schlern Group. The term is ideal for geological overview maps.

The Schlern Group comprises the pre-volcanic **Rosengarten/ Catinaccio Formation**, the post-volcanic **Rosszähne/ Denti di Terra Rossa Formation** and the Cassian Dolomite, respectively the post-volcanic **Sella Dolomite Subgroup**. The cartographic representation of all these carbonate platform formations is easily possible as long as they interfinger with the respective basinal sediment formations (Buchenstein, Wengen and Cassian formations). At Langkofel/Sassolungo, on Sella and in the Geisler/Le Odle group, the subdivision of post-volcanic platforms into Rosszähne Formation and Cassian Dolomite is not possible. Therefore, the new umbrella term **"Sella Dolomite Subgroup"** was introduced. Incidentally, this coincides with earlier names, such as "Dolomia dello Sciliar Superiore" (Leonardi, 1967), "post-volcanic platforms" (= Cassian Dolomite) sensu Bosellini (1984), or the "Upper Schlern Dolomite" (Schlager et al., 1991).

The **"Tschamin-Member"** was added to the Rosengarten Formation as an independent, mapable unit. In the lower section of the Rosengarten Formation, a discordance is developed which can be easily recognized in the Tschamin/Ciamin valley, in the König Laurin/Re Laurino wall of the Rosengarten group and in the Langkofel/Sassolungo cirque. The discordance is located at the top of the Tschamin Member and interpreted as a "drowning-unconformity surface". Clinoforms with a steep inclination overlie a sequence of dolomitized litharenites of variable thickness and with stromatactis and microbial structures. In the König Laurin wall, the carbonate platform interfingers with the Plattenkalk of the Buchenstein Formation. The sequence increases considerably in thickness towards the East (Rosengarten: 130 m, Langkofel: approx. 300 m) and reaches up to 600 m, for example at Monte Carrera. Here, the platform drowns and is covered by pelagic sediments („pelagic drape“) of the Upper Ansian (R. Reitzi-Zone) (Brack et al., 2007). The drowning unconformity can be correlated directly with the unconformity at the top of the Tschamin Member. The former term "Lower Edifice" (De Zanche et al., 1995) partly coincides with the newly introduced Tschamin Member.

Col Rodela-Olisthostrom: This term was newly introduced to take account of the complex geological situation at Col Rodela and in the area south of the Duron valley. This region represents the proximal area of thick sliding blocks which merge distally into the **Caotico Eterogeneo**. These blocks constitute stacks of sedimentary rock layers which can be thrusted on top of each other. The layer stacks consist of sedimentary rocks of the Bellerophon Formation up to the Rosengarten Formation / Marmolada Limestone. To a lesser degree, they include clasts of volcanites. They contain remarkably large hiatuses which Ampferer (1928) recognized and took as cause for his theory of "relief overthrusts". The Caotico Eterogeneo, together with the volcanites of the Fernazza Formation, overlies the Col Rodela Olisthostrom. The area of origin of the gravitational sliding blocks is the transpressive bulging zone in the area of Cima Bocche-Costabella (Doglioni, 1984).

Raibl Group: The Raibl Group is divided into three formations in the mapped area: Pordoi Formation, Heiligkreuz Formation and Travenanzes Formation.

The term **"Pordoi Formation"** was newly introduced. It constitutes a maximally 120 m thick sequence of basal green sandstones, brown dolomites and marly dolomites, doloarenites and intercalated banks of shell detritus with *Myophoria kefersteini kefersteini*. The sequence is located on top of the Sella Dolomite, the surface of which is characterized by synsedimentary extensional tectonics and karstification. The limit between Sella Dolomite and Pordoi Formation is well defined. Local breccias as well as thin-layer conglomerates are present at the base of the Pordoi Formation. At the upper part, there is a gradual transition to the Hauptdolomit/Dolomia Principale. The Pordoi Formation has only been found at Gardenacia, Sella and Langkofel/Sassolungo.

The **Heiligkreuz Formation** (for a definition see Keim et al. 2001) is divided into four members: Lagazuoi Member, Falzarego Member, Dibona Member and Fedares Member. Deviating from the definition of members of the Heiligkreuz Formation by Neri et al. (2007), the Falzarego Member is separately defined here according to Bosellini et al. (1982, "Arenarie del Falzarego") because of the reddish sandstones with cross-stratification.

The new term **"Fedares Member"** was already used in the first edition of the Geological Map of the Western Dolomites (2007). On the basis of surface outcrops in the area of the Heiligkreuz Hospice, and above all, based on the research drilling BS1, the Fedares-Member was defined as a monotonous, up to 100 m thick sequence of black marls and slates, marly limestones and limestone banks exhibiting an ostracod and bivalve fauna with low species diversity. The sequence corresponds only partly to the sequence of the Borca Member (Neri et al. (2007), which is why the term is now used again in the new edition of the Geological Map of the Western Dolomites.

Gardenacia Formation: The newly introduced term denotes a remarkable, 17 m thin facies development at the base of all formations of Cretaceous age. At the eponymous type locality, the formation typically consists of sandy, medium to coarse crystalline dolomites. Their greenish colour (and glauconite content) increases towards the top. Relics of grainstones, ooids and coated grains are visible in thin sections. In addition, breccias with clasts of different sizes occur locally. The Gardenacia-Formation rests on the Hauptdolomit, which shows a distinct relief with karst phenomena at its top surface. The mapping reveals a large bulging zone with synsedimentary graben tectonics and a clearly defined erosional unconformity. The shallow water facies of the Gardenacia Formation is abruptly superimposed by the pelagic Maiolica Formation of late Berrasium to early Valangium age (Gögl, 1999).

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TECTONOSTRATIGRAPHY OF THE WESTERN DOLOMITES IN THE CONTEXT OF THE DEVELOPMENT OF THE WESTERN TETHYS

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In the Dolomites, the transition from the post-Variscan to the Alpine orogen cycle generally takes place in a domain of lithospheric stretching, which is recorded in several plate tectonically controlled megacycles in the sediment sequences. Early Permian and Middle Triassic magmatism are associated with this development. In contrast to the "post-Variscan" magmatism, however, the Middle Triassic magmatism gives rise to numerous discussions due to its orogenic chemistry in the extensional setting of the Dolomites. A new analysis of the tectonostratigraphic development now revealed an interpretation of the processes that differs from the general opinion. Within the general extensional development in the Permo-Mesozoic there are four distinct unconformities caused by compressive or transpressive tectonic intervals.

1ST TECTONOSTRATIGRAPHIC MEGACYCLE (UPPER CARBONIFEROUS TO LOWER PERMIAN)

In the Dolomites, the cycle includes the Athesian Volcanic Group, which spanns the period between 285 - 274 Ma (Marocchi et al., 2008). In the Carnic Alps, this cycle begins with the Auernigg Group already in the Kasimovium and reaches into the Kungurium with the Trogkofel Limestone at the top (Krainer et al., 2009). After the late Variscan overthrust at the Val Bordaglia line (later extensionally reactivated) in the lower Moskovium (Brime et al., 2008), the hiatus (sedimentary gap) at the base covers a much shorter period than that in the Dolomites (see also Cassinis et al., 2018 with further citations). In both cases, the basin formation occurred in the context of the general Lower Permian thinning of the crust, which affects large areas of the former Variscan orogen. The significantly earlier beginning of sedimentation in the Carnic Alps implies a NW-directed back-stepping of the basin formation, which is accompanied by increasing exhumation and erosion of the Variscan basement. Pohl et al. (2018) succeeded for the first time in measuring a top to SE extension direction (according to current coordinates) in early Permian Mylonites of the central Southern Alps ("Grassi Detachment Fault"). This is an important benchmark for the reconstruction of the western Tethys realm, which questions or modifies previous models, e.g. those of Muttoni et al. (2009). Further localities for such detachment faults can be assumed in the area of the Giudicaria line (at the top of the Ifinger granodiorite), as well as at the Val Bordaglia line in the Carnic Alps. The lithospheric thinning reaches far into Central Europe ("Central European Extensional Province", Kroner et al., 2016) and is accompanied by the widespread thermal event ("Permian metamorphic event", Schuster & Stüwe, 2008).

2ND TECTONOSTRATIGRAPHIC MEGACYCLE (MIDDLE PERMIAN TO LOWER ANISIAN)

With the cooling of the crust, continental and marine sedimentation starts in large areas in the Middle and Upper Permian, which overlaps the graben-like extensional tectonics relief like mantle (see Wopfner, 1984 and Italian IGCP 203 Group, 1986). This was preceded by a strong erosional phase ("Middle Permian stratigraphic gap"), which is widespread in Southern Europe (Cassinis et al., 2018). The unconformity resembles a break-up unconformity indicating the formation of a Permian ocean. According to the upper limit of the tectonostratigraphic cycle with signs of compressive tectonics in the Lower to Middle Anisian, this ocean should range into the Middle Triassic. However, only deep-water faunas dated from a few localities are known in the western Tethys region (see Catalano et al., 1991; pers. comm. Leo Krystyn, Vienna). In the Dolomites the megacycle ranges from the continental Gröden/Val Gardena Fm to the shelf facies of the Lower Sarldolomite. The upper limit is formed by a clear erosional unconformity, which reaches in the area of Colfuschg/Colfosco down to the Bellerophon Fm. Here the more than 500 m thick sediment sequence of the Werfen Fm and the Lower Sarldolomite was eroded. The unconformity is overlain by conglomerates, sandstones and siltstones of the continental to marginal marine Peres Formation (incl. Richthofen Conglomerate), which interfingers with the marine sediments of the Prags/Braies Group in three cycles. Detailed mapping yields a asymmetrical anticline of a large wavelenght which shows high-angle westward dipping reverse faults at the side of the Gader/Val Badia Valley. In the following period, these faults of Anisian age were tectonically reactivated several times, so that the original shear sense is difficult to recognize. This is also the reason for the different interpretations of the type of Anisian tectonics: tectonic uplift, transpression/transtension, tectonically controlled sedimentation process (Bosellini, 1965, Brandner 1984, De Zanche & Farabegoli, 1988, Broglio-Loriga et al., 1990) or extensional block tilting (Brandner et al., 2016). The majority of authors are focused only on Middle Triassic rifting in general. However, this begins only after the compressive tectonics in the Upper Anisian, at the beginning of the 3rd megacycle. In the wider surroundings of the western Tethys area the meaning of this Molasse-like facies becomes clearer. It reaches from the Drauzug (Brandner, 1972) over the Dolomites and Montenegro (Budva - Cukali zone: Ciric, 1965, Brandner et al., 2016) up to Crete (Zulauf et al., 2018) and is accompanied until the Upper Ladinian by magmatites with calcalkaline affinity (Bébien et al., 1978). This indicates a subduction of a Permo-Triassic ocean beginning in the Lower Anisian at the active continental margin of Eurasia. The passive continental margin of this ocean is found at the margin of Gondwana (Baud et al., 2012).

3RD TECTONOSTRATIGRAPHIC MEGACYCLE (UPPER ANISIAN TO LOWER CARNIAN)

This cycle starts with several phases of strong subsidence. In the western Dolomites there are three subsidence phases: (1) the flooding of the Etsch-Gadertal high zone with deposition of the Peres Formation and subsequently of the Morbiac and Contrin Formations, which represent the sea level highstand of the Upper Anisian sequence, (2) the break-up of the shallow marine Contrin-platform and subsequently the developement of intraplatform basins with deposition of the Moena Formation and Plattenkalk of the Buchenstein Formation and (3) newly strong subsidence at the transition of the Plattenkalk Member to the Knollenkalk Member of the Buchenstein Formation in a deep sea basin with depths of more than 800 m. In the development of the carbonate platform of the Schlern Group, this subsidence phase has been preserved as a "downlapsurface" at the top of the Tschamin-Member. The "downlapsurface" is equivalent to the drowning of the Cernera platform in the eastern Dolomites during the Reitzi/Secedensis zone of the Upper Anisian (Brack et al., 2007). There is a clear increase in the subsidence rate in the direction to SE. This subsidence period is a widespread phenomenon outside the Southern Alps and can still be found in the Northern Calcareous Alps, in the Dinarides and Hellenides (see e.g. Gawlick et al., 2012 with further citations). The quick change from Anisian compressional tectonics to Upper Anisian extensional tectonics is most comparable to a "backarc" development. A roll-back of the subducted plate causes extensional deformation in the upper plate (Doglioni et al., 1999). The general configuration of the western Tethys in the Middle Triassic indicates a NW directed (today's coordinates) subduction in the front of the Southern Alps, which is accompanied by calcalkaline shoshonitic magmas occuring from the Dolomites to the Hellenides. Similar considerations have already been published by Marinelli et al. (1980), but in the assumption of a completely different spatial constellation. The real high subsidence rates of 800-1000 m/Ma in the Upper Anisian are also generally characteristic for W-directed subductions (Doglioni et al., 1999).

A special tectonic feature of the Dolomites is the evolution of transpressive tectonic structures during the Upper Ladinian. Doglioni (1984) discribed this for the first time in the area of the Stava line and the Cima Bocche anticline. This sinistral WSW-ENE trending fault segment (trending NW after back-rotation) continues in the palaeo-Antelao line towards E (Picotti & Prosser, 1987). The structure is sealed in the West by the magmatites of Predazzo and Monzoni (Abbas et al., 2018). Also the somewhat older siliciclastic detritus fillings of the Zoppé Sandstone in the Upper Fassanian are attributed to the period of transpressive tectonics. The sandstones originate from a tectonically exhumed metamorphic basement south of today's Southern Alps.

On the Geological Map of the Western Dolomites the Schlernplateau fault is a Ladinian transpressive structure too, which is sealed by Upper Ladinian volcanites. The southern, above-mentioned, transpressive antiformal structure collapsed before the onset of the main volcanic extrusion in the Upper Ladinian. Folding close to the surface and gravitational sliding of huge stacks of strata took place in the 800 m deep sea basin at the southern margin of the prevolcanic reef of Rosengarten Fm at Langkofel/Sassolungo. At Col Rodela, south of the Duron Valley as well in the northern Fassa Valley, strata complexes of Bellerophon, Werfen and Contrin Formations (Contrin Dolomite), as well as of Buchenstein Formation are stacked locally in several sheets, sealed by Caotico Eterogeneo and Upper Ladinian volcanic rocks. The diapiric tectonics favoured by Castellarin et al. (1998 and 2004) could not be confirmed. The pile of stacked strata is called "Rodela-Olisthostrom". It is assumed that this zone continues as far as Slovenia. As a result of the superposition of the southern antiformal structure with huge amounts of volcanic rocks, islands were formed (Bosellini, 1998), which were quickly eroded. Large quantities of debris of Marmolada Conglomerate were transported to the offshore marine depressions and sealed the Rodela-Olisthostrom as well as the Caotico Eterogeneo and the volcanites. Similar conglomerates can also be found in the Ladinian strata of Montenegro.

Transfer faults can also be assumed for the necessary decoupling of the backarc basin of the Southern Alps from the Hallstatt-Meliata ocean basin, contemporaneously developed. The latter lacks signs of orogenic magmatism (Kozur, 1991). This presumably broad zone of strike slip faults is concealed in a "Paleo-Insubric Transfer Zone", which probably already originated in the Permian.

The subsidence history of the Middle and Upper Triassic is recorded in the geometry of the carbonate platforms. The general trend is very similar in the Dolomites as in the Northern Calcareous Alps as well in the High Karst Dinarides: in the Anisian and Ladinian there predominates aggradational deposition, whereas in the Lower Carnian strong progradation took place. The platforms were partially exhumed and subaerically exposed, after them they demised and drowned due to environmental reasons. Karstic surfaces of Schlern Dolomite and Wetterstein Limestone are the evidence. The "Carnian pluvial episode" with the sedimentation of large amounts of siliciclastic material immediately follows (Hornung et al., 2007, Dal Corso et al., 2018). At the northern margin of the Tethys this phenomenon is widespread and is related to eo-kimmerian orogeny (Şengör, 1979). West of Turkey, however, it is not clear which colliding Cimmerian continent it is.

4TH TECTONOSTRATIGRAPHIC MEGACYCLE (UPPER TRIASSIC TO UPPER JURASSIC)

With the eo-kimmerian orogeny a major plate boundary reorganization took place in the Tethys area during the opening of the Alpine Tethys (Piedmont Ocean) and the Vardar Ocean, or Maliac Ocean (after Stampfli & Kozur, 2006). This transition period is characterized in the western shelf area by

the extensive development of the Hauptdolomit/Dachstein Limestone platform.
Extensive tectonics in the Western Dolomites already starts in the Upper Carnian with graben-like extensional basins of parts of the Raibl Group along N to NW trending normal faults, associated with scarp breccias (Keim & Brandner, 2001). These were mapped on Langkofel/Sassolungo, Sella and Gardenacia. The extensional tectonics continue into the Jurassic with backstepping at the margins of the Belluno Basin and the Slovenian Basin. It is particularly evident with the drowning of the shallow water carbonates of the Graukalk/Calcari Grigi Group occuring from the Pliensbachian until the Bajocian. The condensed facies of the Fanes Encrinit and the Rosso Ammonitico Veronese was developed on the Trento Plateau until the Upper Jurassic (Picotti & Cobianchi, 2017 with further citationes). It is noticeable that the strike of the E-dipping normal faults tends towards NW. This could be interpreted as an indication for the proximity of the Slovenian basin at the margin of the Maliac Ocean.
In the period from Upper Jurassic to ?Lower Cretaceous we find a clear erosional unconformity with karstic phenomena on the plateaus of Gardenacia and Sella. The map situation and the cross sections show a wide-span antiformal structure, which can be easily recognized by the more complete Upper Triassic to Jurassic stratigraphic succession of the Fanes area in the East and Northeast. In the highest parts of the Puez plateau the entire Jurassic sequence is missing and the Hauptdolomit is reduced erosively to a thickness of about 170 m. At Piz Boé, where still reduced Dachstein Limestone outcrops exist, deep reaching poljes and other karst landforms produced by solution are filled with Cretaceous sediments. On the Puez plateau the shallow water Gardenacia Fm. transgreeds the erosional unconformity. The deposition of the overlying Puez Formation (Lukeneder et al., 2016) begins in the ?Upper Valanginian/Lower Hauterivian. The tectonic uplift occurs between 157-153 Ma during the period of closure of the Maliac Ocean and the obduction of the oceanic crust of the western Vardar Ocean (Schmid et al., 2008). Far-field compression with wide-span folding in front of the Dinaric obduction could have thus involved the north-eastern Jurassic continental margin of the Southern Alps. This probably explaines the developement of the tectonic bulge (see also Picotti & Cobianchi, 2017).

5TH TECTONOSTRATIGRAPHIC MEGACYCLE (VALANGINIAN TO CAMPANIAN WITH THE FOLLOWING PALEOGENE ALPINE BACK THRUST AND NEOGENE DOLOMITES INDENTATION.

The shallow water sediments of the Gardenacia Formation are followed by a new drowning sequence with the condensed lithofacies of Rosso Ammonitico and Maiolica at the base, overlain by marls of the Puez Formation. Their age ranges until the Lower Cenomanian (Lukeneder et al., 2016). The subsidence after the Upper Jurassic uplift was newly active. Probably it was induced by a roll back of the slab of the subducted oceanic plate of the Western-Vardar ocean (Stampfli & Kozur, 2006).
In the area of Antruilles, north of Cortina d'Ampezzo (outside the map sheet, see CARG sheet 029 Cortina), the highly pelagic Cretaceous sequence reaches Campanian age. Turbidites with siliciclastic material deriving from basement areas in the North announce the Alpine orogeny (Stock, 1994).
On the Gardenacia and Sella plateaus, the Raibl beds and the Hauptdolomit outcrop in the hangingwall of the "summit overthrusts", while the footwall consists of the Puez Formation. The hangingwall represents well preserved cliffs of the frontal area of a Palaeogene overthrust. This Doglioni (1992) attributed to the Dinaric Overthrust Belt due to their direction of hangingwall movement to WSW-SW. Folding and thrusting were obviously reactivated along the structures of the previous Jurassic extensional continental margin development, wich occured at the margin of the Maliac and Vardar oceans. However, at the time of the Palaeogene overthrusts, the Southern Alps were already largely separated from the Dinarides by the dextral Alps-Dinarides transfer zone (Handy et al., 2015). Therefore the overthrusts can only correspond to Alpine reverse thrusts, wich are comparable to the pre-Adamello overthrusts of the Central Alps (cf. Schönborn, 1992).
The mapping campaign of the project "Geological Base Map South Tyrol" discovered that the summit overthrusts correspond to the frontal area of a large overthrust. It is called "Kreuzkofel-Nappe". The overthrust can be traced from the footwall flat in the evaporites of the Bellerophon Fm of the western Olang Dolomites via a ramp to the hangingwall flat of the Raibl beds at the base of the Kreuzkofel (2,912 m). The overthrust ends on Gardenacia summits with the large erosional gap of the Gader/Badia Valley in between. The same structural system is to be considered for the summit overthrusts on the Sella plateau.
In the front of the Alpine overthrust, relics of Molasse sediments of the Oligocene-Miocene Parei Conglomerate crop out at Col Bechei in the Eastern Dolomites (outside the map sheet; Keim & Stingl, 2000) and at the W-dipping slope of the Plattkofel/Sasso Piatto in the Western Dolomites. The important outcrop at Col Bechei shows an S-directed overthrust with the conglomerates in the footwall. The well-dated overthrust is part of the widespread Valsugana overthrust system (Castellarin et al., 1998a), which overlays and cuts through the Palaeogene back thrust system. The Neogene, Southalpine overthrust belt develops in the course of the indentation of the Dolomites into the northern Alps. Especially the southern part of the overthrust belt is still active today, as the continuing earthquake activity shows (Viganò et al., 2015; Reiter et al., 2018).

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Landforms and Quaternary deposits in the UNESCO Dolomites: past, present and future studies.

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The landforms and deposits of the Quaternary are closely related to each other. Indeed, many landforms are generated by the accumulation of debris coming from the weathering processes of the bedrock (accumulation landforms), others are generated by erosive processes (erosional landforms).

The Dolomites are recognized by the widespread outcrop and favorable exposure of carbonate rock formations, which provide a unique and spectacular view on the marine life during the Triassic. Moreover, the numerous vertical peaks and the valleys covered by Quaternary deposits present a variety of extraordinary landforms, linked to the morphoselection processes. Pinnacles, spiers and rock towers with contrasting horizontal surfaces such as ledges, crags and plateaus, rise abruptly from extensive talus deposits and from gentle and undulating hills.

The Dolomites have always attracted a multitude of geologists from around the world, thanks to their easy accessibility and the clarity with which the geological phenomena can be observed. On the other hand, there are no unified and integrated overviews taking into consideration the quaternary evolution of the Dolomites region. Information is often spread in a multitude of geological works and case studies, and is therefore discontinuous and lacking in-depth analysis.

A first geomorphological topic that in the past interested Italian and foreign scientists was the inherited morphology of the dolomitic groups. This issue, that still deserves investigation, came from the observation that the current peaks share an uniform top heights, regardless of their shape and structure, which suggests the existence of an ancient landscape with smoothed relief, in contrast with the current one.

Regarding the Quaternary deposits, various authors mostly investigated the glacial ones, which are particularly widespread and the most useful from a chronological point of view. The first attention on Quaternary deposits date back to the first decades of the 20th century. It mainly regards studies on single mountain groups, frequently included in more comprehensive geological works. A significant advance in the study of Quaternary deposits came from several geomorphological works that began towards the end of the last century, with new significant insights starting from the 1970s. These works are often accompanied by detailed geomorphological maps, and investigate the genesis of the deposits, refining their chronology with the help of absolute and relative dating methods. In some specific areas, the dating of deposits allowed to reconstruct an articulated evolutionary framework of the landslides and slope stability phenomena. Unfortunately, these works are sparse and do not provide a full coverage of the entire territory of the Dolomites.

Further advances in Quaternary study came at the end of the 1980s, with the start of the CARG Project, aimed at producing the national geological map at the scale of 1: 50,000. One of the most qualifying and innovative aspects of this project was the importance given to the Quaternary deposits in both their surveying and their cartographic representation. These Quaternary formations, formerly considered as debris coverages that prevent the observation of the underlying bedrock, were finally considered of the same importance as the geological substrate. Unfortunately, in many cases these deposits were classified according to different criteria (e.g. litostratigraphic, allostratigraphic, or using the "unconformity-bounded stratigraphic units"), due to the lack of a uniform methodological approach.

Recently, the advent of new remote sensing techniques (such as airborne, high-resolution LiDAR) enabled to better map and understand landforms and deposits, surveying, for example, complex landform assemblages masked by vegetation. In addition to the traditional ^{14}C dating techniques, new types of chronological investigation methods have been developed, but they are still rarely applied in the Dolomites.

Consequently, if on the one hand the genesis of the various Quaternary deposits in the Dolomites UNESCO World Heritage are in most cases well known, on the other hand much remains to be done for the chronological characterization of single depositional events. In particular, interesting new insights are expected from a better characterization of late-glacial deposits and slope gravitational phenomena.

Finally, it should be pointed out that Quaternary deposits are not only interesting from a stratigraphic point of view, but they also play an important role in slope instability, settlements and land management policies. In the next future, we underline the need for improved understanding and investigations on the ongoing changes of the paraglacial environments, which are widespread in the mountain ranges of the UNESCO Dolomites and subject to rapid modifications in response to climatic changes.

UN CONTRIBUTO ALLA DIFFUSIONE DELLA CULTURA GEOLOGICA

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PERCHÉ DIFFONDERE LA CULTURA GEOLOGICA

In un periodo storico in cui domina la trasmissione di pseudo-informazioni (numerosissime, brevi, parziali, approssimative, sensazionalistiche e frequentemente errate - anche solo per eccesso di sintesi, ma spesso per secondi fini), la diffusione della cultura s.l. rimane lo strumento principale per informare correttamente il pubblico affinché questo possa essere in grado di farsi un'idea sui diversi argomenti e così discernere tra notizie e propaganda. In particolare, i temi ambientali (e, quindi, anche quelli geologici) sono da qualche lustro diventati argomento di valutazione da parte del pubblico relativamente alle scelte politiche e di gestione della cosa pubblica a tutti i livelli. Così questi temi si sono guadagnati un ruolo di primo piano anche nella diffusione di pseudo-informazioni: dalla proclamata pericolosità ambientale delle gallerie sostenuta con argomentazioni non scientifiche; all'ignorante stupore per un evento sismico nel mezzo della Pianura Padana; alla manipolazione del tema relativo al riscaldamento globale in atto, ormai citato in qualunque occasione, anche per spiegare la formazione del Great Blue Hole; alla confusione relativa alle cosiddette polveri sottili).
Vi sono anche più specifiche argomentazioni, a sostegno della opportunità di una diffusione della cultura geologica in generale, in particolare, in Italia: una migliore e diffusa conoscenza di argomenti geologici conduce a una maggiore attenzione verso alcuni processi naturali che hanno un impatto considerevole nella gestione del territorio e, quindi, sulla qualità della vita di tutti. Si accenna solo a qualche esempio che può interessare soggetti diversi:
Saper riconoscere alcuni segni premonitori di movimenti franosi da parte di chi abita o frequenta la montagna può essere di grande aiuto per segnalare situazioni anomale che, vagliate da esperti, potrebbero portare a fondamentali allarmi preventivi. La Regione Lombardia già molti anni fa si mosse in questa direzione pubblicando un piccolo manuale che doveva fornire alcune informazioni di base sul tema (Clerici, 1992).
Avere ben presente che ogni punto della superficie terrestre è continuamente in trasformazione per motivi naturali, talvolta con tempi molto lunghi ma talora con processi rapidi, contribuirebbe a far sì che la progettazione e la realizzazione di interventi sul territorio tengano sempre ben conto di questa dinamica e prevengano situazioni dannose, che potrebbero eventualmente essere favorite o addirittura innescate da nuove strutture o infrastrutture male inserite sul territorio stesso.
Conoscere i materiali lapidei presenti in un'area potrebbe favorirne l'utilizzo sia in interventi di ripristino dell'edilizia storica (fig. 1), sia in nuove progettazioni con materiali del tutto naturali; inoltre favorirebbe sul mercato un prodotto locale con riduzione di problemi legati a trasporti transnazionali.
Conoscere le difficoltà e i costi con i quali si dovrà necessariamente avere a che fare per disinquinare un terreno, o le acque che in esso sono presenti, a causa di una cattiva gestione di sostanze contaminanti potrebbe portare a maggiori cura e rigore, almeno da parte degli enti pubblici preposti, nel legiferare, controllare e sanzionare in materia.

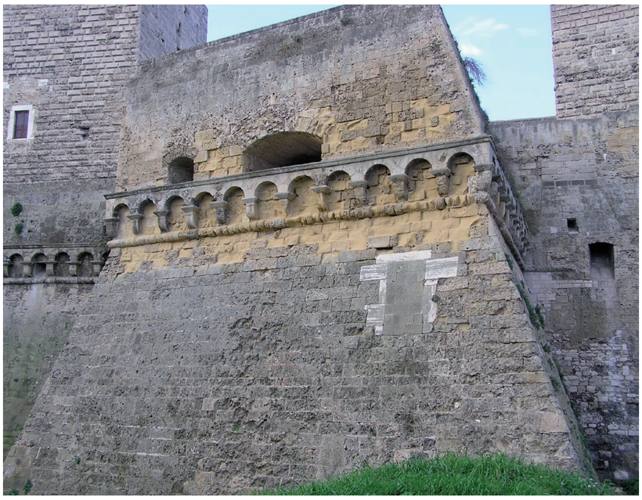

FIG. 1: L'edificio storico presenta ammaloramenti, ma ciò che disturba maggiormente è l'intervento di restauro con materiale lapideo differente da quello originale per litologia, colore, forma, pezzatura e finitura: un palese esempio di ignoranza

CARENZE CULTURALI RELATIVE ALLE MATERIE GEOLOGICHE

Non si può negare che negli ultimi decenni, soprattutto gli ultimi due, anche in Italia i temi ambientali si siano progressivamente imposti all'attenzione dell'opinione pubblica. Si è andata infatti diffondendo una maggiore sensibilità nei riguardi dell'utilizzo del suolo, della necessità della salvaguardia delle risorse idriche, dei patrimoni faunistico e floristico di un territorio, e anche una maggiore attenzione verso una corretta gestione dei rifiuti e verso numerosi altri argomenti riconducibili

all'ambito ambientale.
Anche la Geologia, che – ovviamente – costituisce uno degli aspetti che concorrono a declinare l'ambiente, ha suscitato una qualche attenzione: ad esempio nel 2002 è stato avviato il progetto "Inventario Nazionale dei Geositi" con l'obiettivo, riprendendo la definizione di geosito di Wimbledon (1996), di conservare località di interesse geologico o geomorfologico che possano costituire strumenti utili sia per la conoscenza geologica del territorio, sia per l'attività di pianificazione territoriale, sia per la tutela paesistica e ambientale.
Inoltre, anche in Italia sono stati istituiti i geoparchi, recentemente (2018) rilanciati dall'UNESCO con l'approvazione dell'International Geoscience and Geoparks Programme (IGGP), cioè aree geografiche unitarie ove i luoghi e i paesaggi di significato geologico internazionale sono gestite con un concetto olistico di protezione, educazione e sviluppo sostenibile.
Ancora, nel 2008 l'ISPRA ha dato l'avvio ad un progetto per la valorizzazione dei Global Stratotype Section and Point (GSSP) italiani seguendo quanto deliberato dalla International Union of Geological Sciences (IUGS). I GSSP sono geositi di interesse internazionale in quanto costituiti da una successione rocciosa continente al suo interno un punto che rappresenta un determinato limite cronostratigrafico tra unità di qualunque rango.
Al fianco di questo approccio istituzionale, si sono sviluppate anche attività divulgative, commerciali e turistiche che vanno tutte nella direzione di promuovere la conoscenza geologica di determinate aree.
Ciononostante è difficile sostenere che presso l'opinione pubblica si sia registrato un apprezzabile incremento di interesse nei riguardi delle tematiche geologiche, come invece si è verificato per altri aspetti legati all'ambiente s.l. Ciò è strettamente connesso ad alcuni motivi:
Il primo, strutturale, deriva dalla oggettiva constatazione che la Geologia rimane in complesso, almeno in Italia, molto poco conosciuta soprattutto a causa della scarsa attenzione che i programmi di insegnamento delle scuole mediamente rivolgono ai temi geologici. Nel programma scolastico gli argomenti di Geologia vengono fortemente ridotti o addirittura ignorati, oppure si limitano a superficiali osservazioni di fossili e minerali. Ciò è dovuto, tra l'altro, al fatto che gli insegnanti risultano avere, in prevalenza, una formazione scientifica diversa da quella geologica; da ciò consegue un ridotto interesse rispetto alla materia e anche una minore abilità nel proporla agli studenti. Spesso la si limita a schemi classificativi dei materiali geologici più che alla descrizione dei processi, privilegiando quindi una visione statica al posto di una dinamica. Spesso si registra anche la mancanza di collegamenti tra la Geologia e altre discipline, come ad esempio l'architettura storica, basata largamente sull'utilizzo delle pietre. A tutto ciò si aggiunge la quasi assoluta assenza di attività in sito, giustificata da problemi organizzativi, di gestione della sicurezza ed economici.
Da questa prima mancanza derivano le altre: ignorare un qualunque argomento ci rende – inconsciamente - diffidenti, se non addirittura un poco ostili, verso di esso; di conseguenza è raro che, al di fuori dell'ambito scolastico, si vadano a riprendere argomenti geologici e si cerchi di approfondirli, proprio perché essi ci sono poco familiari. Ne deriva che, anche al di fuori dell'ambito scolastico, di Geologia si senta parlare ben poco e solamente in occasione di periodiche catastrofi come terremoti, inondazioni, frane, fenomeni erosiovi ed eruzioni vulcaniche.
Un ulteriore motivo di disattenzione ai temi geologici è legato alla percezione, errata ma assai diffusa, che un elemento geologico sia, di per sé, molto più resistente rispetto ad altre componenti dell'ambiente naturale e ciò porta a immaginarlo come immutabile nel tempo e, conseguentemente, meno bisognoso di attenzioni. Questa percezione è profondamente sbagliata perché un elemento geologico, di qualunque tipo e dimensione, non è rinnovabile (oppure lo è ma a una scala del tempo che nulla ha a che vedere con quella dell'Uomo) e, già solo per questo motivo, andrebbe salvaguardato.
A sostegno della tesi che la Geologia sia una materia poco conosciuta, è sufficiente considerare che il termine feldspato (il minerale in assoluto e nettamente più abbondante sulla crosta terrestre) è pressoché sconosciuto all'opinione pubblica, anche di buon livello culturale.

COME DIVULGARE LA GEOLOGIA PRESSO UN PUBBLICO GENERICO

La divulgazione della Geologia si può raggiungere naturalmente tramite i mass media, ad esempio con film documentari su determinati temi geologici.
Al di là dell'ambito scolastico, la divulgazione di temi geologici può avvenire in occasioni e modalità diverse, come, ad esempio, con escursioni giornaliere, viaggi di più giorni, somministrazione di corsi e di conferenze, frequentazione guidata di mostre e musei. Una parte di queste attività può essere ricompresa nel cosiddetto geoturismo (o turismo geologico). Questo costituisce un sottoinsieme del turismo tematico (o culturale) che comprende anche il turismo storico, architettonico, artistico, religioso, eno-gastronomico e sportivo, distinguendosi dal turismo generico (di relax, ludico o ricreativo).
In ogni caso, nella divulgazione si devono affrontare alcune difficoltà specificatamente connesse con la materia. Ad esempio **la scala del tempo geologico**: a monte di tutto il resto, in Geologia vi è una questione fondamentale da trasferire al pubblico. La storia geologica di un territorio può essere molto lunga e, di conseguenza, la scala dei tempi da considerare risulta estremamente ampia. Alcune rocce che troviamo nelle Alpi hanno alcune centinaia di milioni di anni, alcuni processi che hanno segnato diffusamente e marcatamente il territorio sono invece molto più recenti e numerose forme sono tuttora in evoluzione. Questo dover considerare diversi ordini di grandezza nella scala dei tempi può ingenerare confusione nel pubblico.
Anche **la scala spaziale**, ricompresa tra forme che interessano l'intero globo e il particolare del minerale di dimensioni millimetriche (o del microfossile) pone difficoltà perché anche in questo caso l'intervallo di valori da considerare, comprendendo diversi ordini di grandezza, non è familiare al pubblico generico.
I tempi e le dimensioni, sommate alla natura dei materiali geologici, pongono insieme anche difficoltà alla riproduzione sperimentale dei fenomeni geologici, a differenza di quanto accade in altre materie naturalistiche.
Si pone quindi il problema di come si possa affrontare il tema della diffusione della cultura geologica. Non esiste, naturalmente, una ricetta sempre e comunque valida, ma senza dubbio si possono evitare alcuni errori palesi in cui non è raro imbattersi.
Ad esempio, una cartellonistica con scritti prolissi, che cerca di comprendere numerosi argomenti e impiega termini complessi, va senz'altro evitata perché risulta addirittura controproducente e allontana, invece di coinvolgere, il pubblico.

Avendo ben in mente la possibile eterogeneità culturale dei fruitori e facendo riferimento a una platea costituita da adulti, interessati ma non specialisti, le esperienze maturate dagli scriventi suggeriscono di:

- utilizzare un linguaggio quanto più semplice possibile, evitando il ricorso a termini tecnici, che andrebbero a loro volta spiegati: se il tecnicismo è senz'altro utile o addirittura indispensabile nel consentire un dialogo più spedito tra specialisti di una materia, esso diventa un ostacolo in più alla comprensione di un argomento quando esso non fa già parte del bagaglio culturale di chi ascolta; analoga considerazione si può fare per l'impiego di termini in lingue straniere;
- scegliere i luoghi da visitare tenendo conto della loro qualità in termini di aspetto estetico, di accessibilità e comprensibilità degli argomenti che propongono;
- preferire gli itinerari a piedi, in quanto il ritmo di somministrazione delle informazioni fornite risulta più compassato, e quindi maggiormente recepibile, da chi ascolta;
- preferire luoghi che consentano di accoppiare una visione di insieme dell'assetto geologico e della sua storia con osservazioni di dettaglio, giungendo anche all'esperienza tattile dell'oggetto geologico (roccia, terreno, piano di faglia, ecc.)
- evitare percorsi lunghi, fisicamente o tecnicamente impegnativi in quanto potrebbe risultare difficile pretendere la concentrazione di un pubblico affaticato
- preferire dove possibile la guida diretta da parte di un geologo che lungo l'itinerario possa dare ai neofiti le giuste chiavi di lettura per la comprensione del paesaggio e per l'individuazione e la corretta interpretazione dei segni conservati nelle rocce.

L'esperienza editoriale (nelle monografie in preparazione e in quelle già pubblicate) suggerisce inoltre:

- di utilizzare una cartografia dettagliata e facilmente leggibile, arricchita da una simbologia che aiuti ad affrontare il percorso;
- di ordinare gli itinerari in modo da procedere descrivendo l'evoluzione geologica del territorio dagli eventi più lontani nel tempo a quelli più recenti;
- di sviluppare in ogni itinerario un unico argomento geologico principale (naturalmente in qualunque singola località gli spunti geologici sono numerosissimi ma, per non ingenerare confusione, si ritiene preferibile concentrare l'attenzione su un solo tema alla volta);
- di inserire, al termine di ogni itinerario, un paragrafo di approfondimenti che, pur non essendo indispensabili per la comprensione di quanto illustrato nel corso dell'itinerario, siano utili per chi volesse approfondire un poco un argomento e inquadrare meglio la materia;
- di evitare capitoli di introduzione alla Geologia preferendo trattare "direttamente" i singoli argomenti nei diversi capitoli in modo da ottenere tre risultati: evitare la parte introduttiva che, per il suo carattere "scolastico" potrebbe essere poco gradita a chiunque non abbia intenzione di studiare la Geologia; ridurre il rischio di ripetizioni tra concetti espressi in una parte introduttiva e successivamente ripresi in quella descrittiva degli itinerari; rendere immediatamente visibile, e comprensibile, sul terreno ciò che può essere di interesse geologico.

ESEMPI DI DIVULGAZIONE: LA MOSTRA GEOSCIENTIFICA DELL'ISTITUTO DI GEOLOGIA DELL'UNIVERSITÀ DI INNSBRUCK

Quando il Dipartimento di Scienze della Terra fu trasferito nel 1986 nell'edificio Bruno-Sander dell'Università di Innsbruck, gli venne assegnata una sala di 380 m^2 con lo scopo di raccogliere collezioni e organizzare esposizioni. Nel 2014, nel quadro di un progetto cofinanziato dall'Università, dal Tiroler Landesmuseen e dal Ministero dell'Educazione austriaco, vennero messi a disposizione del personale fondi allo scopo di: (a) reperire, ripulire e procedere a una nuova inventariazione delle collezioni scientifiche (fase 1, anni 2014 ÷ 2016), e (b) installare una nuova mostra geologica a carattere scientifico (fase 2, anni 2016 ÷ 2018).

La mostra, inaugurata il 15 marzo 2019, è rivolta soprattutto ai giovani, sia ai bambini delle scuole elementari che ai ragazzi delle superiori – i potenziali studenti di domani. Per raggiungere questo obiettivo, si è deciso di installare supporti interattivi, come un contenitore virtuale di sabbia, una stazione sismografica che registra i "terremoti" prodotti dai salti (fig. 2) e uno schermo interattivo della sismicità globale in tempo reale. Vari pannelli in plexiglass informano sugli argomenti che vengono trattati nell'Istituto (come ricerche sui laghi, sugli speleotemi, sulla geologia strutturale, ecc.). Si è data anche enfasi alla dimostrazione dell'utilità pratica delle Scienze della Terra, ad esempio con poster sul progetto del Tunnel di Base del Brennero (BBT), sui vari aspetti della pericolosità ambientale, sulle materie prime e su molti altri argomenti.

Nella realizzazione dei pannelli si è strettamente seguito un preciso orientamento che ha previsto di trattare gli argomenti in modo semplice, con brevità e in maniera che siano ben leggibili anche da una certa distanza.

La mostra è progettata in modo che i gruppi di visitatori, (ad esempio una classe scolastica) siano guidati da guide studentesche oppure da personale in grado di fornire ulteriori dettagli a eventuali domande. Nel corso della realizzazione della mostra sono sorte ulteriori idee, come ad esempio una esposizione tematica su Bruno Sander e Otto Ampferer. Infine, è stata installata un'opera d'arte a tema geoscientifico realizzata da artisti di fama internazionale quali Christine Prantauer e Ernst Trawöger. L'opera mostra tre linee tracciate su un muro di 12 metri di larghezza che rappresentano: (1) l'aumento dell'anidride carbonica nell'atmosfera nel periodo 1920 ÷ 2015, (2) l'aumento

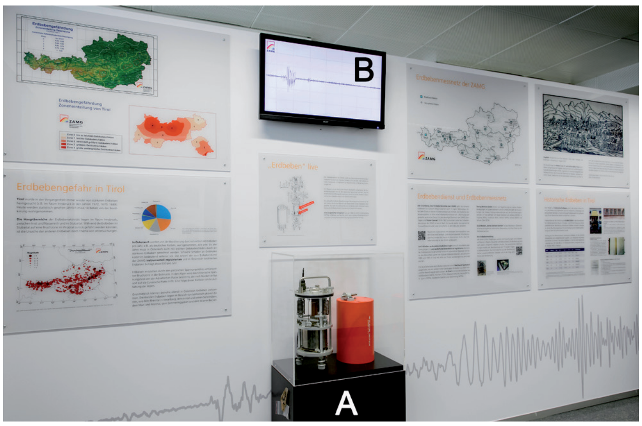

FIG. 2: Il settore relativo alla sismica alla mostra geoscientifica dell'Istituto di Geologia dell'Università di Innsbruck: saltando si genera un "terremoto personale" che viene registrato dal sismografo (A) e la cui magnitudo viene mostrata sullo schermo (B). Alcuni pannelli forniscono informazioni sugli aspetti generali della sismicità in Austria

della temperatura media annua a Innsbruck (1900 ÷ 2016) e (3) la diminuzione delle dimensioni degli organismi marini aventi parti scheletriche costituite da carbonato di calcio (1990 ÷ 2015). Sul pavimento è stato riprodotto un disegno della calotta glaciale artica che verrà gradualmente ridotto in funzione del suo progressivo scioglimento. Ad una parete vi è una bacheca con articoli scientifici di vario genere e su diversi argomenti relativi alla Terra.
L'opera artistica è in questo modo interattiva e può essere continuamente modificata e aggiornata. Per le persone che accompagnano i visitatori, la mostra nel suo insieme fornisce un ambiente flessibile che può essere adattato a seconda della età dei visitatori: ci sono spunti perché i più giovani possano provare meraviglia e possano sperimentare, qualche argomento che, si spera, risulti di interesse per i ragazzi più grandi e molto materiale da mostrare e di cui discutere con i visitatori adulti interessati.

ESEMPI DI DIVULGAZIONE: IL DOLOMITES UNESCO GEOTRAIL

Il Dolomites Unesco Geotrail è un percorso escursionistico a piedi in 10 tappe che attraversa tutto il patrimonio delle Dolomiti dalla Valle dell'Adige fino alla Val Pusteria. Esso è stato inaugurato nel 2018 ed è usufruibile da tutti grazie ad una guida realizzata ad hoc. Scopo del Geotrail è quello di condurre l'escursionista attraverso i luoghi più caratteristici delle Dolomiti e di introdurlo alla comprensione della straordinaria storia geologica in essi conservata.
La guida al Geotrail è costituita da un pacchetto in formato tascabile contenente una carta panoramica 3D con indicato tutto il percorso, gli estratti su base topografica al 25.000 di ogni singola tappa e un libretto esplicativo e descrittivo. Il libro contiene una parte estetico-descrittiva, una tecnico-logistica e la proposizione di due stop geologici particolarmente interessanti o significativi per la storia delle Dolomiti. Gli stop sono stati elaborati in modo da riuscire a dare un'informazione scientificamente corretta ed aggiornata con un linguaggio semplice; il tutto in maniera coincisa (poco testo con schemi e foto esplicative di quello che si vede realmente – fig. 3) e breve (massimo due pagine). Inoltre ogni tappa è stata dedicata ad un tema caratteristico particolarmente evidente lungo il percorso, di modo che complessivamente tutte le 10 tappe del Geotrail siano legate da un filo rosso geologico, che funga da guida e orientamento per l'escursionista, portandolo lentamente alla scoperta e alla comprensione del paesaggio circostante e della lunga storia geologica che ha condotto alla formazione delle Dolomiti.
Per le sue caratteristiche la guida si rivolge in particolare a un pubblico che non ha particolari conoscenze geologiche ma che possiede una sensibilità e curiosità verso i luoghi e i paesag-

FIG. 3: Un esempio di come un paesaggio viene descritto e spiegato nella guida del Dolomites Unesco Geotrail

gi che si attraversano durante una vacanza o nel tempo libero. Essa vuole fungere da accompagnatrice e suggeritrice discreta senza voler occupare tutta la scena o innondare il lettore con una marea di informazioni. Può infine risultare un utile strumento per molti operatori e guide escursionistiche locali.

ESEMPI DI DIVULGAZIONE: GEOWELT MAULS

Il paese di Mules anni fa ha deciso che una parte dei fondi per i progetti di compensazione ambientale del progetto della Galleria di Base del Brennero venisse utilizzata per la progettazione e la costruzione di un sentiero geologico in grado di spiegare la complessa e interessante geologia attorno a Mules.
Questa idea ha avuto l'approvazione di diversi enti locali, a cui è seguita la decisione finale positiva del governo dell'Alto Adige. Basandosi sui fondi così garantiti, il Bildungsausschuss di Mules, un gruppo di persone che aveva, tra l'altro, come obiettivo quello di formare future guide nella GeoWelt di Mules, ha deciso di appogiare questa idea e di organizzare un corso per chi fosse interessato alla materia geologica.
Questa iniziativa non solo ha portato ad un maggiore coinvolgimento della popolazione, ma anche alla divulgazione della geologia a gruppi di persone che normalmente svolgono attività del tutto differenti, come: casalinghe, maestri, pensionati, studenti, dottori in medicina, forestali, ecc.
Il programma educativo, conclusosi nel 2018, è stato molto vario, con lezioni tenute in diversi luoghi e numerose escursioni geologiche condotte in varie zone delle Alpi.
Esso ha costituito anche l'occasione di cercare e trovare insieme ad alcuni specialisti della materia geologica i metodi più opportuni per divulgare la geologia anche ai bambini e ai giovani.

CONSIDERAZIONI

Comunque si voglia affrontare il tema della divulgazione della Geologia, occorre mantenere sempre in evidenza il concetto che divulgare la scienza non deve significare banalizzarne i contenuti ma aumentarne la comprensibilità.
Se, inoltre, si riesce a combinare l'aspetto scientifico proprio della Geologia con quello ludico di una camminata in montagna, si è reso senz'altro un servizio culturale alla comunità.

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LOOKING AT THE TIMING OF TRIASSIC MAGMATISM IN THE SOUTHERN ALPS

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Middle Triassic volcanics and volcanoclastics interbedded in sedimentary successions are well known from the Southern Alps and especially from the Dolomites region (e.g. Buchenstein Fm., Fernazza Fm.), where several studies have been portrayed in order to define petrographic patterns and timing of magmatic product emplacement (cf. Abbas et al., 2018; Storck et al., 2018 and references therein). However, the increasing amount of available information allows to better define the timing and distribution of the whole Triassic magmatism in the general framework of the Southern Alps, and adjacent plates composing the Western Tethys margin. Additionally, improvements in biostratigraphy, sequence stratigraphy and geochronology allowed to revise sedimentary successions in which the magmatic products are intercalated and to establish new correlations.

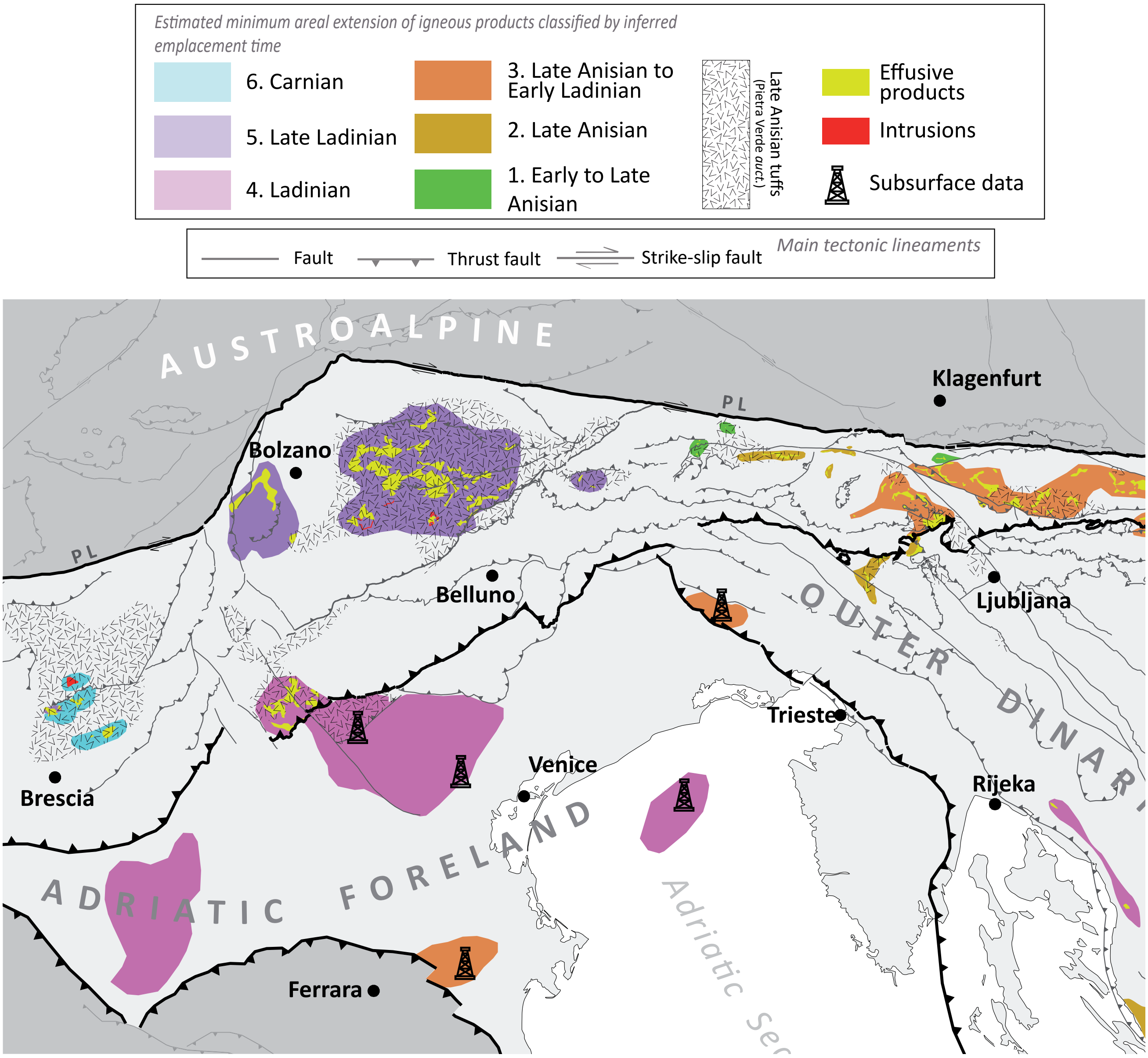

FIG. 1: Distribution of Triassic magmatic products throughout the Southern Alps, Adriatic Foreland and northern Outer Dinarides, classified by estimated time of emplacement. Modified from (Lustrino et al., in press).

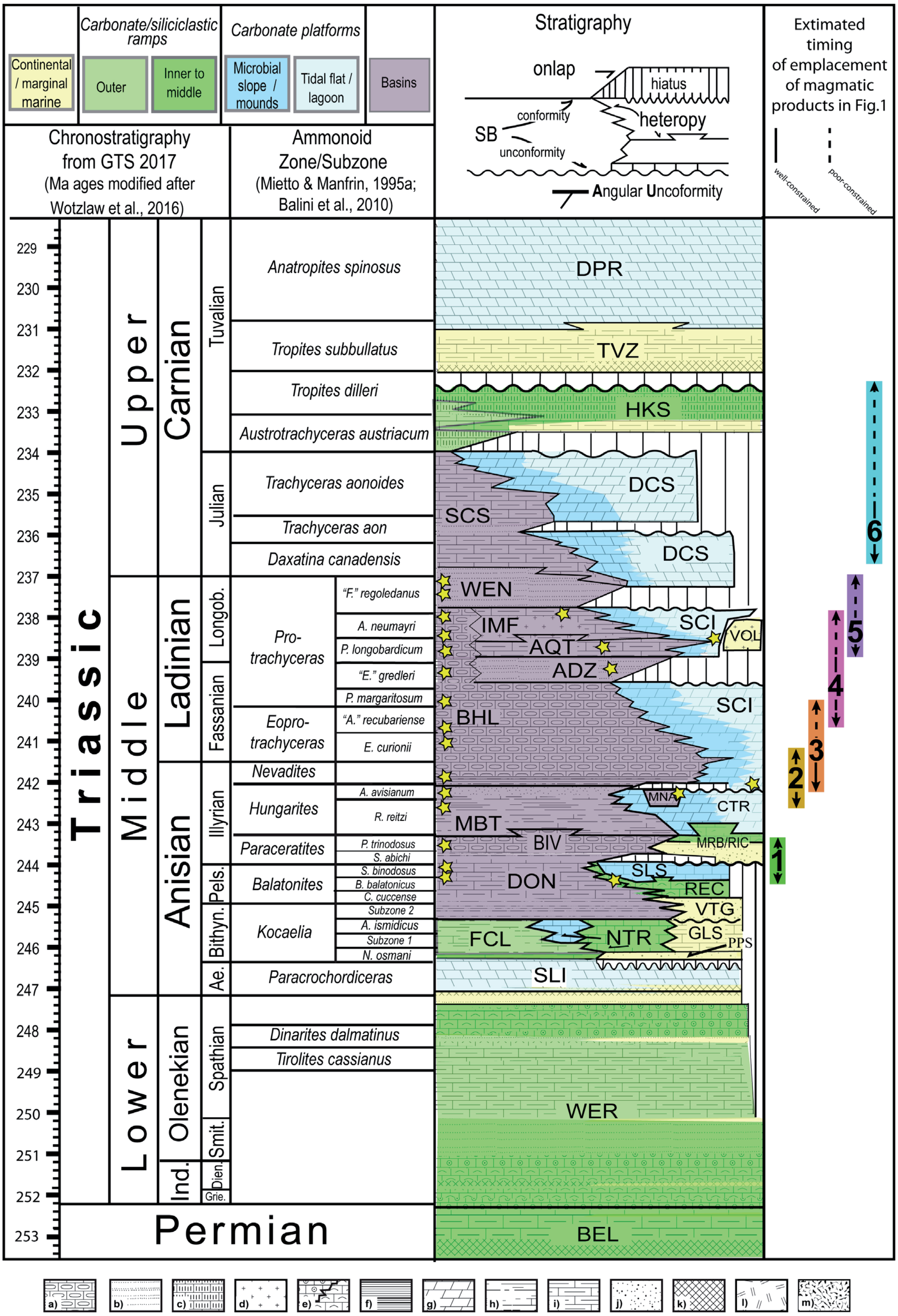

FIG. 1: Scheme showing the bio-chrono-stratigraphy of the Middle-Upper Triassic succession of the Dolomites: the occurrence of ash falls and tephras are marked by yellow stars. On the right column, the time-span of intrusive and effusive products displayed in Fig. 1 for the whole Southern Alps is shown. Lithostratigraphic abbreviations: BEL: Bellerophon Formation; WER: Werfen Formation; SLI: Lower Serla Dolomite; PPS: Piz da Peres Conglomerate; FCL: Coll'Alto dark Limestones; NTR: Monte Rite Formation; GLS: Gracilis Formation; VTG: Voltago Conglomerate; DON: Dont Formation; REC: Recoaro Limestone; SLS Upper Serla Dolomite/Formation; MRB/RIC: Richthofen Conglomerate and Morbiac dark Limestone; BIV: Bivera Formation; MBT: Ambata Formation; MNA: Moena Formation; CTR: Contrin Formation; BHL: Buchenstein Formation; SCI: Sciliar Formation; ADZ: Zoppè Sandstone; AQT: Aquatona Formation; IMF: Fernazza Volcanic Complex (Fernazza Formation); WEN: Wengen Formation; SCS: San Cassiano Formation; DCS: Cassian Dolomite; HKS: Heiligkreuz Formation; TVZ: Travenanzes Formation; DPR: Dolomia Principale. Lithologies: a) cherty limestone; b) sandstone; c) sandy limestone; d) volcanics and volcaniclastics; e) oolitic-bioclastic limestone; f) black platy limestone or dolostone, black shale; g) dolostone; h) marlstone, claystone and shale; i) marly limestone; j) conglomerate; k) evaporates; l) tuffs, pyroclastics; m) lava, pillow-lava, pillow breccia. Modified from (Abbas et al., 2018).

First clear evidences of volcanic deposits come from small outcrops in the Carnic Alps and Southern Karawanken (Buser, 1980; Obenholzner and Pfeiffer, 1991), where intermediate tuffs were emplaced both in subaerial and shallow marine environments during the late Pelsonian (early late Anisian). In other parts of the Southern Alps, few tufitic intercalations have been found in coeval basinal successions (e.g. Dont Fm. and Recoaro Lm.). During the Illyrian (late Anisian) magmatism expanded in a wider region and significant horizons of ignimbrites and other pyroclastics were emplaced in shallow environments from eastern Carnia to the Julian Alps (Lucchini et al., 1980; Gianolla, 1992; Celarc et al., 2013). Greenish tuffs rarely occurring in coeval basinal successions of the Southern Alps (e.g. Bivera Fm.) progressively increased, reaching significant thickness in the uppermost Anisian (Lower Pietra Verde, Ambata and Buchenstein fms cf. Viel, 1979; Brack and Muttoni, 2000) in the Southern Alps and nearby regions (e.g. External Dinarides; (Smirčić et al., 2018). At this time, intense acid magmatism involved also the eastern Julian Alps, Southern Karawanken and Kamnik-Savinja region, originating relatively thick porphyritic deposits (Dozet and Buser, 2009; Kralj and Celarc, 2002). In the Dolomites, pyroclastics and volcanogenic sedimentary deposits seems to be thicker and proximal in the southernmost areas and locally in the northern part (Cros and Houel, 1983).

From the latest Anisian to the Ladinian, magmatism (of acid to intermediate character) developed widely in the southern portion of the Southern Alps (Vicentinian Prealps cf, Barbieri et al., 1982; De Vecchi and Sedea, 1983) and in the Adriatic Foreland (ENI subsurface data), as well as in Outer Dinarides (northern Dalmatia e.g., Lugović and Majer, 1983), locally giving raise to thick successions of (mainly massive) porphyrites. Trachybasalts and andesites occurring in the Brescia Prealps have been dated to the Ladinian as well (Cassinis et al., 2008).

A strong tectono-magmatic phase affected the Dolomite region during the late Ladinian, leading to large fault-scarp collapses, effusions of huge amounts of mafic volcanics in the basins (Viel, 1979) and to the emplacement of almost three main intrusions, related to as many magmatic chambers (cf. Abbas et al., 2018 and references therein). Subaerial, basaltic lava bodies overlapped shallow carbonate successions also in the region westward to the Adige valley (Avanzini et al., 2007; 2013). The parossistic mafic phase is recorded by the Fernazza Fm. and is mainly confined in a very short time between Longobardicum and Regoledanus Subzones (Fig. 2), anyway, some effusive products and few pyroclastic levels are documented also in the mainly post-volcanic Wengen Fm (Bosellini et al., 1977; Storck et al., 2018).

Evidences of magmatism in the Early Carnian are limited to the central part of Southern Alps, where porphyrites and lavas were emplaced subaerially or in subvolcanic bodies (Cassinis et al., 2008).

Even if the geochemical variation of igneous products in space and time doesn't show a clear trend, the younging direction of Triassic magmatism in the whole Southern Alps seems to follow a roughly NE-SW direction, and this should be considered when geodynamic settings are proposed to explain the development of magmatism in the Dolomites region and in the Southern Alps.

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ASPECTS OF QUATERNARY STRATIGRAPHY ON THE GEOLOGICAL MAP OF THE WESTERN DOLOMITES: PROBLEMS AND APPLICATIONS.

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The geological mapping of the Western Dolomites was mainly carried out within the framework of the project Geological Base Map South Tyrol, Sedimentary Part in the years 1995 to 2003. The main focus of the project was on the bedrock and structural geology, less on the quaternary geological mapping. The mapping of quaternary deposits was therefore carried out partly according to lithofacial, partly according to lithogenetic, and often according to geomorphological criteria using aerial photography interpretations. This applies in particular to the widespread landslides, which in the main valleys have frequently reworked the sediments and altered the morphology of the Würmian Late Glacial Maximum (LGM) and the Würmian Lateglacial. For the 2nd edition of the Geological Map of the Western Dolomites, the quarternary deposits and the landforms were revised by the interpretation of aerial photographs and laser scan images, field observations and consultation of new research results. The stratigraphic subdivision of the quarternary deposits follows the guidelines of the Italian national geological map programme CARG for terrestrial quarternary deposits (Guida al rilevamento della Carta Geologica d'Italia 1:50.000 - Quaderno 1 serie III, 1992, with additions 2001 and 2003). This provides for a subdivision according to allostratigraphic aspects into so-called "UBSU" (= unconformity-bounded stratigraphic units, Salvador, 1994). These are units which are limited by discordances. The basic unit of the UBSU is the synthem, subunits are called subsynthems, superordinate units are called supersynthems. In the lithostratigraphic subdivision, the synthem roughly corresponds to the rank of a Group. The synthems are represented on the geological map with different colors. In turn, they are composed of different deposits, lithofacies types and lithogenetic units that can be mapped at a scale of 1:10.000, such as glacial and glaciofluvial deposits, ice-marginal deposits, talus breccias, etc. However, these are always provided with the same oversignatures. For the 2nd edition, the German nomenclature of the Quaternary legend was revised and adapted to the modern international standards and terms used by the CARG. The newly developed terminology catalogue for Quaternary and landslides of the Geological Survey of Austria (Steinbichler et al., submitted) was also taken into account. Following this, the term moraine, which in German is traditionally used to refer to sediments as well as morphology, is replaced by till (e.g. basal till of a laterofrontal moraine) and moraine ridges (moraine). Also in the case of landslides, the rock bodies detached from the original rock units and gravitatively moved by falling, sliding, creeping and flow processes are regarded as deposits. In the Dolomites, due to the special lithological succession characterised by significant dolomite cliffs and underlying weak marly strata, many rockfall deposits, rapid landslide deposits, debris flow deposits and earth flow deposits can usually be well delimited according to these criteria. The lithogenetic units are summarized on the present geological map as in the CARG under the term lithofacies, the geomorphological units and quaternary phenomena under the term landforms. The chronostratigraphic classification is done by assigning the lithofacies and landforms to the respective synthems and subsynthemes.

The age-related classification of the Quaternary and landslide deposits and forms on the map sheet is based almost exclusively on stratigraphic evidences and analogies to better investigated areas of the nearer and wider surroundings (Brixen/Bressanone Basin, Überetsch/Oltradige, Etsch/Adige Valley, Venetian-Friulan Foreland, Inn Valley) and on the most recently published absolute dates from the Dolomites. In the last decades, quaternary geologists and geomorphologists of the University of Modena dated numerous organic remains in different quaternary deposits in the upper Gader/Badia Valley by means of a large number of radiocarbon-datings (also taken from drill cores). For the first time they could prove pre-LGM- (46-38 ka BP) and early Lateglacial (about 16 ka BP) ages of deposits on the Pralongià plateau. In addition, numerous radiocarbon-datings of organic remains (woods) in landslide deposits or their underlying or backwater deposits allow a good cronological delimitation of the numerous landslides of this area. The data show clusters of landslide activities from the Early Holocene (10 ka BP) until the present day, triggered probably by climate variations or induced by earthquakes (Corsini et al. 2001; Soldati et al., 2004; Borgatti et al., 2007; Soldati & Borgatti, 2009; Panizza et al., 2011; cf. also Brandner & Keim 2011). Numerous historical landslide events are also documented in reports.

The Synthem classification applied to the Geological Map of the Western Dolomites had to be modified as compared to adjacent new CARG map sheets (e.g., Toblach/Dobbiaco, Cortina) due to lacking field evidence or contexts which are difficult to interpret.

TIERS/TIRES SYNTHEM

One of the main discordances of alpine quarternary deposits is the contact of non-glacial deposits with glacial deposits (till deposits). For example, in the Tiers/Tires Valley, in the area of Völs am Schlern/Fiè allo Sciliar and in the Gröden/Gardena Valley, there are slope, debris flow and torrent deposits as well as lacustrine deposits overlain by till (especially basal till) of the LGM. These "pre-LGM"? deposits have been grouped under the name "Tiers/Tires-Synthem". Referring to the common synthem-structure of the CARG project, this synthem is part of the Monte Spinale Supersynthem.

DOLOMITES SYNTHEM

The glacial deposits of the Last Glacial Maximum are named after the catchment areas of the individual large ice streams of the ice flow network, which mostly also followed the valleys of today's main rivers and bear their names. The "Garda-Synthem" comprises the catchment area of the former Etsch/Adige glacier. Its name derives from its main glacial tongue in the Lake Garda basin with its wellknown amphitheatre-shaped terminal moraines (Ravazzi et al., 2014). The delimitation of the Garda-Synthem causes great difficulties in the western Dolomites. In their central areas, the flow directions of the LGM ice streams are still largely unclear. The main reason for this is primarily the special topography with the plateau-like mountain ranges, which are separated by wide, low passes. This results in the absence of large contiguous glacier accumulation areas. Ice transfluences are possible in all directions. Furthermore, the glaciers of the Dolomites were significantly backlogged and deflected by the thick central alpine ice streams of the Rienz/Rienza and Eisack/Isarco glaciers. Mutschlechner (1933), Klebelsberg (1956), Panizza et al. (2011) and Marchetti et al. (2017) all postulate the penetration of the Rienz/Rienza glacier from north to south into the uppermost Gader/Badia Valley and a transfluence to the south into the Cordevole Valley, based on sparse isolated finds of crystalline clasts in till. They presume the advance of the Eisack/Isarco glacier into the upper Gröden/Gardena Valley with a transfluence to the East over the Gröden/Gardena pass. This assumption has to be questioned, however, as important erratic blocks such as amphibolite and quartz porphyry are missing. In addition, the subglacial striations on the Seiser Alpe/Alpe di Siusi and on the Puflatsch/Bullaccia plateau, which are approximately E-W-oriented in the laser scan image, indicate ice transports out of the valley for most of the Gröden/Gardena Valley. Only in the lower Gröden/Gardena Valley an ice flow in NE-SW direction is clearly visible. The general lack of ice flow direction indicators and informative erratic blocks from the Dolomite region do not allow a clear delineation of the Garda synthema or any sub-synthema for the central part of the map sheet area. For this reason, the term "Dolomites Synthem" was introduced, which applies to all areas with LGM glacial deposits consisting of debris from the upper Permian to Cretaceous strata (Bellerophon Fm to Puez Fm) of the Dolomites.

EISACK/ISARCO SUBSYNTHEM

The till deposits of the LGM with frequent clasts of crystalline and Permian quartz porphyry are distributed throughout the entire Tiers/Tires Valley and partly in the Villnöß/Funes and outer Gröden/Gardena valleys. They are evidence of the dominance of the Eisack glacier in these valley sections and show its advance to the slopes of the Rosengarten/Catinaccio, as for example in the Tiers/Tires Valley. Here the term "Eisack/Isarco subsynthem" was used, which is a subsynthem of the Garda synthem. On the other hand, neither a separate Rienz/Rienza subsynthem and Avisio subsynthem as parts of the Garda synthem nor a Cordevole subsynthem as spart of the Piave synthem have been identified. This is because the few finds of crystalline clasts in the quaternary deposits of the upper Gader/Badia Valley (Mutschlechner, 1933; Klebelsberg, 1956) do not imply the southward advance of the Rienz/Rienza glacier during the LGM and its overflow to Buchenstein/Livinallongo Valley. In addition, the crystalline clasts could also derive from older glaciations and be reworked. Similarly, ice flow directions and potential transfluences over the Sella Pass or Pordoi Pass in the upper Fassa Valley have not yet been clarified. For these reasons, the LGM sediments in the entire Gader/Badia Valley, Fassa Valley and Buchenstein/Livinallongo Valle have been subsumed under the Dolomites synthem (cf. Geological Map Sheet 029 Cortina d'Ampezzo, 2007; Panizza et al., 2011; Marchetti et al., 2017).

LATEGLACIAL SYNTHEM

The conditions of the Lateglacial deposition history are very complex. They are characterized by the early Lateglacial deglaciation and subsequent pulses of glacier advances remaining in upper valleys (valley glaciers). The advances occured during distinct climate deteriorations in the Oldest and Younger Dryas (stadials). The cold phases were interrupted by warmer periods (Bølling/Allerød interstadial) Each of these valleys is to be regarded as a separate deposition system with corresponding till, ice-marginal deposits, talus breccias, debris flood deposits, etc. The correlation of these sediment bodies, limited by unconformities, from one valley to the next is therefore extremely difficult, especially in the absence of absolute age dating. To prevent the introduction of new names (subsynthems), the informal name "Lateglacial Synthem" was used for all glacial and non-glacial deposits of the Lateglacial. The Lateglacial moraine stratigraphy was established in the Central Alps and is named after stabilised terminal moraines of glacier advances in the valleys of the Stubai Alps (Tyrol, Austria) (Gschnitz, Daun and Egesen stadial moraines). Meanwhile, the exposure ages of a number of these terminal moraines have been dated (cf. Ivy-Ochs et al., 2008; Reitner et al., 2016). For the Dolomites there are no absolute dates available so far. The Lateglacial moraine stratigraphy, transferred from the Central Alps to the Dolomites, has been applied by some autors until the recent past (cf. Klebelsberg, 1927; Castiglioni, 1964; Ghinoi & Soldati, 2017). The previous data on the Gschnitz, Daun and Egesen stadial moraines in the Dolomites, which are based exclusively on calculating the equilibrium line altitudes (ELA) in relation to the 1850s moraines of the Little Ice Age, are, however, no longer valid according to modern scientific knowledge. This is because the topographical and climatic conditions of the Dolomites deviate fundamentally from the Central Alps and moraines of the 1850s are scarce. Absolute age dating of stabilised glacier moraines or rock glacier deposits is still lacking. Therefore, only temporally undifferentiated Würmian Lateglacial moraines and till are identified on the geological map. Due to the lack of age dating information, there are also overlaps between the Lateglacial and the Alpine Postglacial Synthem with regard to the age classification of, e.g., landslide deposits, rock glacier deposits, alluvial and debris fan deposits.

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THE PERMIAN–TRIASSIC BOUNDARY AND THE END-PERMIAN MASS EXTINCTION IN THE SOUTHERN AND EASTERN ALPS

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At the end of the Permian (ca. 252 Ma), the most severe mass extinction of the Phanerozoic occurred (e.g., Algeo et al., 2015 and references therein). The end-Permian extinction event had a profound effect on terrestrial and marine ecosystems, but affected the various plant and animal groups and ecosystems differently (Chen & Benton, 2012). Still not much is known about the exact effect and timing of the end-Permian mass extinction in terrestrial ecosystems and about the possible influence of preservational/taphonomic bias on the apparent extinction patterns. The Southern Alps are one of the most important regions for the study of the end-Permian mass extinction since the boundary interval succession is continuous, fossiliferous, crops out in numerous places, and represents terrestrial, as well as coastal and marine settings. While many studies have been conducted in this region, they all had a limited scope. Furthermore, outcrops with successions of the same age in the neighbouring Eastern Alps are barely studied. A three-year research project has now been conducted to examine the PTB interval in various outcrops across the Southern and Eastern Alps and across different palaeoenvironmental settings with a multidisciplinary approach.

The study area (Fig. 1) of the Euregio-Project "The end-Permian mass extinction in the Southern and Eastern Alps: extinction rates vs taphonomic biases in different depositional environments" includes the Dolomites and Carnic Alps of Northern Italy (Southern Alps) and the Lienz Dolomites and Gailtal Alps of Austria (Drau Range, Eastern Alps). The fossil-rich late Permian sequences of the Dolomites represent terrestrial environments (Gröden/Val Gardena Formation) followed by marine strata (Bellerophon Formation; Fig. 2M),

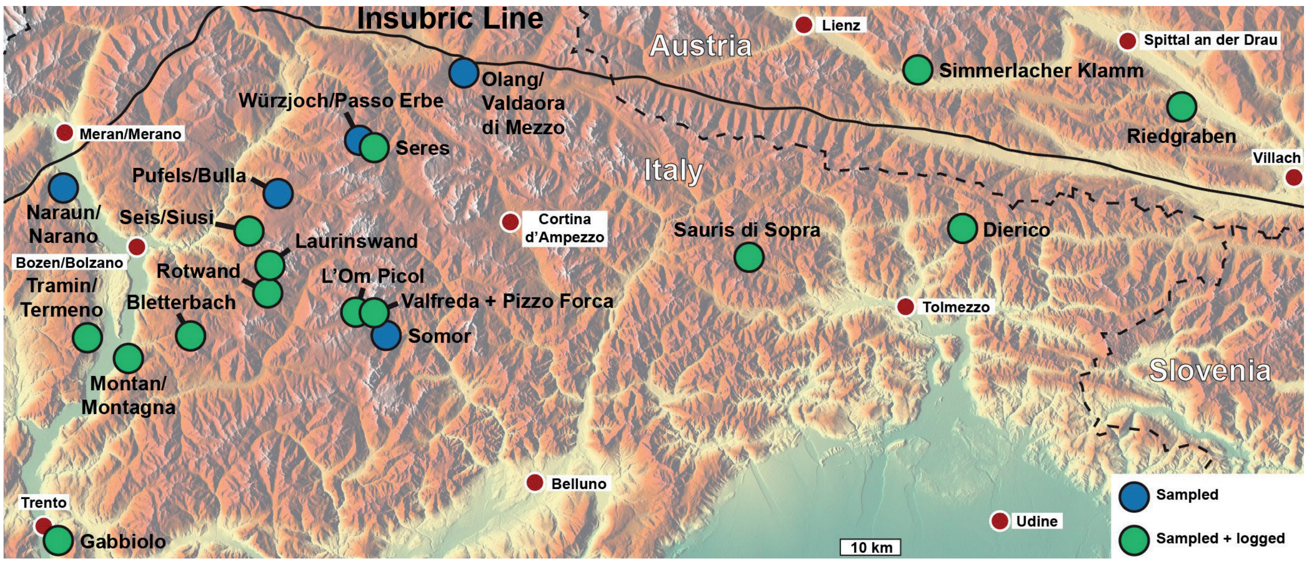

FIG. 1: Map of the study area with marked sections visited during field work campaigns in 2016–2018. Topographic base map © OpenStreetMap contributors, SRTM.

while the Early Triassic deposits are of marginal marine origin (southalpine Werfen Formation). The basal part of the Werfen Formation in the western Dolomites consists of oolite which constitute the Tesero Member (Fig. 2N). The Tesero Member is overlain and laterally interfingering with the Mazzin Member, which consists mostly of marly mudstones. In the Eastern Alps, the late Permian terrestrial continental sediments (Gröden/Val Gardena Formation) are overlain by Early Triassic terrestrial sediments (Alpine Buntsandstein) and marginal marine deposits (northalpine Werfen Formation).

During field work campaigns in 2016, 2017 and 2018, we logged and sampled ten sections in the Dolomites (Bletterbach, Tramin/Termeno, Montan/Montagna, Gabbiolo, Seres, Göma, Laurinswand, Rotwand, L'Om Picol, Valfreda, Pizzo Forca), two in the Carnic Alps (Felempecle near Sauris di Sopra, Dierico) and two in the Drau Range (Simmerlacher Klamm, Riedgraben). Several more localities were sampled, but not logged (Seis, Würzjoch/Passo delle Erbe, Pufels/Bulla, Naraun, Olang, Somor, Passo San Pellegrino). Samples were collected for isotope geochemistry (organic and inorganic), palynology, conodonts, microfacies and magnetostratigraphy. Macrofossils (invertebrates, tetrapod ichnofossils, plants, fishes) were collected where possible.

The Gröden/Val Gardena Fm. in the Bletterbach Gorge (Wuchiapingian, late Permian) yielded diverse fossil assemblages of plants and tetrapod footprints. Some of the plants show damage caused by insects (Fig. 2G). The footprints can be attributed to pareiasaurs (Fig. 2J), youginiformes, herbivorous and faunivorous therapsids (Fig. 2I), captorhinids, and archosauriforms. The most common plants are conifers (Fig. 2F) and ginkgophytes (Fig. 2E). Also present are seed ferns, rare taeniopterids and very rare sphenophytes (Kustatscher et al., 2017). Taken together, the fossils provide an unusually complete picture of a late Permian ecosystem with multiple trophic levels (Bernardi et al., 2017). The distribution of the fossils follows sea-level changes, as footprints are mostly found closely below and above the so-called "Cephalopod Bank", which represents a marine transgression (Kustatscher et al., 2017). The composition of the palaeofloras also changes, with ginkgophytes being the most common elements below the cephalopod bed, but rare above. The cephalopod bank itself contains a fossil assemblage of coiled and orthoconic nautiloids, bivalves and *Skolithos* burrows (Prinoth, 2017).

At the Seres section, the exposed Bellerophon Fm. can be divided into Interval I, Interval II and (above a sharp lithologic boundary) the Bulla Member. The overlying (lower) Werfen Fm. is represented by the Tesero Mb. and lower part of the Mazzin Mb.. In Interval I, bioclastic wackestone and packstone containing abundant foraminifers (Fig. 2K) and calcareous algae (Fig. 2L) are the most common microfacies. In Interval II, limestone of the lower part is less diverse (ostracod and bioclastic mudstone). In the upper part, individual limestone beds contain abundant calcareous algae and foraminifers. The basal bed of the Bulla Mb. is composed of algal and foraminiferal wackestone to packstone, overlain by bioclastic wackestone containing abundant algal fragments and foraminifers. The most common microfacies of the upper part of the Bulla Member is packstone. The topmost grainstone of the Bulla Mb. is sharply overlain by oolitic grainstone of the Tesero Mb. The boundary shows stylolitic overprinting and probably represents an erosional surface. The dominant microfacies of the lower part of the Mazzin Mb. is mudstone containing ostracods. Less common is bioclastic mudstone, ostracod-bivalve wackestone and grainstone.

Previously, no plant fossil assemblages apart from root traces had been described from the Bellerophon or Werfen formations, although the presence of plant fossils in the Bellerophon Fm. at Tramin/Termeno (Brandner et al., 2012) and Seis/Siusi (Siegert et al., 2011) was mentioned. Several plant fossils were now collected in these localities, which are awaiting description. At Seis, the same beds partly yielded fish remains as well. In addition, we found root body fossils in the Bletterbach Gorge, in the uppermost part of the Bellerophon Formation, just below the Tesero Mb., and at Seres, within the Tesero Mb. (Fig. 2H). Additional plant remains were found in the upper part of the Werfen Fm. at the Weisshorn and in the Alpine Buntsandstein in the Gailtal Alps.

Spore/pollen assemblages from the Bellerophon Fm. are diverse and dominated by bisaccate pollen (Fig. 2A). The assemblages indicate a flora of primarily conifers and seed ferns, with more rare lycophytes, sphenophytes, cycadophytes and/or ginkgophytes, as well as possible gnetophytes.

Palynological assemblages from near the PTB are marked by three conspicuous signals that have been found in many places across the world, including the Dolomites: The so-called "fungal spike", a "spore spike" and the frequent occurrence of spore tetrads (Fig. 2B). The "fungal spike" refers to the mass occurrence of *Reduviasporonites* Wilson 1962 (Fig. 2C), a problematic organic-walled microfossil type that has been interpreted on morphological and biogeochemical grounds as both fungal and algal remains (Eshet et al., 1995; Visscher et al., 1996). One of the classical examples is the almost exclusive presence of this taxon (ca. 98 % of organic particles) in assemblages from the Tesero Mb. at Tesero. However, we found mass occurrences (> 50 % of organic particles) of *Reduviasporonites* in the Bellerophon Formation at Pizzo Forca, as well as in the Mazzin Mb. at the Laurinswand section. Conversely, a mass occurrence in the Tesero Mb. could so far only be found at Tesero (Spina et al., 2015). This seems to indicate that there were multiple, possibly local events.

The "spore spike" relates to an increase in the spore/pollen ratio close to the PTB. This is usually taken as an indication for the demise of the Permian floras and their replacement with a disaster flora dominated by herbaceous lycophytes (Looy et al., 1999). In the Werfen Formation, this increase in spores is pervasive, but various pollen types are still present, indicating the continued presence of gymnosperms. Due to a very low overall yield of samples from the Werfen Formation, it is not yet clear if the assemblages reflect an extinction among plants, but a drastic change is indicated.

The higher relative abundance of spores is also related to the frequent occurrence of spore tetrads (Fig. 2B). Permanent tetrads can be found significantly more often near the PTB, e.g. in the Dolomites within the Tesero Mb. (Visscher et al., 2004; Looy et al., 2005). This has been interpreted as a disturbance of plant reproduction due to increased UV-B radiation, which in turn can be related to the destruction of the ozone layer caused by the Siberian Traps volcanism (Visscher et al., 2004; Benca et al., 2018).

Vertebrate remains are scarce around the PTB. Some sections, notably Seis, yielded fairly common fish remains in the uppermost Bellerophon Fm., and a couple of fish teeth were discovered in the Werfen Fm. (possibly Siusi Mb.) of Passo Rolle. Fish ichnofossils were also documented in both the Gröden/Val

Gardena Fm. and the Campil Mb. of the Werfen Fm. (Olenekian) (Ronchi et al., 2018).

More results are to be expected as the work is ongoing. Ultimately, the goal is to compare findings from different sections in order to identify taphonomic constraints.

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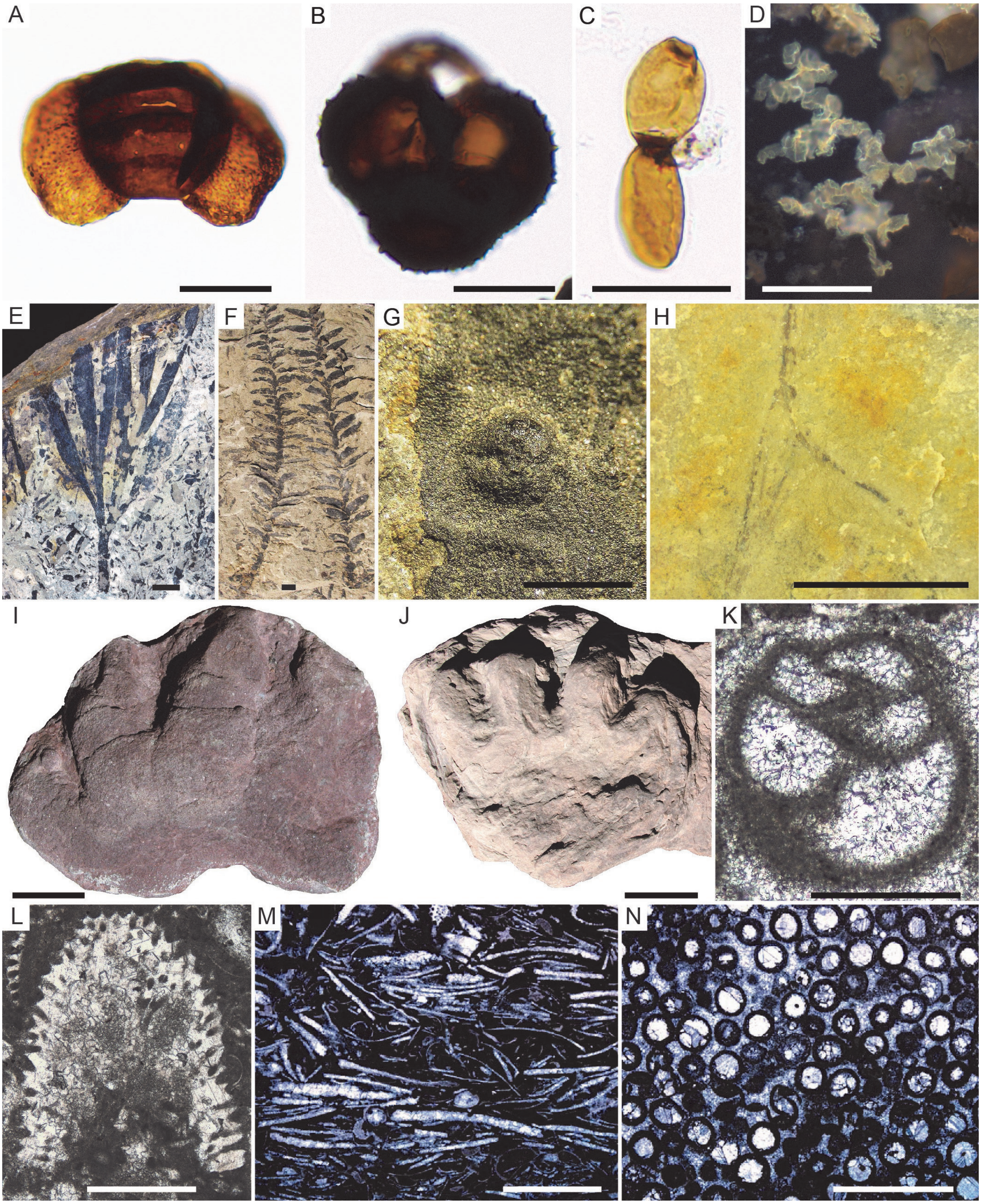

FIG. 2: Examples of fossils from the Permian–Triassic boundary interval in the Eastern and Southern Alps. Scale bars = 50 µm for A–D; 1 cm for E–I; 10 cm for J; 200 µm for K–L; 2 mm for M–N. **A**, *Lunatisporites labdacus* (Klaus, 1963) Visscher, 1971, Bellerophon Fm., Tramin/Termeno. **B**, Spore tetrad, Tesero Mb., Tramin/Termeno. **C**, *Reduviasporonites chalastus* (Foster 1979) Elsik 1999, Bellerophon Fm., Tramin/Termeno. **D**, Unidentified algal or fungal remains (fluorescence), Bellerophon Fm., Laurinswand. **E**, *Baiera digitata* (Brongniart) Heer 1876, Gröden/Val Gardena Fm., Bletterbach. **F**, *Ortiseia leonardii* (Florin) Clement-Westerhof 1984, Gröden/Val Gardena Fm., Bletterbach. **G**, Insect gall, Gröden/Val Gardena Fm., Bletterbach. **H**, Root body fossil in marine sediment, Tesero Mb., Seres. **I**, Therapsid footprint indet., Gröden/Val Gardena Fm., Bletterbach. **J**, *Pachypes dolomiticus* Leonardi et al. 1975, Gröden/Val Gardena Fm., Bletterbach. **K**, Foraminifer, Bellerophon Fm., Seres. **L**, Calcareous Alga, Bellerophon Fm., Seres. **M**, Packstone with ostracods and mollusc shells, Bellerophon Fm., Laurinswand. **N**, Oolithic grainstone, Tesero Mb., Laurinswand.

THE GREAT LANDSLIDES OF THE DOLOMITES: SOME EXAMPLES

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The mountainous slopes of the Dolomites (Southern Alps, NE Italy) bear evidence of numerous deep-seated catastrophic rock-slope failures. Many of these evolved into long-runout rock avalanches with volumes of several 100 Mm^3.
Some of the most spectacular rock avalanches are concentrated in the Brenta Dolomites area like the Marocche di Dro (Marocca Principale 1000 Mm^3; Kas 300 Mm^3) located in the middle reach of the lower Sarca valley, and Molveno (500 Mm^3) and Tovel (300 Mm^3) in the core of the Brenta massif. Other rock avalanches are present in the surrounding valleys: the Lavini di Marco (200 Mm^3) in the middle reach of the Adige valley and the Nago-Torbole (260 Mm^3) near Lake Garda (Fig. 1).
Other huge landslides are present in the Venetian Dolomites such as: the Vajont (270 Mm^3) on the northern slope of Mt. Toc, the Mt. Peron (170 Mm^3), Alleghe (20 Mm^3) and Antelao (5 Mm^3) in the Cordevole valley (Rossato et al., 2018), the Fadalto deposit in the Lapisina valley (~135 Mm^3) and the Sasso Lungo (Città dei Sassi) landslide (Montandon, 1933) (Fig. 2).
Many of the colossal landslide events, once thought to have occurred between 17,000 and 12,000 years ago, are now shown by ^{36}Cl dating to have failed much more recently, within historical times (Martin et al. 2014, Ivy-Ochs et al. 2017a; 2017b). To date the events, we use cosmogenic ^{36}Cl dating of limestone and dolomite boulders in the deposits.

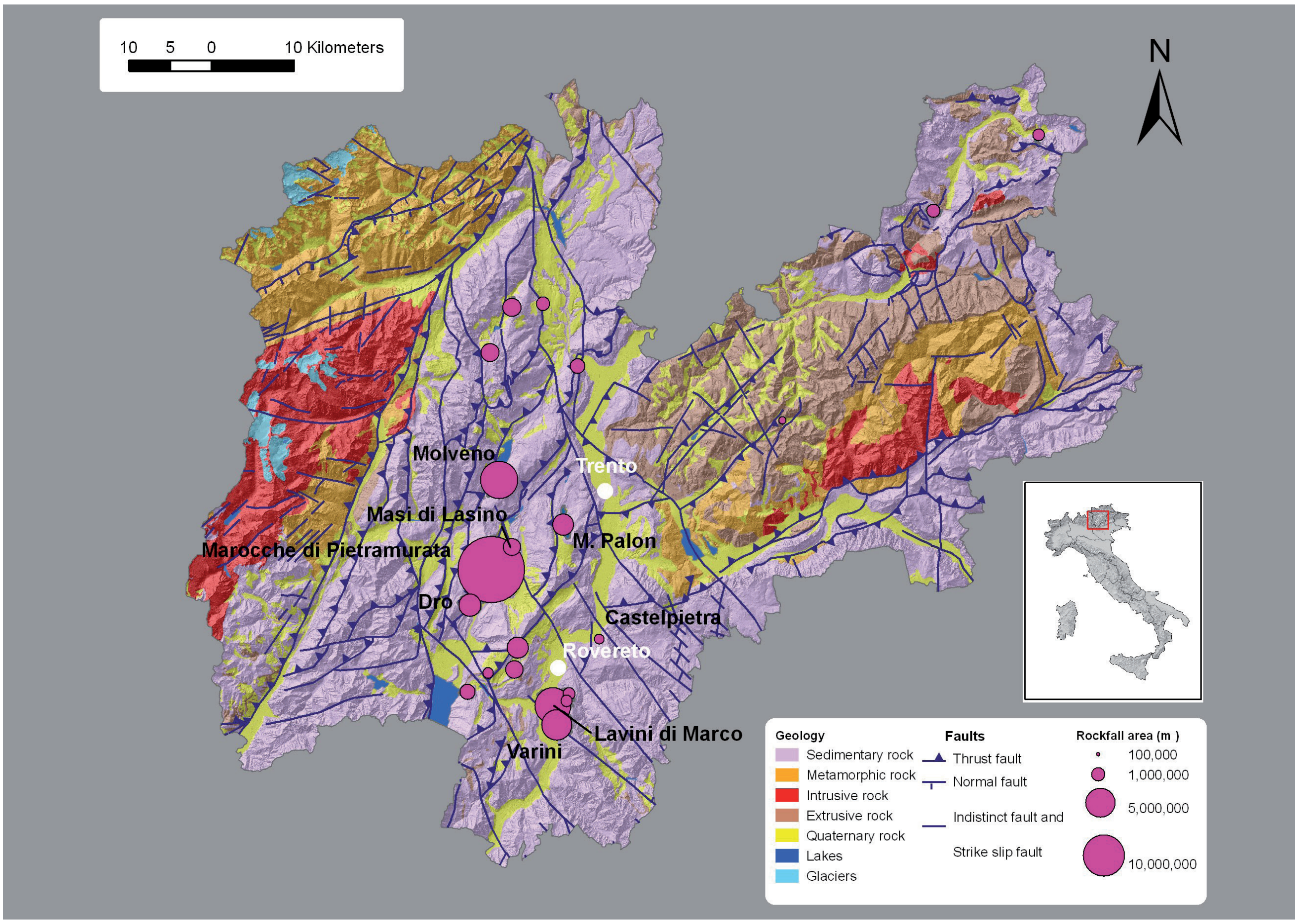

FIG. 1: Landslides of the Trentino Dolomites (modified from Ivy-Ochs et al., 2017b).

A summary of all dated and large landslides in the Alps has shown three periods of enhanced slope activity during the Holocene: 10-9 ka, 5-3 ka and 2-1 ka, the latter especially in the Southern Alps. Usually we have observed a repetition of the rock-slope failure in the same mountainous site with events during the pre-historic time and some others during the historic one, mostly concentrated within the latter two periods.

The results of this study based on ^{36}Cl dating are interpreted in the framework of geomorphological and structural field mapping, remote sensing analysis and runout modelling, focusing on the type of event, timing and impact on human life and activities, and discussing their predisposing and triggering factors.

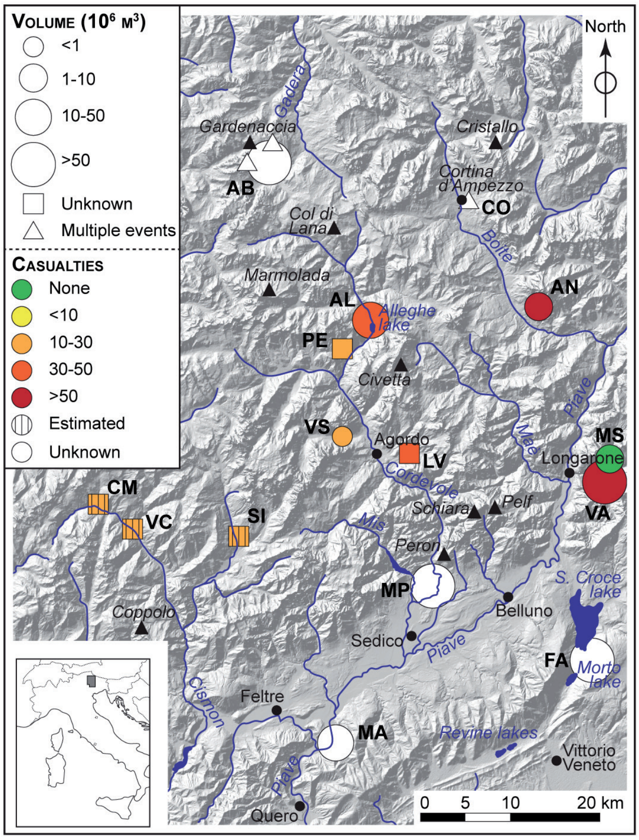

FIG. 2: Landslides of the Venetian Dolomites (modified from Rossato et al., 2018). The size of the symbols corresponds to the volume; casualties are shown with color coding. **AB** Alta Badia, **AL** Alleghe, **AN** Antelao, **CM** Col Mandro, **CO** Cortina d'Ampezzo, **FA** Fadalto, **LV** La Valle. **MA** Marziai, **MS** Mt. Salta, **PE**: Pecol, **MP** Mt. Peron, **SI** Siror, **VA** Vajont, **VC**: Val Cia, **VS** Valle San Lucano.

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PERMIAN–TRIASSIC MACRO- AND MICROFLORAS OF THE SOUTHERN ALPS

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Extensive Permian and Triassic rock sequences crop out in numerous places in the Southern Alps and have yielded, among other things, several important palaeofloras. We here provide an overview of the stratigraphic distribution of fossil floras from the Permian and Triassic found so far in the Southern Alps (mostly northern Italy), including macrofossils as well as spore/pollen assemblages.

The Cisuralian (lower Permian) in the Southern Alps is mostly represented by the volcanic rocks of the Athesian Volcanic Complex, but with some sedimentary intercalations bearing fossils. Cisuralian plant fossils have been found in Collio in the Val Tompia (Collio Formation; Sakmarian–Artinskian; Remy & Remy, 1978), Sinich/Sinigo in the Etsch/Adige Valley (upper Artinskian; Fritz & Krainer, 2006), Tregiovo in the Val di Non (Tregiovo Formation, Kungurian; Forte et al., 2018) and Gerola Alta in the Orobic Alps (Ponteranica Conglomerate, undated; Kerp et al., 1996). Spores and pollen have also been found in Collio (Cassinis & Doubinger, 1991), Sinich/Sinigo (Hartkopf-Fröder et al., 2001) and Tregiovo (Forte et al., 2018), as well as in some chert layers within the Athesian Volcanic Complex (Hartkopf-Fröder et al., 2001).

No plant fossils of Guadalupian (middle Permian) age are known from the Southern Alps, although the basal part of the fossiliferous Gröden/Val Gardena Formation (also known as Grödner Sandstein/Arenarie di Val Gardena) may represent the latest Guadalupian (Capitanian). The main part of the Gröden/Val Gardena Fm. covers the Wuchiapingian (lower Lopingian = upper Permian), and it may reach the Changhsingian (upper Lopingian) in some places. Palaeofloras of the middle–upper Wuchiapingian were found in the Gröden/Val Gardena Fm. in the Bletterbach Gorge of the Dolomites (Kustatscher et al., 2017). Plant macrofossil assemblages of the Gröden/Val Gardena Fm. with uncertain ages are known from several localities in the Dolomites (Cuecenes, Sankt Ulrich/Ortisei: Florin, 1964; Alpe di Siusi/Seiser Alm: Jung, 1977; the Rosengarten/Catinaccio Massif: Kustatscher et al., 2014) as well as from Mölten/Meltina (Krainer, 2000), Auer/Ora (Leonardi, 1948), the Val di Non (Kustatscher et al., 2014), Recoaro (Vicentinian Alps; Massalongo, 1863; Gümbel, 1879), Somor, and the Passo San Pellegrino. Another upper Permian palaeoflora has been reported from Valtellina (Sondrio) in the Orobic Alps (Brambilla et al., 1989). The presence of spore/pollen assemblages is apparently common throughout the Gröden/Val Gardena Fm. in the Dolomites (Klaus, 1963; Massari et al., 1994). The Gröden/Val Gardena Fm. is overlain by the Changhsingian Bellerophon Formation. This formation is primarily marine and mostly void of macroscopic plant fossils except for nondescript root casts (in the Western Dolomites), but a well-preserved fossil flora has now been found near Seis/Siusi. In addition, some roots in body preservation are present at the top of the Bellerophon Fm. in the Bletterbach Gorge. The Bellerophon Fm. in the Dolomites is generally rich in palynofloras with well-preserved spores and pollen (Cirilli et al., 1998; Klaus, 1963; Massari et al., 1994; Spina et al., 2015).

The Bellerophon Fm. is succeeded by the Werfen Formation (uppermost Changhsingian–Lower Triassic), which is also mostly void of plant macrofossils. A bed with roots was found at Seres (Val Badia) in the Tesero Member (the lowermost member). The Tesero and Mazzin members (uppermost Changhsingian–Induan [=lower Lower Triassic]; Cirilli et al., 1998; Looy et al., 2005; Nowak et al., in press; Spina et al., 2015) as well as the Val Badia and Cencenighe members (Olenekian; Visscher, 1974) have yielded spores and pollen. Some plant macrofossils have been collected in the upper part of the Werfen Fm. (Olenekian, upper Lower Triassic) in the Bletterbach Gorge.

The Middle Triassic stratigraphy in the Southern Alps is complex, but well-resolved, with several formations containing well-dated palaeofloras. Anisian (lower Middle Triassic) macrofloras were found in the Valle San Lucano (Formazione di Agordo; Bithynian–Pelsonian; Kustatscher et al., 2010a), at the Kühwiesenkopf/Monte Prá della Vacca (Dont Formation; middle–upper Pelsonian; Kustatscher et al., 2010b), in the Val di Non (upper Pelsonian; Kustatscher et al., 2012), at Recoaro (Voltzia beds, Recoaro Formation; Pelsonian; Schenk, 1868) and Piz da Peres/Passo Furcia (Richthofen Formation; lower Illyrian; Todesco et al., 2008). In addition, a macroflora of general Anisian age has been reported from the Val Duron (Kustatscher & Roghi, 2014a). Spore/pollen assemblages were reported also from the Dont Fm. at the Kühwiesenkopf/Monte Prá della Vacca (Kustatscher & Roghi, 2006), the Dont and Ambata formations in the Valle di Zoldo (Pelsonian–Illyrian; Roghi, 1995), the Marne della Val di Centa at Valsugana (Illyrian; Roghi, 1995) and from multiple stratigraphical units at Recoaro (Lower Sarl/Serla Dolomite, Gypsum Member, Gracilis Formation, Voltzia beds, Recoaro Limestone, Tretto Conglomerate; Aegean/Bithynian, Pelsonian, Illyrian; Brugman, 1986), as well as from Val Gola and a core taken at the Seceda (Buchenstein/Livinallongo Formation; Illyrian; Hochuli et al., 2015).

Ladinian palaeofloras have been described from the Meride Limestone (Fassanian) at Monte San Giorgio in Switzerland (Stockar & Kustatscher, 2010), the Fernazza Formation (lower–middle Longobardian) at Seewald (Prags/Braies; Kustatscher et al., 2004; Kustatscher & Van Konijnenburg-van Cittert, 2005) and Ritberg (Wengen/La Valle; Kustatscher et al., 2004; Kustatscher & Van Konijnenburg-van Cittert, 2005), the Wengen Formation (upper Longobardian) at Innerkohlbach, the Wengen Group ("Wengener Schichten" s.l.) at Pufels/Bulla, St. Leonhard im Abteital/S. Leonardo in Badia, Forcella Giau, Sappada, Cercena, Monte Sief, Corvo Alto, Corvara, Laste (Livinallongo), Cercenà, Sappada, Spiz Agnelessa, Schgaguler Alm/Malga Scagul and Puflatsch/Bullaccia (Kustatscher & Van Konijnenburg-van Cittert, 2005), as well as the "Caotico eterogeneo" (between Buchenstein/Livinallongo Fm. and Wengen Group) at the Monte Agnello near Tesero (Kustatscher et al. 2014b). Spore/pollen assemblages from the Ladinian are known from the Buchenstein/Livinallongo Fm. (Val Gola, the Seceda core, Aschkler, Moena, Piave di Livinallongo, Pieve di Cadore; Fassanian and Longobardian; Hochuli et al., 2015; Roghi, 1995; Van der Eem, 1983), the Wengen Group (Pordoi, Pana-Scharte/Forcella Pana; Longobardian; Van der Eem, 1983) and the "Tufi a Pachicardie" at Seis/Siusi (Longobardian; Roghi, 1995). The uppermost Ladinian is represented by spores/pollen from the Stuores Wiesen/Prati di Stuores section (GSSP section for the base of the Carnian; Wengen/La Valle and St. Cassian/San Cassiano formations; Broglio Loriga et al., 1999; Roghi, 1995; Van der Eem, 1983).

Carnian (lower Upper Triassic) palaeofloras were found at St. Kassian/San Cassiano (St. Cassian/San Cassiano Fm.; lower Carnian; Kustatscher et al. 2011), Dogna (Rio del Lago Formation; lower Carnian; Roghi et al., 2006a) and Raibl/Cave del Predil (Predil Limestone; lower Carnian; Dobruskina et al., 2001). Carnian spore/pollen assemblages have been described from the Stuores Wiesen/Prati di Stuores section (St. Cassian/San Cassiano Fm.; Broglio Loriga et al., 1999; Roghi, 1995; Van der Eem, 1983), Dogna (Roghi and Kustatscher, 2006) and from the area of Raibl/Cave del Predil (Predil, Rio del Lago, Conzen, Tor and Carnitza formations; lower and upper Carnian; Roghi, 2004). A palaeoflora from Bergamo (Monte Pora) approximately represents the boundary between lower and upper Carnian (Passoni & Van Konijnenburg-van Cittert, 2003). The Heiligkreuz/Santa Croce Formation (upper Carnian) yielded plant macrofossils and amber at the Rifugio Dibona near Cortina d'Ampezzo and at Pralongià (Lastoni di Formin; Roghi et al., 2006b). Norian (middle Upper Triassic) floras are known from the Dolomia di Forni in the Carnic Prealps and the Calcari di Zorzino in the Bergamasc Alps (Dalla Vecchia, 2000). Norian/Rhaetian spore/pollen assemblages are known from the Hauptdolomit/Dolomia Principale in the Carnian and Julian Alps (Jadoul et al., 2005).

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THE CARNIAN PLUVIAL EPISODE IN THE DOLOMITES AND NEARBY REGIONS: HISTORY OF THE RESEARCH AND PERSPECTIVES

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The Carnian Pluvial Episode (CPE) was a perturbation of the Late Triassic climate that had a strong impact on marine and terrestrial ecosystems (Fig. 1). The CPE is still a relatively neglected episode if compared to the other global ecosystem turnovers of the Mesozoic. Nevertheless, the CPE is synchronous with a major biological turnover, with both extinction among many marine and terrestrial groups and, remarkably, one of the most important evolutionary phases in the entire history of Life. The first significant radiation of dinosaurs, the spread of conifers and bennettitaleans, the first common occurrence of calcareous nannofossils, and the first reefs built by scleractinian corals all occurred during or soon after the CPE. Furthermore, the first common occurrence of amber dates to the CPE. Ammonoids and conodonts, the two most important groups for the biostratigraphy of the Triassic, were also subject to a significant turnover. Many localities in Italy had a primary role for the understanding of the CPE, and still represent benchmarks for new studies. Some of these localities are paradigmatic examples of the geological and biotic processes that were occurring during this interval of geologic time, and should be designated as geosites. While recent studies on the CPE focused on identifying the episode globally, and far from the best studied regions of Western Tethys and the European continent, the Italian CPE localities could still provide a wealth of information on this event, especially concerning the evolution of shallow marine and terrestrial groups. Indeed, a significant portion of present knowledge of the CPE derives from studies on stratigraphic sections of the Carnian of the Dolomites and nearby areas, where several sections that encompass the CPE have been described. Furthermore the Dolomites' CPE fossil association is among the most relevant at the global scale as testified for example by the presence of the oldest quantitatively important deposit of amber and the best dated archosaur ichnoassociations that recently allowed to link, for the first time, the timing of the first dinosaur diversification to the CPE. Finally, CPE-related morphologies are one of the key features that contributed significantly to shape the unique landscape of the Dolomites, recognised as a UNESCO World natural heritage site.

In this talk we will provide a review of the history of research on the CPE in the Dolomites and elaborate on some perspectives both on research and scientific dissemination aspects that might shape further projects by universities, museums, administrations and the private sector.

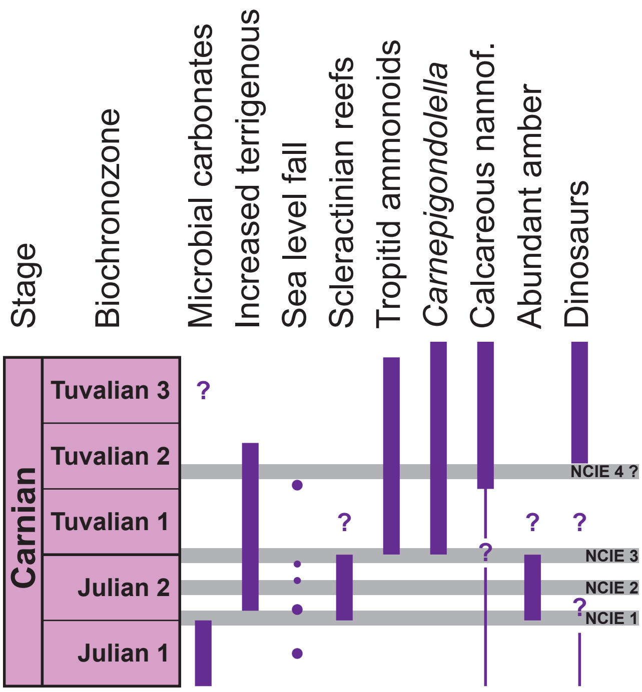

FIG. 1: A life scene from 232 million years ago, during the Carnian Pluvial Episode © Davide Bonadonna.

CONSERVATION, COMMUNICATION AND ENHANCEMENT OF THE UNESCO DOLOMITES GEOLOGY AND GEOMORPHOLOGY

→ Geological Heritage Operating Network of the UNESCO Dolomites Foundation
(Coordination) UMST Rapporti Istituzionali e Attività Legislativa, Provincia autonoma di Trento
(Technical Coordination) Servizio Geologico, Provincia autonoma di Trento
(info@dolomitiunesco.info; umst.istituzionali@provincia.tn.it; serv.geologico@provincia.tn.it)

Over the centuries, geologists have swarmed over the Dolomites making their beauty known to the world. Today the Dolomites can widen the future of science and nourish the mind and soul of everyone who experiences the magnificence of their landscape and colours. Geology has left an incredible legacy to the Dolomites and it is the origin of the landscape we can see today.
After the recognition of the Dolomites as a natural UNESCO World Heritage site in 2009, the UNESCO Dolomites Foundation has been established (www.dolomitiunesco.info) in order to improve communication and collaboration between the local authorities that manage the World Heritage site, through the definition of a common strategy for management policies of this serial property. The five operating networks are instrumental to the Foundation to implement the participatory process, planning management actions about geology, landscape and protected areas, tourism, socio-economic development and mobility, education and scientific research.
The Geological Heritage operating network of the UNESCO Dolomites Foundation is a team of provincial/regional administrations (Provincia autonoma di Bolzano, Provincia autonoma di Trento, Provincia di Belluno, Regione del Veneto, Regione autonoma Friuli Venezia Giulia), the UNESCO Dolomites Foun-

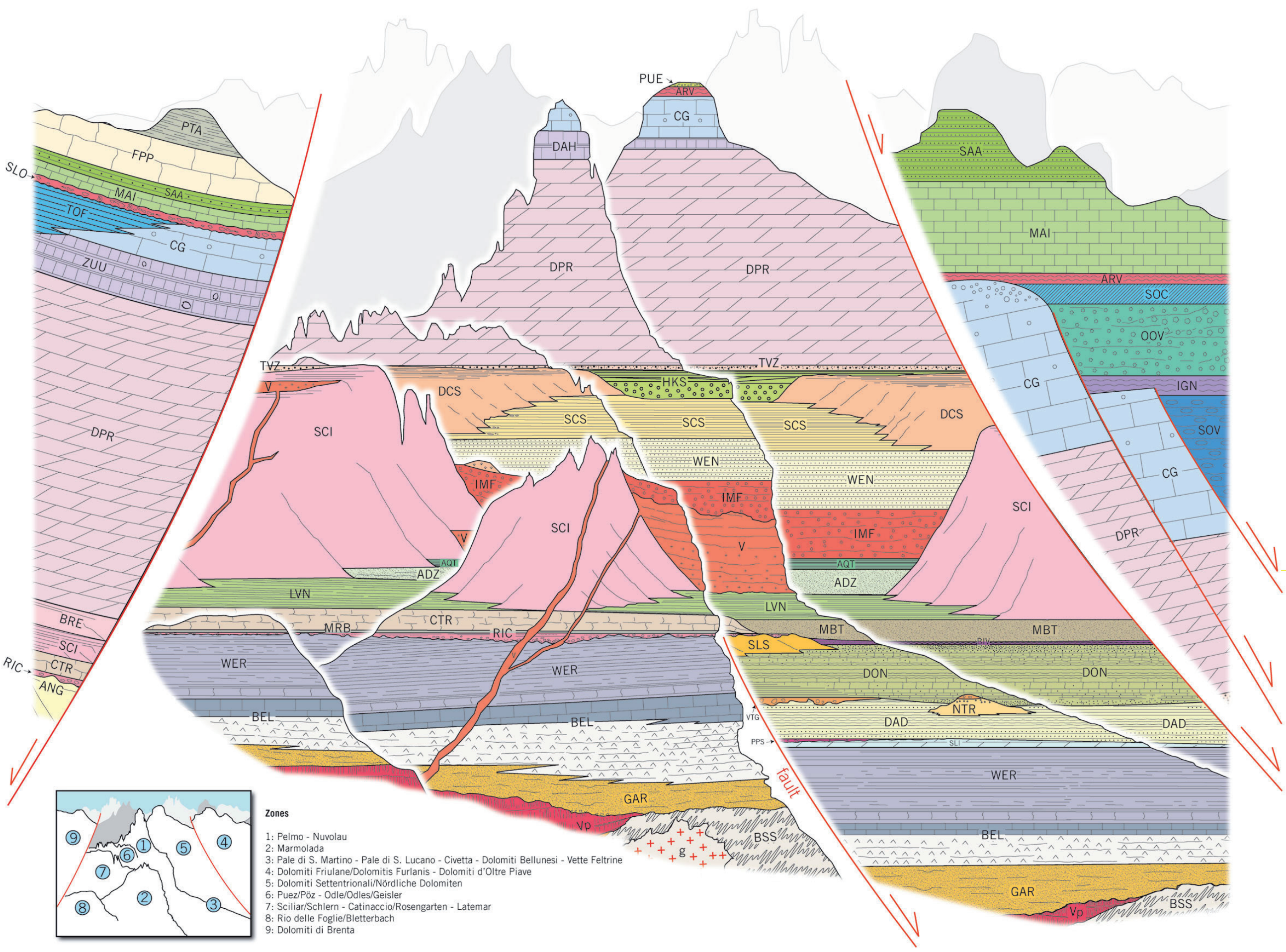

FIG. 1: Schematic stratigraphic scheme of the UNESCO Dolomites (Gianolla et al., 2009), with major structural domains (faults in red) and position of the nine systems (1–9 in the lower left inset). Geological formation codes (CARG standard and other) are shown.

dation, the MUSE of Trento, the Parco Naturale Adamello Brenta Geopark, the Parco Naturale Paneveggio Pale di San Martino, and academic departments (University of Ferrara and University of Padova) representatives. All of them have expertise in geology and geomorphology. This network is devoted to conservation, communication and enhancement of all the geological aspects of the property, implementing both long-term planning and immediate practical actions. A constant exchange of ideas, proposals and discussions is achieved through regular meetings and data sharing via dedicated repositories.
Current projects are:

1. Draft of a geological map of the UNESCO Dolomites (1:150.000 scale) to promote the geological knowledge of the Dolomites to a broad public (e.g., geo-tourists) and to different stakeholders within the dolomitic region (e.g., tourism and economic operators, scientific disseminators, professionals). The map is mostly based on recently acquired geological data (CARG standard) while the complex stratigraphy of the Dolomites (Figure 1) is represented using a specifically-designed simplified legend.

2. Identification of Dolomites UNESCO geotrails, thematic geo-touristic guides for each of the nine mountain systems of the serial property. Each guide describes in detail the individual stages of a long-distance hiking trail and its geological highlights (including illustrations, sketches, maps; Figure 2). The first guide on the South Tyrol UNESCO Dolomites has already been published (Ladurner and Morelli, 2018). At present, the work is focused on the Belluno and Brenta Dolomites.

FIG. 2: Actualistic view of the Triassic atolls of the Dolomites (on the left, Sciliar at the close up), with the position of ancient coral reef, lagoons and the deep sea.

3. Identification and cataloguing (georeferenced inventory) of the geological excellences of the UNESCO Dolomites. The selected criteria regard morphology, stratigraphy, lithology, palaeontology, mineralogy, structural geology and historical geology, with attention to landscape, environmental and cultural values.

Moreover, the Geological Heritage Operating Network is involved in dissemination activities in collaboration with other operating networks as the Education and Scientific Research network (e.g., The#FossilSeaChallenge project, now at its third edition).

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