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The pre-Variscan sequence of the Carnic Alps (Italy-Austria)

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The pre-Variscan sequence of the Carnic Alps (Italy-Austria)

90° Congresso della Società Geologica Italiana – Trieste, 13-18 settembre 2021

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Cover page Figure: Panoramic view of the eastern side of Mt Cellon/Creta di Collinetta. In the background Mt Creta di Collina/Kollinkofel (left) and Mt Gamskofel (right).

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Abstract

The pre-Variscan sequence of the Carnic Alps is exposed across the state border between north-east Italy and Austria. It includes Middle Ordovician to Lower Pennsylvanian rocks that, although affected by both Variscan and Alpine orogeny, preserve continuous and non-metamorphosed successions. Depositional settings vary from shallow water to open marine environments. Remarkable is the presence of the largest Devonian reefs of Europe, and related deposits from back reef to fore-reef and basin. The field trip is organised as a pre-congress excursion of the 90th congress of the Italian Geological Society (Trieste, September 2021) and includes three days to visit the main localities of the central sector of the Carnic Alps, focusing on various aspects of stratigraphy, palaeontology and tectonics of the sequence.

Key words

stratigraphy, tectonics, Palaeozoic, Ordovician, Silurian, Devonian, Carboniferous, North Gondwana.

Program summary

The field trip includes three days, to show most of the geology and stratigraphy of the pre-Variscan sequence of the Carnic Alps (Fig. 1). Some localities will be reached hiking on well traced paths. Panoramic geological overviews alternate to observation of sections and outcrops, in order to offer a survey of the general geological context and the different depositional settings in the area.

The first day is focused on the area around Passo di Monte Croce Carnico/Plöckenpass. From the parking at the Italian/Austrian border (1360 m) we will reach the famous Cellon section (1550 m), reference for many Silurian studies in the world, with a short walk along path 427-3. Then we will move to the Italian side of the pass, and we will hike along path 148-161 to the Val di Collina abandoned quarry (1520 m) to observe a fragment of the Middle Devonian reef. On the way back we will stop to uppermost Devonian/lowermost Carboniferous limestones cropping out along path 148. Geological overviews will be given, too.

The second day is spent hiking to the Mt Freikofel area to visit outcrops of the so called "transitional" units. Starting from the parking place at Plöcken Haus (1215 m) we will reach Passo Cavallo (1622 m) by a nice easy walk in the forest along path n. 403, 436 and the forestry road. After a panoramic stop on the eastern side of

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Mt Freikofel, we will continue along the eastern and southern slopes of the mountain along path n. 401, and we will reach the summit (1757 m) via the old military mule track. Rocks from uppermost Silurian to Upper Devonian will be shown in this sector. People suffering from vertigo may reach the top of the mountain via path 401 and 413, avoiding the military mule track.

At the summit, beside panoramic views on the geology of the surrounding mountains, it is possible to explore trenches and barracks from the First World War. Then, after visiting the Upper Devonian limestones of the Pal Grande Fm. we will continue along path 413. After a short deviation to a Lochkovian section in the Rauchkofel Fm., we will go back to the parking spot via paths 401 and 436.

The third day is devoted to the Mt Zermula area, and several stops are scheduled along the road or to visit sections reachable after short walks. Rocks of Upper Ordovician to earliest Carboniferous age will be shown, as well as a classical outcrop of the back reef "*Amphipora* limestone" (Spinotti Fm.) at Cason di Lanza Pass.

The field trip will finish in the early afternoon with a panoramic view to the Mt Zermula massif overthrust; then we will move back to Trieste.

Safety

The field trip goes along well traced paths through rough mountain terrains and reaches heights of about 1800 meters. Therefore, adequate technical personal equipment is required. Water can be found along the itinerary, but it is recommended to bring at least one litre water bottle per person. In some of the areas visited in days 2 and 3 there is no telephone coverage.

At place, the paths can be exposed (mainly the old military mule track of day 2) and are not recommended for those suffering from vertigo.

The best seasons for the visit are summer and early fall. In case of bad weather (rain, snow, thunderstorm or fog) the itinerary of day 2 is strongly discouraged. An alternative can be to visit the Carnic Alps Geopark visitors centres in Timau and Dellach (see below per addresses).

Emergency Phone numbers:
Mountain Rescue (Italy) - 112
Mountain Rescue (Austria) - 140

Hospitals

Italy – via Giobatta Morgagni 18-20, Tolmezzo. Ph. +39 0433 4881
Austria - Laas 39, 9640 Kötschach-Mauthen. Ph. +43 4715 7701

Accommodation

There are several hotels, B&B, etc. in the villages of the Carnic Alps. According to the field trip programme, it is suggested booking an accommodation in Sutrio, Paluzza, Timau (Italy) or Mauthen (Austria).

Places of interest

Geoparco delle Alpi Carniche/Karnische Alpen Geopark
Italy - https://www.geoparcoalpicarniche.org/it/
Tel: +39 0433 487726; e-mail: info@geoparcoalpicarniche.org
Visitor centre: Laghetti di Timau locality, 33026 Paluzza (UD)
Austria - Gail 65, A-9635 Dellach. http://www.geopark-karnische-alpen.at
Tel: +43 (0) 4718 / 301- 17, e-mail: office@geopark-karnische-alpen.at
Visitor centre: Gail 65, A-9635 Dellach

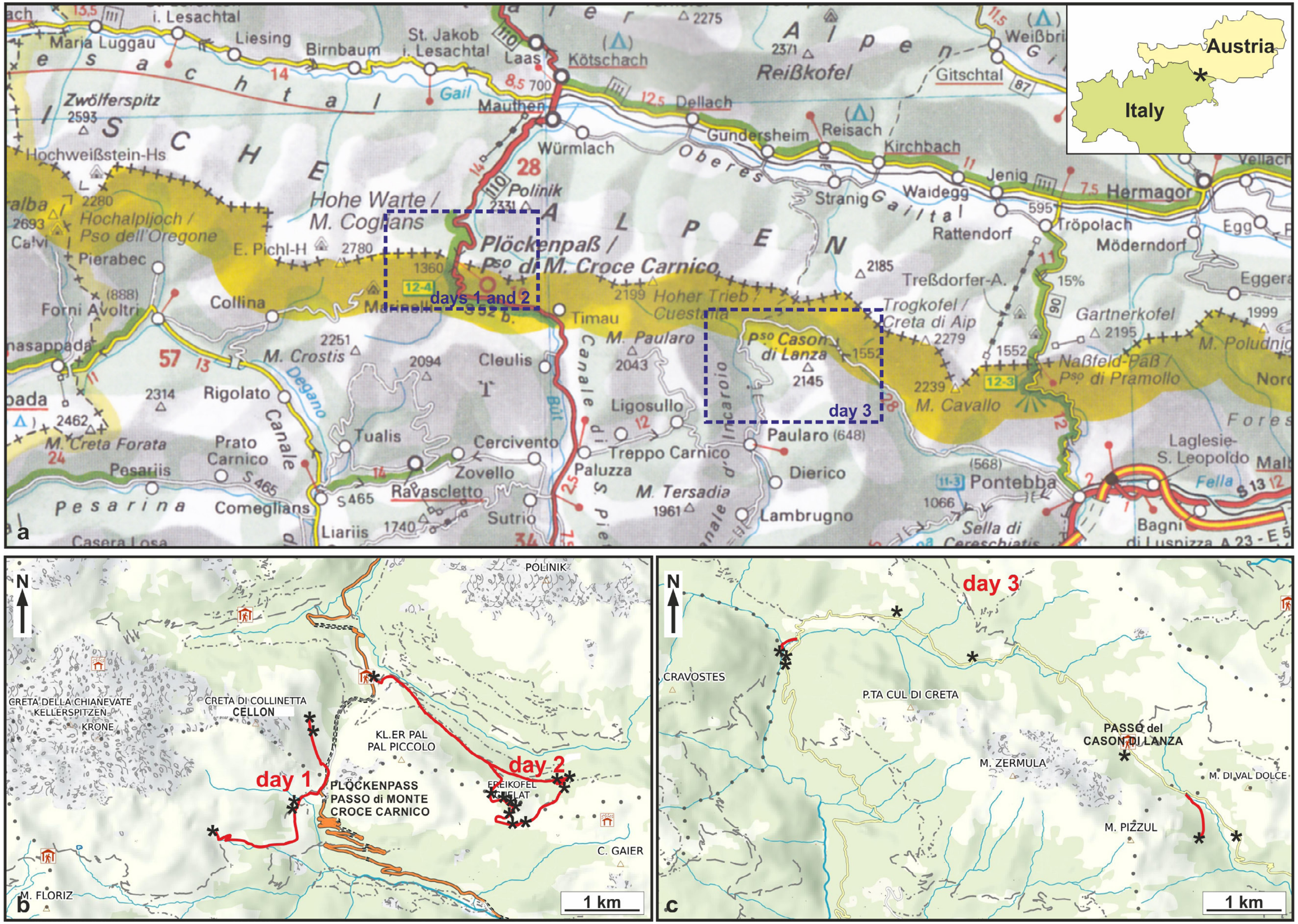

Fig. 1 - Itinerary of the field trip. a) Road map of the Carnic Alps with indication of the visited areas. b-c) Maps of the areas of Passo di Monte Croce Carnico (b) and Mt Zermula, with indication of the hiking itineraries (red lines) and stops (asterisks). For detailed maps of the three excursion days see figs 11, 20 and 34, respectively.

Introduction

Rocks deposited between the Middle Ordovician and the Upper Triassic crop out in the Carnic Alps, and represent one of the better exposed and complete Palaeozoic sequence of the world. They are subdivided into three sequences: the pre-Variscan, Permo-Carboniferous and Alpine sequences. The pre-Variscan sequence includes rocks of Middle Ordovician to Early Pennsylvanian age, which were affected by the Variscan orogeny during the late Bashkirian and Moscovian (Schönlaub, 1980; Venturini, 1990; Schönlaub and Forke, 2007; Pasquarè Mariotto and Venturini, 2019). The Permo-Carboniferous sequence ranges from the late Carboniferous to the middle Permian. The youngest Palaeozoic rocks of the Carnic Alps are dated to the late Permian and represent the lower part of the so-called "Alpine" sequence (Venturini, 1990).

The pre-Variscan sequence is part of the Variscan ancient core of the Eastern Alps in the Southalpine domain, and extends as a narrow strip for more than 100 km in a W-E direction, with a N-S width that rarely exceeds 15 km (Fig. 2). To the North it is bordered by the Gailtail Line, part of the Periadriatic Lineament, separating the Austroalpine domain from the Southalpine domain; towards the S it is unconformably covered by upper Palaeozoic and Triassic successions (Venturini and Spalletta, 1998; Schönlaub and Forke, 2007). The cropping out area can be subdivided into two parts (Fig. 2), separated by the Val Bordaglia thrust (Brime et al., 2008), a prominent NE-SW trending fault: the western zone is made of greenschist facies metamorphic rocks, the eastern zone mainly consists of non- to low-metamorphic sedimentary successions (Schönlaub, 1980, 1985,

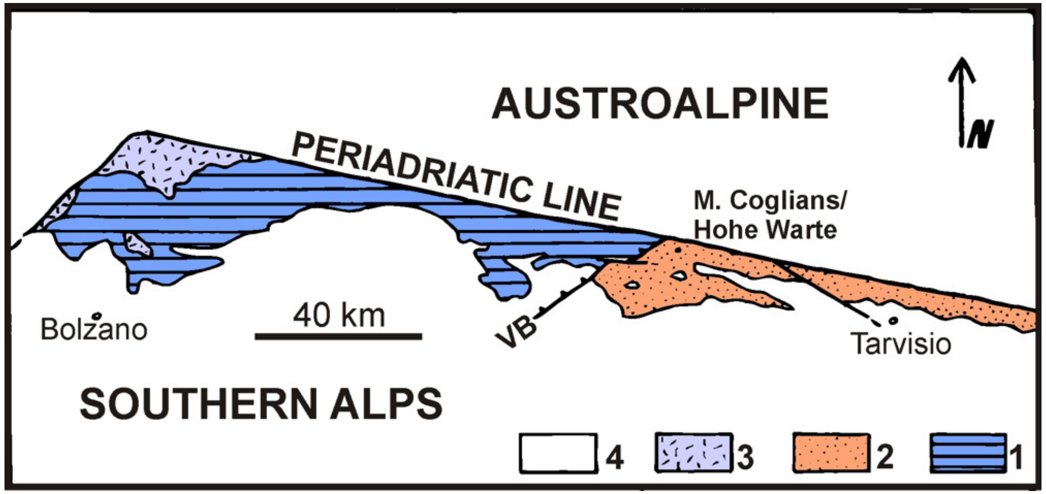

Fig. 2 - Simplified geological map of the Southern Alps showing the partition of the Palaeocarnic Chain into a West and an East Zone (after Venturini and Spalletta, 1998, modified). VB: Val Bordaglia thrust; 1: low- to middle-grade metamorphic basement; 2: non- to anchi-metamorphic units; 3: Variscan intrusive bodies; 4: post-Palaeozoic units.

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1997; Venturini and Spalletta, 1998; Brime et al., 2008) except for the northernmost part where banded limestones occur.

Tectonic overview

The Carnic Alps underwent compressional as well as extensional deformational events during Variscan and Alpine orogenies, which originated a complex structural framework including some low-metamorphic terrains (Fig. 3) (Brime et al., 2008; Bartel et al., 2014). According to Brime et al. (2008), during Variscan times, anchizonal conditions predominated although epizonal conditions were reached mainly in the northernmost part of the belt. The thermal peak was reached due to an extensional regime during the Bashkirian. During the Alpine orogeny, the thermal overprint reached up to high diagenetic–anchizonal conditions.
According to Venturini (1990) and Pasquarè Mariotto and Venturini (2019), Variscan compression originated roughly N120°E trending top to the south thrusts and folds. Anticlinal structures at the kilometric scale formed as a result of fault propagation and are probably the most prominent structures visible in the area. After an extensional phase that controlled the deposition of the Permo-Carboniferous sequence, the first Alpine compression of Chattian-Burdigalian age was coaxial with the Variscan one, thus reactivating the older structures and enhancing their shortening (Venturini, 1990; Pasquarè Mariotto and Venturini, 2019). The two more recent Alpine events (Tortonian-Serravallian and Plio-Pleistocene respectively) depicted a strike-slip stress regime also with some compressional and extensional features (Venturini, 1990; Pasquarè Mariotto and Venturini, 2019). Particularly, several N90°-120°E trending structures originated as compressional during the Variscan and Chattian-Burdigalian phases, were reactivated as dextral strike-slip faults. During these last Alpine events, multi-kilometer-scale vertical folding formed along the strike-slip Gailtal and Bordaglia lines.

Palaeogeographic overview

During the early Palaeozoic the Carnic Alps belong to a group of terranes that detached from the northern Gondwana margin during the Ordovician, and moved northward faster than the main continent (Fig. 4). These terrains include the Barrandian, Sardinia, Montagne Noire and the Pyrenees, among others, and are known as Galatian terrane assemblage (von Raumer and Stampfli, 2008). However, the mutual position of these terrains during the middle Palaeozoic, is still unclear.

The drift from about 50°S in the Late Ordovician, to 35°S in the Silurian and to tropical belt in the Devonian (Schönlaub, 1992) is reflected in evident litho- and biofacies differences along the Carnic Alps.

The pre-Variscan sequence

Rocks from the Middle Ordovician to the Lower Pennsylvanian that were affected by the Variscan orogeny during the late Bashkirian and Moscovian (Venturini, 1990, Schönlaub and Forke, 2007) constitute the so-called

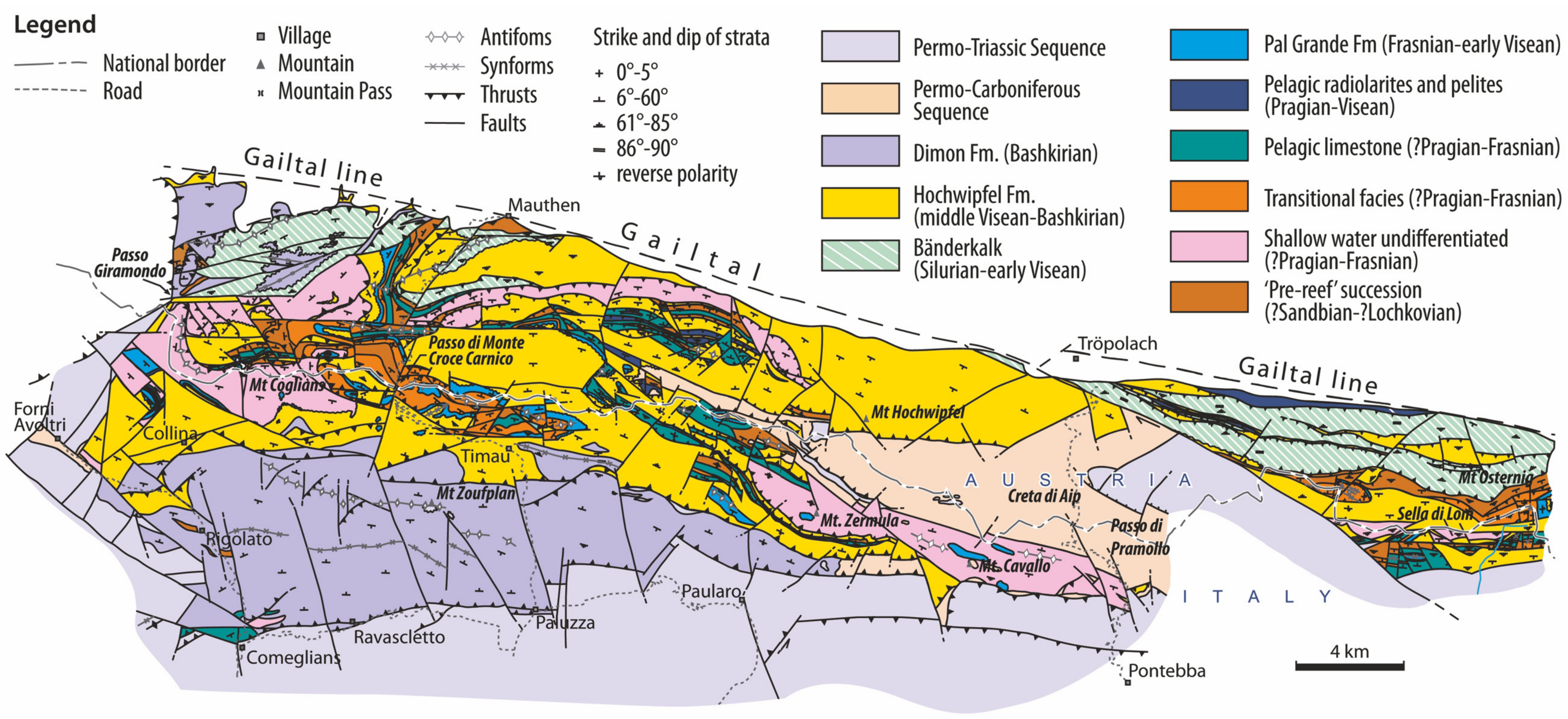

Fig. 3 - Sketch of the geology of the Carnic Alps (after Brime et al., 2008, simplified).

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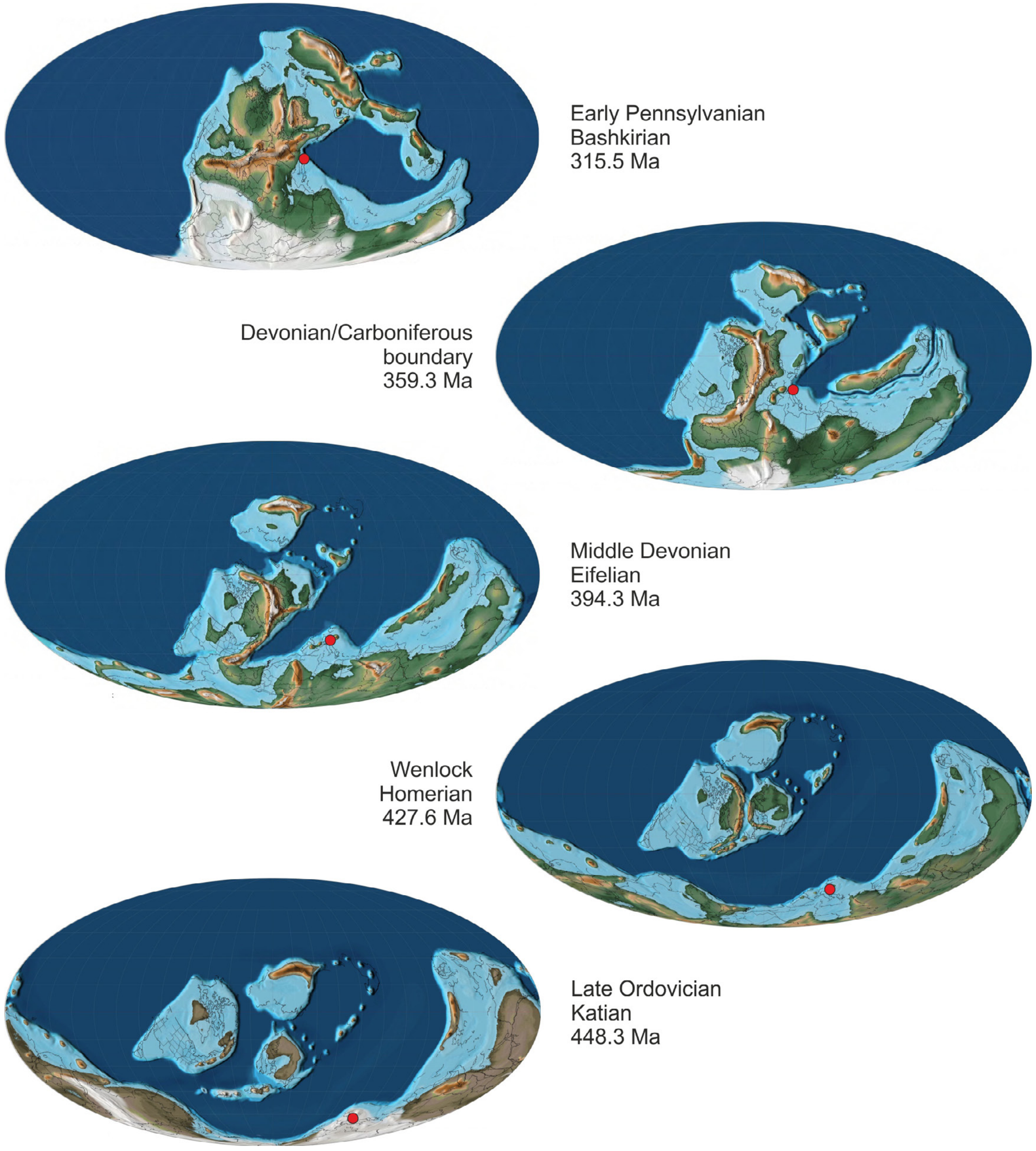

Fig. 4 - Palaeogeographic position of the Carnic Alps (red circle) from the Ordovician to the lower Carboniferous (maps after Scotese, 2014 a, b, c modified).

pre-Variscan sequence. The lithostratigraphy of this sequence was recently revised and 36 formations were finally discriminated in the pre-Variscan sequence of the Carnic Alps (Corradini and Suttner, 2015) (Fig. 5).

The oldest rocks of the Carnic Alps are Middle Ordovician in age and crop out west of the Val Bordaglia Line. They are represented by phyllitic schists and quartzites, with subordinate conglomeratic layers (Val Visdende Fm.), followed by “porphyroids” (Comelico Fm.) and volcano-clastic sediments (Fleons Fm.).

With the exception of rare fossil occurrences in the Fleons Fm., the oldest fossiliferous rocks of the Carnic Alps belong to the Valbertad Fm. (Katian). They are represented by up to 100 m of shallow-water pelites, sandstones and rare conglomerates deposited at medium-high southern latitudes. Fossils, mainly bryozoans, brachiopods, echinoderms, trilobites and gastropods, are abundant. In the central part of the basin a coarser grained sandstone unit (Himmelberg Fm.) crops out. The basal clastic sequence is followed by an encrinitic parautochthonous limestone (Wolayer Fm.) in the central part of the chain and by the coeval slightly-deeper-water limestones of the Uqua Fm. Both these units are late Katian in age, even though an extension to the basal Hirnantian cannot be excluded. The global glacially-induced regression of the Hirnantian is documented by

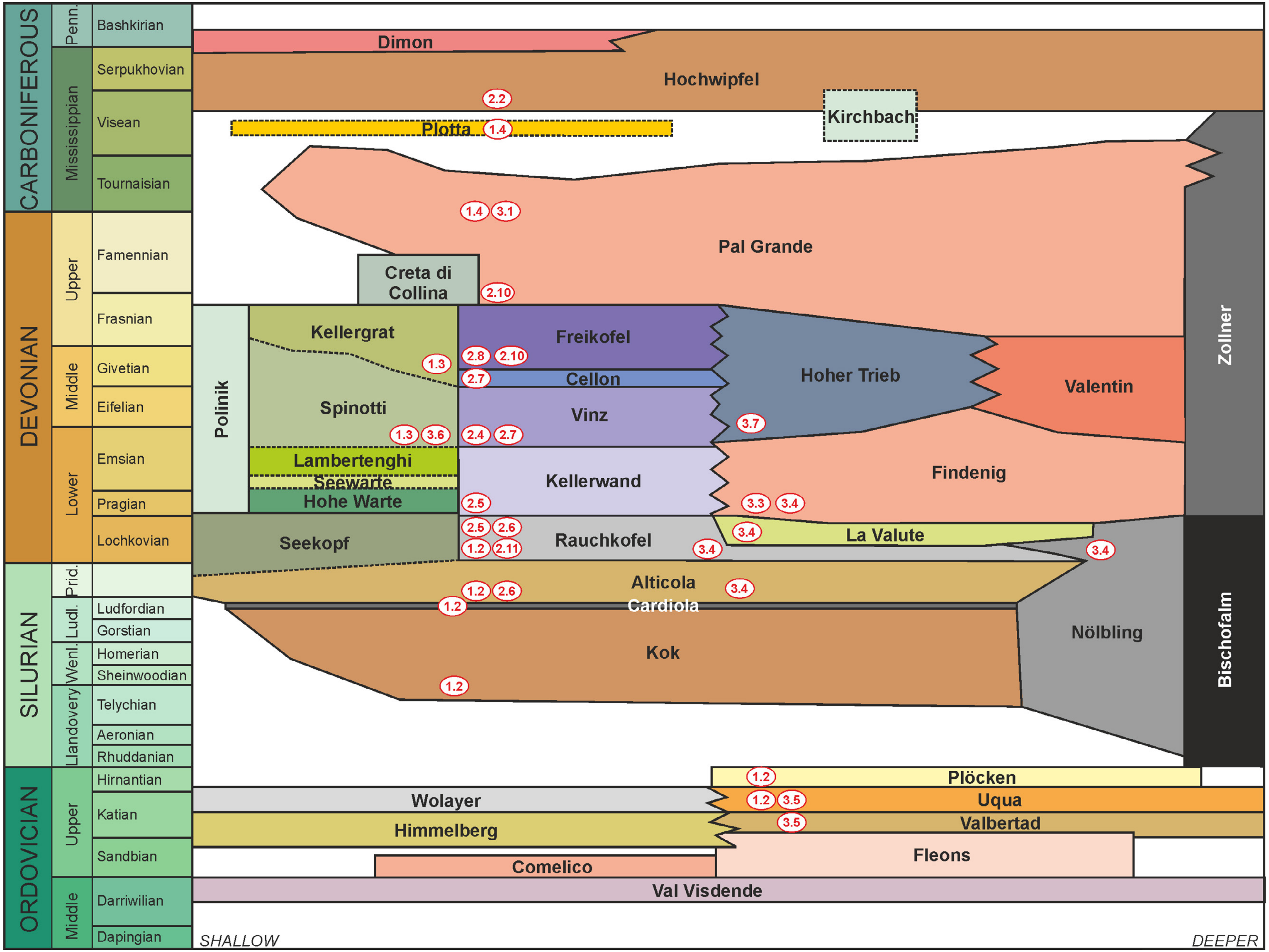

Fig. 5 - Lithostratigraphic scheme of the pre-Variscan sequence of the Carnic Alps (after Corradini et al., 2015c, modified). Red numbers indicate the stops where the formations will be observed.

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the calcareous sandstone of the Plöcken Fm., providing evidence of the Hirnantian Carbon Isotope Excursion (HICE) $\delta^{13}C$ excursion (Schönlaub et al., 2011). The regression generated erosion and local non-deposition, as also indicated by Silurian strata resting disconformably above the Upper Ordovician sequence (Schönlaub and Histon, 1999; Brett et al., 2009; Hammarlund et al., 2012; Pondrelli et al., 2015; Corriga et al., 2021).

Silurian rocks vary from shallow water bioclastic limestones to nautiloid-bearing limestones, interbedded shales and limestones to outer-shelf or basinal black graptolitic shales and cherts (“lydites”). The overall thickness does not exceed 60 m. The Silurian transgression started at the base of the Llandovery, and, due to the disconformity separating Ordovician and Silurian strata, a hiatus extending at place up to the Ludlow is documented (Fig. 6). For a summary refer to Corriga et al. (2021).

Three calcareous units are vertically developed in the proximal parts of the basin: the Kok Fm. (Telychian-lower Ludfordian), the Cardiola Fm. (Ludfordian) and the Alticola Fm. (upper Ludfordian-basal Lochkovian). These units mostly correspond to the “*Orthoceras* limestones” of earlier authors, and are represented by bioclastic wackestones-packstones. Fossils, mainly orthoconic cephalopods, are abundant; trilobites, bivalves and conodonts are common; crinoids, gastropods and more rare ostracods, brachiopods and chitinozoans are present as well (Brett et al., 2009; Corradini et al., 2010, 2015a; Histon, 2012); ferruginous ooids were reported by Ferretti (2005). In the deeper part of the basin, the Bischofalm Fm., consisting of black graptolitic shales, with chert interbedded at place, was deposited. Graptolites are generally abundant (Jaeger, 1975; Jaeger and Schönlaub, 1977, 1994; Schönlaub, 1997).

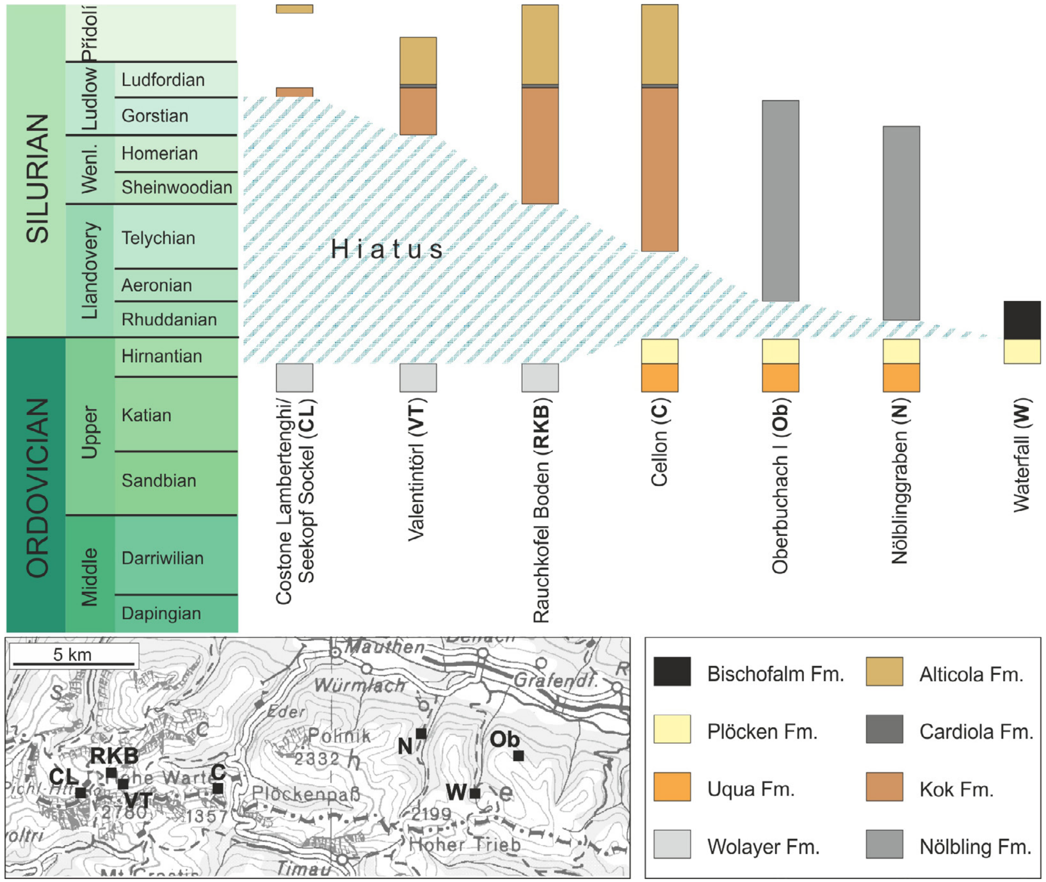

Fig. 6 – Stratigraphic range of the main sections spanning the Ordovician-Silurian boundary in the Carnic Alps, highlighting the hiatus between the two systems in the Carnic Alps (after Corriga et al., 2021, modified).

Intermediate sedimentary conditions between calcareous and shaly facies are represented by the Nölbling Fm., composed of alternating black graptolitic shales, marl and limestone beds (Jaeger and Schönlaub, 1980; Schönlaub, 1997).

During the Lochkovian (Early Devonian) in the Carnic basin the calcareous part of the succession started to differentiate more noticeably (Kreutzer, 1990, 1992; Schönlaub, 1992; Kreutzer et al., 1997; Suttner, 2007; Corriga et al., 2012, Corradini et al., 2019a). The Seekopf Fm. was deposited in moderately shallow water, and the Rauchkofel Fm. and La Valute Fm. on the outer platform. In the deeper parts of the basin the Nölbling Fm. and the Bischofalm Fm. continued up to the top of the stage (*M. hercynicus* graptolite Zone). Eustatic variations at the Lochkovian/Pragian boundary resulted in an unconformity between the Rauchkofel and the Kellerwand formations (Pondrelli et al., 2020).

Starting from the Pragian, the differences within the sedimentary basin increased: "the Devonian Period is characterized by abundant shelly fossils, varying carbonate thicknesses, reef development and interfingering facies ranging from near-shore sediments to carbonate buildups, lagoonal and slope deposits, condensed pelagic cephalopod limestones to deep oceanic off-shore shales" (Schönlaub and Histon, 1999, p. 15). From the Pragian to the early Frasnian, within short distances a strongly varying facies pattern developed, indicating highly diverse depths in the basin (Fig. 7). More than 1000 m of reef and near-reef limestones (Hohe Warte Fm., Seewarte Fm., Lambertenghi Fm., Spinotti Fm., Kellergrat Fm.) and various intertidal lagoonal deposits (Polinik Fm.) are time equivalent to less than 100 m of pelagic limestones (Findenig Fm. and Valentin Fm.). In the intermediate fore-reef areas thick piles of mainly gravity-driven deposits accumulated (Kellerwand Fm., Vinz Fm., Cellon Fm., Freikofel Fm.); the thickness of these units decreases from west to east in the Central sector of the Carnic Alps (Fig. 8), according to the distance from the

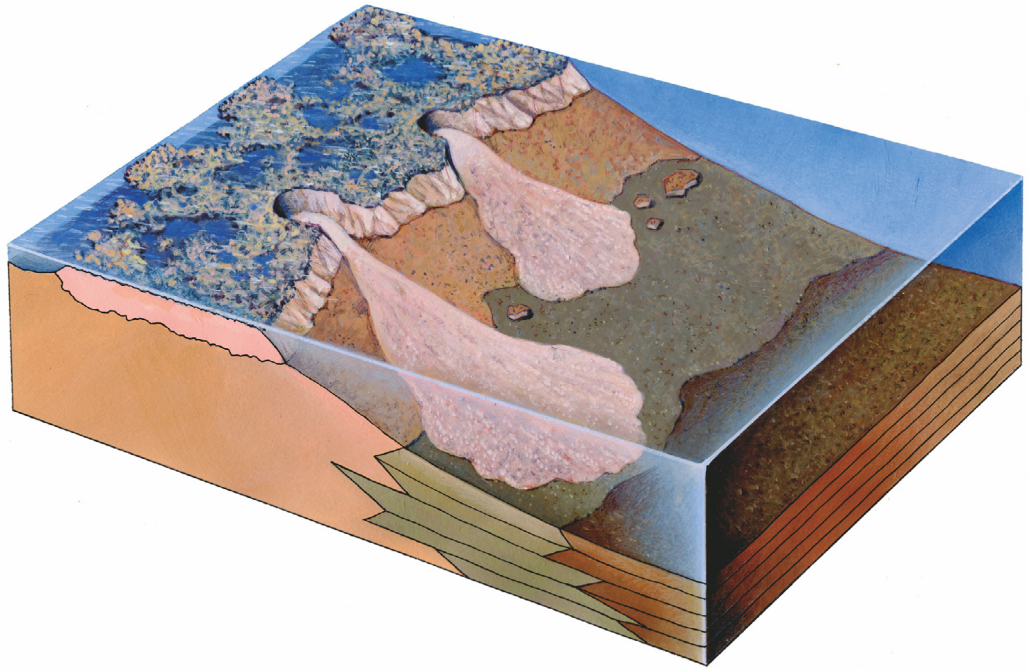

Fig. 7 – Block diagram of the depositional settings of the Middle Devonian of the Carnic Alps.

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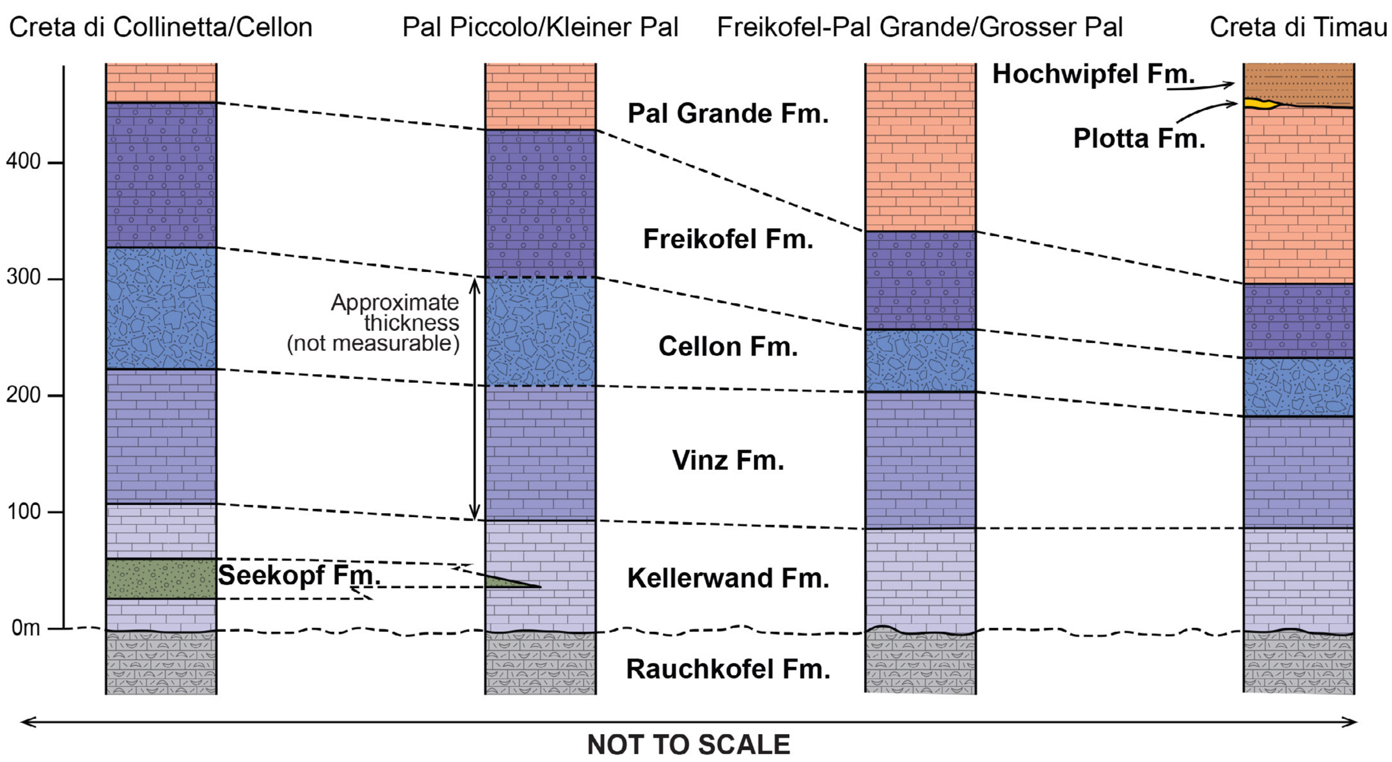

Fig. 8 – Thickness of the "transitional units" in the central part of the Carnic Alps (after Pondrelli et al., 2020, modified).

main source area (Pondrelli et al., 2020). Between the fore-reef and the deeper part of the basin the gravity-driven deposits alternated with pelagic limestones and black shales (Hoher Trieb Fm.). Pelites and cherts were deposited in the deeper part of the basin (Zollner Fm.).

Reefs reached their maximum extension during the Givetian and early Frasnian, when the current Carnic Alps were located at a latitude of about 30° S (Schönlaub, 1992). Four major reef areas developed, now represented by the cliffs of Mt Coglians/Hohe Warte, Mt Zermula, Mt Cavallo/Roßkofel and Mt Sagran, beside several minor buildups. The fossil content (Fig. 9) is always very high: stromatoporoids, tabulate and rugose corals, crinoids, brachiopods, gastropods, bivalves, ostracods, cephalopods, trilobites, algae, calcispheres, and foraminifers (Kreutzer, 1990, 1992; Kreutzer et al., 1997; Schönlaub, 1992; Rantitsch, 1992; Corradini et al., 2019b).

Starting from the early Frasnian, the basin was subjected to a combination of extensional tectonic activity and eustatic fluctuations, which combined effects caused reefs extinctions. From the late Frasnian (upper *rhenana* conodont Zone) a uniform pelagic environment developed, which continued up to the early Visean (Schönlaub, 1969; Schönlaub and Kreutzer, 1993; Perri and Spalletta, 1998c; Corradini et al., 2017): the Pal Grande Fm. is represented by a greyish, pinkish, reddish wackestone with cephalopods. At places cherty sediments (Plotta Fm.) unconformably capped the Pal Grande Fm. indicating at least one paleokarstic event in the early Carboniferous

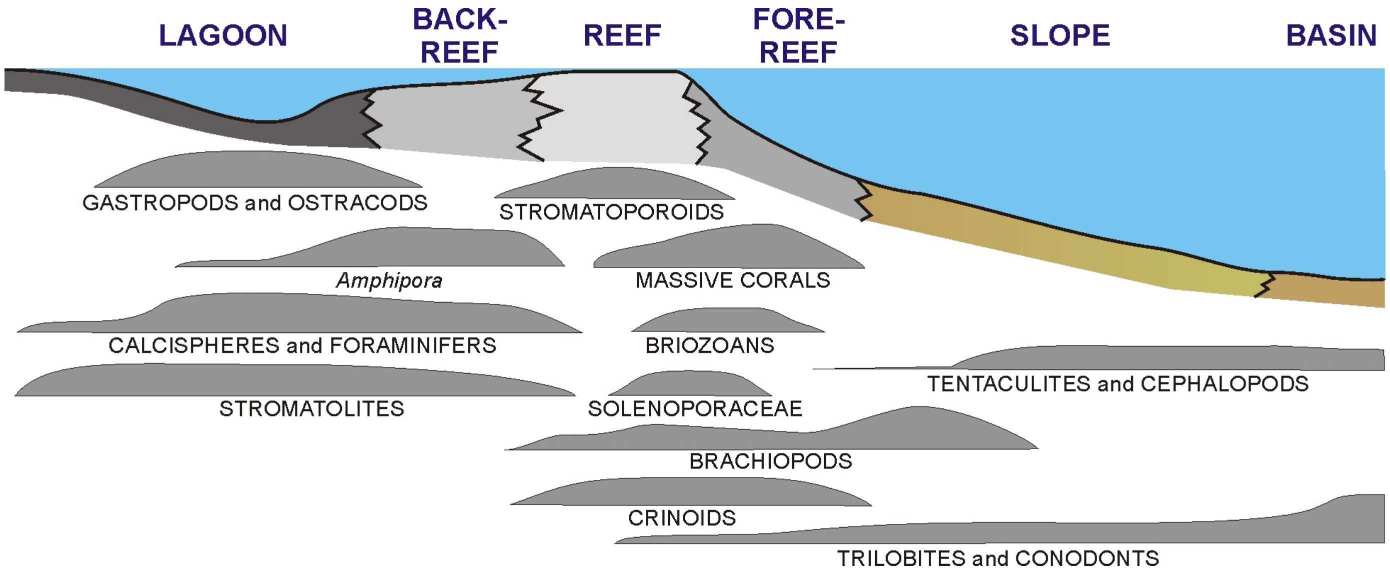

Fig. 9 – The distribution of main fossil groups in the Devonian of the Carnic Alps (after Vai, 1998, modified).

(Schönlaub et al., 1991; Pondrelli et al., 2015; Corradini et al., 2017). Starting from the late Visean, up to 1000 m of arenaceous pelitic turbidites of the Hochwipfel Fm. were deposited. It is interpreted as a Variscan Flysch sequence (Vai, 1963; Amerom et al., 1984; Spalletta and Venturini, 1988 and references therein). These deposits indicate a Variscan active plate margin in a collisional regime following the extensional tectonics during the Devonian and the early Carboniferous (Vai, 1976). The Hochwipfel Fm. consists of quartz-sandstones and greyish shales, turbidites, with intercalations of mudstones, chaotic debris flows, chert and limestone breccias. At place, plant remains and rare trace fossils are present (Amerom et al., 1984; Amerom and Schönlaub, 1992). Short local episodes of carbonatic deposition from the late Visean to the earliest Serpukhovian are represented by the Kirchbach Fm. In the upper part of the early Carboniferous, the basic volcanites and volcanoclastic deposits of the Dimon Fm. occur, and are widely exposed in the south-central part of the chain. They are related to crustal thinning associated to a rifting episode (Vai, 1976; Rossi and Vai, 1986; Läufer et al., 1993, 2001). These conditions continued up to the late Bashkirian (Pennsylvanian), when the Variscan orogeny in the Carnic area marked the end of the deposition of the pre-Variscan sequence (Venturini, 1991).

The Variscan orogeny and the post-Variscan rocks

The Variscan orogeny had its climax during the Moscovian and affected the pre-Variscan sequence, producing different systems of asymmetric folds, faults and thrusts distributed along a N 120°-140°E direction (Venturini, 1990).

The uplift of the Paleocarnic chain generated an erosional-depositional sedimentary hiatus. In places (Forni Avoltri, Pramollo and Tarvisio sectors), this gap lasted until the latest Moscovian, when, due to the subsidence related a to strike-slip tectonic system, the Permo-Carboniferous sequence deposited in disconformity on top of the pre-Variscan sequence. The Permo-Carboniferous sequence consists of alternating cycles of fluvio-deltaic and marine deposits, caused by frequent eustatic sea level changes due to the Permo-Carboniferous glaciation. Different lithostratigraphic (Fig. 10) schemes have been established by Italian (Venturini, 1990) and Austrian authors (Forke et al., 2006; Schönlaub and Forke, 2007).

The sequence starts with basal breccias and conglomerates, resulting from the erosion of the Paleocarnic Chain. These Basal Conglomerates (attributed to the Bombaso Fm. by Venturini, 1990) are overlaid by sediments subjected to frequent transgressive-regressive cycles, with alternating fluvio-deltaic clastic sediments and calcareous shallow water deposits. Within this succession different authors discriminate five formations belonging to the Pramollo Group (Venturini, 1990), or several members within the Auernig Fm. (Forke et al., 2006; Schönlaub and Forke, 2007).

Across the Carboniferous-Permian boundary and in the lower Permian, calcareous facies are dominant; the three formations (Schulterkofel Fm., Val Dolce Fm. and Zweikofel Fm.), grouped in the Rattendorf Group (Venturini, 1990) indicate a general transgression with more stable marine conditions. The transgressive trend continues throughout the lower Permian, and ends up with the Trogkofel Group (Venturini, 1990) (Trogkofel Fm. according to Forke et al., 2006), characterised by reefs up to 400 metres thick.

Within the middle Permian, a transpressional tectonic phase causes extensive emersion and karstification. In the late Permian an extensional phase starts, controlling the deposition of a sequence of continental ruditic deposits (Tarvisio Breccia and Sesto Conglomerates) followed by marine to terrigenous deposits (Val Gardena Sandstones), and finally evaporitic, lagoonal and shallow marine water (*Bellerophon* Fm.). This sequence was deposited in an environment characterised by alluvial fans deposits (Tarvisio Breccia and Sesto Conglomerates), alternating with alluvial plains with irregular braided rivers, which deposited a thick sequence of pelites and sandstones (Val Gardena Sandstones). The *Bellerophon* Fm., marking the end of the Carnic Palaeozoic, indicates a slow rise in sea level, and is characterised by gypsum, graywackes and evaporitic dolostone in the lower part of the succession and by dolostone and black limestone in the upper part.

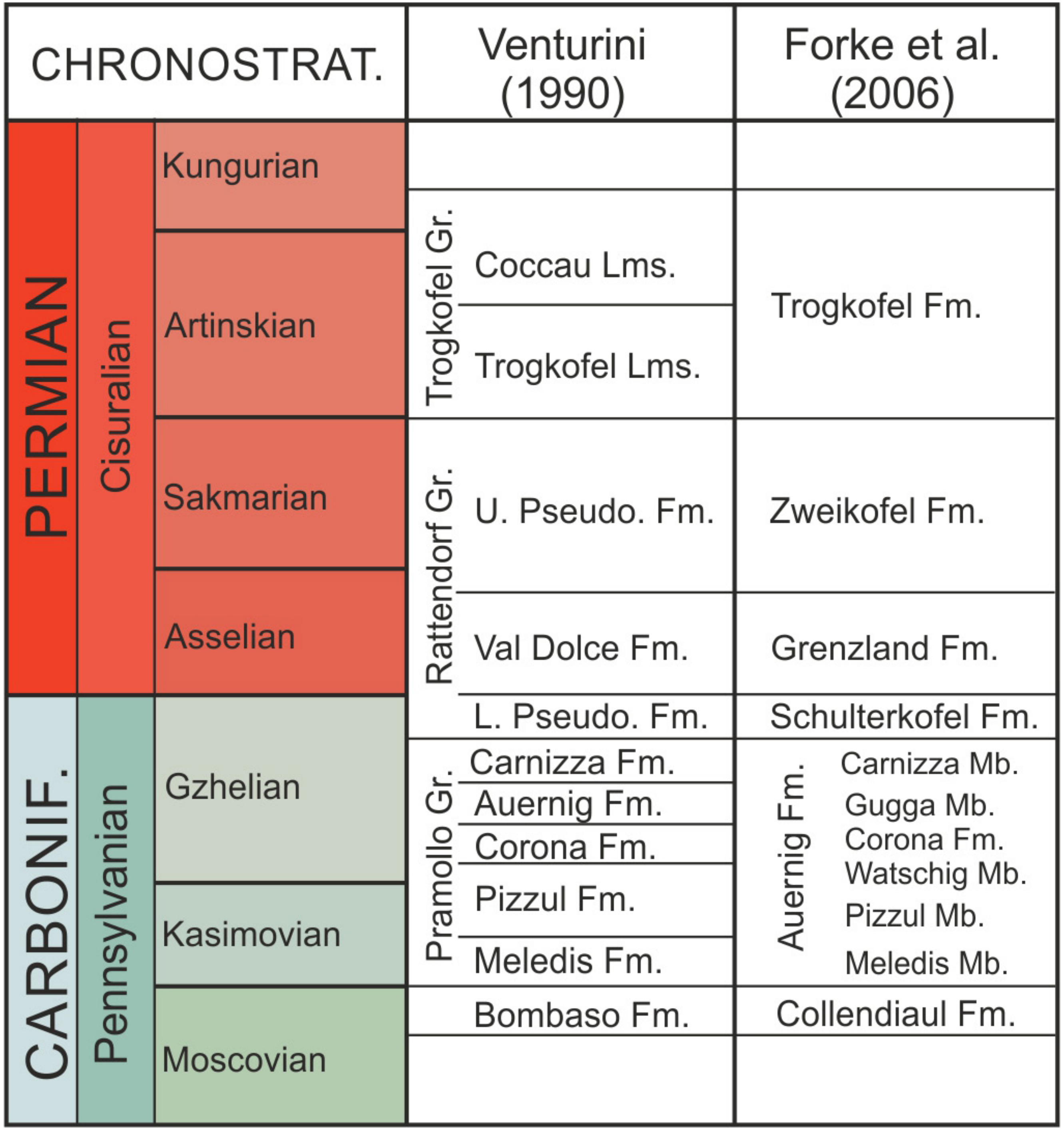

Fig. 10 - Lithostratigraphic scheme of the Permo-Carboniferous sequence of the Carnic Alps. The Italian (Venturini, 1990) and Austrian (Forke et al., 2006) schemes are compared. Age calibration after Forke et al. (2006).

Day 1

The first excursion day is devoted to the area around Passo di Monte Croce Carnico (Fig. 11), that is is a deep pass in the central Carnic Alps between Creta di Collinetta/Cellon to the west, and Pal Piccolo to the east (Fig. 12). The pass, that now is the main connection between Italy and Austria in the central Carnic Alps, was the scene of heavy fighting during World War I, as evidenced by fortifications, trenches, galleries still observable in the surrounding mountains.

This area shows a prominent lateral transition between different environmental settings developed in correspondence of the Devonian "syn-reef" succession. A NW trending fault of presumable Variscan age, rejuvenated in Alpine times first as a compressional structure (Tortonian-Serravallian) and then as a dextral strike-slip (Plio-Pleistocene), borders the southern limit of the Creta di Collinetta/Cellon mountain right to the south-west of Passo di Monte Croce Carnico/Plöckenpass (Fig. 13). This fault puts in contact a shallow water Middle Devonian to Frasnian succession (to the southwest of the fault) with the lateral correspondent slope succession. Both successions are covered by the "post-reef" Famennian-Visean Pal Grande Fm. and then by the disconformable siliciclastics of the Hochwipfel Fm.

The terrains located southwest of the fault form a southeast-dipping (roughly 35°-40°) monocline while to the northeast of the fault a north-verging fold is present, originated by progradation on a south-dipping, north verging thrust.

The shallow water succession in this area consists of the Middle Devonian to Frasnian Kellergrat and Spinotti formations, representing reefal and lagoonal deposits, respectively. These units are locally covered by the brachiopods bearing Frasnian-Famennian Creta di Collina Fm. which grades upward to the Pal Grande Fm., while elsewhere they are disconformably covered by the Pal Grande Fm. To the northeast of the fault, the Middle Devonian to Frasnian succession consists of alternating gravity-driven and pelagic deposits, respectively reflecting phases of high and low reef productivity. The highest reef production appears to be reached during topmost Eifelian and Givetian times.

Stop 1.1 – Panoramic view on Pal Piccolo
Coordinates: 46°36’30.6” N, 12°56’32.2” E. Altitude 1510 m

Pal Piccolo represents an anticline at the plurikilometric scale of Variscan age (Venturini, 1990), later shortened by a south-dipping north verging thrust and a north-dipping south verging inverse fault (Pondrelli et al., 2020)

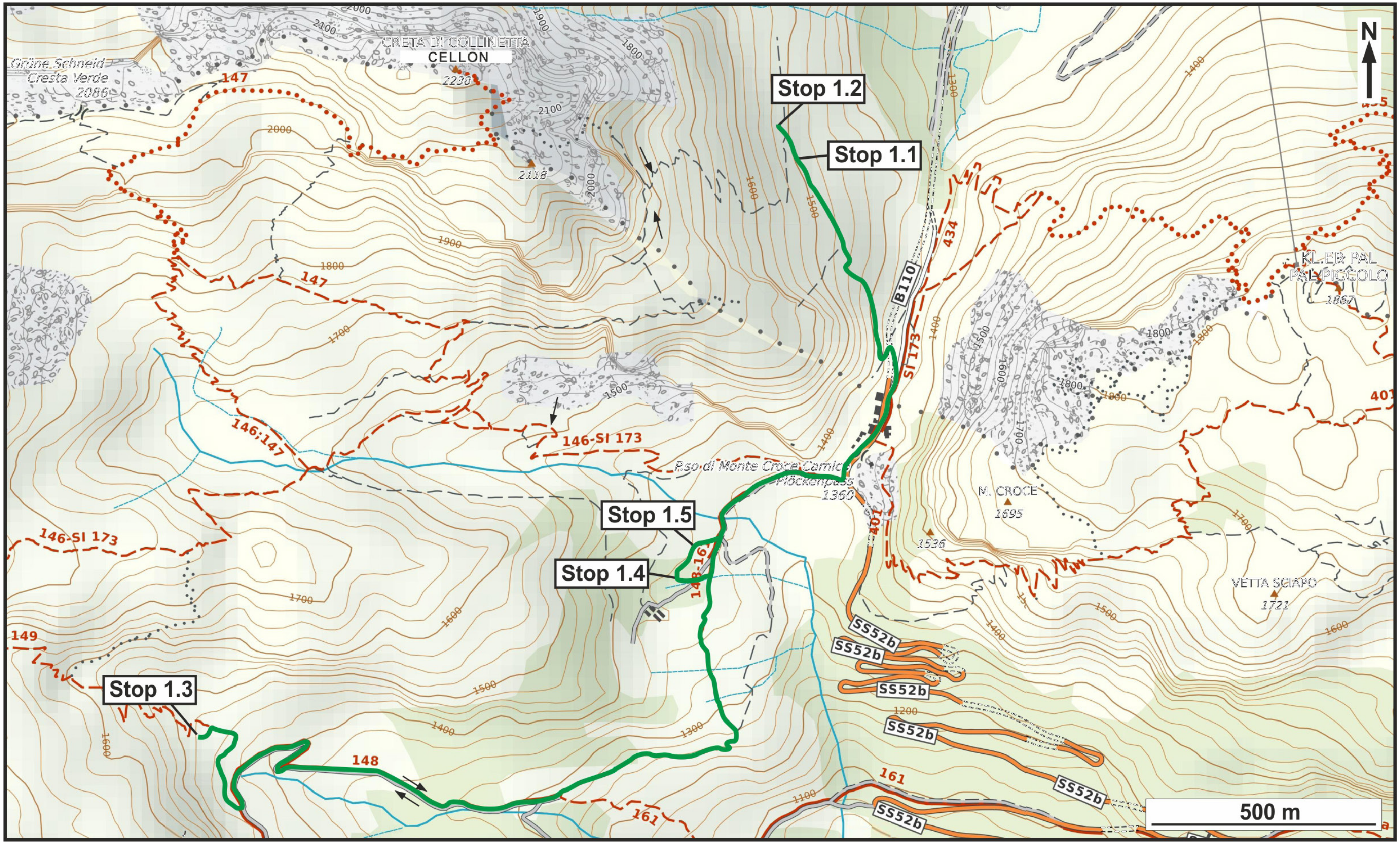

Fig. 11 – Topographical map of the itinerary of day 1.

(Fig. 14). Here the Devonian part of the succession consist of slope and basinal alternating deposits reflecting the development (and dismissal) of the platform succession in the shallower parts of the basin. Due to the combining effects of the compressive structures affecting the anticline, some units are very extensively exposed (e.g., Freikofel and Pal Grande formations) and other barely visible or absent (e.g., Vinz and Cellon formations). The core of the anticline shows the top of the Alticola Fm. followed by the Rachkofel and Kellerwand formations.

Fig. 12 – Panoramic view to the north of Passo di Monte Croce Carnico.

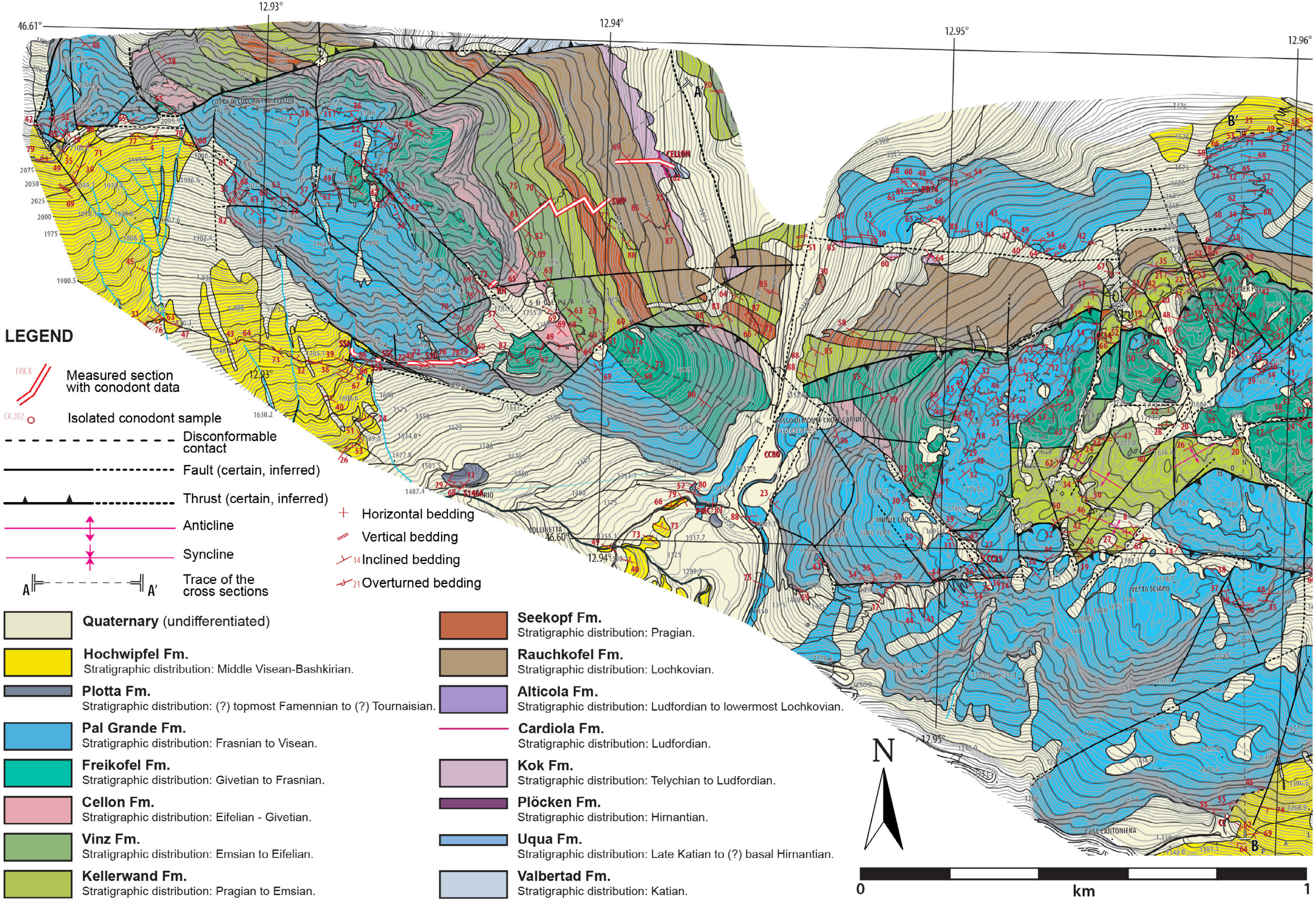

Fig. 13 – Geological map of the Passo di Monte Croce Carnico area (after Pondrelli et al., 2020, modified).

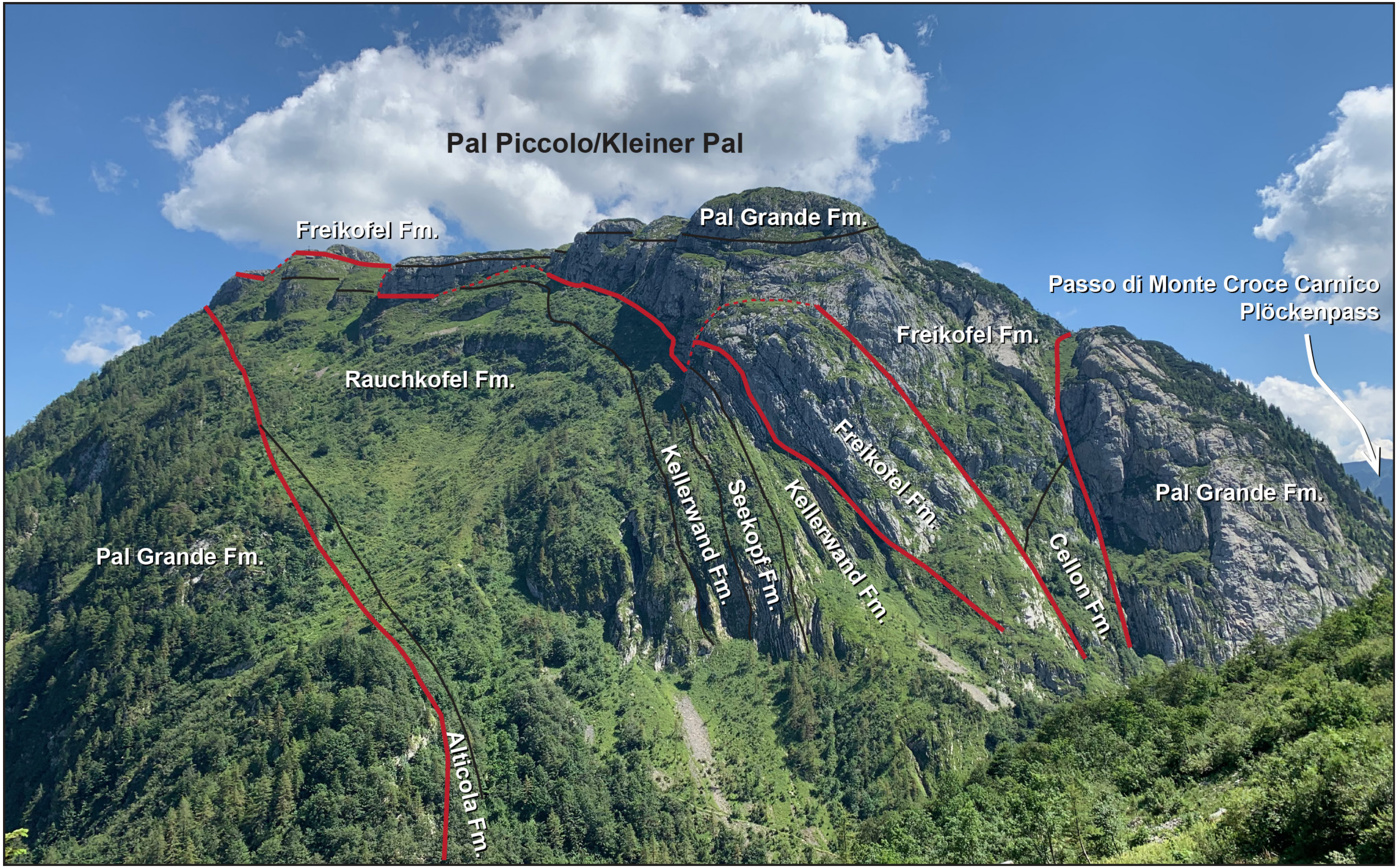

Fig. 14 – Panoramic view of the western flank of Mt Pal Piccolo, with indication of the lithostratigraphic units and the main structural features.

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The lower part of this succession is cut by the north-dipping fault located in the northernmost part of the mountain, that put in contact the Alticola Fm. with the Pal Grande Fm. Moving to the south, the upper part of the succession is cut by the north-dipping fault. The hangingwall shows a limited extension of the Cellon Fm. and then the Freikofel and Pal Grande formations that reach the top of the mountain.

Stop 1.2 – Cellon section
Coordinates: 46°36’32.2” N, 12°56’31.4” E. Altitude 1520 m

The Cellon section is located in a narrow avalanche gorge on the eastern flank of Mt Cellon, close to the Austrian/Italian border (Fig. 15). It is probably the most famous Silurian section in the world, and is the reference section for studies on Ordovician, Silurian and Lower Devonian. The section is known since 1894, when Geyer (1894) first described the rock succession exposed here. The conodont fauna was studied and described by Walliser (1957, 1964), whose pioneering work on the section included the first proposed Silurian conodont zonation for the world (Walliser, 1964). Subsequent studies on the Cellon section deal on several fossil groups (acritarchs, bivalves, brachiopods, chitinozoans, cephalopods, corals, foraminifers, graptolites, ostracods and trilobites), microfacies, isotopes, taphonomic and palaeoenvironmental indicators and eustatic sea-level changes. A precise biostratigraphy has been provided thanks of the rich conodont fauna by Walliser (1964), Ferretti and Schönlaub (2001), Corradini et al. (2015a) and Corriga et al. (2016). The Cellon section is the stratotype of five formations: Uqua Fm. (Schönlaub and Ferretti, 2015a), Plöcken Fm. (Schönlaub and Ferretti, 2015b), Kok Fm. (Ferretti et al., 2015a), Cardiola Fm. (Ferretti et al., 2015b) and Alticola Fm. (Ferretti et al., 2015c). For a complete review of the previous studies on the Cellon section refer to Corradini et al. (2015a).

The section exposes rocks from the Upper Ordovician to the Lower Devonian (Figs. 15-16). However, although the conformable sequence suggests continuity of sedimentation, several small gaps have been recognised, reflecting eustatic sea level changes in an overall shelf water environment (Schönlaub et al., 1994).

Seven formations are exposed in the Cellon section (from base to top) (Figs. 15-16).

The Valbertad Fm. is poorly exposed, below the base of the measured section, and is at least 15 m thick. It consists of greenish and greyish siltstones and shales. Age: Katian, based on the occurrence of the deep-water *Foliomena* brachiopod fauna (Harper et al., 2009).

The Uqua Fm. occur from bed 1 to 5, and is about 5 m thick. The unit consists of greyish to brownish flaser limestone of Katian age, *Amorphognathus ordovicicus* conodont Zone.

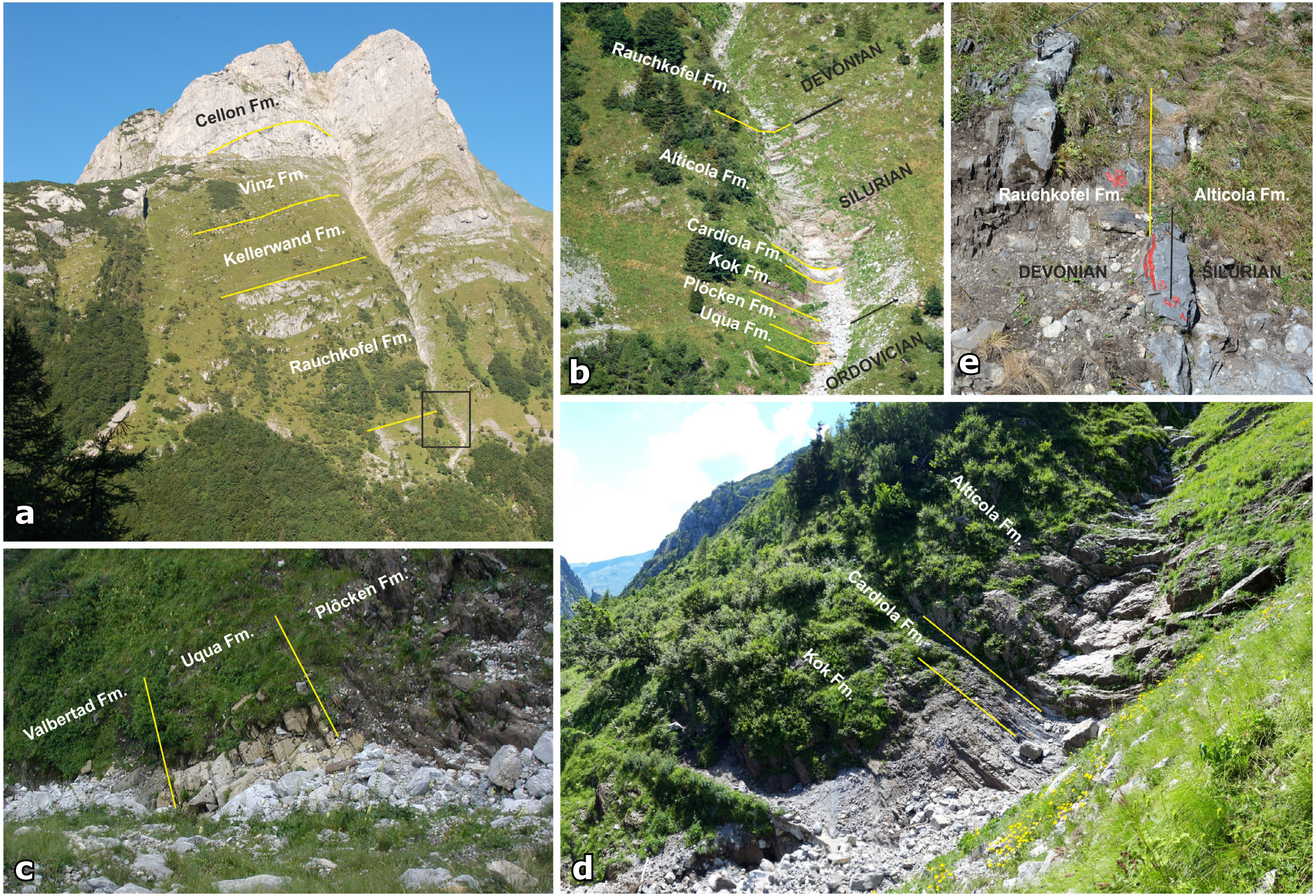


Fig. 15 – Views of the the Cellon section. a) Panoramic view to the west of Mt Creta di Collinetta/Cellon with indication of the lithostratigraphic units; the box indicates the area enlarged in b. b) Detail of the units in the Cellon Section. c) The Ordovician part of the Cellon section. d) The Silurian part of the section. e) Detail of the Silurian/Devonian boundary.

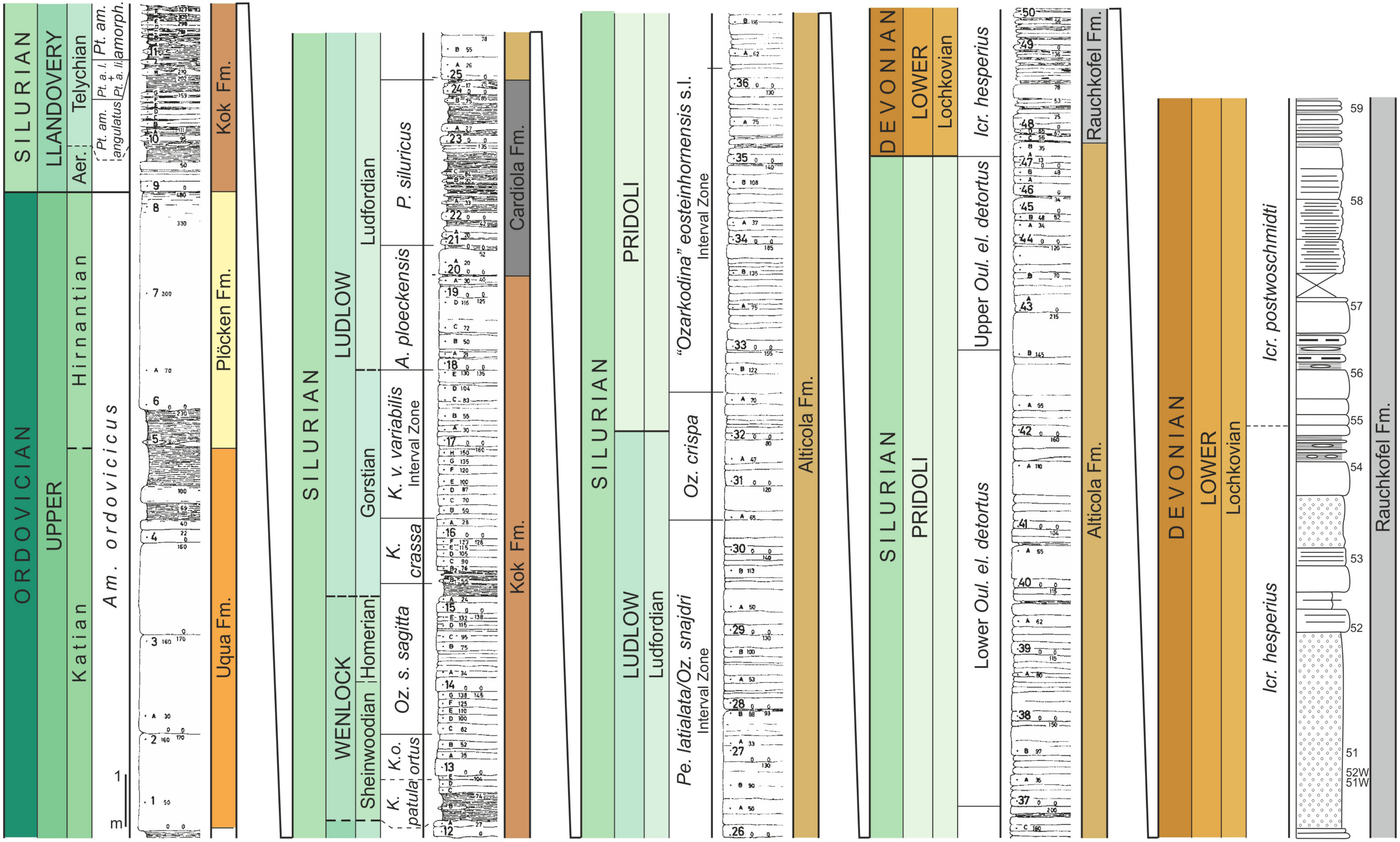


Fig. 16 – Stratigraphic log of the Cellon section. Log and sample numbers after Walliser (1964) and Corriga et al. (2016). Chrono-, litho- and conodont bio-stratigraphy after Corradini et al. (2015a) and Corriga et al. (2016).

The Plöcken Fm. is a greyish siltstone intercalating with impure bioclastic limestone at the base and grading into calcareous pyritic limestone and sandstone higher in the section. It is exposed in beds 6-8, and is 6.2 m thick. The lowermost strata suggest a diamictite origin, while the upper part displays contorted deformation structures, slumping, channel fillings and interbeds of fossil debris. The Plöcken Fm. is dated to the Hirnantian thanks to brachiopods and graptolites documented at the base of the unit (Jaeger et al., 1975). A carbonate-δ13C excursion corresponding with the Hirnantian Carbon Isotope Excursion (HICE, Bergström et al., 2009) prominent peak at the Katian/Hirnantian boundary has been documented (Schönlaub et al., 2011).

The Kok Fm. is represented by well bedded highly fossiliferous brownish ferruginous cephalopod limestone, at the base alternating with black shale and marly interbeds. The thickness is 13.5 m (beds 9-19). The age spans from Telychian to Ludfordian, *Pterospathodus celloni* to *Ancoradella ploeckensis* conodont zones.

The Cardiola Fm. (beds 20-24A) is a characteristic 3.5 m thick horizon of dark gray to black limestone with marly and shaly interbeds, deposited in a short interval of the Ludfordian, *A. ploeckensis* to *Polygnathoides siluricus* conodont zones. The unit approximately corresponds to the Lau Event (Jeppsson et al., 2012), one of the major extinction events of the Silurian. A hardground occurs at the top of the unit, marking a hiatus between the Cardiola and the overlying Alticola formations.

The Alticola Fm. is about 28 m thick (beds 25-47B). It consists of gray to pinkish cephalopod limestone with some thin marly layers and coarse bioclastic interbeds. The age spans from Ludfordian to earliest Lochkovian, *Pedavis latialata–Ozarkodina snajdri* IZ to *Icriodus hesperius* conodont zone. The Silurian/Devonian boundary is placed in the uppermost part of the formation at the bedding plane between samples 47A and 47B, where the first occurrence of the index conodont *Icriodus hesperius* is documented.

The Rauchkofel Fm. (beds 47C-59 and above) is a blackish platy and laminated limestone with black marly and shaly interbeds, with calcarenitic beds, more frequent in the upper part. The thickness of the unit at Mt Cellon is about 150 m, but only the lower 16.5 m were studied in the Cellon section, before a steep wall made impossible further sampling. Conodonts and graptolites (Walliser, 1964; Jaeger, 1975; Corriga et al., 2016) indicate a Lochkovian age, *Icriodus hesperius – Icriodus postwoschmidti* conodont zones.

Higher in the mountain, the Kellerwand, Vinz and Cellon formations are exposed (Fig. 15a).

Several chronostratigraphic boundaries can be traced in the Cellon section. For detail see Fig. 16. and refer to Corradini et al. (2015a, b).

Stop 1.3 – Val di Collina Quarry

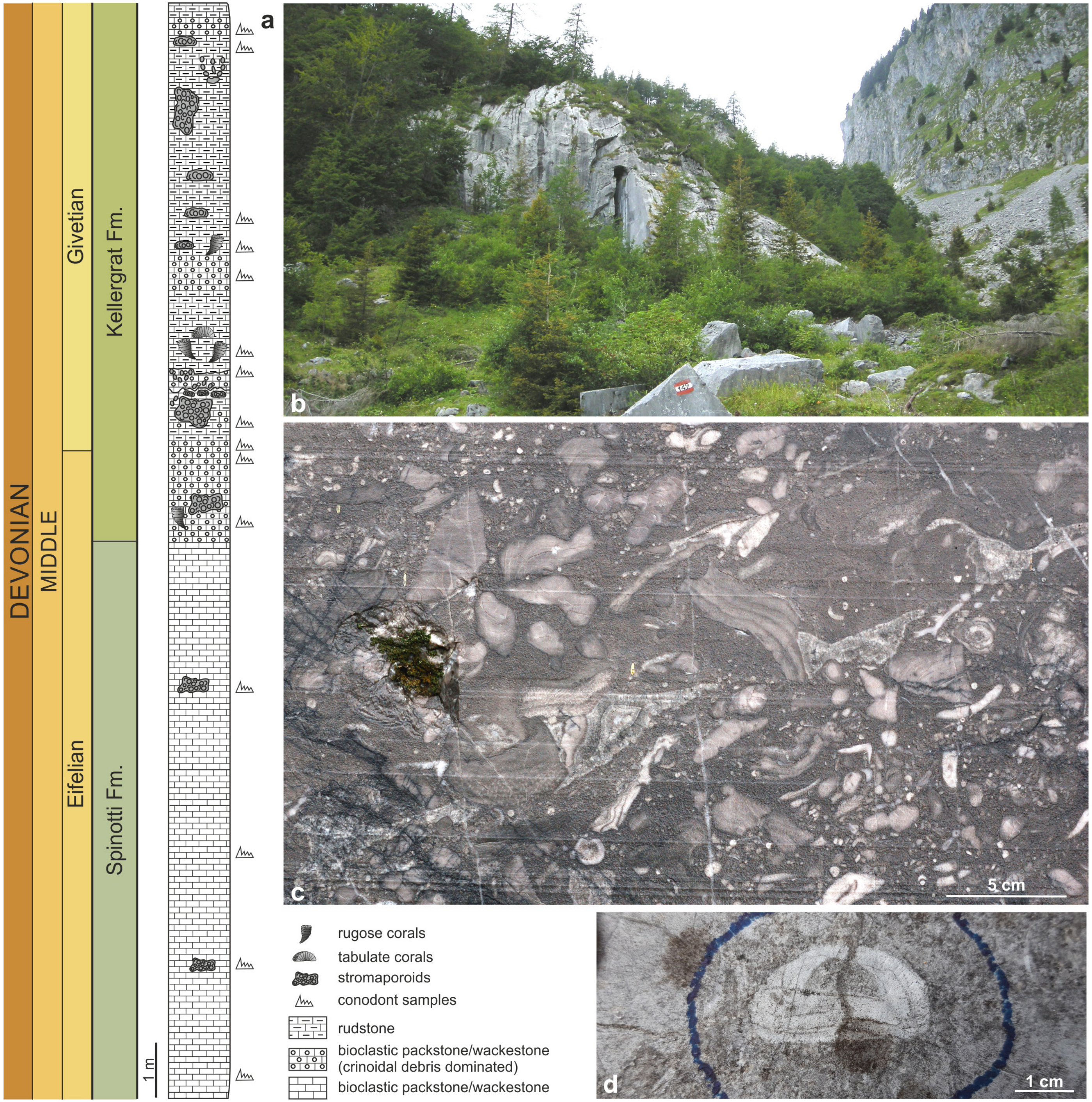
Coordinates: 46°35’47.4” N, 12°55’32.6” E. Altitude 1520 m

Val di Collina quarry is located along trail 149 via Rifugio Marinelli to Collina, approximately 1.5 km southwest of Passo di Croce Carnico/Plöckenpass, on the southeastern slope of Mt Coglians/Hohe Warte massif (Fig. 17). Within the quarry area several large cubed boulders (once cut for commercial use) with a size between 2 to 15 m^2 can be found. Due to plain orthogonal sectional surfaces three-dimensional views on depositional phases are provided (Fig. 17b-c). Although the area was mentioned by several authors (e.g., Hubmann et al., 2003; Schönlaub et al., 2004; Kido et al., 2015; Suttner et al., 2017b; Corradini et al., 2019b) detailed palaeontological studies are ongoing. Deposits include layers of reef debris and large stromatoporoids belonging to the Kellergrat Fm. Below the coral-rich reef debris, bright grey limestones of the uppermost part of the Spinotti Fm. are cropping out in the quarry area. The age of the section is ascribed to the Middle Devonian by conodonts assemblages, that include species diagnostic for the *Polygnathus ensensis* and *Polygnathus hemiansatus* biozones (Suttner et al., 2017b).
The reef debris consists of a diverse fauna including stromatoporids, rugose (e.g., *Dendrostella*, *Neospongophyllum*, *Solipetra*, *Alaiophyllum* and *Phillipsastrea*) and tabulate corals (e.g., *Favosites*, *Alveolites*, *Thamnopora*, *Heliolites*), bryozoans, ostracods and brachiopods. The sedimentary succession shows stromatoporoid/coral-breccia layers alternating with fine crinoidal debris layers.

Stop 1.4 – Casera Collinetta di Sotto section

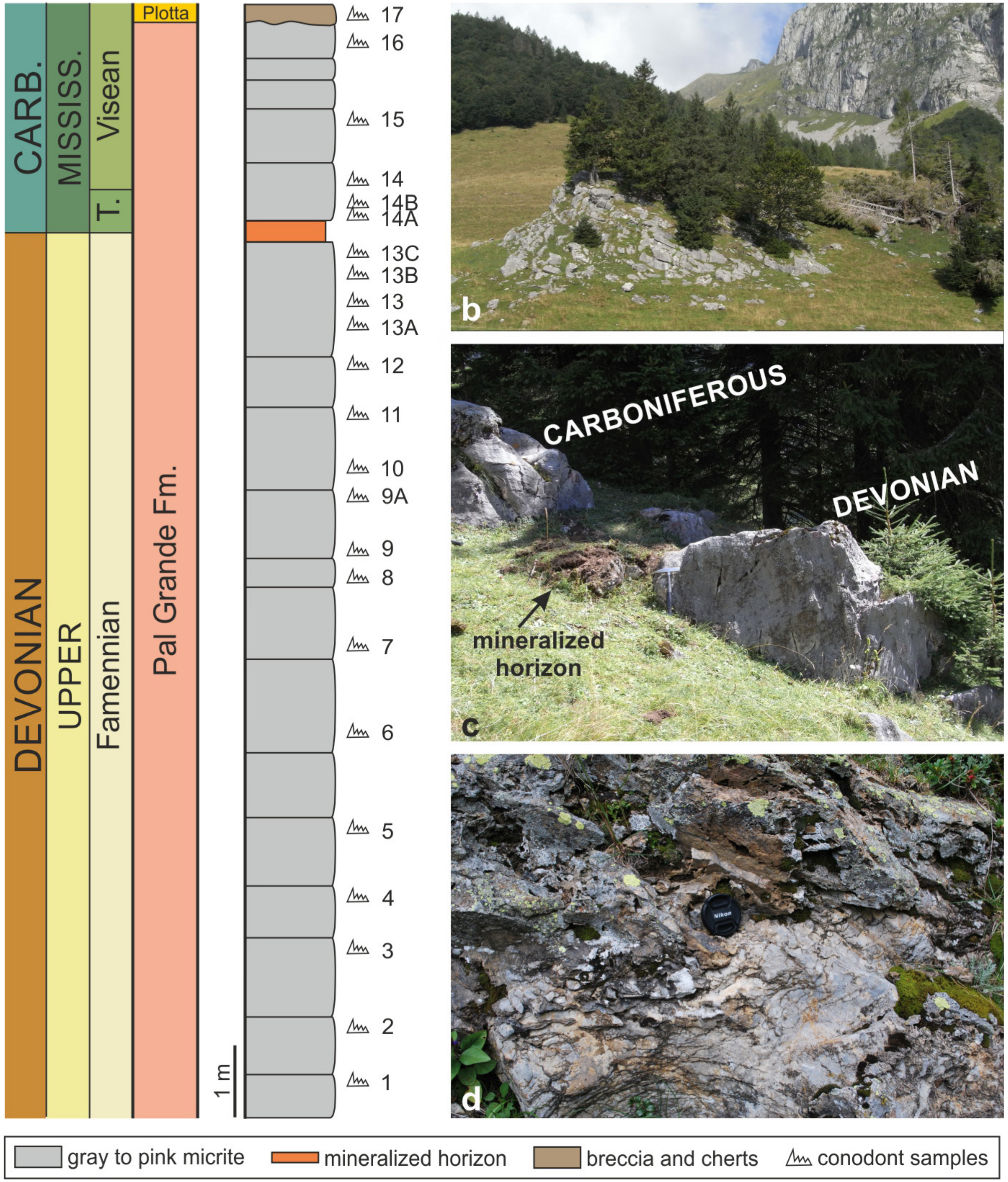
Coordinates: 46°36’00.4” N, 12°56’21.3” E. Altitude 1375 m

The “Casera Collinetta di Sotto A” section is located about 100 m NE of the eponymous hut, and 500 m SW of Monte Croce Carnico Pass. About 15 m of the grey to pinkish micritic limestones of the Pal Grande Fm. are here exposed, unconformably capped by a silcrete level attributed to the Plotta Fm.
The limestone sedimentation is interrupted after 12.3 m by a 30 cm thick mineralised horizon (Fig. 18 c) and is then resumed with other 2.7 m of micritic limestone, which are in turn unconformably capped by the chert and breccia of the Plotta Fm. The Devonian part is represented by well bedded wackestone with remains of brachiopods, ammonoids, trilobites and ostracods; a level with stromatoporoids is present between samples 3 and 4. The Carboniferous part consists of a wackestone/packstone rich in goniatites, trilobites, brachiopods, ostracods and rare crinoids.



A detailed biostratigraphy was provided by Perri and Spalletta (1998b) thanks to rich conodont fauna, showing a large hiatus in correspondence of the mineralised horizon: the lower part is referred to the middle to uppermost Famennian *Pseudopolygnathus granulosus* to *Bispathodus ultimus* Zone, whereas the first level above (sample 14A) contain conodonts of the upper Tournaisian *Scaliognathus anchoralis* Zone (Perri and Spalletta, 1998b). It results that the top of the Famennian and most of the Tournaisian are missing in the carbonate succession, with a hiatus of at least 10 Ma. Mineralogical and geochemical studies with the goal to obtain information on the origin of the missing sedimentary

Fig. 17 – The Val di Collina quarry section. a) Stratigraphic log (after Suttner et al., 2017b). b) Panoramic view to the west of the quarry. c) Surface of a large blocks of reef-debris limestones formatted for commercial purpose. d) The rugose coral *Calceola sandalina*.



interval are in progress. The upper part of the section is attributed to the Visean *Gnathodus texanus* Zone.

Stop 1.5 – Panoramic view on the southern slope of Mt Creta di Collinetta *Coordinates*: 46°36’02.0” N, 12°56’23.4” E. Altitude 1370 m

The calcareous massif of the Creta di Collinetta (Fig. 19) is fault-bounded to the south by an almost vertical dextral strike slip structure of Tortonian-Serravalian or Plio-Pleistocene age, that most probably reactivated older, possibly Variscan, compressive structures (Venturini, 1990). This fault separates the Devonian reef and reef-related successions (although here only the lower Carboniferous Hochwipfel Fm. is visible) with the slope to basin successions, that are represented in the Creta di Collinetta mountain. From this perspective view, only

Fig. 18 – The Casera Collinetta di Sotto A section (CSA). a) Stratigraphic log. b) Panoramic view to the north-west of the section. c) Close view around the Devonian/Carboniferous boundary, where a 30 cm mineralised horizon interrupts the calcareous sequence. d) The Plotta Fm. in the uppermost part of the section.
Abbreviations: CARB. = Carboniferous; MISSISS. = Mississippian; T. = Tournaisian.

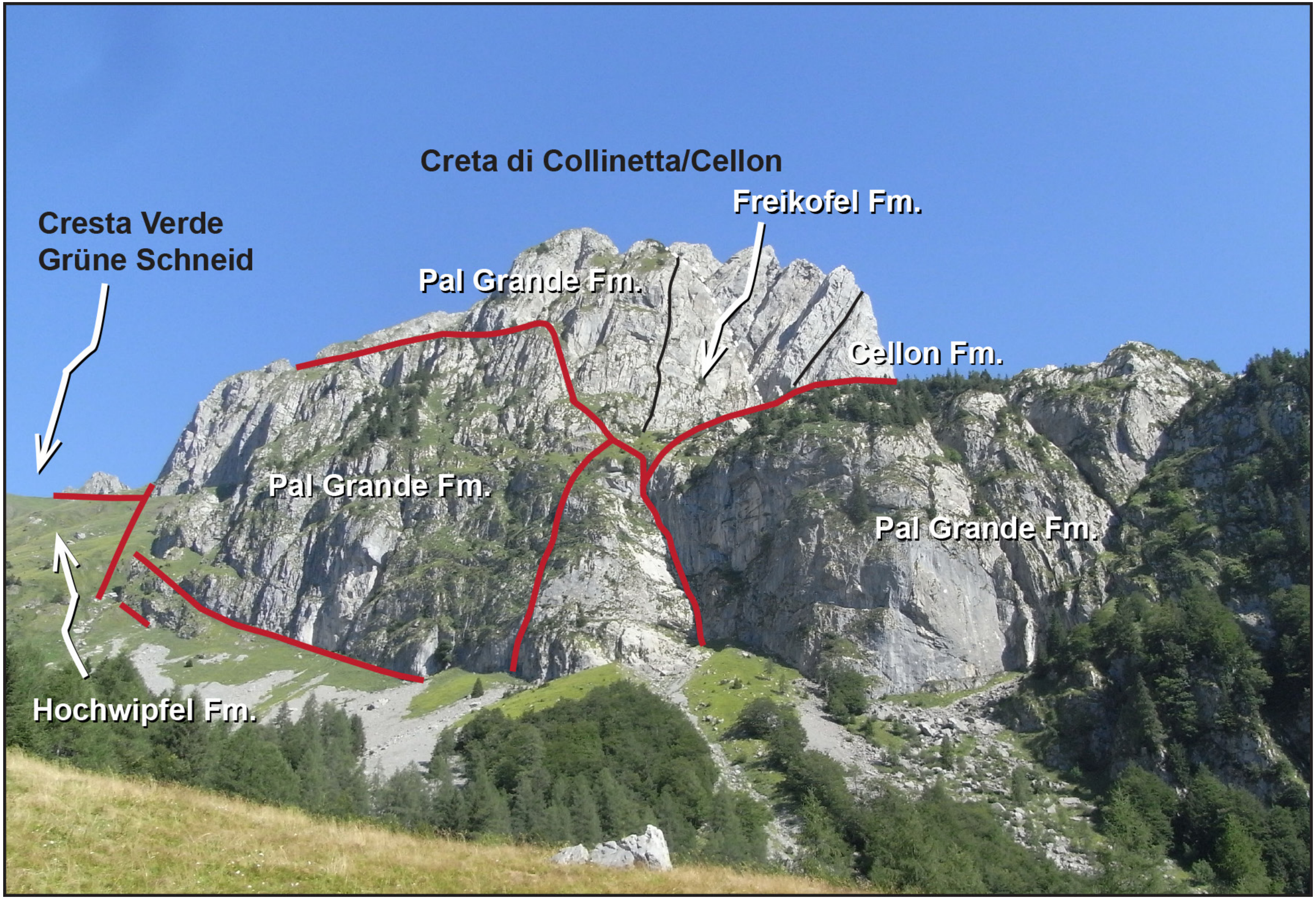


Fig. 19 – Panoramic view of the southern flank of the Mt Creta di Collinetta/Cellon, with indication of the lithostratigraphic units and the main structural features.

the southern part of the fold forming the mountain is observable, with increasingly south-dipping layers (up to ~80°) exposing the entire Pal Grande Fm. Immediately below the mountain peak, the base of the Pal Grande Fm. is visible lying on top of the Freikofel Fm. Looking down stratigraphically and topographically, in correspondence of the most massive part of the succession, the Cellon Fm. occurs.

Day 2

The second excursion day examine the so-called "transitional units" and consists of a hike to Mt Freikofel, crossing the state border between Italy and Austria (Fig. 20).
Starting from Plöckenhaus we will walk along the southern side of the Angerbach valley, which is cut into the siliciclastic rocks of the Hochwipfel Fm., representing the younger part of a huge anticline mostly characterised by pelagic Devonian strata while in the core of the folded structure even Upper Silurian limestones are exposed between Plöckenpass and the summit of Kleiner Pal (Pal Piccolo). To the North the prominent E-W trending dextral strike-slip fault located right in front of the Mt Polinik bounds the Devonian peritidal deposits of the Polinik Fm.
The core of the anticline roughly corresponds to the valley south of the Mt Freikofel (Fig. 21), where the oldest parts of the succession, including Upper Ordovician deposits of the Valbertad and Uqua formations and Silurian of the Kok and Alticola formations, crop out, while the younger strata are exposed progressively (with some minor deformations) towards the top of the surrounding mountains.

Stop 2.1 - Parking Plöckenhouse: Panoramic view to Creta di Collinetta
Coordinates: 46°36'58.2" N, 12°57'08.0" E. Altitude 1215 m

From the starting point, we have a good view of the same units that we will touch during the day, exposed on the other side of the valley in the eastern flank of Mt Cellon/Creta di Collinetta (Fig. 22). The sequence starts with the Upper Ordovician-lowermost Devonian sequence that have been described in Stop 1.2 at Cellon section and continues with the complete sequence of the transitional units. The stratotypes of the Kellerwand and Vinz formations are located there. On top of a disconformity roughly located around the Lochkovian-Pragian transition, the Kellerwand Fm. lies on top of the Rauchkofel Fm. Within the Kellerwand Fm., an indentation of the Seekopf Fm. occurs in the northern side of the Creta di Collinetta. This indentation decreases in thickness in the Pal Piccolo area and disappears more to the east in the Freikofel and Pal Grande sectors. The Kellerwand

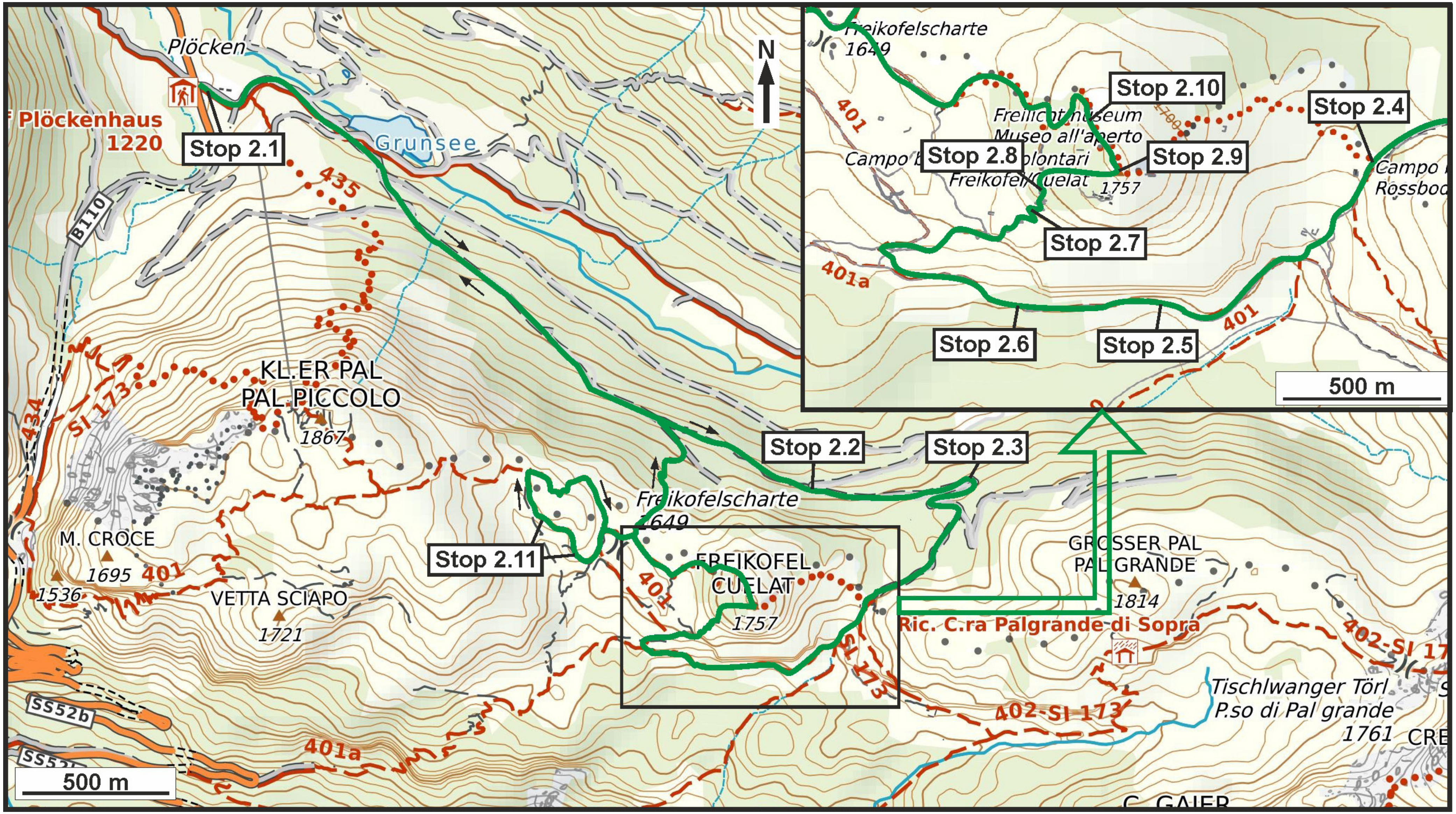


Fig. 20 – Topographic map of the itinerary of day 2.

Fm. is then overlain by the Vinz, Cellon, Freikofel, and Pal Grande formations. The layers attitude become increasingly dipper towards the southwest, being the Creta di Collinetta part of the same anticlinal structure that continues to the east in correspondence of the Pal Piccolo, Freikofel and Pal Grande mountains (Fig. 21).

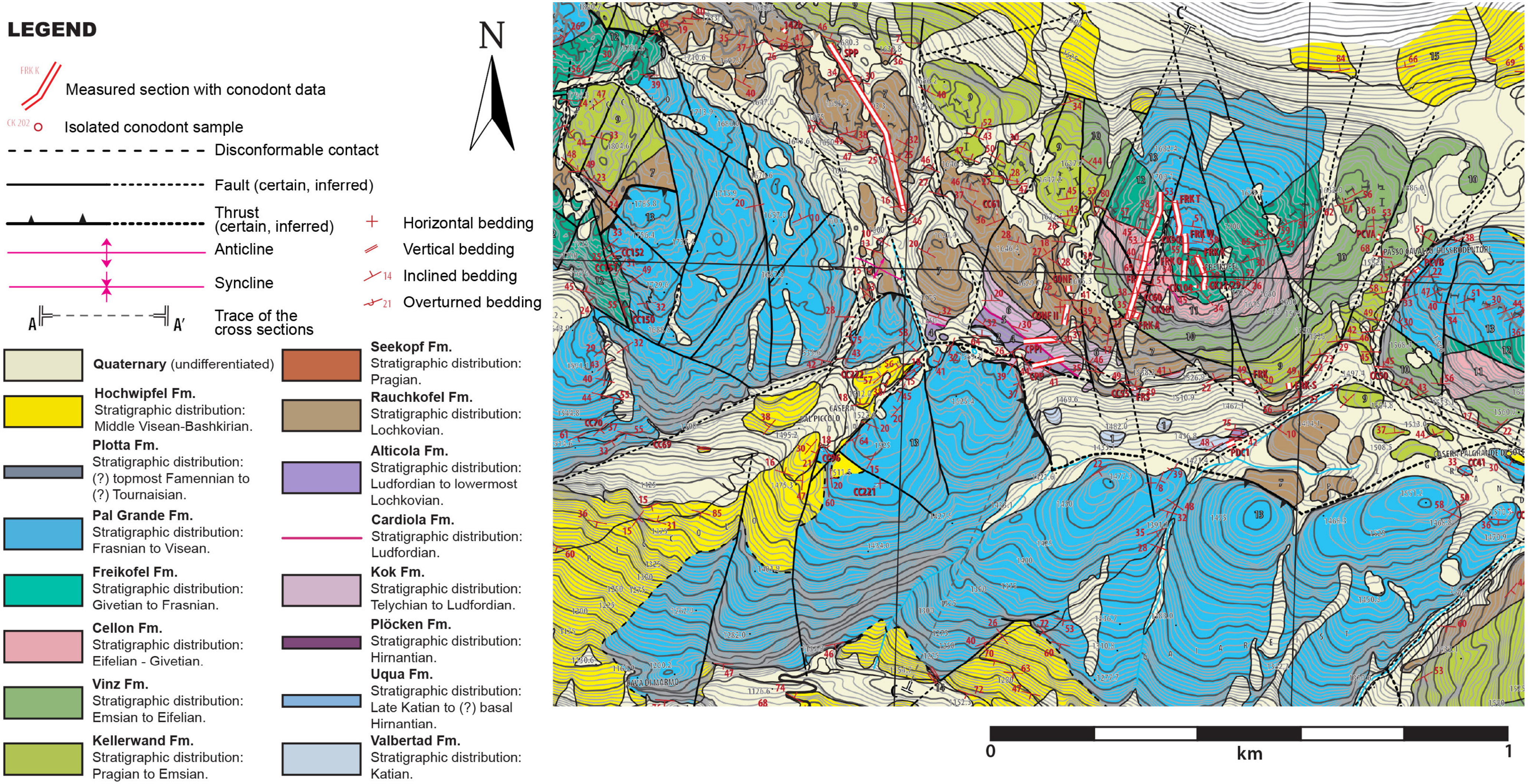


Fig. 21 – Geological map of the Mt Freikofel area (after Pondrelli et al., 2020, modified).

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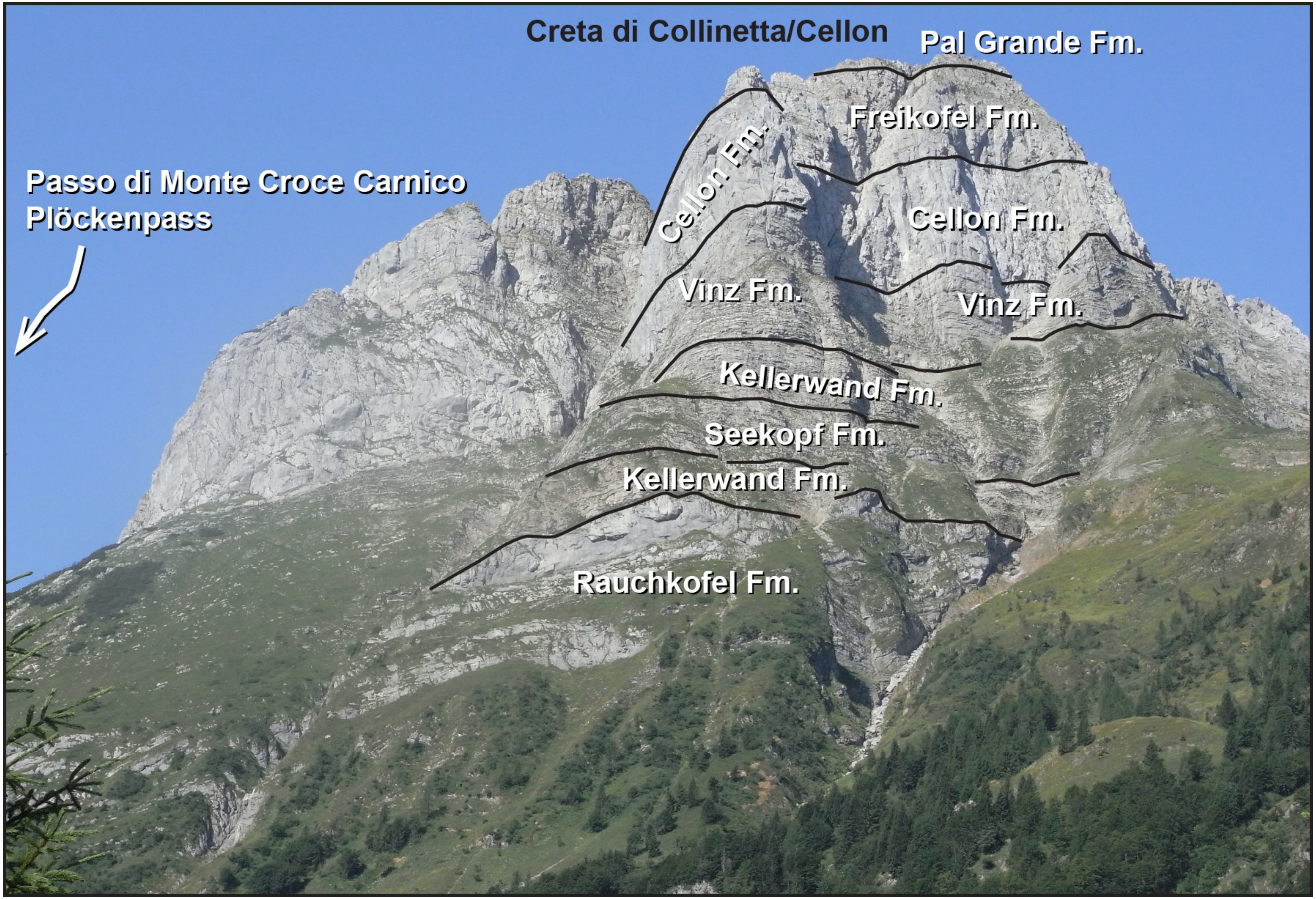

Fig. 22 – View of the north-eastern flank of Mt Creta di Collinetta/Cellon from the parking spot at Plöckenhouse. The lithostratigraphy is evidenced.

Stop 2.2 - Hochwipfel Formation

Coordinates: 46°36’15.8” N, 12°58’48.3” E. Altitude 1464 m

The Hochwipfel Fm. is exposed in the deepest part of the Angerbach valley showing prevalently the fine-grained part of this unit. Here we observe very dark grey beds and laminae of slates interbedding with dark to very dark grey beds and laminae of fine-grained sandstones. In other areas, such as in this example from nearby the Volaia lake (Fig. 23), the genesis as turbidites of this unit is shown by the well preserved Bouma sequences.

Fig. 23 – Example of the Hochwipfel Fm. taken from nearby the Volaia lake, where a Bouma sequence is nicely exposed.

Stop 2.3 - panoramic view on Mt Polinik

Coordinates: 46°36’16.7” N, 12°59’12.5” E. Altitude 1510 m

The peak of Mt Polinik exposes the Polinik Fm. This unit is fault-bounded toward the north by an E-W trending dextral strike-slip fault. South of the fault the Hochwipfel Fm. is exposed on top of a Devonian succession made by distal transitional units. To the north of the fault (Fig. 24a), about 700 m of algal laminites and *Amphipora* limestone with some minor lithoclastic beds occur, representing deposition in a sheltered lagoon in intertidal to supratidal depth. Fig. 24b represents an exemplary outcrop of Polinik Fm. located nearby Mt Maderkopf. The age of these deposits is poorly constrained but it is interpreted to span at least from the Pragian to possibly the Frasnian (Pohler et al., 2015).

Stop 2.4 - Passo Cavallo: panoramic view on Mt Freikofel
Coordinates: 46°36'03.3" N, 12°58'58.3" E. Altitude 1622 m

Passo Cavallo/Rossboden Törl is the saddle between mountains Freikofel and Pal Grande. Middle Devonian rocks of the Vinz Fm. are here widely exposed.

Fig. 24 – a) Panoramic view of the southern slope of Mt Polinik. b) Outcrop representing the Polinik Fm. nearby Mt Maderkopf.

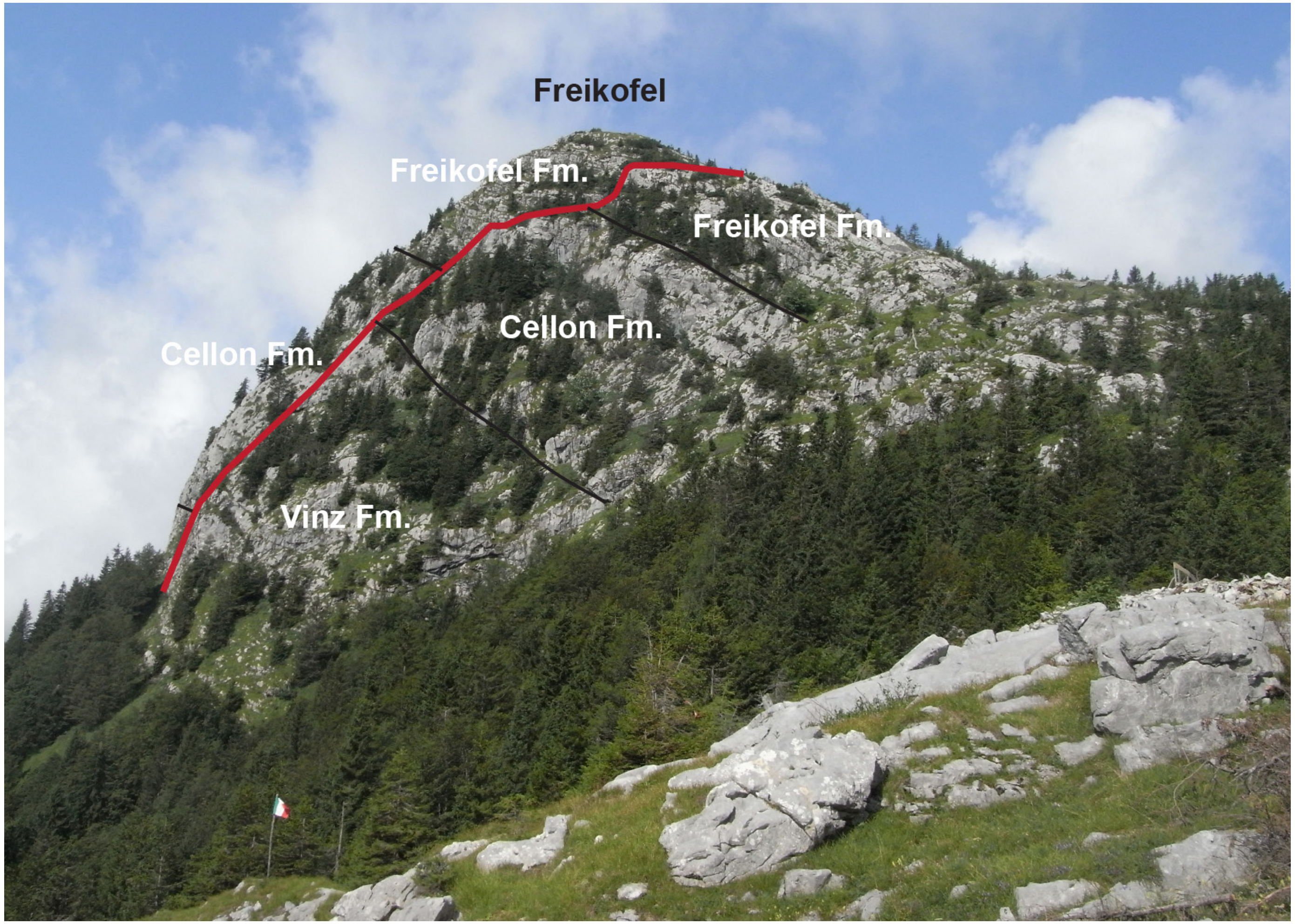

Fig. 25 – Panoramic view to the east flank of Mt Freikofel from Passo Cavallo with indication of the lithostratigraphy.

Looking to the west, we have a good view on the eastern flank of Mt Freikofel (Fig. 25), where the whole succession of the transitional units is exposed: Kellerwand Fm. (Pragian-Emsian), Vinz Fm. (Emsian-lower Givetian), Cellon Fm. (Givetian) and Freikofel Fm. (Givetian-Frasnian). The transitional units provide an insight into the development of the entire platform, reflecting the depositional evolution of the moderately shallow water part of the basin, with the advantage of an almost complete sedimentary record, also datable by conodonts. The sequence is capped by the pelagic limestones of the Pal Grande Fm. (Frasnian-Visean).

From here only the upper units are visible (Fig. 25), whereas the older terms will be seen in the next stops.

Stop 2.5 - The Rauchkofel Fm.-Kellerwand Fm. transition at Freikofel B section

Coordinates: 46°35’55.5” N, 12°58’44.2” E. Altitude 1525 m

The Freikofel (FRK B) section exposes the uppermost part of the Rauchkofel Fm. and the lower part of the Kellerwand Fm. (Fig. 26a). The top of the Rauchkofel Fm. consists of a several metres thick coarse breccia bank with an undulated upper surface. The Kellerwand Fm. consists of thin to medium-bedded wackestone and packstone interbedded with lithoclastic beds of packstone and grainstone generally showing normal grading and sometimes a faint lamination.

The boundary between the two units is sharp, and emphasised by a dark brown siliciclastic irregular level (Fig. 26b), suggesting an unconformity between the two formations. Conodonts from the upper part of the Rauchkofel Fm. indicate a late Lochkovian age, whereas the lower beds of the Kellerwand Fm. yielded a lower Pragian fauna dominated by shallow water icriodids.

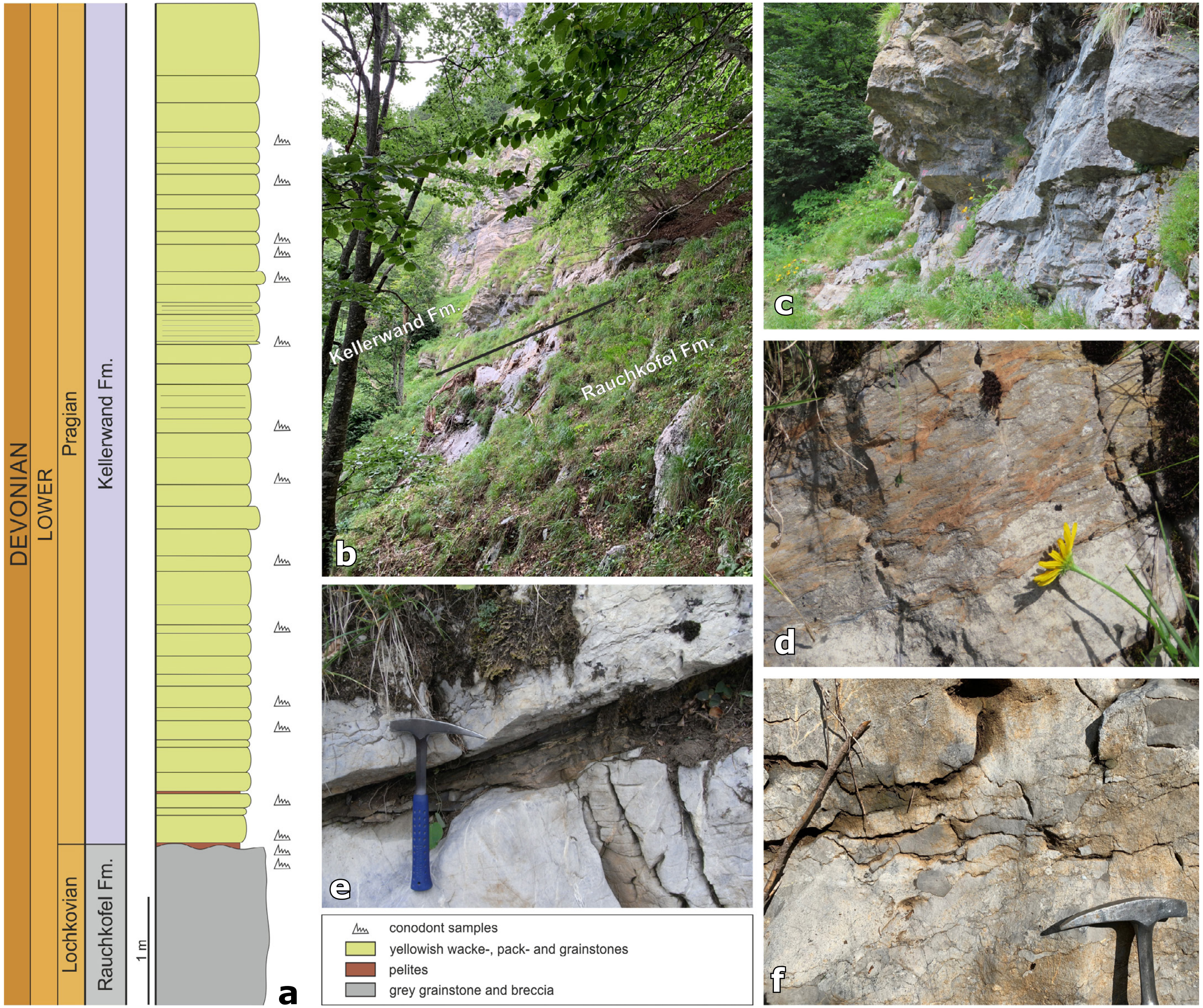

Fig. 26 – The Freikofel B section (FRK B). a) Log of the section. b) Panoramic view showing the unconformable boundary between the Rauchkofel and the Kellerwand formations. c) Detail of the upper part of the section, with the well bedded beds of the Kellerwand Fm. d) Detail of the lower part of the Kellerwand Fm., marked by a cyclic interbedding between wackestone and mudstone/silt beds. e) Detail of the unconformable boundary between the Rauchkofel and the Kellerwand formations. The base of the Kellerwand Fm. is marked by an interval with interbedded thin beds of mudstone and silt. f) Detail of the coral-bearing rudstone forming the top of the Rauchkofel Fm.

Continuing to walk along the path, a few dozen of metres after the FRS section a glade in the forest allows a nice view on the southern slope of Mt Freikofel (Fig. 27).

Stop 2.6 - The Alticola Fm.-Rauchkofel Fm. transition at Freikofel South II section

***Coordinates*: 46°35’54.9” N, 12°58’32.3” E. Altitude 1552 m**

The Freikofel South II (FRS) section (Fig. 28) is located along path n. 401 and exposes the boundary between the Alticola and Freikofel formations about 40 cm above the base of the section (between samples FRS 1 and FRS 2).

The Alticola Fm. is represented by well bedded grey cephalopod limestone. The Rauchkofel Fm. consists of packstones to grainstones showing hummocky-cross stratification at place passing to wave ripples and interlayered with shales, which suggest deposition within the offshore transition. The whole section was dated by conodonts to the basal Devonian *Icriodus hesperius* Zone (Corradini et al., 2020a).

At the top of the measured section, a coarser-grained very thick bed suggests a transition to shoreface conditions. Such coarse banks were

Fig. 27 – View of the southern slope of Mt Freikofel with indication of lithostratigraphy.

documented in a similar stratigraphic position in other localities of the Carnic Alps, as in the Cellon (Corriga et al., 2016) and Valentintörl (Corriga et al., 2021) sections. This succession suggests that the basin profile at the base of the Devonian corresponded to a ramp-type margin.

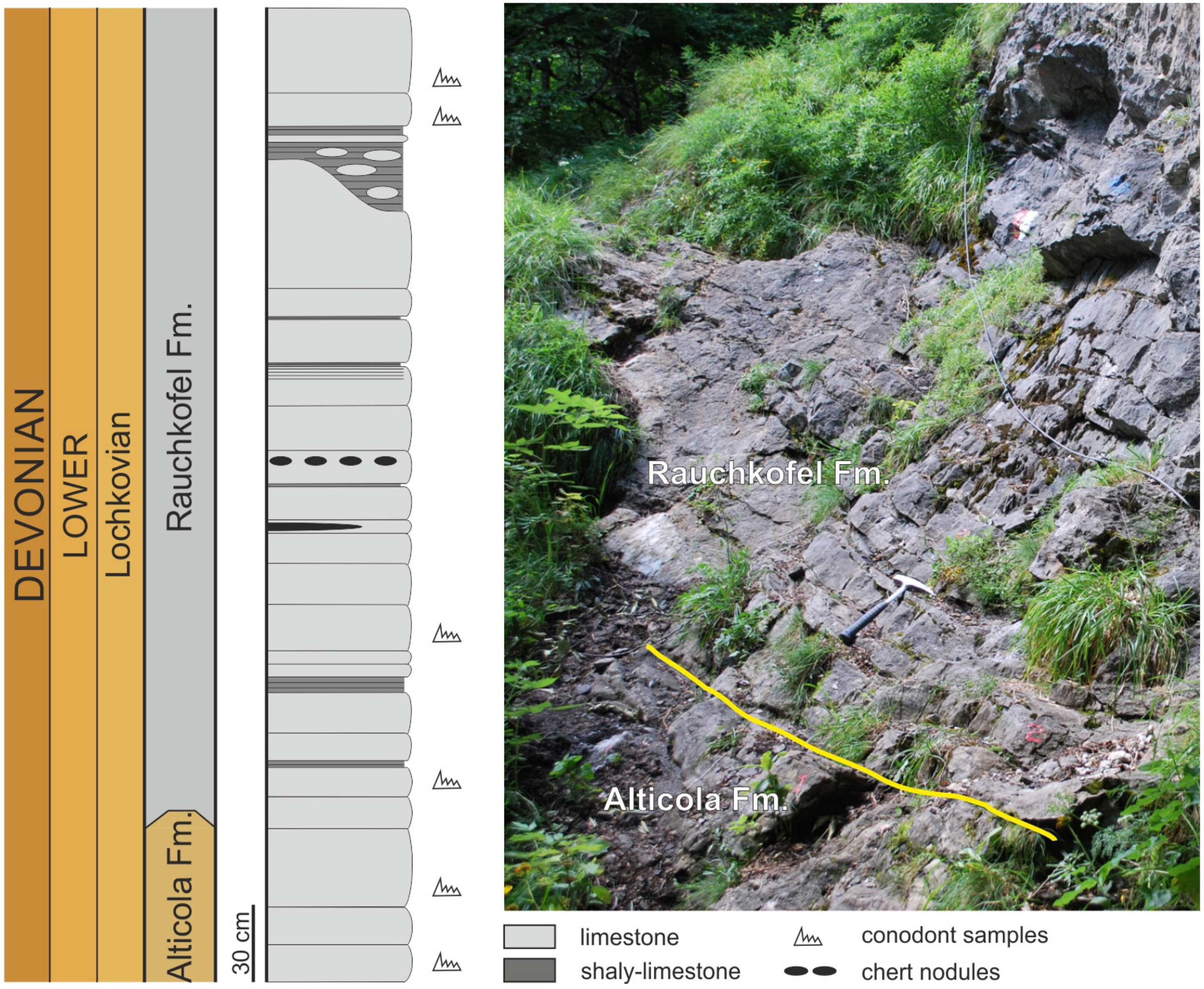

Fig. 28 – Stratigraphic log (after Corradini et al., 2020a, modified) and panoramic view of the Freikofel South II section.

Stop 2.7 – The Vinz and the Cellon formations in the old military mule track

***Coordinates*: 46°36’00.3” N, 12°58’31.3” E. Altitude 1642 (base of the section)**

A NW-SE trending fault separates the Rauchkofel Fm. from the upper part of the Vinz Fm. (Figs. 21, 29). In this part of the unit, two facies interfinger one into the other: medium dark grey, thin to medium bedded, wackestone to packstone (Fig. 30a) and medium dark grey, medium to thick bedded, poorly sorted coral- and stromatoporoid-bearing rudstone (more rarely floatstone) and grainston matrix (Figs. 30a, b) (Pondrelli et al., 2020). In these latter facies sometimes rudstone shows a fining upward trend up to grainstone. The base of this section belongs already to the Eifelian stage, but the base of the

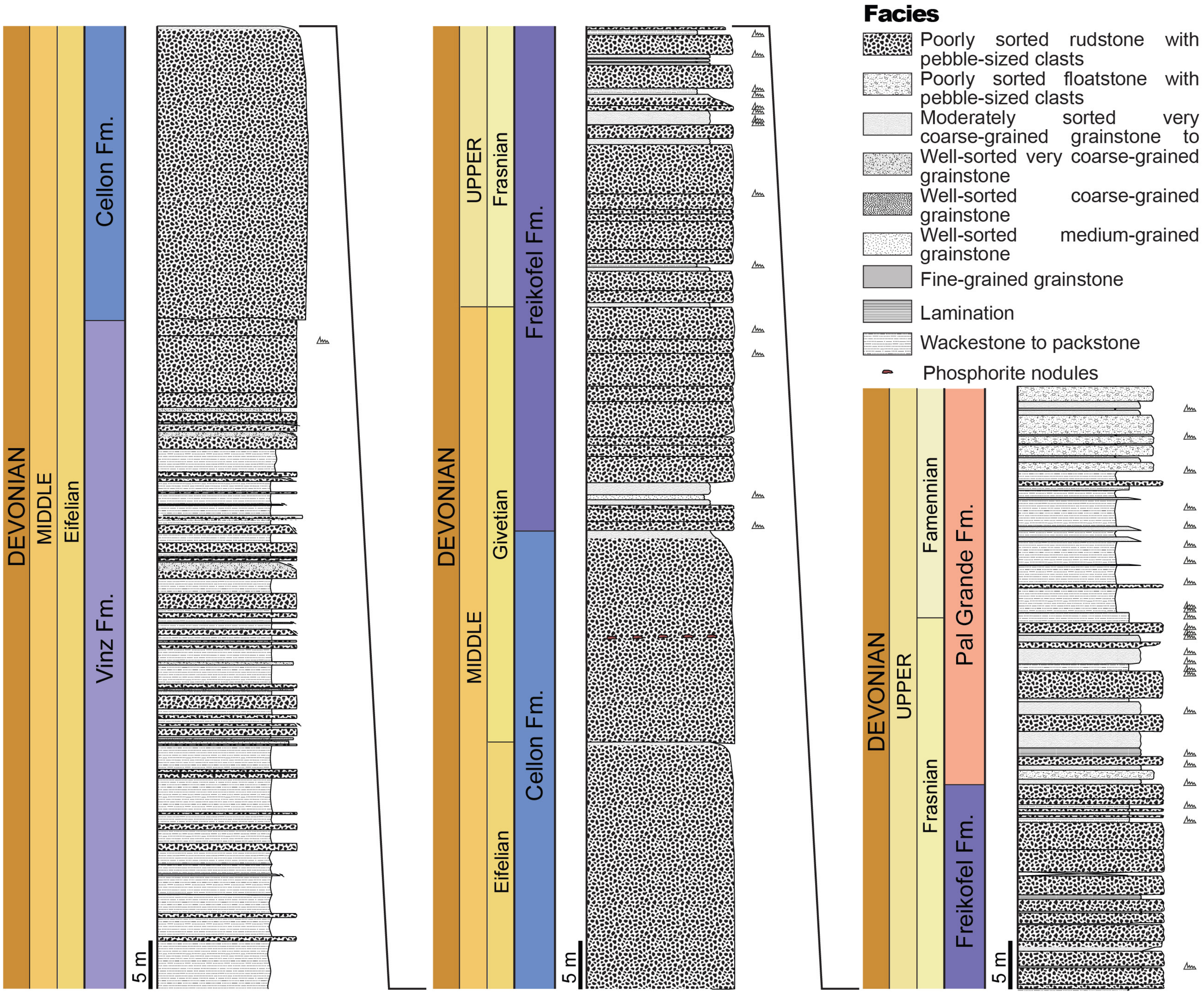

Fig. 29 – Stratigraphic log of the upper part of the Vinz Fm., and the Cellon and Freikofel formations up to the transition to the Pal Grande Fm. along the military mule-track (after Pondrelli et al., 2020, modified).

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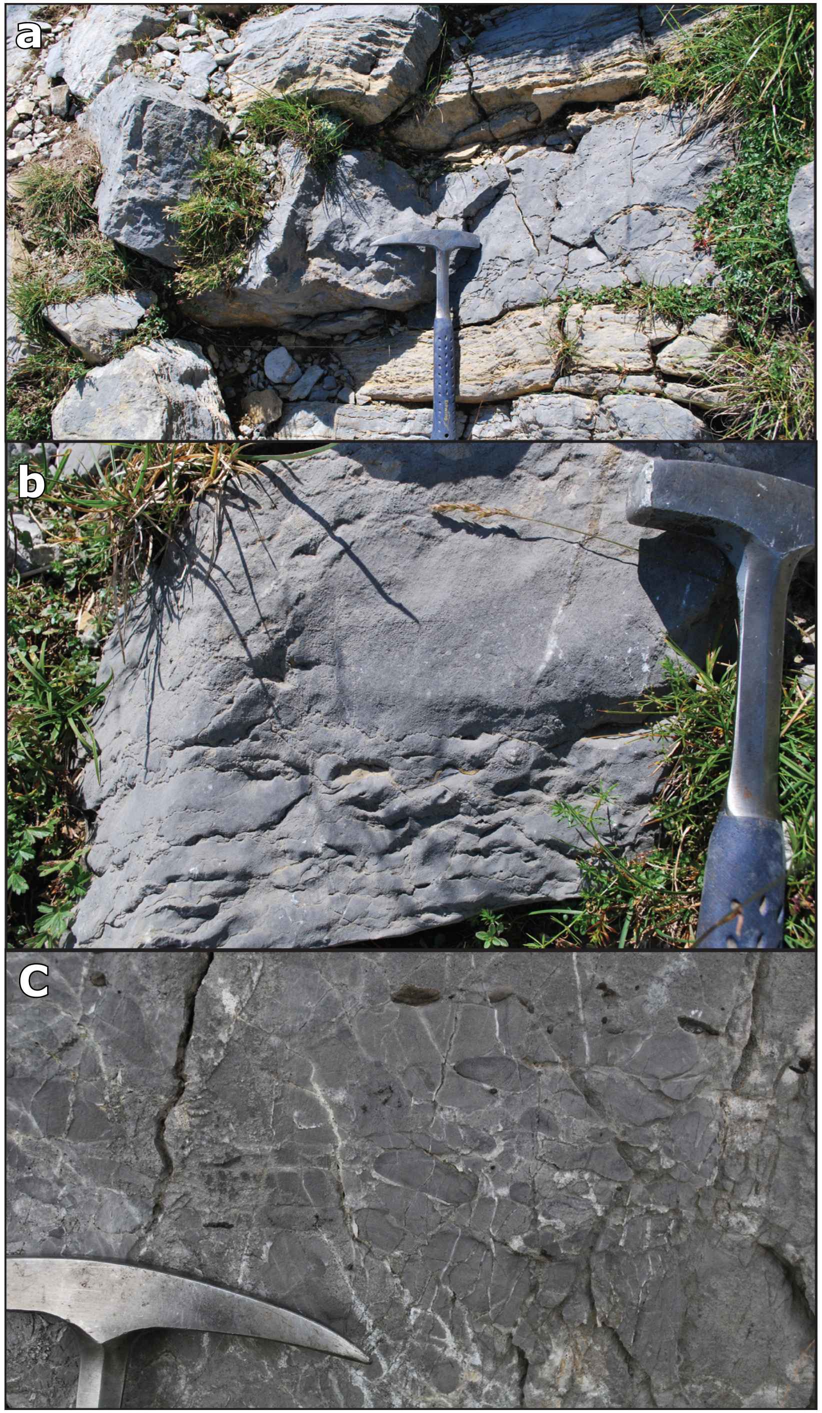


Vinz Fm. goes back to the Emsian. A thickening and coarsening upward trend characterise the upper part of the Vinz Fm. and its transition to the Cellon Fm. which occur in the uppermost part of the Eifelian (Pondrelli et al., 2020). The Cellon Fm. consists of medium dark grey, very thick bedded, poorly sorted, coral- and stromatoporoid-bearing rudstone with clasts up to ~40 cm of diameter and grainstone matrix; sometimes a fining upward trend up to grainstone can be recognised at the top of the beds, which are characteristically multidecametric thick. The Cellon Fm. correspond to the maximum extension of the reefal (and related environments) facies developing laterally (Bandel, 1972; Schönlaub, 1985, Kreutzer, 1992). A characteristic phosphorite-rich horizon, with phosphorite clasts reworked within the rudstone, occurs about 9 m below the top of the unit (Fig. 30c) (Bandel, 1972).
In general, the wackestone to packstone facies were deposited in a pelagic depositional setting, while the breccia deposits reflect gravity driven flows reworking shallow water, mostly reef-derived materials.

Stop 2.8 - The type section of the Freikofel Fm.
Coordinates: 46°36’01.6” N, 12°58’38.2” E. Altitude 1720 m

Continuing the path toward the summit of the mountain, the Cellon Fm. passes sharply to the Freikofel Fm. (Figs. 21, 29). The transition, dated as lower Givetian (Pondrelli et al., 2020), is marked

Fig. 30 – Details of the facies of the Vinz and Cellon formations (after Pondrelli et al., 2020, modified). a) Interbedded wackestone/packstone and rudstone (Vinz Fm.). b) Coral bearing rudstone bed (Vinz Fm.). c) Phosphorite clasts within a rudstone (Cellon Fm.).

Fig. 31 – Details of the facies of the Freikofel Fm. (after Pondrelli et al., 2020, modified). a) Interbedded red mudstone/wackestone and rudstone. b) Microbialite-bearing mudstone/wackestone. c) Coral bearing rudstone.

by a remarkable decrease in bed thickness, from multidecametric to metric in rough approximation. Moreover, the rudstone facies, although with some fluctuations, progressively decrease. The Freikofel Fm. consists of three well-bedded facies: medium dark grey, medium to thick bedded, lithoclastic rudstone (subordinately floatstone) with matrix made of grainstone (subordinately wacke-/packstone) (Figs. 31a, c); medium dark grey, thin to medium bedded grainstone and subordinate packstone locally showing planar and subordinate cross lamination is present; very thin to thin bedded, moderate pink to grey mud-/wackestone (Fig. 31b) (Bandel, 1972; Spalletta and Vai, 1984; Kreutzer, 1992; Pas et al., 2014). The lower part of the Freikofel Fm. is similar to the Vinz Fm., thus suggesting continuing, although less abundant than in the Cellon Fm., reef productivity (Fig. 31c). Deposits of hyperconcentrated density flows and turbidity flows predominate. Thin interbeds of pelagic sediments are rarely preserved. Moving in the upper part of the Frasnian the reef-derived materials become rarer (Vai, 1980; Spalletta et al., 1983; Spalletta and Vai, 1984; Pas et al., 2014), suggesting deposition during low carbonate productivity within the shallow water setting (Pas et al., 2014). Within the mud-/wackestone, and interbedding with these lithoclastic beds poorly in reef-derived materials, some microbial levels have been recognised (Fig. 31b) (Farabegoli et al., in prep). This evolution suggests dismantling of the platform rather than reef productivity, possibly associated with a sea level drop that exposed part of the platform (Pondrelli et al., 2020).

Stop 2.9 - Mt Freikofel summit: panoramic view to the Creta di Timau

Coordinates: 46°36'02.8" N, 12°58'39.4" E. Altitude 1757 m

The top of Mt Freikofel offers to the southeast a spectacular panoramic view on the northwestern wall of the Gamspitz-Creta di Timau massif (Fig. 32). This mountain is part of a huge Variscan anticlinal structure, subsequently dismembered by vertical faults during the Alpine orogeny (Venturini, 1990).

The southern part of the anticlinal structure can be seen, showing south-dipping beds of the Rauchkofel Fm. and the sharp transition to the Kellerwand Fm., marked by an unconformity. On the eastern end of the cliff, the fault-bounded Creta di Timau, constituted by Upper Devonian limestones of the Pal Grande Fm., represents part of the north-dipping flank of the anticline.

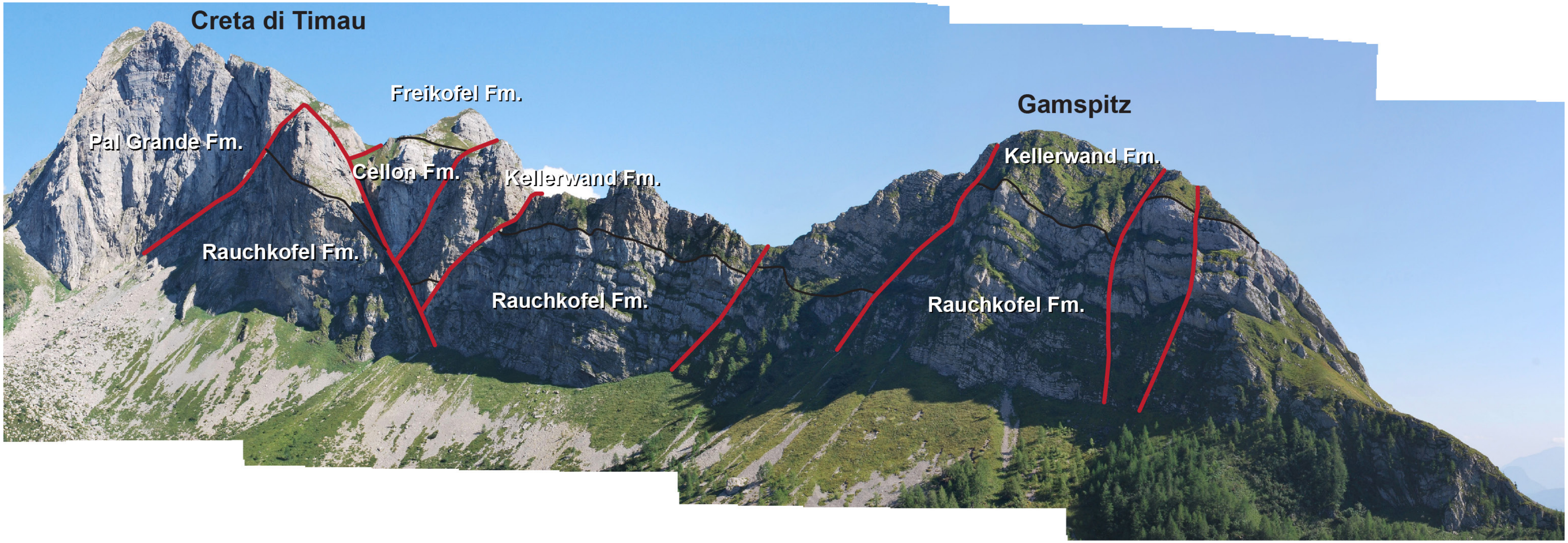


Fig. 32 – Panoramic view of the north slope of the Creta di Timau-Gamspitz massif with indication of lithostratigraphy.

Stop 2.10 - The Freikofel Fm.-Pal Grande Fm. transition and the Frasnian/Famennian boundary

***Coordinates*: 46°36’04.7” N, 12°58’37.4” E. Altitude 1730 m**

Descending from Mt Freikofel toward the west, the transition from the Freikofel Fm. to the Pal Grande Fm. is visible. The transition is marked by an evident increase in thin-bedded gray and pink wackestone and packstone (Fig. 29). Lithoclastic levels (mostly rudstone) are still present, but thinner and rarer. This transition is assigned to the Frasnian according to conodont data (Spalletta et al., 2015).

The Frasnian-Famennian boundary was recognised, and it is currently under study in order to identify its significance in term of environmental changes. The deposition around the Freikofel Fm.-Pal Grande Fm. transition shows the continuation of the evolution documented in the upper part of the Freikofel Fm., suggesting a deposition during a period of low carbonate productivity within the shallow water settings, which in turn suggests that the early Frasnian reefs of the Carnic Alps were in decline earlier than in most of the reef localities throughout the Middle-Upper Devonian world (Pas et al., 2014).

Stop 2.11 - The Rauchkofel Fm. in the Sopra Casera Pal Piccolo section

***Coordinates*: 46°36’02.6” N, 12°58’21.0” E. Altitude 1620 (base of the section)**

The Sopra Casera Pal Piccolo (SPP) section is a spectacular exposition of the middle and upper part of the Rauchkofel Fm. (Fig. 33). This unit is here represented by an alternation of well bedded limestone and thick calcarenitic and breccia banks. The bedded part is made by sets of 5 to 20 cm thick strata of dark grey mudstone to packstone, with rare thin pelite intercalations. Slumps are observable here and there in the section. Small orthoceratid cephalopods and rare solitary rugose corals are present; fossils are often silicized, mainly in the lower part of the section. The sedimentation is interrupted by at least five episodes of deposition of thick banks, that are constituted by calcarenites in the lower part and breccia above. The thickness of these banks is variable, up to 25 m; however, it cannot be excluded that the thickest banks may results of the amalgamation of various deposition events. An erosional surface is present at the top of the younger breccia bank.

Preliminary conodonts data from the bedded sectors indicate that the section was deposited during the middle and late Lochkovian (*Ancyrodelloides carlsi* to *Masaraella pandora* β zones).

The thickness of the Rauchkofel Fm. in the SPP section is about 180 m, and the unit is disconformably capped by a few metres of wackestones to grainstones belonging to the Kellerwand Fm.

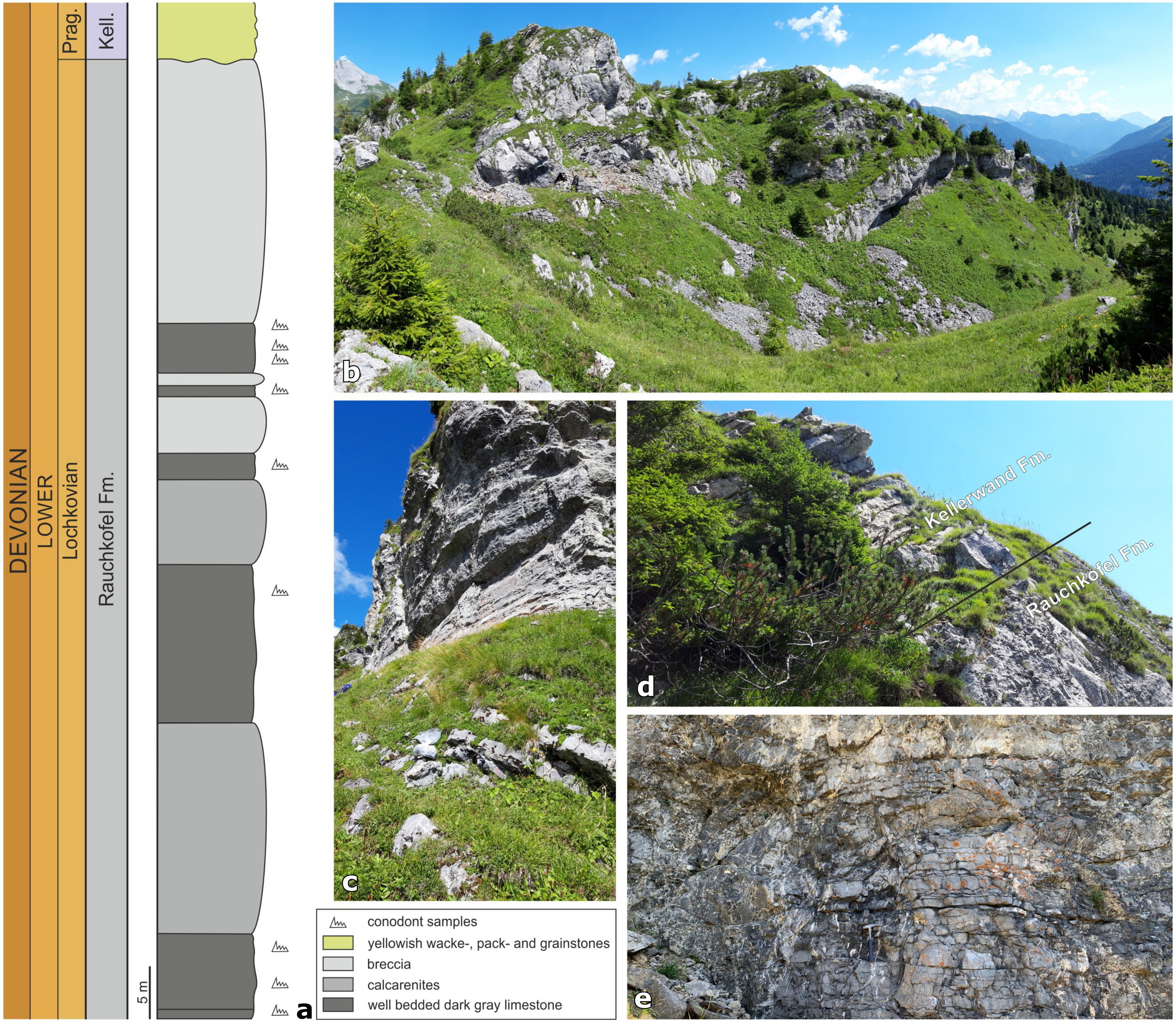


Fig. 33 – The Sopra Casera Pal Piccolo section (SPP). a) Log of the sectionto the east of the section. b) Panoramic view. c) Detail of the lower part of the section, where well bedded beds are overlain by the first calcarenitic bank. d) The upper part of the section with the unconformable transition between the Rauchkofel and the Kellerwand formations. e) Limestone beds followed by a thick calcarenitic bank in the central part of the section. A slump is observable in the central part of the view. Abbreviations: Kell. = Kellerwand Fm.; Prag. = Pragian.

Day 3

The third excursion day is devoted to the area of Mt Zermula. Several stops are scheduled along the road connecting Paularo to Passo di Monte Croce Carnico and Pontebba, or are reached through short walks (Fig. 34). Mount Zermula represents one of the four main Devonian platforms of the Carnic Alps. However, the whole area was overturned during the Variscan orogeny. The thrusts and folds present in this area show a constant top to the south vergence (Venturini, 1990). The higher parts of Mt Zermula represent Devonian platform rocks thrusted on top of an Upper Ordovician to lower Carboniferous succession showing mostly basin to slope depositional environments (Fig. 35). In stop 3.8 we will have a good view of this thrust. The NW-SE trending structures were later reactivated during Alpine times as compressive structures during the Tortonian-Serravallian phase and as dextral strike slip during the Plio-Pleistocene phase (Venturini, 1990). At Cason di Lanza Pass this phase is expressed by the N120°E trending dextral strike-slip Cason di Lanza line (Fig. 3), inherited from a syn-sedimentary Permo-Carboniferous fault (Venturini, 1990), which offset the Variscan multi-kilometric anticline, placing in contact the Variscan and the Permo-Carboniferous sequences (Venturini, 1990).
For recent geological overviews on the area visited today, refer to Corradini et al. (2012, 2016, 2020b) and Pondrelli et al. (2015).

Stop 3.1 – The Devonian/Carboniferous boundary in the Plan di Zermula A section
Coordinates: 46°34’22.8” N, 13°06’43.5” E. Altitude 1010 m

The Plan di Zermula A (PZA) section (Fig. 36) is one of the four sections in the Carnic Alps where the Devonian/Carboniferous boundary is exposed. It is a short, overturned, section, located along the limb of one of the minor, parasitic folds pertaining to the macro, pluri-kilometric, asymmetric fold constituting the Mt Zermula massif (Venturini, 1991).
The PZA section is part of a larger outcrop of Upper Devonian to lower Carboniferous limestone of the Pal Grande Fm. The limestone sedimentation is interrupted by a 10 to 20 cm thick black shale interval interpreted as an equivalent of the Hangenberg Black Shales (Perri and Spalletta, 2001). The irregular shape of the black shale level was attributed to weak tectonic displacement. Above the black shales the calcareous sedimentation restarted with the deposition of about 80 cm of limestone, conformably followed by 20-50 cm of black radiolarian chert of the Zollner Fm., overlain by grey pelites of the Hochwipfel Fm.

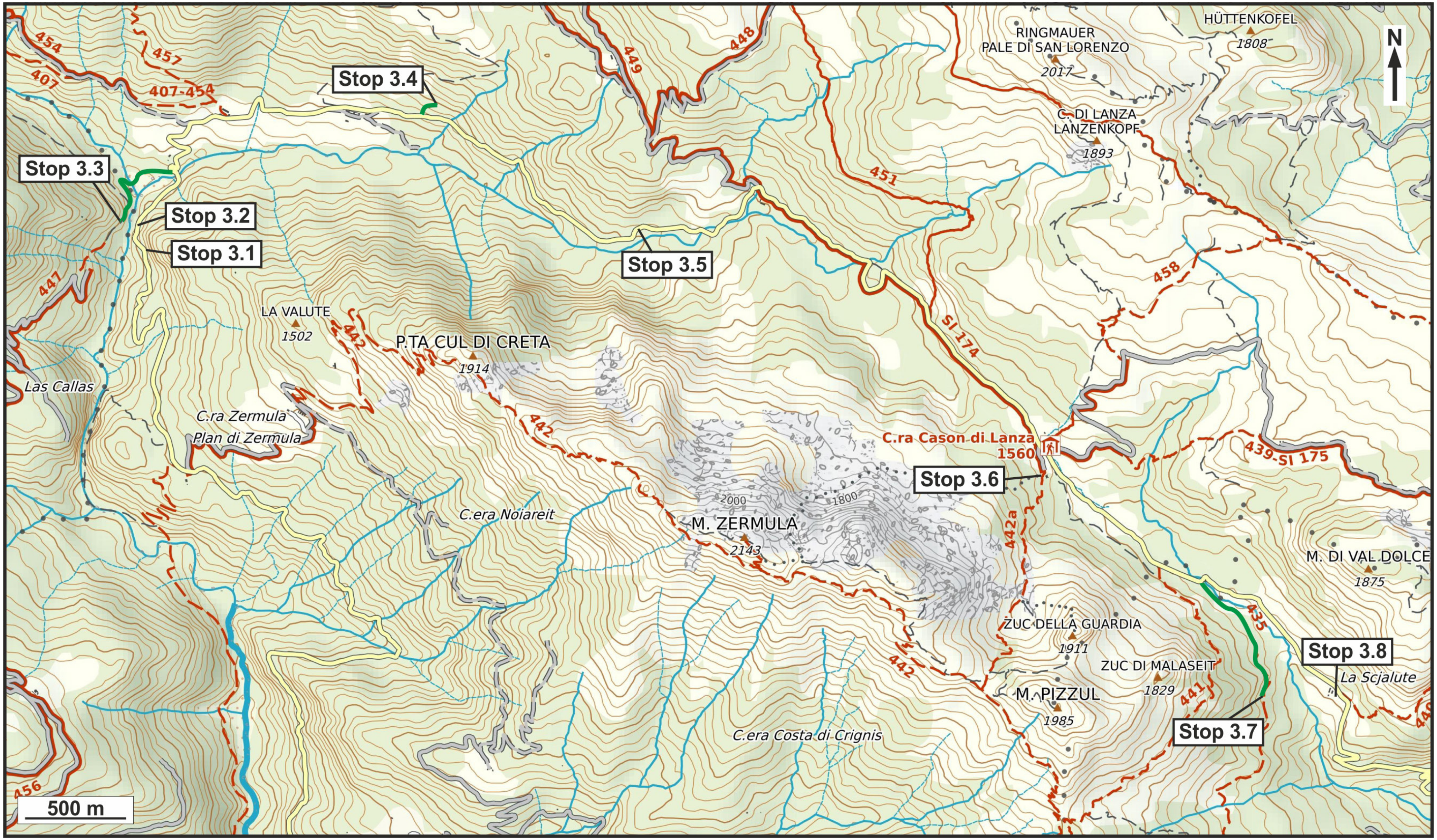


Fig. 34 – Topographic map of the itinerary of day 3.

A detailed conodont biostratigraphy was provided by Perri and Spalletta (2001), Kaiser et al. (2009) and Spalletta et al. (2021), showing that the section ranges from the middle Famennian *Palmatolepis marginifera utahensis* to the lower Tournaisian *Siphonodella quadruplicata* zones. Whole rock geochemistry and selected mineral components of the interval around the Hangenberg Black Shale equivalent were studied by Pisarzowska et al. (2020) and Rakociński et al. (2020). The latter authors demonstrate a clear mercury enrichment associated with the Hangenberg event, and proposed a volcanic related methylmercury poisoning as possible driver of the end-Devonian mass extinction.

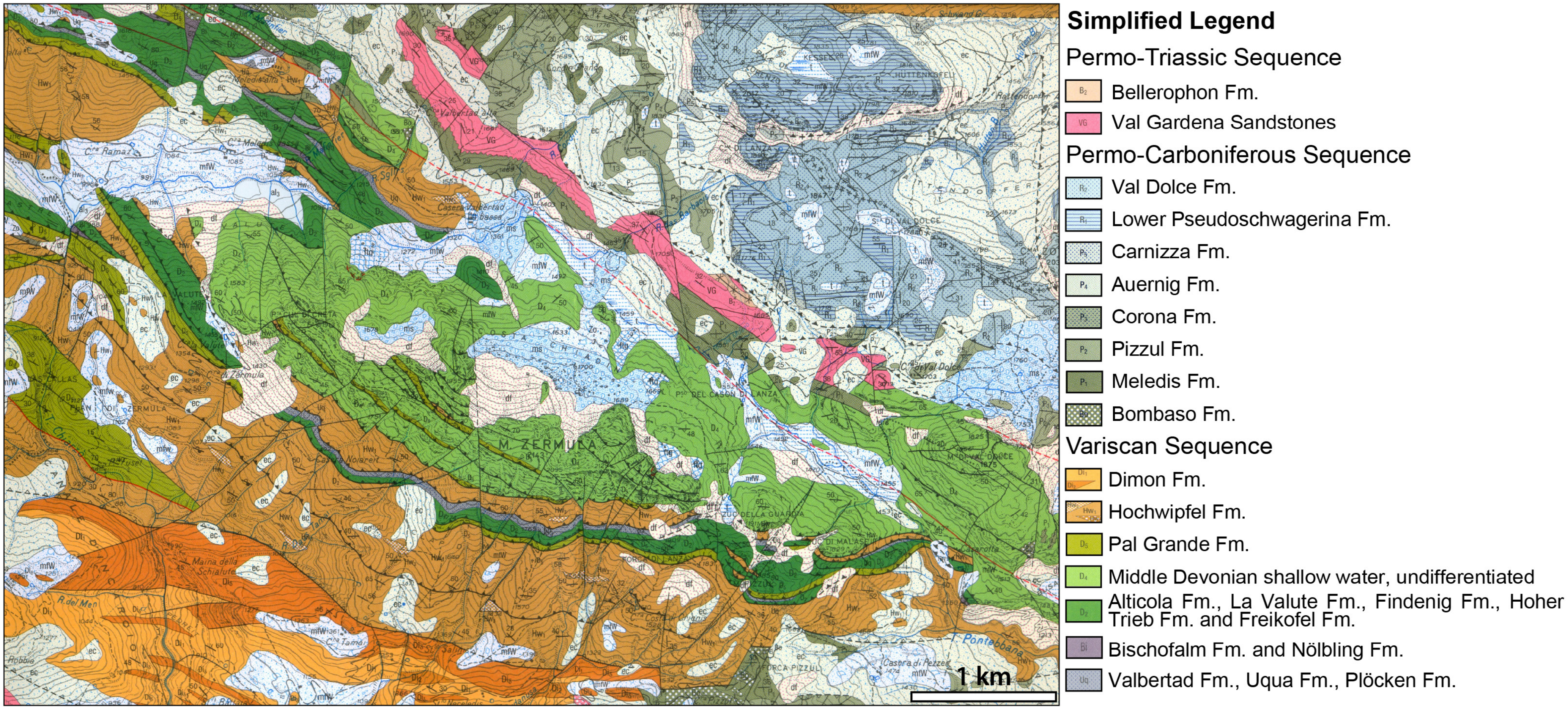


Fig. 35 – Simplified geological map of the Mt Zermula area (after Venturini et al., 2002, modified).

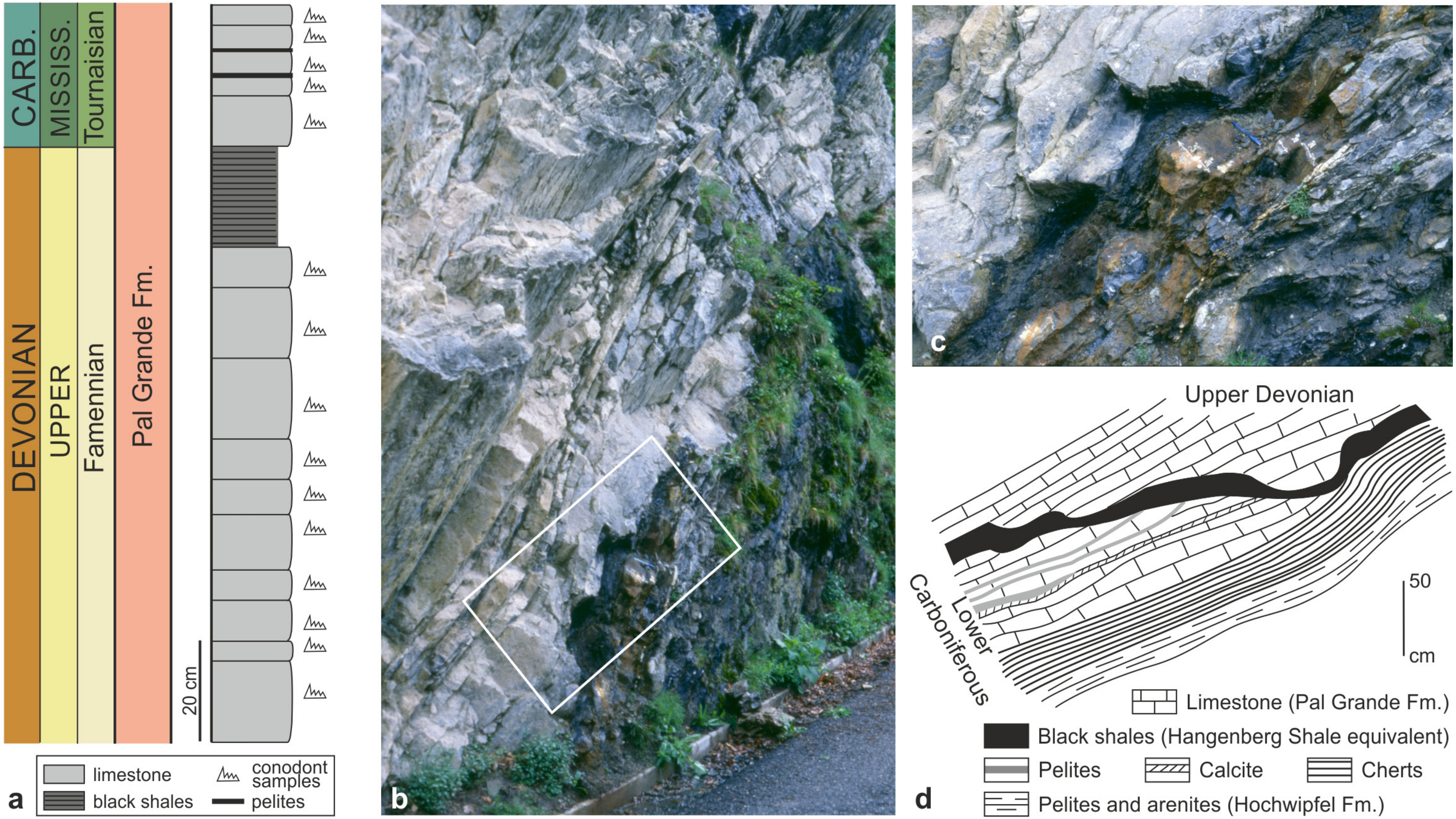


Fig. 36 – The Plan di Zermula A section. a) Log of the section (after Spalletta et al., 2021, modified). b) Panoramic view of the section, note that the section is overturned. The box approximates the area enlarged in c). c) Close view of the Hangenberg Shales equivalents, between Devonian and Carboniferous limestones; the System boundary is traced at the top of the shales. d) Sketched drawing of the Plan di Zermula A section (after Perri and Spalletta, 2001, modified).
Abbreviations: CARB. = Carboniferous; MISSISS. = Mississippian; T. = Tournaisian.

Stop 3.2 – Panoramic view on Mt Culet
Coordinates: 46°34'27.3" N, 13°06'40.7" E. Altitude 995 m

Mt Culet is the hangingwall of a top to the south thrust associated with other minor faults, consistently top to the south sometimes reactivated as dextral strike-slip, which conceal the transition between the Hoher Trieb and the Pal Grande formations (Fig. 37). The overall structure is complicated by a up to decameter scale asymmetric top to the south folds mostly, but not exclusively, confined within the Findenig Fm., which lithology favors ductile deformations (Fig. 37). This part of the succession is separated by the succession including the Stua Ramaz section, that will be visited in the next stop, by a top to the south, north dipping fault. Conodont data from the Hoher Trieb Fm. in the footwall of this structure constrain the deposition spanning the Emsian-Eifelian transition (Perri

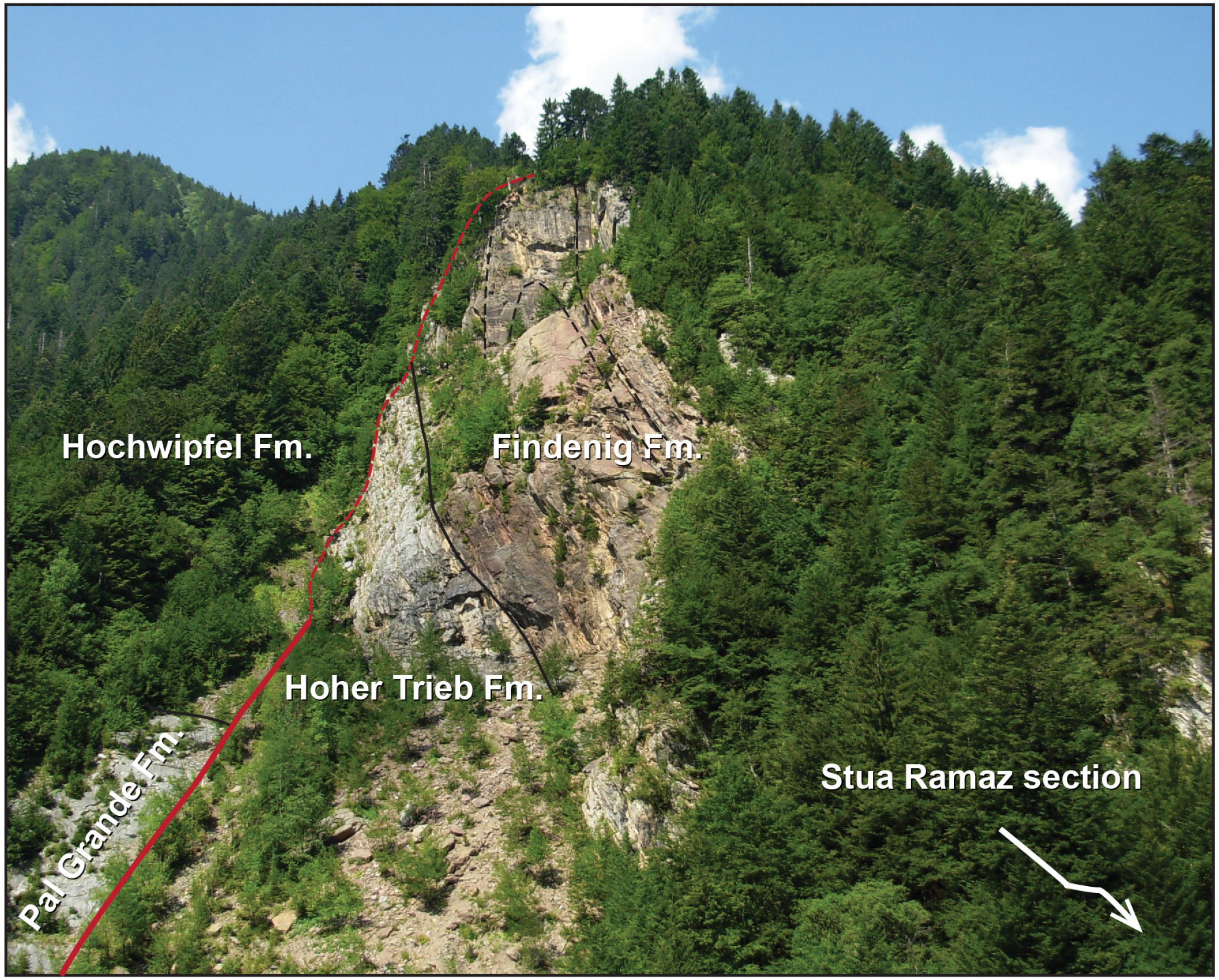
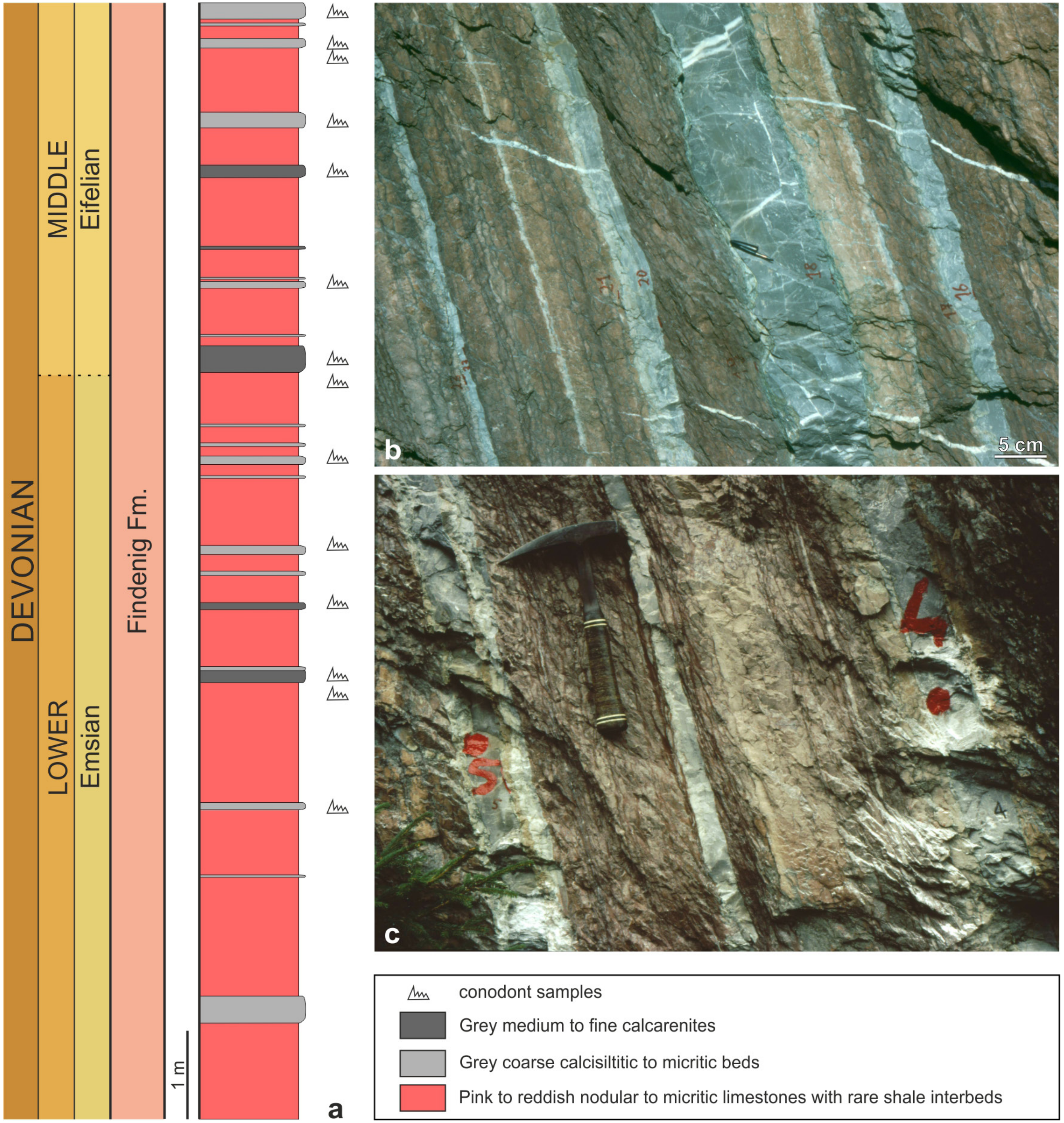


Fig. 37 – Panoramic view of the eastern side of Mt Culet showing the folded beds of the Findenig Fm. passing to the Hoher Trieb Fm. at the hangingwall of an inverse fault. The footwall shows the unconformable boundary between the Pal Grande and the Hochwipfel formations.



and Spalletta, 1998a). The same age is documented, in the hangingwall of the fault, in the Stua Ramaz section, evidencing the lateral transition between the two units.

Stop 3.3 – Allodapic beds in the Stua Ramaz section

***Coordinates*: 46°34’32.3” N, 13°06’37.6” E. Altitude 1000 m**

The Stua Ramaz section is located at the beginning of path n. 447, and will be reached with a short walk from Stua Ramaz bridge. The section is the classical exposure of allodapic beds within the Findenig Fm. (Vai, 1980). It consists of about 12.5 m of pink to reddish, locally nodular, tentaculitid limestones with rare shaly interbeds, and several allodapic beds, 1 to 30 cm thick (Fig. 38). These grey beds are constituted by calcisiltite to very fine calcarenite, rich in bioclasts derived

Fig. 38 – The Stua Ramaz section. a) Log of the section (redrawn and modified after Vai, 1980). b-c) Close views of the allodapic layers in the central part of the section.

from shallow water environment; the uppermost part is often represented by thin discontinuous bioturbated micrite layers. The boundaries between the reddish limestone and the allodapic beds is sharp. Vai (1980, p.85) interpreted these beds as settling from “a turbid, mostly superficial, coarse to finer detrital cloud originated on shallow water platforms by hurricane storms”.

The section was dated to the Emsian-Eifelian (*Polygnathus serotinus* to *Polygnathus partitus* conodont zones) on the basis of a scarce conodont fauna (Perri and Spalletta, 1998a), that prevented to place precisely the Lower/Middle Devonian boundary.

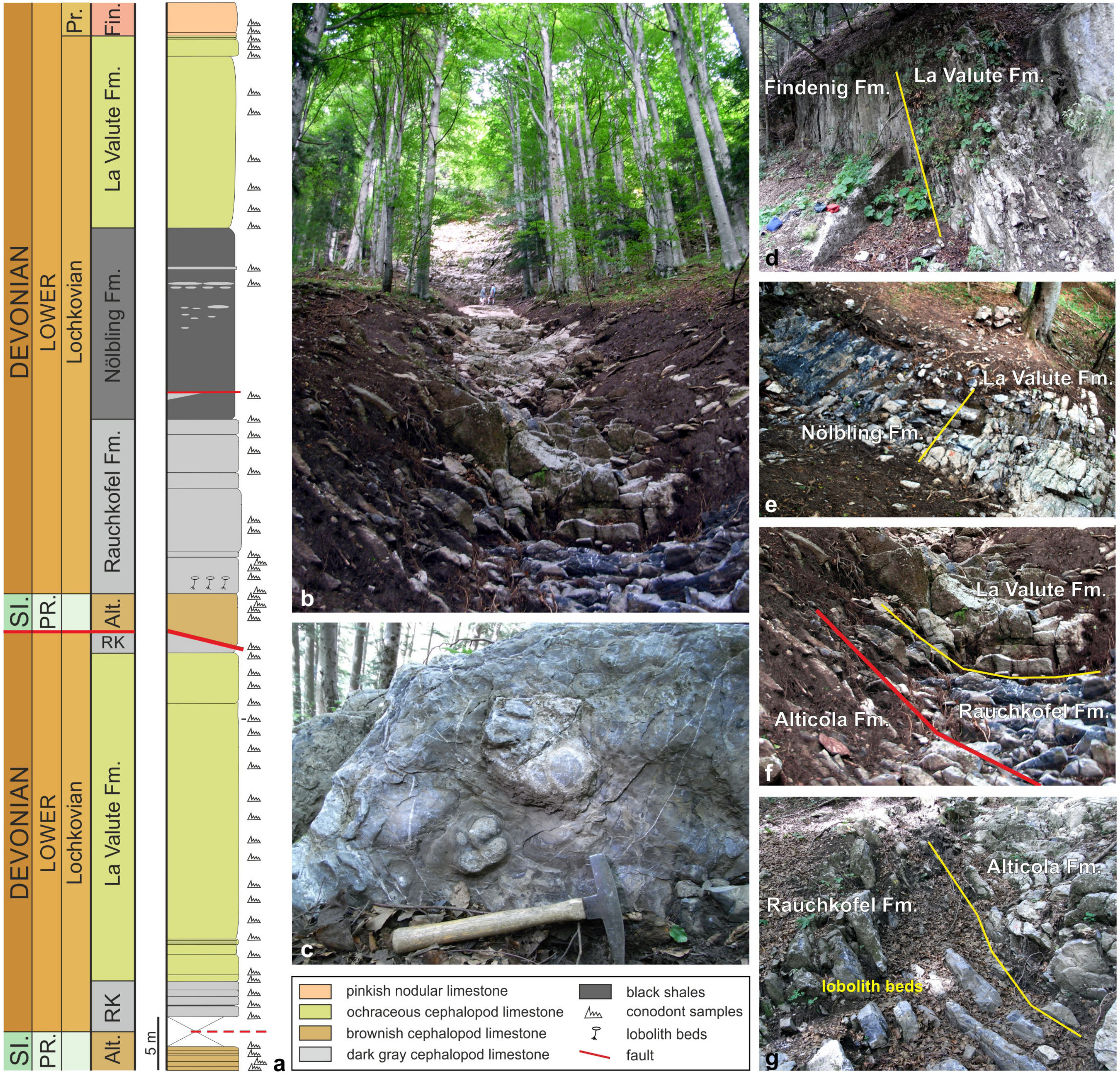
Stop 3.4 – Lochkovian sediments in the Rio Malinfier West section

Coordinates: 46°34’5 0.8” N, 13°07’53.7” E. Altitude 1175 m

The Rio Malinfier West (RMW) section is exposed in the forest about 100 m west of the Rio Malinfier creek, along a narrow and steep creek cleaned by a local flood in August 2008. About 100 m of limestones and black shales attributed to the Alticola, Rauchkofel, La Valute, Nolbling and Findenig formations are exposed (Fig. 39). After preliminary works on conodont biostratigraphy (Corriga, 2011; Corriga et al., 2017) and the lithological sequence (Corradini et al., 2012; Corriga et al., 2017), the section was discussed in detail by Corradini et al. (2019a).

The section is partly overturned and strongly tectonised. A distinct fault, roughly E-W trending, running at about 40 m above the base, cuts the section in two main exposures. Although the units exposed below and above the fault are mostly the same, the two parts of the section largely differ, suggesting that the fault is not responsible of a small local repetition, but that it adjoins two sequences of the same age possibly deposited in slightly different environments. While in the footwall of the fault the succession is fairly undisturbed, with just very gentle folding and a minor fault, the hangingwall is characterised by a tight inclined decameter-scale syncline associated to smaller-scale asymmetric folds, in turn gently folded by a larger-scale structure (Fig. 40).

The section starts (Fig. 39b) with a steep wall constituted by about 2 m of cephalopod-rich limestones belonging to the Alticola Fm., and continues after 3 m of detrital cover accumulated at the base of the steep cliff with 3.2 m of dark limestones and intercalated black shales of the Rauchkofel Fm., which, in turn, passes with a sharp contact into the La Valute Fm. The latter unit here is more than 30 meters thick, because this part of the section is affected by the aforementioned tight fold which causes the repetition. Close to the repeated transition to the Rauchkofel Fm., the bed thickness seems to decrease, probably because of the ductile shear associated to the fold propagation. Less than 2 m of Rauchkofel Fm. crop out before the fault (Fig. 39f).



In the footwall of the fault, the section continues with about 4 m of limestones of the Alticola Fm., slightly tectonised in the upper part, close to the sharp transition with the Rauchkofel Fm. (Fig. 39g). The Rauchkofel Fm. is here represented by about 16 m of dark limestone,

Fig. 39 – Sketched stratigraphic log and views of the Rio Malinfier West (RMW) section. a) Log of the section. b) Panoramic view of topographically higher part of the section. c) The lobolith beds in the field, with several plate lobolith preserved. d) Gradual transition from the La Valute Fm. to the Findenig Fm. in the uppermost part of section. e) The sharp boundary between the Nölbling and La Valute formations. f) The roughly E-W trending fault separating the Rauchkofel Fm. and the Alticola Fm. in the middle part of the section. g) The transition from the Alticola to the Rauchkofel formations in the central part of the section. Abbreviations: Alt. = Alticola Fm.; Fin. = Findenig Fm.; PR. = Pridoli; Pr. = Pragian; RK = Rauchkofel Fm.; SI. = Silurian.

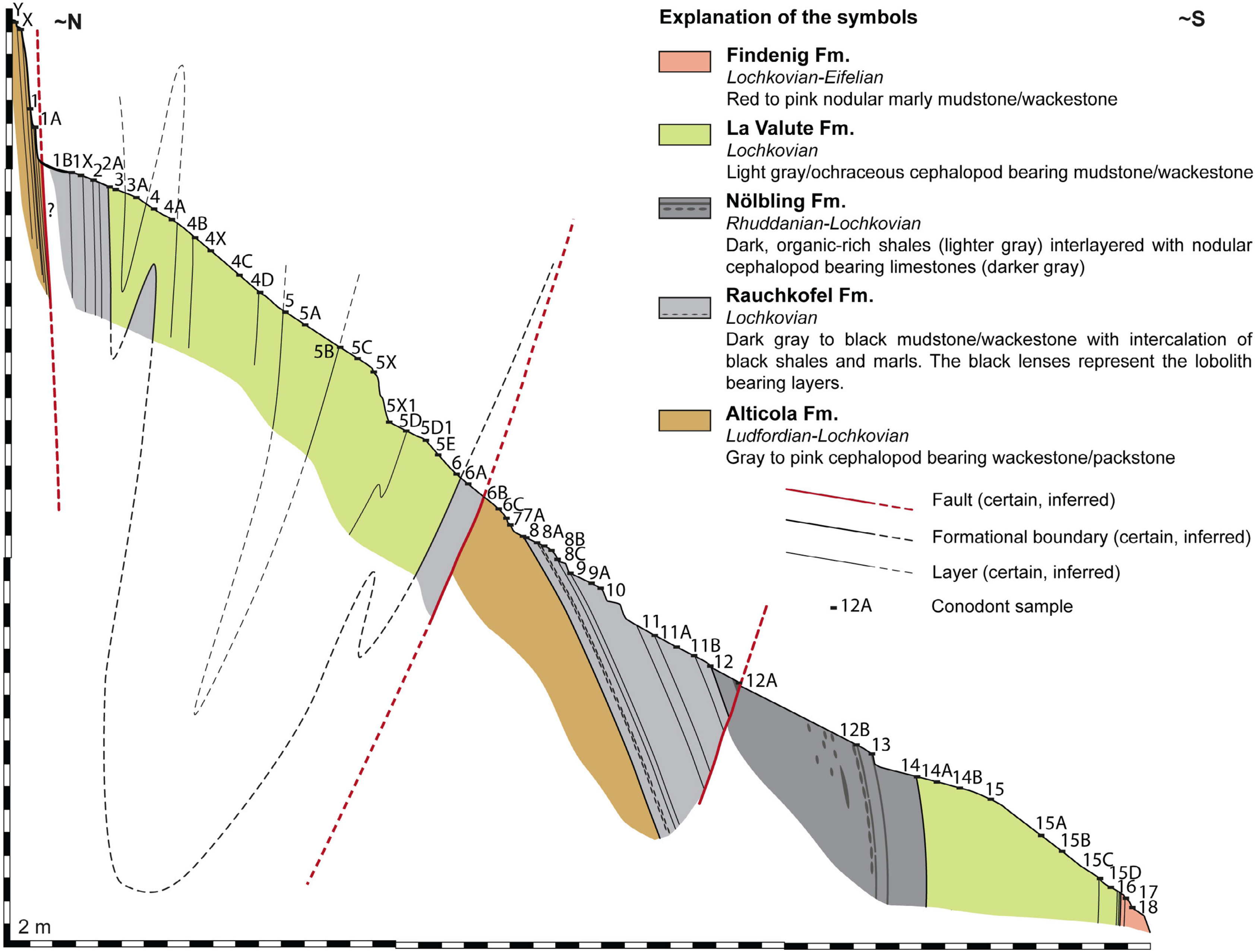


Fig. 40 – Geological section through the RMW profile with location of conodont samples (after Corradini et al., 2019a, modified).

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with thin black shale intercalations. Limestone beds are thicker in the lower part of the units, and become thinner in the upper part of the unit before the transition to the Nölbling Fm. This unit is here represented mainly by black shales with a few carbonate levels and lenses intercalated, and is about 18 m thick. The Nölbling Fm. is overlain by the La Valute Fm. with a sharp conformable contact (Fig. 39e). Compared to the same formation on the lower part of the section the unit is here slightly more abundant in marl and the beds are thinner, probably indicating a slightly deeper depositional environment. In the uppermost part the La Valute Fm. is more nodular and marly, and grades into the reddish nodular mudstone of the Findenig Fm. (Fig. 39d).

Orthoceratid cephalopods are present throughout the section, but the state of preservation is in general poor, being the specimens often weathered by dissolution and frequently recrystallised. A few gastropods, rare trilobites and solitary corals have been collected from the Alticola and the Rauchkofel formations in the central part of the section, and poorly preserved monograptid graptolites from the lower Lochkovian black shales of the Rauchkofel Fm.

Crinoids are the most spectacular macrofossils of the RMW section, where several well preserved loboliths occur just above the base of the Rauchkofel Fm., about 46 m from the base of the section (Fig. 39c, g). The lobolith bearing beds are about 20 cm thick, and a few lobolith are present also on thinner beds between the thicker ones. Several loboliths, in general well preserved, are closely spaced on bedding plane. Some specimens maintain the typical wall structure of the plate loboliths.

Stop 3.5 – The Upper Ordovician Valbertad section
Coordinates: 46°34’31.5” N, 13°08’39.3” E. Altitude 1346 m

The Valbertad section exposes about 36 m of Upper Ordovician siltstones, sandstones and limestones of the Valbertad and Uqua formations (Fig. 41), and is the type section of the Valbertad Fm. This unit is here 34 m thick and consists of sandstones and siltstones; about 25 m above the base of the section a few cm-thick nodular fine-grained calcareous lenses began to appear in concentrated intervals alternating with sandstones, and become progressively more abundant in the upper part of the unit. The uppermost 2 m of the section belong to the Uqua Fm., and are represented by nodular micritic limestone.

Fossils are relatively abundant within the unit: brachiopods and bryozoans are common, whereas trilobite and corals (Tabulata) are rare, and gastropods and conulariids very rare; cystoids, mainly Rhombifera, are abundant in the central part of the section. A few trace fossils and bioturbations are also present.

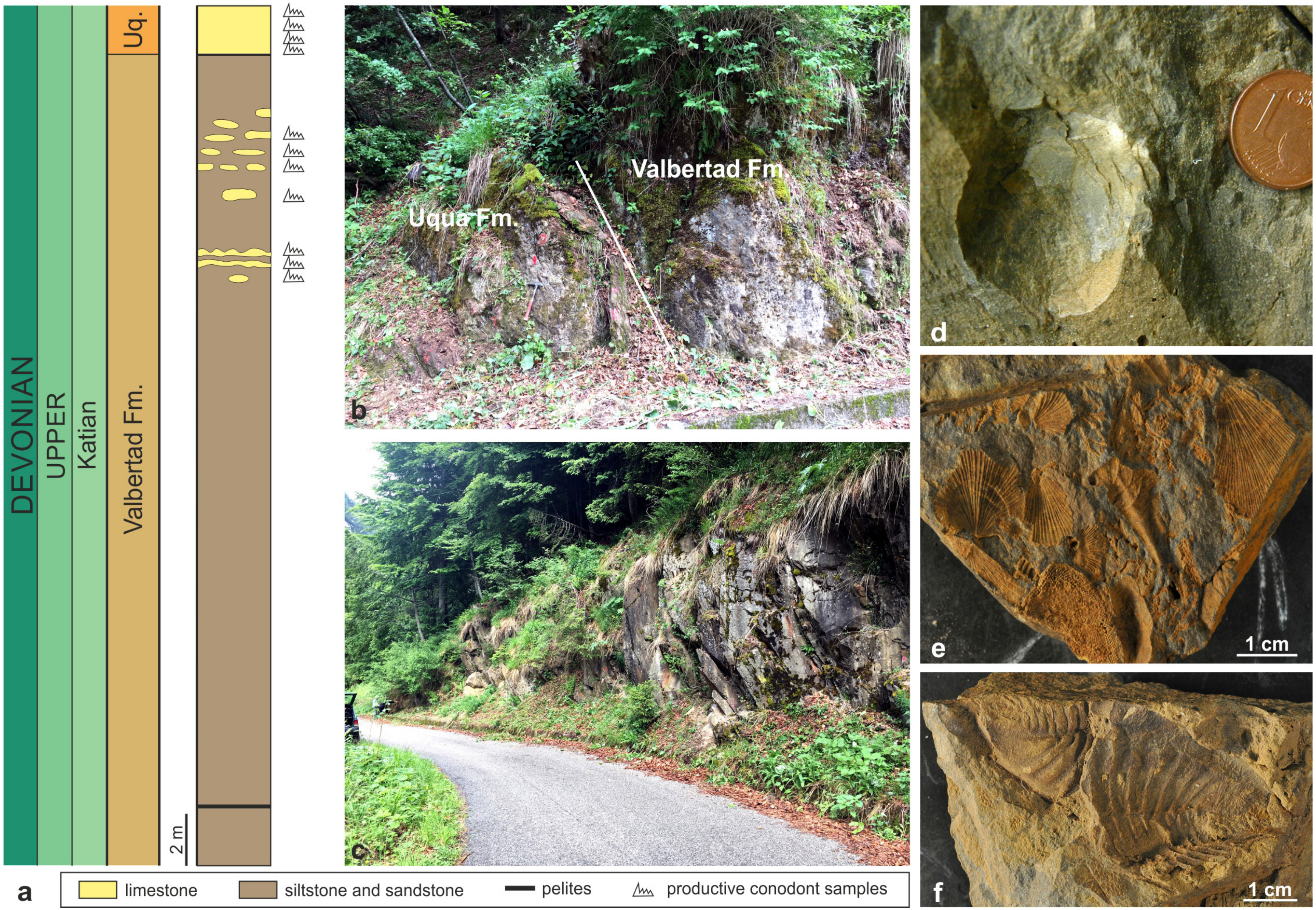

Fig. 41 – The Valbertad section. a) Log of the section. b) View of the upper part of the section with the boundary between the Valbertad and the Uqua formations evidenced. c) View of the lower-central part of the section. d) Cystoid. e) Slab with brachiopods and bryozoans. f) Slab with trilobite remnants. Abbreviation: Uq. = Uqua Fm.

The whole section was sampled for conodonts, but only the carbonate nodules and levels were productive and yielded a rich association (19 species) belonging to the Katian-Hirnantian *Amorphognathus ordovicicus* Zone (Bagnoli et al., 1998, 2017); however, typical Hirnantian species are missing (Bagnoli et al., 2017).

Stop 3.6 – The "*Amphipora* limestone" (Spinotti Fm.) at Cason di Lanza Pass

Coordinates: 46°33'52.5" N, 13°10'16.7" E. Altitude 1567 m

At Cason di Lanza Pass an important lineage ("Linea di Lanza", Venturini, 1990), a dextral strike-slip alpine fault roughly NNW-SSE oriented, separates the pre-Variscan sequence to the south and the Permo-Carboniferous sequence to the north.

On the southern side of Cason di Lanza Pass, sediments pertaining to the calm lagoonal back-reef environment crop out. They are better exposed around the old military house, recently restored, at the beginning of path n. 442a to Mt Zermula (Fig. 42). These rocks, belonging to the Spinotti Fm. and informally named "*Amphipora* limestone", are mainly constituted of "prairies" of *Amphipora ramosa*, trapping carbonatic mud. The amphiporoid animal was a small, cylindrical, branching, calcified sponge (Fig. 42c, d), belonging to class Stromatoporoidea, even if its phylogenetic relationships with other representatives of the group are still unclear (Stearn, 1997). The Genus *Amphipora* is known from Emsian to early Famennian, with the most widespread distribution in Middle Devonian time. It lived in shallow, calm waters, and was anchored inefficiently by irregular outgrowths at the base or cemented into the substrate.

Beside *Amphipora*, rugose corals predominantly of the genus *Dendrostella* are present (Fig. 42e); additionally, in darker levels the brachiopod *Stringocephalus burtinii* occurs (Fig. 42f), allowing to attribute the outcrop to the Givetian (Middle Devonian).

Stop 3.7 – The Kacak Event in the Zuc di Malaseit Bassa section

Coordinates: 46°33'19.6" N, 13°11'10.6" E. Altitude 1465 m

The Zuc di Malaseit Bassa section is located on the eastern flank of Zuc di Malaseit, and will be reached after a short walk along path n. 435, starting from the small parking near the bridge on Pontebbana Creek.

The section exposes an overturned sequence of rocks belonging to the Hoher Trieb Fm. of Middle Devonian age, and has a total thickness of about 15 m (Fig. 43). A detailed conodont stratigraphy, based not only on conodont samples, but also on data obtained by residues of sample collected for geochemical analyses, was provided by Suttner et al. (2017a, b), who also studied the general fossil content; stable isotope and magnetic susceptibility data were presented by Kido et al. (2012) and Suttner et al. (2021).

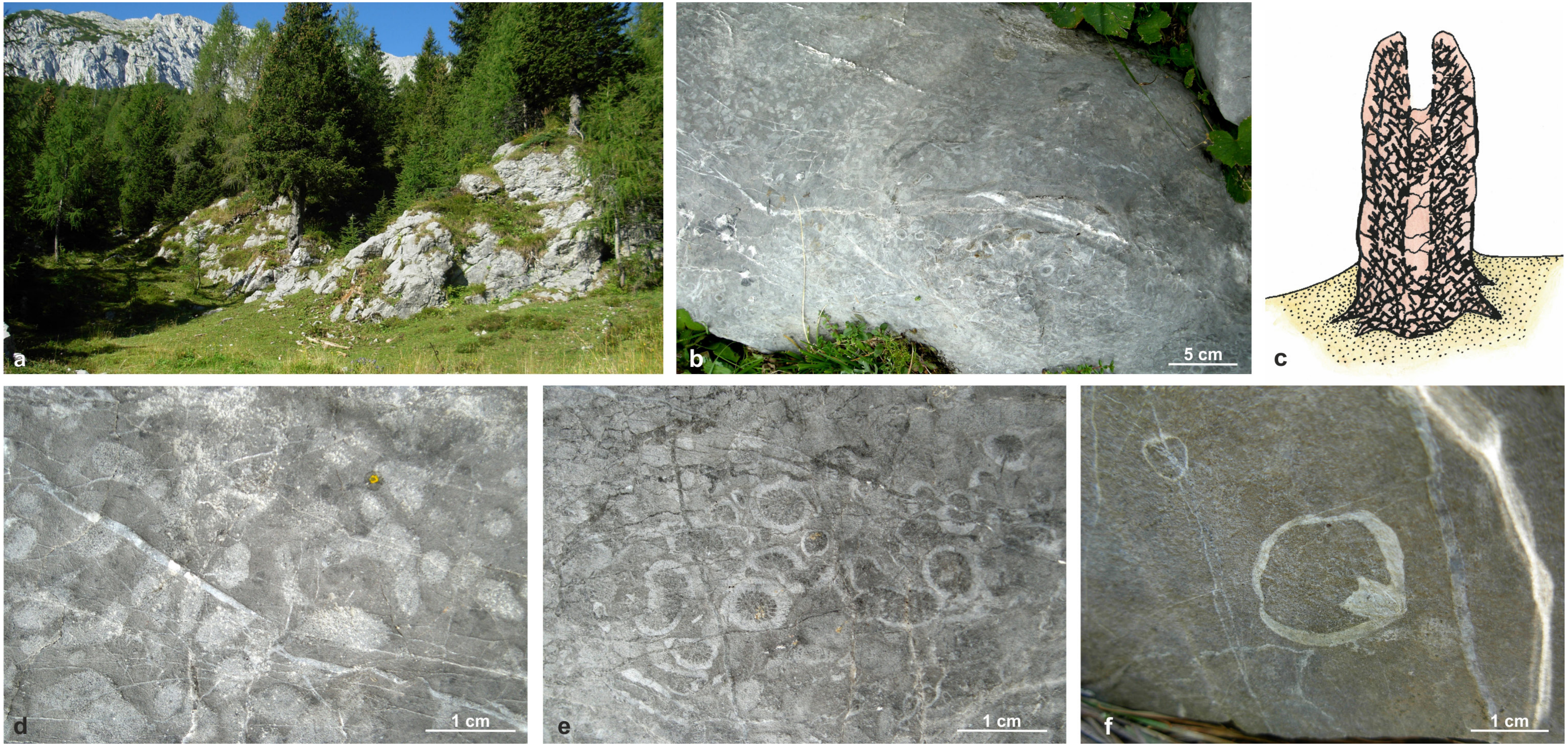

Fig. 42 – The "*Amphipora limestone*" at Passo del Cason di Lanza. a) view to the south of one of the outcrops in the area. b) general view of a bed rich in *Amphipora* and corals. c) Reconstruction of *Amphipora ramosa* (after Stearn, 1997, modified). d) Close view of a rock surface with abundant *Amphipora* remnants. e) Close view of a rock surface with remnants of *Amphipora* and several rugose corals (*Dendrostella* sp.). f) The brachiopod *Stringocephalus burtinii*.

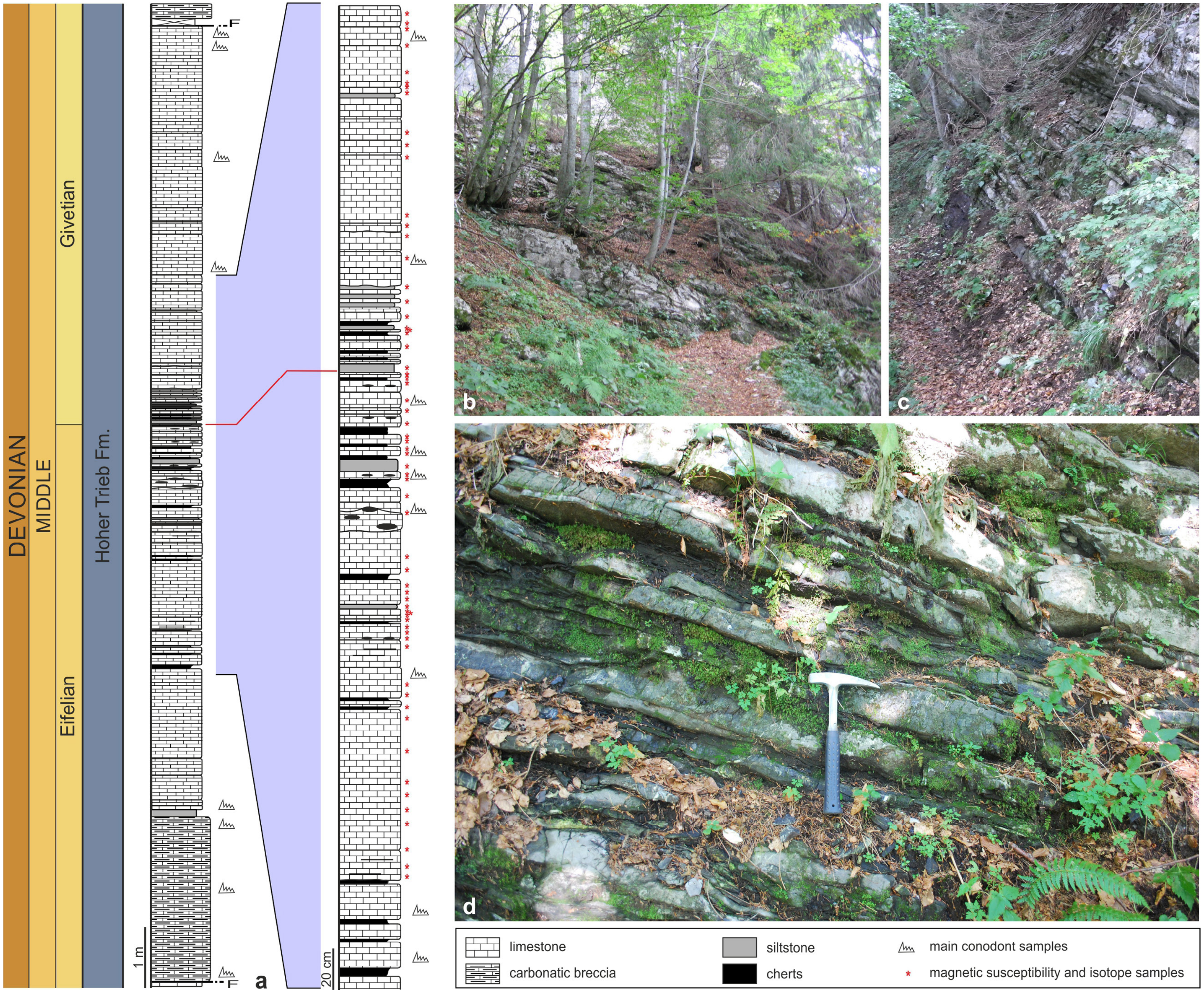

Fig. 43 – The Zuc di Malaseit Bassa section. a) Log of the section (after Suttner et al., 2017b, modified). b) Panoramic view of the section; note that it is tectonically overturned. c) Close view of the central part of the section. d) Detail of part of the section across the Kacak Event (Eifelian/Givetian boundary).

Two several meters-thick limestone breccia levels are present at the base and the top of the section. The central part of the section consists mainly of limestone beds which are intercalated by chert layers; siltstone layers are also present, and are more abundant across the Eifelian/Givetian boundary. Chert nodules occur here and there within limestone beds.

Limestone breccias are composed of lithoclasts of peloidal grainstone, stromatoporoids, corals, brachiopods and crinoid stem plates. Limestone beds mainly consist of peloidal grainstone with crinoids and sometimes foraminifera, ostracods, bryozoans and calcispheres. Some chert-rich intervals consist of argillaceous, dark brown organic-rich grainstone with layers of recrystallised skeletal grains and radiolarians. Some siltstones are organic-rich with a high clay content and yield crinoidal stem plates. Additionally, laminated carbonaceous siltstones that yield ostracod valves, broken tentaculitids, crinoids and calcispheres occur.

The central part of the section is a good exposition of the Kačák Event (House, 1985). It is one of the main extinction events of the Devonian, caused by widespread dysoxic/anoxic conditions, and is represented by a black shale and chert interval documented globally in sedimentary sequences across the Eifelian/Givetian boundary. The event interval in general is characterised by significant extinctions among benthic invertebrate groups and distinctive faunal changes observed in pelagic and planktonic groups.

Stop 3.8 – Panoramic view on the Zuc di Malaseit overthrust

Coordinates: 46°33’17.8” N, 13°11’28.1” E. Altitude 1421 m

Moving down toward Pontebba, from the area nearby Caserutte, a panoramic view of the eastern side of the Zuc di Malaseit exposes the north-dipping thrust that pile the Devonian shallow water units on top of the Upper Ordovician-lower Carboniferous slope to basin succession (Fig. 44). The top to the south movement, probably formed or at least reactivated during the Tortonian-Serravallian phase, is associated to other minor structures. These structures disrupt a multi-kilometric asymmetric fold presumably formed during Variscan times (Pondrelli et al., 2015), forming a puzzle of “normal” polarity and overturned successions.

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We want to dedicate this field guide to Silvio Cescutti, recently passed away, who managed Casera Cason di Lanza for long time. We spent so many nights there during our field work campaigns in the Mt Zermula area and we

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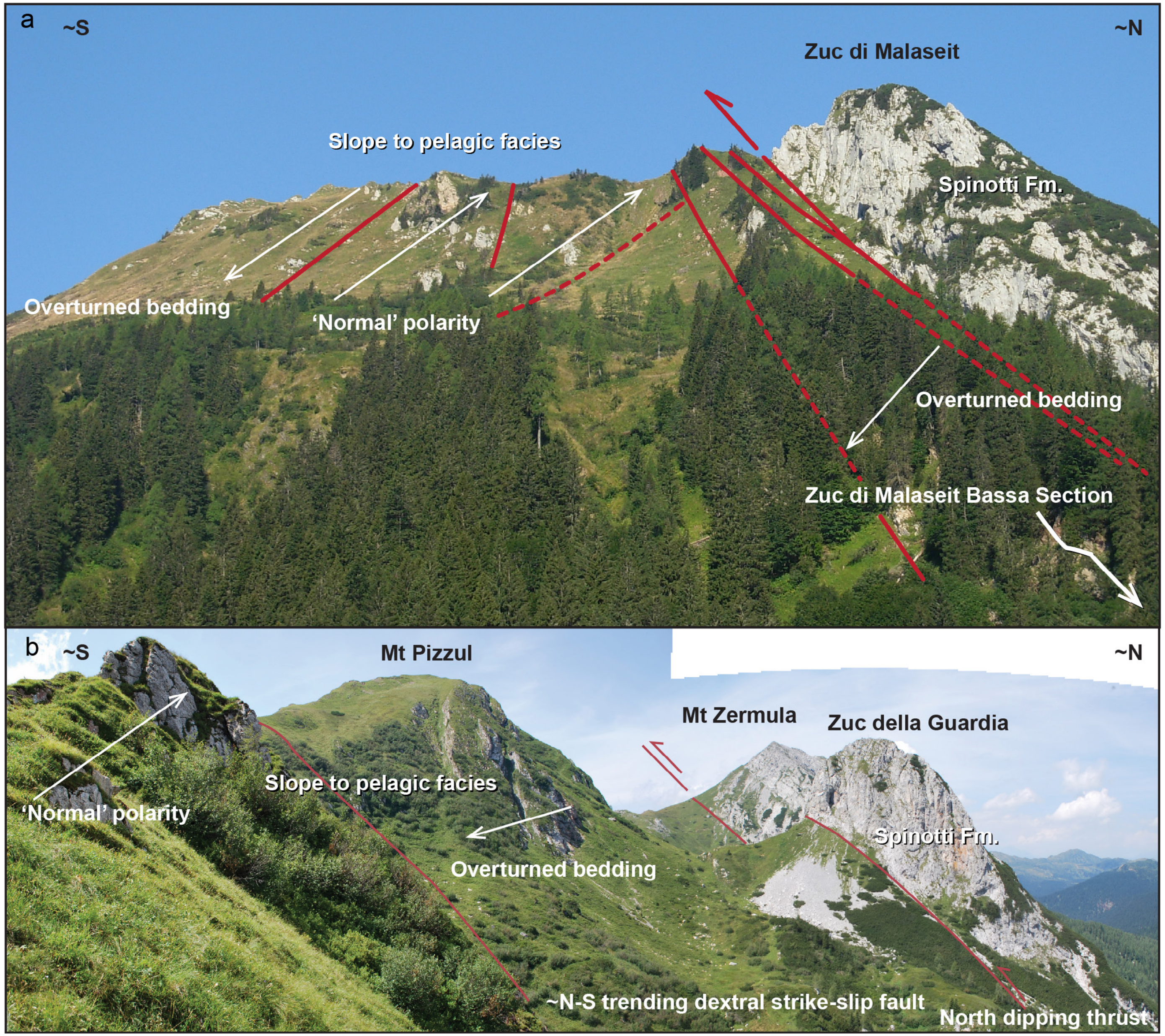

Fig. 44 – a) Panoramic view of the eastern flank of the Zuc di Malaseit showing a north dipping thrust bringing the shallow water units of the Spinotti Fm. on top the slope to basin Upper Ordovician to lower Carboniferous succession. b) Westward continuation of the thrust structure, leading the Zuc della Guardia and Mt Zermula shallow water units of the Spinotti Fm. on top of the Mt Pizzul slope to basin succession (redrawn after Pondrelli et al., 2015).

References

Amerom H.W.J., Van Flajs G., Hunger G. (1984) - Die “Flora der Marinelli-Hütte” (Mittleres Visé) aus dem Hochwipfelflysch der Karnischen Alpen (Italien). Mededelingen Rijks Geologische Dienst, 37, 1-41.

Amerom H.W.J. Van, Schönlaub H.P. (1992) - Pflanzenfossilien aus dem Karbon von Nötsch und der Hochwipfel-Formation der Karnischen Alpen (Österreich). Jahrbuch der Geologischen Bundesanstalt, 135/1, 195-216.

Bagnoli G., Ferretti A., Serpagli E., Vai G.B. (1988) - Late Ordovician conodonts from the Valbertad Section (Carnic Alps). In M.C. Perri & C. Spalletta (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, 60, Special issue, 138-149.

Bagnoli G., Ferretti A., Simonetto L., Corradini C. (2017) - Upper Ordovician conodonts in the Valbertad section. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 23, 228-231.

Bandel K. (1972) - Palökologie und Paläogeographie im Devon und Unterkarbon der zentralen Karnischen Alpen. Palaeontographica Ab. A, 141, 1-117.

Bartel E.M., Neubauer F., Genser J., Heberer B. (2014) - States of paleostress north and south of the Periadriatic fault: Comparison of the Drau Range and the Friuli Southalpine wedge. Tectonophysics, 637, 305-327.

Bergström S.M., Chen X, Gutiérrez-Marco J.C., Dronov A. (2009) – The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to the $\delta^{13}C$ chemostratigraphy. Lethaia, 42, 97-107.

Brett C.E., Ferretti A., Histon K., Schönlaub H.P. (2009) - Silurian sequence stratigraphy of the Carnic Alps, Austria. Palaeogeogr. Palaeoclimatol. Palaeoecol., 279, 1-28.

Brime C., Perri M.C., Pondrelli M., Spalletta C., Venturini C. (2008) - Polyphase metamorphism in the eastern Carnic Alps (N Italy-S Austria): Clay minerals and conodont Colour Alteration Index evidence. Int. J. Earth. Sci., 97, 1213-1229.

Corradini C., Corriga M.G., Männik P., Schönlaub H.P. (2015a) - Revised conodont stratigraphy of the Cellon section (Silurian, Carnic Alps). Lethaia, 48, 56-71. https://doi.org/10.1111/let.12087.

Corradini C., Corriga M.G., Pondrelli M., Serventi P., Simonetto L. (2010) - Il Siluriano di Monte Cocco (Alpi Carniche). Gortania Geologia, Paleontologia, Paletnologia, 31, 23-30.

Corradini C., Corriga M.G., Pondrelli M., Serventi P., Simonetto L., Ferretti, A. (2019a) - Lochkovian (Lower Devonian) marine-deposits from the Rio Malinfier West section (Carnic Alps, Italy). Ital. J. Geosci., 138 (2), 153-170. https://doi.org/10.3301/IJG.2018.33.

Corradini C., Corriga M.G., Pondrelli M., Suttner T.J. (2020a) - Conodonts across the Silurian/Devonian boundary in the Carnic Alps (Austria and Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol., 549, 109097. https://doi.org/10.1016/j.palaeo.2019.02.023.

Corradini C., Kido E., Suttner T., Simonetto L., Pondrelli M., Corriga M.G., Spalletta C. (2019b) - Devonian reefs of the Carnic Alps and related environments. 13th International Symposium on Fossil Cnidaria and Porifera, Modena, 3-6 September 2019. Pre-Conference field Trip. 24 pp.

Corradini C., Mossoni A., Pondrelli M., Simonetto L., Spalletta C., Zucchini R. (2017) - Sub-aerial exposures in the Tournaisian (lower Carboniferous) of the central Carnic Alps. Stratigraphy, 14, 87-96. https://doi.org/10.29041/strat.14.1-4.87-96.

Corradini C., Pondrelli M., Corriga M.G., Simonetto L., Kido E., Suttner T.J., Spalletta C., Carta N. (2012) - Geology and stratigraphy of the Cason di Lanza area (Mount Zermula, Carnic Alps, Italy). Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 17, 83-103.

Corradini C., Pondrelli M., Simonetto L., Corriga M.G. (2020b) - Geology of Mount Zermula massif (Carnic Alps, Italy). Gortania Geologia, Paleontologia, Paletnologia, 42, 5-24.

Corradini C., Pondrelli M., Simonetto L., Corriga M.G., Spalletta C., Suttner T.J., Kido E., Mossoni A., Serventi P. (2016) - Stratigraphy of the La Valute area (Mt Zermula massif, Carnic Alps, Italy). Boll. Soc. Paleontol. It., 55 (1), 55-78. https://doi.org/10.4435/BSPI.2016.06.

Corradini C., Pondrelli M., Suttner T.J., Schönlaub H.P., (2015b) - The Pre-Variscan sequence of the Carnic Alps. Berichte der Geologisches Bundesantsalt, 111, 5-40.

Corradini C. and Suttner T.J. (Eds.) (2015) - The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Bundesanstalt, 69, 158 pp.

Corradini C., Suttner T.J., Ferretti A., Pohler S.M.L., Pondrelli M., Schönlaub H.P., Spalletta C., Venturini C. (2015c) - The Pre-Variscan sequence of the Carnic Alps - an introduction. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 7-15.

Corriga M.G. (2011) - Biostratigrafia a conodonti attorno al limite Siluriano-Devoniano in alcune aree del Nord Gondwana. PhD Thesis, Università di Cagliari, Italy, 174 pp.

Corriga M.G., Corradini C., Ferretti A., Pondrelli M., Simonetto L., Serventi P. (2017) - Lochkovian conodonts in the Rio Malinfier West section. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 23, 235-241.

Corriga M.G., Corradini C., Pondrelli M., Schönlaub H.P., Nozzi L., Todesco R., Ferretti A. (2021) - Uppermost Ordovician to lowermost Devonian conodonts from the Valentintörl section and comments on the post Hirnantian hiatus in the Carnic Alps. Newsl. Stratigr., 54, 183-207. https://doi.org/10.1127/nos/2020/0614.

Corriga M.G., Corradini C., Pondrelli M., Simonetto L. (2012) - Lochkovian (Lower Devonian) conodonts from the Rio Malinfier section (Carnic Alps, Italy). Gortania Geologia, Paleontologia, Paletnologia, 33, 31-38.

Corriga M.G., Corradini C., Schönlaub H.P., Pondrelli M. (2016) - Lower Lochkovian (Lower Devonian) conodonts from Cellon section (Carnic Alps, Austria). Bull. Geosci., 91, 261-270. https://doi.org/10.3140/bull.geosci.1594.

Ferretti A. (2005) - Ooidal ironstones and laminated ferruginous deposits from the Silurian of the Carnic Alps, Austria. Boll. Soc. Paleontol. It., 44, 263-278.

Ferretti A. and Schönlaub H.P. (2001) – New conodonts from the Late Ordovician of the central Carnic Alps, Austria. Boll. Soc. Paleontol. It., 40, 3-15.

Ferretti A., Schönlaub H.P., Corradini C., Corriga M.G., Pondrelli M., Simonetto L., Serventi P. (2015a) - Kok Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 46-51.

Ferretti A., Schönlaub H.P., Corradini C., Corriga M.G., Pondrelli M., Simonetto L., Serventi P. (2015b) - Cardiola Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 52-55.

Ferretti A., Schönlaub H.P., Corradini C., Corriga M.G., Pondrelli M., Simonetto L., Serventi P. (2015c) - Alticola Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 56-60.

Forke H.C., Schönlaub H.P., Samankassou E. (2006) - Late Palaeozoic of the Carnic Alps (Austria/Italy). Berichte der Geologisches Bundesanstalt, 70: 57 pp.

Geyer G. (1894) - Zur Stratigraphie der palaeozoischen Schichtserie in den Karnischen Alpen. Verhandlungen der kaiserlich königlichen Geologischen Reichsanstalt 1894, 102-119.

Hammarlund E.U., Dahl T.W., Harper D.A.T., Bond D.P.G., Nielsen A.T., Bjerrum C.J., Schovsbo N.H., Schönlaub H.P., Zalasiewicz J.A., Canfield D.E. (2012) - A sulfidic driver for the end-Ordovician mass extinction. Earth Planet. Sci. Lett., 331, 128-139.

Harper D.A.T., Histon K., Schönlaub H.P. (2009) - Late Ordovician, deep-water *Foliomena* brachiopod fauna from Cellon, Carnic Alps. – 53rd Annual Meeting of the Palaeontological Association, Birmingham, UK, December 2009, 53.

Histon K. (2012) - The Silurian nautiloid-bearing strata of the Cellon Section (Carnic Alps, Austria): Color variation related to events. Palaeogeogr. Palaeoclimatol. Palaeoecol., 367-368, 231–255.

House M.R. (1985) - Correlation of mid-Palaeozoic ammonoid evolutionary events with global sedimentary perturbations. Nature, 313, 17-22. https://doi.org/10.1038/313017a0.

House M.R. (2002) - Strength, timing, setting and cause of mid-Palaeozoic extinctions. Palaeogeogr. Palaeoclimatol. Palaeoecol., 181, 5-25. https://doi.org/10.1016/S0031-0182 (01)00471-0.

Hubmann B., Pohler S., Schönlaub H.P., Messner F. (2003) - Paleozoic Coral-Sponge Bearing Successions in Austria. - Field Trip Stops. Berichte der Geologischen Bundesanstalt, 61, 63-64.

Jaeger H. (1975) - Die Graptolithenführung im Silur/Devon des Cellon-Profils (Karnische Alpen). Carinthia II, 165 (185), 111-126.

Jaeger H., Havlicek V., Schönlaub H.P. (1975) - Biostratigraphie der Ordovizium/Silur-Grenze in den Südalpen – Ein Beitrag zur Diskussion un die Hirnantia-Fauna. Verhandlungen der Geologischen Budesanstalt, 1975, 271-289.

Jaeger H. and Schönlaub H.P. (1977) - Das Ordoviz/Silur-Profil im Nolblinggraben (Karnische Alpen, Osterreich). Verhandlungen der Geologischen Budesanstalt, 1977, 349-359.

Jaeger H. and Schönlaub H.P. (1980) - Silur und Devon nördlich der Gundersheimer Alm in den Karnischen Alpen (Österreich). Carinthia II, 1980, 403-444.

Jaeger H. and Schönlaub H.P. (1994) - "Graptolithengraben" (graptolite gorge) north of Upper Bischofalm. In: Schönlaub, H.P. & Kreutzer, L.H. (Eds): Field meeting Eastern + Southern Alps, Austria 1994, Guidebook + Abstracts. Berichte der Geologischen Bundesanstalt, 30, 97-100.

Jeppsson L., Talent J.A., Mawson R., Andrew A., Corradini C., Simpson A.J., Wigforss-Lange J., Schönlaub H.P. (2012) - Late Ludfordian correlations and the Lau Event. In Talent J.A. (Ed.), Earth and Life, International Year of Planet Earth, Springer Verlag, 653-675. https://doi.org/10.1007/78-90-481-3428-1_21.

Kaiser S.I., Becker R.T., Spalletta C., Steuber T. (2009) - High-resolution conodont stratigraphy, biofacies, and extinctions around the Hangenberg Event in pelagic successions from Austria, Italy, and France. In D.J. Over (Ed.), Studies in Devonian Stratigraphy: Proceedings of the 2007 International Meeting of the Subcommission on Devonian Stratigraphy and IGCP 499. Palaeontogr. Am., 63, 99-143.

Kido E., Pohler S.M.L., Pondrelli M., Schönlaub H.P., Simonetto L., Spalletta C., Suttner T.J. (2015) - Kellergrat Formation. In: Corradini, C. & Suttner T. J. (Eds): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Bundesanstalt, 69, 101-104.

Kido E., Suttner T.J., Pondrelli M., Corradini C., Corriga M.G., Simonetto L., Vodrazkova S., Koptikova L. (2012) - Magnetic susceptibility and carbon isotopic record across the Eifelian-Givetian boundary in the Carnic Alps. 4th International Geologica Belgica Meeting 2012. Moving Plates and Melting Icecaps – Processes and Forcing Factors in Geology. Brussels 11-14/09/12. Abstract book, 43.

Kreutzer L.H. (1990) - Mikrofazies, Stratigraphie und Paläogeographie des Zentralkarnischen Hauptkammes zwischen Seewarte und Cellon. Jahrbuch der Geologisches Bundesanstalt, 133 (2), 275-343.

Kreutzer L.H. (1992) - Palinspastische Entzerrung und Neugliederung des Devons in den Zentralkarnischen Alpen aufgrund von neuen Untersuchungen. Jahrbuch der Geologisches Bundesanstalt, 135 (1), 261-272.

Kreutzer L.H., Schönlaub H.P., Hubmann B. (1997) - The Devonian of Austria. In Schönlaub H.P. (Ed.), IGCP-421 North Gondwanan Mid-Palaeozoic Biodynamics, Guidebook. Berichte der Geologisches Bundesanstalt, 40, 42-60.

Läufer A., Hubich D., Loeschke J. (2001) - Variscan geodynamic evolution of the Carnic Alps (Austria/Italy). Int. J. Earth. Sci., 90, 855-870.

Läufer A., Loeschke J., Vianden B. (1993) - Die Dimon-Serie der Karnischen Alpen (Italien) - Stratigraphie, Petrographie und geodynamische Interpretation. Jahrbuch der Geologischen Bundesanstalt, 136/1, 137-162.

Pas D., Da Silva A.C., Suttner T.J., Kido E., Bultynck P., Pondrelli M., Corradini C., De Vleeschouwer D., Dojen C., Boulvain F. (2014) - Insight into the development of a carbonate platform through a multi-disciplinary approach: a case study from the Upper Devonian slope deposits of Mount Freikofel (Carnic Alps, Austria/Italy). Int. J. Earth. Sci., 103, 519-538. https://doi.org/10.1007/s00531-013-0969-2.

Pasquaré Mariotto F. and Venturini C. (2019) - Birth and evolution of the Paleocarnic Chain in the Southern Alps: A review. Int. J. Earth. Sci., 108, 2469-2492. https://doi.org/10.1007/s00531-019-01774-y.

Perri M.C. and Spalletta C. (1998a) - Updating of the conodont biostratigraphy in the Carnic Alps (Italy). In M.C. Perri & C. Spalletta (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, 60, Special Issue, 116-119.

Perri M.C. and Spalletta C. (1998b) - Latest Devonian and Early Carboniferous conodonts from the Casera Collinetta di Sotto A section (Carnic Alps, Italy). In M.C. Perri & C. Spalletta (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, 60, Special Issue, 168-181.

Perri M.C. and Spalletta C. (1998c) - Conodont distribution at the Tournaisian/Visean boundary in the Carnic Alps (Southern Alps, Italy). Palaeontol. Pol., 58, 225-245.

Perri M.C. and Spalletta C. (2001) - Hangenberg Event al limite Devoniano/Carbonifero al Monte Zermula, Alpi Carniche, Italia. Giornale di Geologia, 62, 31-40.

Pisarzowska A., Rakociński M., Marynowski L., Szczerba M., Thoby M., Paszkowski M., Perri M.C., Spalletta C., Schönlaub H.P., Kowalik N., Gereke M. (2020) - Large environmental disturbances caused by magmatic activity during the Late Devonian Hangenberg Crisis. Glob. Planet. Change, 190, 103155. https://doi.org/10.1016/j.gloplacha.2020.103155.

Pohler S.M.L., Bandel K., Kido E., Pondrelli M., Suttner T.J., Schönlaub H.P., Mortl A. (2015) - Polinik Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 81-84.

Pondrelli M., Corradini C., Corriga M.G., Kido E., Mossoni A., Simonetto L., Spalletta C., Suttner T., Carta N. (2015) - Depositional and deformational evolution of a Lower Paleozoic portion of the Southalpine domain: the Mt Pizzul area (Carnic Alps, Italy). Int. J. Earth. Sci., 104, 147-178. https://doi.org/10.1007/s00531-014-1069-7.

Pondrelli M., Corradini C., Spalletta C., Suttner T.J., Simonetto L., Perri M.C., Corriga M.G., Venturini C., Schönlaub H.P. (2020) - Geological map and stratigraphic evolution of the central sector of the Carnic Alps (Austria-Italy). Ital. J. Geosci., 139, 469-484. https://doi.org/10.3301/IJG.2020.16.

Rantitsch G. (1992) - Fazies und Diagenese devonischer Riffkalke des Seeberger Aufbruches (Kärnten, Österreich). Jahrbuch der Geologischen Bundesanstalt, 135, 273-285.

Rakociński M., Marynowski L., Pisarzowska A., Bełdowski J., Siedlewicz G., Zatoń M., Perri M.C., Spalletta C., Schönlaub H.P. (2020) - Volcanic related methylmercury poisoning as the possible driver of the end-Devonian mass extinction. Scientific Reports 10, 7344.

Rossi P.L. and Vai G.B. (1986) - New geochemical data on Silesian volcanics (Dimon Fm.) from the Carnic Alps and geodynamic implication. IGCP Pr. No. 5, Final Meeting, Cagliari 1986, Abstracts: 77.

Schönlaub H.P. (1969) - Conodonten aus dem Oberdevon und Unterkarbon des Kronhofgrabens (Karnische Alpen, Österreich). Jahrbuch der Geologischen Bundesanstalt, 112, 321-354.

Schönlaub H.P. (1980) - Carnic Alps. Field Trip A. In Schönlaub H.P. (Ed.), Second European Conodont Symposium (ECOS II), Guidebook, Abstracts. Abhandlungen der Geologischen Budesanstalt, 40, 5-57.

Schönlaub H.P. (1985) - Das Paläozoikum der Karnischen Alpen. In Schönlaub H.P. (Ed.): Arbeitstagung der Geologischen Bundesanstalt 1985 Kötschach-Mauthen, Gailtal. Geologische Bundesanstalt, 34-52.

Schönlaub H.P. (1992) - Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its implications for Plate Movements. Jahrbuch der Geologischen Budesanstalt, 135, 381-418.

Schönlaub H.P. (1997) - The Silurian of Austria. In: Schönlaub H.P. (Ed.), IGCP-421 North Gondwanan Mid-Palaeozoic Biodynamics, Guidebook. Berichte der Geologischen Bundsanstalt, 40, 20-41.

Schönlaub H.P. and Ferretti A. (2015a) - Uqua Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 38-41.

Schönlaub H.P. and Ferretti A. (2015b) - Plöcken Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 42-45.

Schönlaub H.P., Ferretti A., Gaggero L., Hammarlund E., Harper D.A.T., Histon K., Priewalder H., Spötl C., Štorch P. (2011) - The Late Ordovician glacial event in the Carnic Alps (Austria). In: Gutiérrez-Marco J.C., Rábano I., Garcia-Bellido D. (Eds), Ordovician of the World. Cuadernos del Museo Geominero, 14, 515-526.

Schönlaub H.P. and Forke H.C. (2007) - Die post-variszische Schichtfolge der Karnischen Alpen – Erläuterungen zur Geologischen Karte des Jungpaläozoikums der Karnischen Alpen 1:12.500. Abhandlungen der Geologischen Budesanstalt, 61, 3-157.

Schönlaub H.P. and Histon, K. (1999) - The Palaeozoic of the Southern Alps. In: Histon K. (Ed.), V International Symposium, Cephalopods – Present and Past. Carnic Alps. Excursion Guidebook. Berichte der Geologischen Bundesanstalt, 47, 6-30.

Schönlaub H.P., Histon K., Pohler S. (2004) - The Palaeozoic of the Carnic Alps. Field trip Stops: Stop 3 – Abandoned quarry near base of trail # 149 to Rifugio Marinelli. Field Trip Carnic Alps Guidebook. June 23-24, 2004, Carinthia Austria. Geologische Bundesanstalt, Wien, 2-32.

Schönlaub H.P., Klein P., Magaritz M., Rantitsch G., Scharbert S. (1991) - Lower Carboniferous paleokarst in the Carnic Alps (Austria, Italy). Facies, 25, 91-117.

Schönlaub, H.P. and Kreutzer, L.H. (1993) - Paleozoic boundary sections of the Carnic Alps (southern Alps). Erlanger Geol. Abh, 122, 77-103.

Schönlaub H.P., Kreutzer L.H., Priwalder H. (1994) - Section 2: Cellon Section. In: Schönlaub H.P., Kreutzer L.H. (Eds.), IUGS Subcommission on Silurian Stratigraphy - Field Meeting Eastern + Southern Alps, Austria 1994. Berichte der Geologischen Bundesanstalt, 30, 83-93.

Scotese C.R. (2014a) - Atlas of Permo-Carboniferous Paleogeographic Maps, The Late Paleozoic, PALEOMAP Atlas for ArcGIS, 4, PALEOMAP Project, Evanston, IL. (U.S.A.) https://doi.org/10.13140/2.1.1837.8244.

Scotese C.R. (2014b) - Atlas of Devonian Paleogeographic Maps, PALEOMAP Atlas for ArcGIS, 4, PALEOMAP Project, Evanston, IL. (U.S.A.) https://doi.org/10.13140/2.1.1542.5280.

Scotese C.R. (2014c) - Atlas of Silurian and Middle-Late Ordovician Paleogeographic Maps, PALEOMAP Atlas for ArcGIS, 5, PALEOMAP Project, Evanston, IL. (U.S.A.). https://doi.org/10.13140/2.1.1087.2324.

Spalletta C., Corradini C., Feist R., Korn D., Kumpan T., Perri M.C., Pondrelli M., Venturini C. (2021) - The Devonian/Carboniferous Boundary in the Carnic Alps (Austria and Italy). Paleobiodivers. Paleoenviron., 101, 487-505. https://doi.org/10.1007/s12549-019-00413-3.

Spalletta C., Perri M.C., Vai G.B. (1983) – Pattern of conodont reworking in the Upper Devonian of the Alps: palaeoenvironmental and palaeotectonic implications. Lethaia, 16, 51-66.

Spalletta C., Perri M.C., Pondrelli M., Corradini C., Mossoni A., Schönlaub H.P. (2015) –Pal Grande Formation. In Corradini C. & Suttner T. (Eds), The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). Abhandlungen der Geologischen Budesanstalt, 69, 137-140.

Spalletta C. and Vai G B. (1984) - Upper Devonian intraclast parabreccias interpreted as seismites. Mar. Geol., 55, 133-144.

Spalletta C. and Venturini C. (1988) - Conglomeratic Sequences in the Hochwipfel Formation: a new palaeogeographic hypothesis on the Hercynian Flysch Stage of the Carnic Alps. Jahrbuch der Geologischen Bundesanstalt, 131, 637-647.

Stearn C.W. (1997) - Intraspecific variation, diversity, revised systematics and type of the Devonian stromatoporoid *Amphipora*. Palaeontology, 40, 833-854.

Suttner T.J. (2007) - Conodont stratigraphy, facies-related distribution patterns and stable isotopes (carbon and oxygen) of the uppermost Silurian to lower Devonian Seewarte section (Carnic Alps, Carinthia, Austria). Abhandlungen der Geologischen Budesanstalt, 59, 1-111.

Suttner T.J., Kido E., Corradini C., Corriga M.G., Pondrelli M., Simonetto L. (2017a) - Late Eifelian to early Givetian conodonts of the Zuc di Malaseit Basso (ZMB) section. Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 23, 242-245.

Suttner T., Kido E., Corradini C., Vodrážková S., Pondrelli M., Simonetto L. (2017b) - Conodont diversity across the late Eifelian Kačák Episode of the southern Alpine realm (central Carnic Alps, Austria/Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol., 479, 34-47. https://doi.org/10.1016/j.palaeo.2017.04.015.

Suttner T.J., Kido E., Joachimski M.M., Vodrážková S., Pondrelli M., Corradini C., Corriga M.G., Simonetto L., Kubajko M. (2021) - Paleotemperature record around the Middle Devonian Kačák Episode. Scientific reports, 11, 16599. https://doi.org/10.1038/s41598-021-96013-3

Vai G.B. (1963) - Ricerche geologiche nel gruppo del M. Coglians e nella zona di Volaia (Alpi Carniche). Giornale di Geologia, 30, 137-198.

Vai G.B. (1976) - Stratigrafia e paleogeografia ercinica delle Alpi. Mem. Soc. Geol. It., 13 (1), 7-37.

Vai G.B. (1980) - Sedimentary environment of Devonian pelagic limestones in the Southern Alps. Lethaia, 13 (1), 79-91.

Venturini C. (1990) - Geologia delle Alpi Carniche centro-orientali. Pubblicazioni del Museo Friulano di Storia Naturale, 36, 220 pp.

Venturini C. (1991) – Introduction to the geology of Pramollo Basin (Carnic Alps) and its surrondings. In: Venturini C. (Ed.), Workshop proceedings on ‘Tectonics and Stratigraphy of the Pramollo Basin (Carnic Alps)’. Giornale di Geologia 53, 13-47.

Venturini C., Pondrelli M., Del Zotto S., Fontana C., Discenza K. (2002) - Carta Geologica delle Alpi Carniche - Foglio Orientale, scala 1:25000. Selca, Firenze.

Venturini C. and Spalletta C. (1998) – Remarks on the Palaeozoic stratigraphy and the Hercynian tectonics of the Palaeocarnic Chain (Southern Alps). In M.C. Perri & C. Spalletta (Eds), Southern Alps Field Trip Guidebook, ECOS VII. Giornale di Geologia, 60, Special Issue, 69-88.

von Raumer J.F. and Stampfli G.M. (2008) - The birth of the Rheic Ocean - Early Palaeozoic subsidence patterns and subsequent tectonic plate scenarios. Tectonophysics, 461, 9-20.

Walliser O.H. (1957) - Conodonten aus dem oberen Gotlandium Deutschlands und der Karnischen Alpen. Notizblatt des Hessischen Landesamtes für Bodenforschung zu Wiesbaden, 85, 28-52.

Walliser O.H. (1964) - Conodonten des Silurs. Abhandlungen des Hessischen Landesamtes fur Bodenforschung Wiesbaden 41, 1-106.

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