The Pre-Variscan sequence of the Carnic Alps

Carlo Corradini, Monica Pondrelli, Thomas J. Suttner & Hans Peter Schönlaub

with contributions from
Maria G. Corriga, Annalisa Ferretti, Erika Kido, Luca Simonetto & Claudia Spalletta

30 figures

Carlo Corradini - Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, via Trentino 51, 09127 Cagliari, Italy; corradin@unica.it
Monica Pondrelli - International Research School of Planetary Sciences, Università d'Annunzio, viale Pindaro 42, 65127, Pescara, Italy; monica@irsps.unich.it
Thomas J. Suttner - Institute for Earth Sciences (Geology & Paleontology), NAWI Graz, University of Graz, Heinrichstrasse 26, 8010 Graz, Austria; suttner.thomas@uni-graz.at
Hans Peter Schönlaub - Austrian Academy of Sciences, Commission for Geosciences, Dr. Ignaz Seipel-Platz 2, 1010 Vienna, Austria; hp.schoenlaub@aon.at

Contents

Abstract

The Pre-Variscan sequence of the Carnic Alps includes rocks deposited between the Middle Ordovician and the early Late Carboniferous, and represents one of the most continuous sequence of the world in that time interval. In a relatively small area it is possible to distinguish rocks deposited at various latitudes and climate (from cold in the Ordovician to tropical in the Devonian), and in different sedimentary environments (from shallow water, including reef deposition, to basin). The lithostratigraphy of the sequence has been recently revised and formalised, and 36 formations have been discriminated.

1. Topics and area of the Field Trip

The Carnic Alps are located along the Italian-Austrian border (Fig. 1). One of the better exposed and complete Palaeozoic sequences of the world, is here exposed.

Fig. 1. Location of the Carnic Alps.

Rocks deposited between the Middle Ordovician and the Upper Triassic crop out in the Carnic Alps. They are subdivided into three sequences: the Pre-Variscan, the Permo-Carboniferous and the Alpine sequences. The Pre-Variscan sequence includes rocks of Middle Ordovician to early Late Carboniferous age, which were affected by the Variscan orogeny during the late Bashkirian and Moscovian (SCHÖNLAUB, 1980; VENTURINI, 1990; SCHÖNLAUB & FORKE, 2007). 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 Permo-Carboniferous sequence ranges from the Late Carboniferous to the Middle Permian. The youngest Palaeozoic rocks of the Carnic Alps are Late Permian and Middle Triassic in age, and are part of the so-called 'Alpine' sequence (VENTURINI, 1990).

Fig. 2. Road map of the Carnic Alps, with indication of the areas visited during the field trip. Black rectangle: Day 1 (Fig. 7); red rectangle: Day 2 (Fig. 10); blue rectangle: Days 3-4 (Fig. 20). The yellow rectangle enhance the village of Dellach, where the Visitor Centre of the Carnic Alps Geopark is located.

The field trip focuses on the Pre-Variscan sequence, with special attention to the newly established lithostratigraphic subdivision (Corradini & Suttner, 2015). Several sections and outcrops in the central part of the Carnic Alps will be visited during the four days field trip (Fig. 2) and thus provide a chance to recognise the great majority of the 36 formations which were recently revised and newly defined in the area. All the localities will be reached by hiking on well-marked paths in a mountain environment. This will give also the opportunity to visit some military evidences (trenches, fortifications, cemeteries) of First World War: in fact, the Carnic Alps were theater of hard fighting in that period. A visit to the Visitor Centre of the Carnic Alps Geopark is also scheduled.

2. Geological overview

The Carnic Alps are located along the Italian-Austrian border. One of the better exposed and complete Palaeozoic sequences of the world, ranging from the Middle Ordovician to the Permian/Triassic boundary up to the Middle Triassic, is here exposed.

The "Palaeocarnic Chain" is considered as a 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. 3). 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 & Spalletta, 1998; Schönlaub & Forke, 2007). The Palaeocarnic Chain can be subdivided into two parts (Fig. 3), 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 sedimentary successions (Schönlaub, 1980, 1985, 1997; Venturini & Spalletta, 1998; Brime et al., 2008) except for the northernmost part where banded limestones occur.

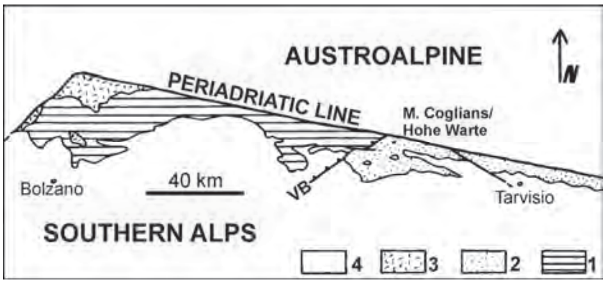

Fig. 3. Simplified geological map of the Southern Alps showing the partition of the Palaeocarnic Chain into a West and an East Zone (Venturini & Spalletta, 1998, modified). VB: Val Bordaglia thrust; 1: Low to middle grade metamorphic basement; 2: Non- to anchi-metamorphic units; 3: Variscan intrusive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

The Carnic Alps underwent compressional as well as extensional deformational events during Variscan and Alpine times, which originated a complex structural framework including some low metamorphic terrains of Variscan age (Fig. 4) (Brime et al., 2008; Barthel et al., 2014).

According to Venturini (1990), Variscan compression originated roughly N120°E trending top to the south thrusts and folds. The first Alpine compression of Chattian-Burdigalian age is coaxial with the Variscan one, thus reactivating the older structures and enhancing their shortening (Venturini, 1990). The two more recent Alpine events (Tortonian-Serravallian and Plio-Pleistocene respectively) depict a strike-slip stress regime also with some compressional and extensional features (Venturini, 1990). These phases were very important to originate pluri-kilometer-scale vertical folding along the Gailtal and Bordaglia lines while in the rest of the Carnic Alps they fragmented the previously formed structural setting mostly by high angle strike-slip faults.

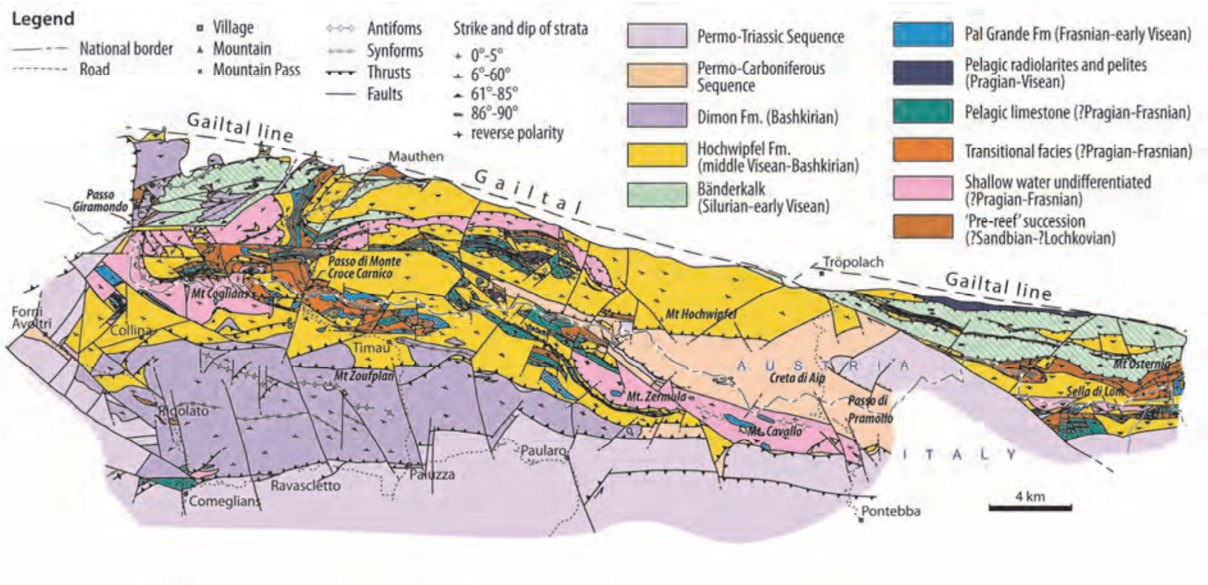

Fig. 4. Sketch of the geology of the Carnic Alps (after BRIME et al., 2008, simplified).

According to BARTHEL et al. (2014) in a N-S profile along the axis of maximum shortening between the Drau Range and the Friuli Southalpine wedge five kinematic groups can be distinguished: (1) N-S compression; (2) NW-SE compression; (3) NE-SW compression, Ʊ3 changes gradually from subvertical to subhorizontal; 4) N-S compression; and (5) NW-SE compression. The authors concluded that the deformation sequence on either side of the PAF (Periadriatic Fault) is similar.

2.1 Palaeogeographic remarks

During the early Palaeozoic the Carnic Alps belong to those group of terrains that detached from the northern Gondwana margin within the Ordovician, and moved northward faster than the main continent (Fig. 5a). These terranes, often indicated as Galatian terrane assemblage (VON RAUMER & STAMPFLI, 2008), include among others the Pyrenees, Montagne Noire, Sardinia, the Graz Palaeozoic, Barrandian and Saxothuringian, beside the Carnic Alps (Fig. 5b). However, the mutual position of these areas, and their distance from the emerged continents is not completely clear.
Important is to note that 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 clear evident differences in litho- and biofacies along the Carnic Alps.

2.2 The Pre-Variscan sequence

The oldest rocks of the Carnic Alps are Middle Ordovician in age (Fig. 6) 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 local fossil occurrences in the Fleons Fm., the most ancient fossiliferous rocks of the Carnic Alps belong to the Valbertad Fm. (Katian). They are

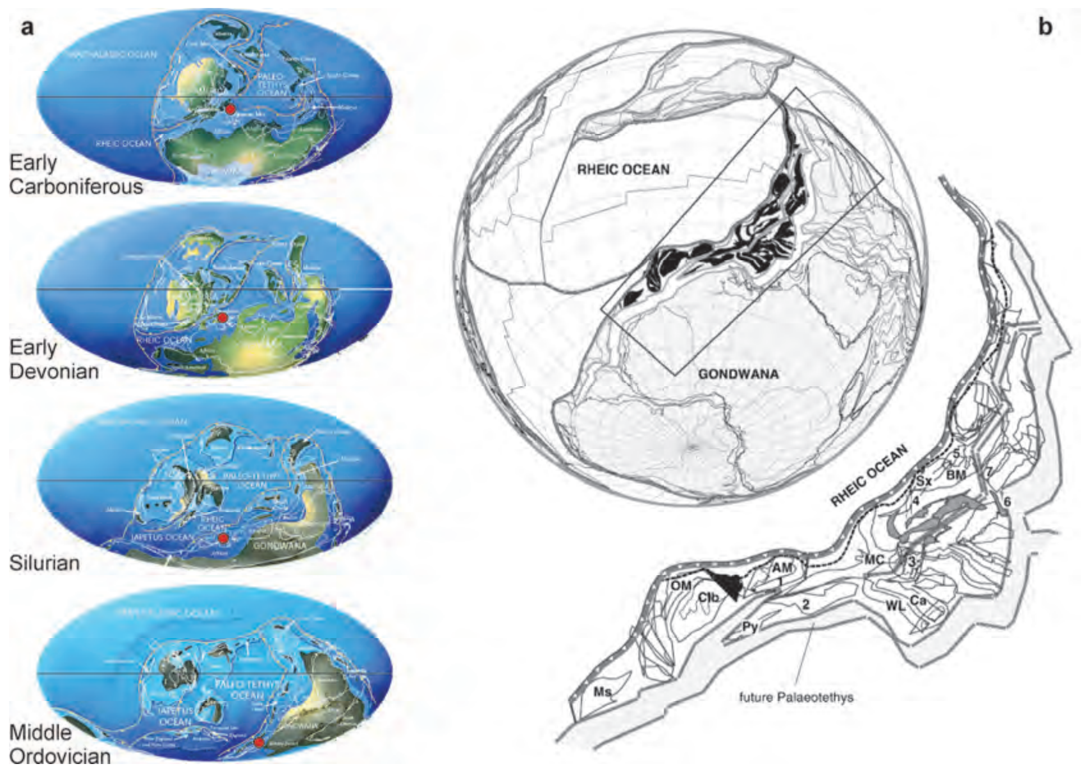

Fig. 5. Palaeogeography of the Carnic Alps. a) Position of the Carnic Alps (red circle) from the Ordovician to the Lower Carboniferous (maps after www.scotese.com). b) Global tectonic situation at the beginning of the Devonian (after VON RAUMER & STAMPFLI, 2008) and detail of the Galatian terrane assemblage. 1: Southern Brittany; 2: North Spain; 3: Sardinia; 4: S. Black Forest; 5: Barrandian; 6: Carnic Alps; 7: Graz Palaeozoic. AM: Armorican Massif; BM: Moldanubian part of the Bohemian Massif; Ca: Cantabrian Zone; CIb: Central Iberia; MC: French Massif Central; Ms: Meseta; OM: Ossa Morena Zone; Py: Pyrenees; Sx: Saxothuringian; WL: Westasturian Leonese Zone.

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 so an extension to the basal Hirnantian cannot be excluded. The global glacially-induced regression of the Hirnantian is documented by the calcareous sandstone of the Plöcken Fm., providing evidence of the HICE $\delta^{13}C$ excursion (SCHÖNLAUB et al., 2011). It resulted in erosion and local non-deposition, as also indicated by Silurian strata resting disconformably upon the Upper Ordovician sequence (SCHÖNLAUB & HISTON, 1999; BRETT et al., 2009; HAMMARLUND et al., 2012; PONDRELLI et al., 2015a).

Silurian deposits are irregularly distributed within the Carnic Chain, and range from shallow water bioclastic limestones to nautiloid-bearing limestones, interbedded shales and limestones to deep-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 the Ordovician and the Silurian, an unknown thickness of sediments is locally missing, which corresponds to several conodont zones of Llandovery to Ludlow age (SCHÖNLAUB & HISTON, 1999; BRETT et al., 2009; ŠTORCH & SCHÖNLAUB, 2012; CORRADINI et al., 2015a).

The Silurian of the Carnic Alps is subdivided into four lithological facies representing different depths of deposition and hydrodynamic conditions (SCHÖNLAUB, 1979, 1980; WENZEL, 1997). The Wolayer facies is characterised by proximal sediments, while the Bischofalm facies corresponds to deep water euxinic deposits. The Plöcken facies and the Findenig facies are intermediate between the ones mentioned above. In rough approximation, the four facies seem to be distributed north-west to south-east in the central sectors of the chain. The depositional features suggest an overall transgressional regime from Llandovery to Ludlow times. Uniform limestone sedimentation within the Prídoli suggests that more stable conditions developed (SCHÖNLAUB, 1997).

In terms of lithostratigraphy, 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. Nautiloid cephalopods are very 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).

In the deeper part of the basin, the Bischofalm Fm. was deposited. It is a tripartite succession, up to 60 m thick, of black siliceous shales, with cherts interbedded (1), clayish alum shales (2), and black graptolitic shales (3) which mainly were deposited in a euxinic environment. Graptolites are generally abundant (JAEGER, 1975; JAEGER & SCHÖNLAUB, 1977, 1994; SCHÖNLAUB, 1997). Intermediate sedimentary conditions between calcareous and shaley facies are represented by the Nölbling Fm., composed of alternating black graptolitic shales, marls and limestone beds (JAEGER & SCHÖNLAUB, 1980; SCHÖNLAUB, 1997).

During the Lochkovian (Lower Devonian) the Carnic basin started to differentiate (SCHÖNLAUB, 1992; KREUTZER, 1990, 1992; KREUTZER et al., 1997; HUBMANN et al., 2003; SUTTNER, 2007; CORRIGA et al., 2012). 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).

Starting from the upper Lochkovian, differences within the sedimentary basin increased: "the Devonian Period is characterised 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 & HISTON, 1999: 15). From the Pragian to the lower Frasnian, within short distances a strongly varying facies pattern developed, indicating highly diverse depths in the basin. 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.). Pelites and cherts were deposited in the deeper part of the basin (Zollner Fm.). Between the fore-reef and the deeper part of the basin the gravity driven deposits alternated with pelagic limestone and black shales (Hoher Trieb Fm.).

Reefs reached their maximum extension during the Givetian and early Frasnian, when the present Carnic Alps were 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,

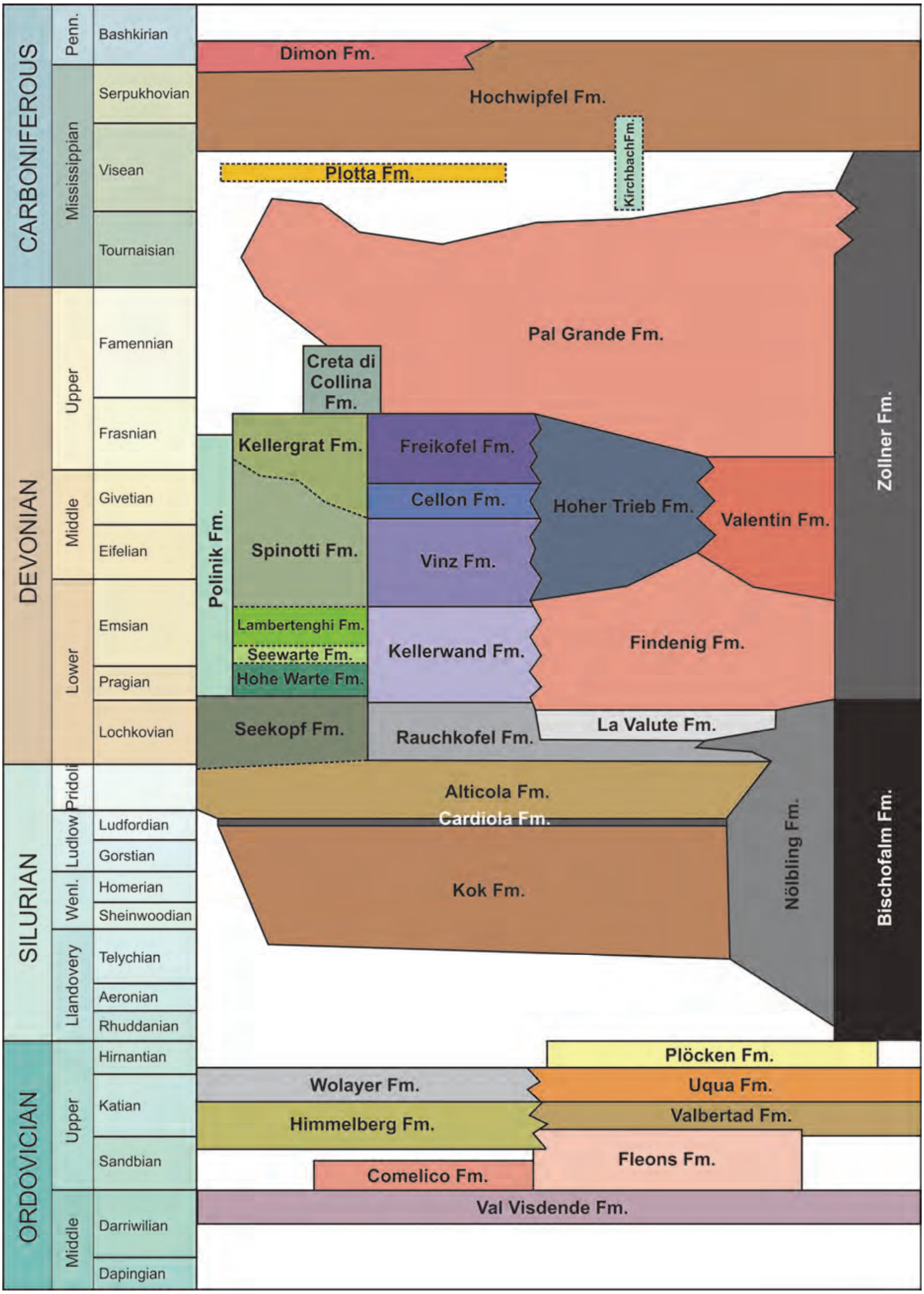

Fig. 6. General lithostratigraphic scheme of the Pre-Variscan sequence of the Carnic Alps (CORRADINI & SUTTNER, 2015).

Mt. Cavallo/Roßkofel and Mt. Oisternig, beside several minor buildups. The fossil content is always very high: stromatoporoids, tabulate and rugose corals, brachiopods, crinoids, gastropods, ostracods, bivalves, cephalopods, trilobites, algae, calcispheres, and foraminifers (KREUTZER, 1990, 1992; KREUTZER et al., 1997; SCHÖNLAUB, 1992; RANTITSCH, 1992).

During the early Frasnian, extensional tectonic activity caused collapse of the basin and consequently reefs rapidly drowned and reefal organisms disappeared. Starting from the upper Frasnian (Upper *rhenana* conodont Zone) a uniform pelagic environment developed, which continued up to the lowermost Visean (SCHÖNLAUB, 1969; SCHÖNLAUB & KREUTZER, 1993; PERRI & SPALLETTA, 1998): 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 a palaeokarstic event in the lowermost Carboniferous (SCHÖNLAUB et al., 1991).

Starting from the upper 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 & 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 (SCHÖNLAUB & HISTON, 1999). The Hochwipfel Fm. consists of quartz-sandstones and greyish shales, turbidites, with intercalations of mudstones, chaotic debris flows and chert and limestone breccias. At place plant remains are present and rare trace fossils can be found (AMEROM et al., 1984; AMEROM & SCHÖNLAUB, 1992). Short local episodes of carbonatic deposition during the Lower Visean to the Serpukhovian boundary 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. They are related to crustal thinning associated to a rifting episode (VAI, 1976; ROSSI & VAI, 1986; LÄUFER et al., 1993, 2001). These conditions continued up to the Late Bashkirian (Late Carboniferous), when the Hercynian orogeny in the Carnic area marked the end of the deposition of the Pre-Variscan sequence (VENTURINI, 1991).

2.3. Summary of the lithostratigraphic units

A complete description of the lithostratigraphic units of the Pre-Variscan sequence of the Carnic Alps (Fig. 6) is available in volume 69 of the *Abhandlungen der Geologischen Bundesanstalt* (CORRADINI & SUTTNER, 2015).

3. The Field Trip

3.1. Mt. Cellon area (Day 1)

We will leave Graz moving westward on the highway A2 up to Villach, and we will continue along the Gail Valley to Dellach where we will stop at the Visitor Centre of the Geopark of the Carnic Alps. Then, we will proceed through Kötschach-Mauthen to Plöckenpass/Passo di Monte Croce Carnico (1360 m). We will park close to the Austrian/Italian border, and we will continue by foot in a narrow mountain path up the Cellon section.

3.1.1. Stop 1 – Cellon section

The Cellon section is located in a narrow avalanche gorge on the eastern flank of Mt. Cellon, at an altitude of about 1500 m, at coordinates 46°36'32" N, 12°56'31" E, close to the Austrian/Italian border. It is reachable by a short walk from Plöcken Pass/Passo di Monte Croce Carnico (Fig. 7).

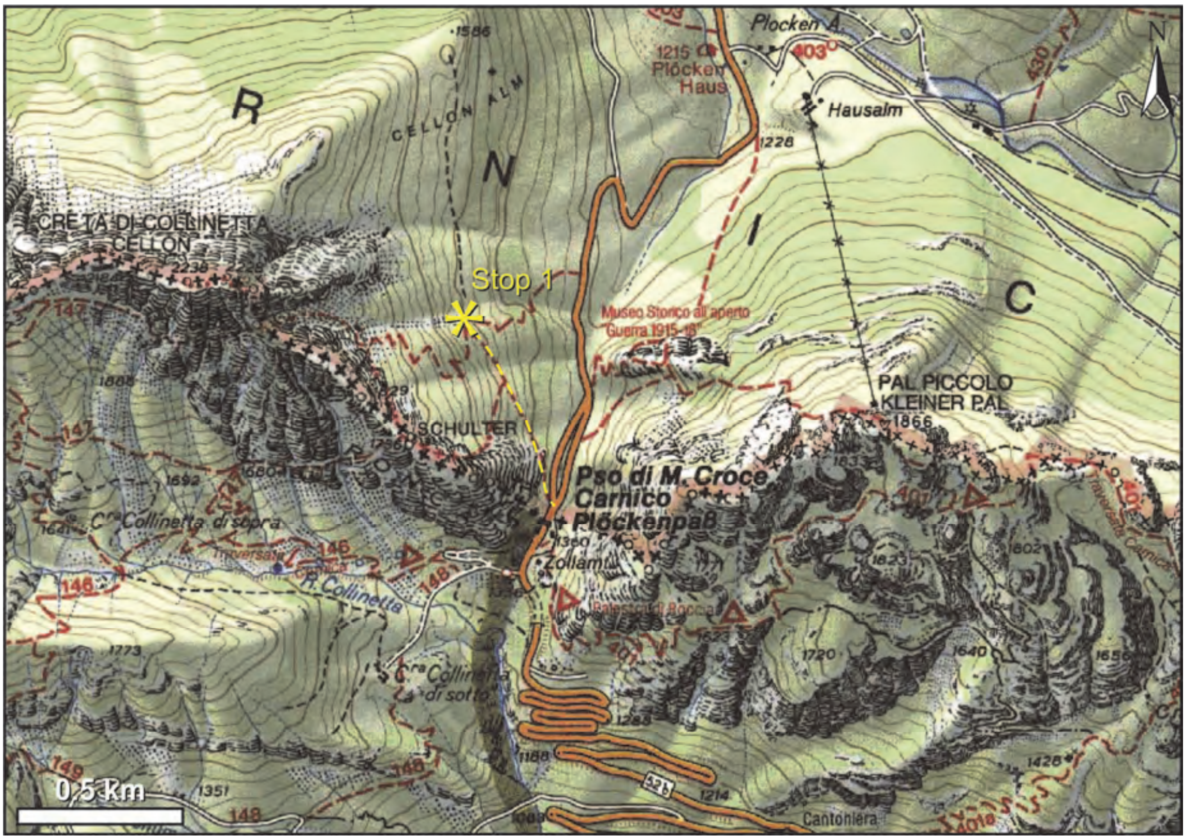

Fig. 7. Topographic map with indication of the itinerary of Day 1 and location of the Cellon section (stop 1).

It probably represents the most famous Silurian section in the world, and is the reference section for many Silurian studies. The conodont fauna from the section was studied and described by WALLISER (1964), whose pioneering work on the section included the first proposed Silurian conodont zonation. Subsequent studies on the Cellon section have documented the composition and distribution of several fossil groups, microfacies, isotope signatures, taphonomic and palaeoenvironmental indicators and eustatic sea-level changes (SCHÖNLAUB & LAMMERHUBER, 2009). For a complete review of the previous studies on the Cellon section, and a revision of the Silurian conodont biostratigraphy, refer to CORRADINI et al. (2015a).

The section exposes rocks from the Upper Ordovician to the Lower Devonian and represents the classical exposure of the Silurian “Plöcken facies”. 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).

The following lithostratigraphic units can be recognised (from base to top) (Figs. 8–9):

1) Valbertad Formation. Lithology: greenish and greyish siltstones and shales. Thickness: More than 100 m. Age: Katian based on the occurrence of the deep-water *Foliomena* brachiopod fauna (HARPER et al., 2009).

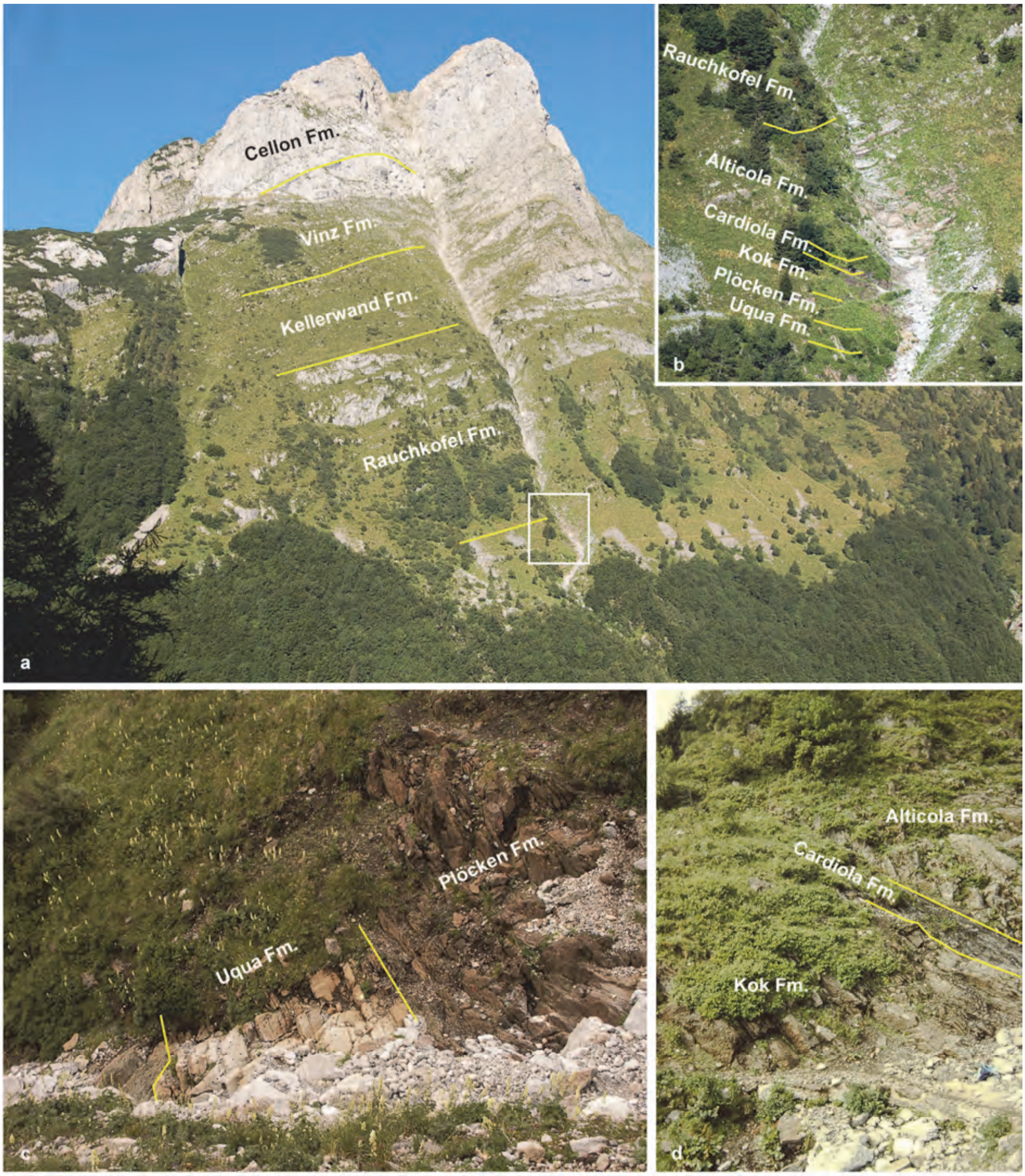

Fig. 8. General views of the Cellon section. a) Panoramic view to the west of Mt. Cellon/Creta di Collinetta, with indication of the lithostratigraphic units; b) Detail of the units of the Cellon section (box in fig.a); c) The Ordovician part of the Cellon section; d) The lower part of the Silurian sequence at Cellon section.

2) Uqua Formation. Lithology: Greyish to brownish flaser limestone with layer of bioclastic debris. Thickness: 4.96 m. Age: Katian (Upper Ordovician), *Amorphognathus ordovicicus* conodont Zone (beds 1–5).

3) Plöcken Formation. Lithology: Greyish siltstone intercalating with impure bioclastic limestone at the very base and grading into calcareous pyritic limestone and sandstone higher in the section. The lowermost strata of the formation are evidently of diamictite origin, the upper strata display contorted deformation structures, slumping, channel fillings and interbeds of fossil debris. Thickness: 6.17 m. Age: Hirnantian (Upper Ordovician), *Normalograptus persculptus* graptolite Zone (beds 6–8).

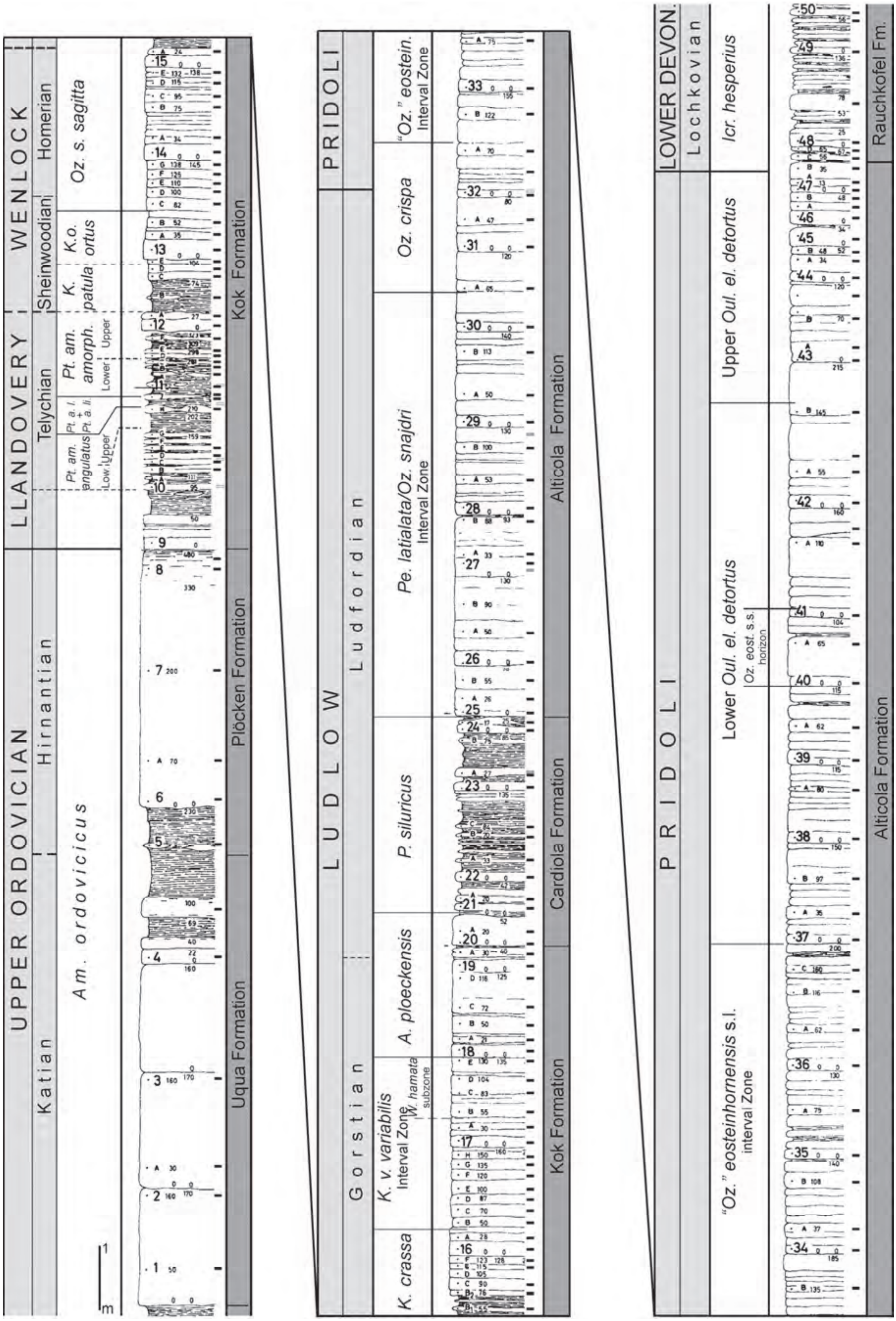

Fig. 9. Stratigraphic log of the Cellon section (after WALLISER, 1964) with indication of sample position, chronostratigraphy, biostratigraphy (after FERRETTI & SCHÖNLAUB, 2001 and CORRADINI et al., 2015a) and lithostratigraphy.

4) Kok Formation. Lithology: Well bedded brownish ferruginous nautiloid limestone, at the base alternating with black shale and marly interbeds. Thickness: 13.5 m. Age: Llandovery to Ludlow, *Pterospathodus celloni* SZ to *Ancoradella ploeckensis* conodont Zone (beds 9–19).
5) Cardiola Formation. Lithology: Dark grey to black limestone with marly and shaly interbeds. Thickness: 3.5 m. Age: Ludlow, *A. ploeckensis* to *Polygnathoides siluricus* conodont zones (beds 20–24A).
6) Alticola Formation. Lithology: Grey to reddish nautiloid limestone with some marly layers and coarse bioclastic interbeds. Thickness: 28 m. Age: Ludlow to Pridoli, *Pedavis latialata–Ozarkodina snajdri* IZ to *Icriodus hesperius* conodont Zone (beds 25–47B).
7) Rauchkofel Formation: Lithology: Blackish platy limestone with black marly interbeds. Thickness: 80 to 120 m. Only the lowermost part of the unit has been studied for conodonts and graptolites (WALLISER, 1964; JAEGER, 1975); a study of conodont biostratigraphy and revision of this part of the section is in progress (CORRIGA & CORRADINI, pers. comm. 2015). Age: Lochkovian (Lower Devonian), *Icriodus hesperius* conodont Zone (bed 47C and above).

Higher in the mountain, the Kellerwand, Vinz and Cellon Fm. are exposed.
The Cellon section is the type section for five lithostratigraphic units: Uqua Fm. (SCHÖNLAUB & FERRETTI, 2015b), Plöcken Fm. (SCHÖNLAUB & FERRETTI, 2015c), Kok Fm. (FERRETTI et al., 2015a), Cardiola Fm. (FERRETTI et al., 2015b) and Alticola Fm. (FERRETTI et al., 2015c).

In terms of chronostratigraphy, several boundaries can be traced along the section (SCHÖNLAUB & KREUTZER, 1994, CORRADINI et al. 2015a):
- the Katian/Hirnantian boundary can be tentatively traced at the transition between the Uqua Fm and the Plöcken Fm., even if an earliest Hirnantian age cannot be excluded for the uppermost part of the Uqua Fm.
- the Ordovician/Silurian boundary is drawn between the Plöcken and the Kok Fm. It should be noted that a large hiatus is present, since most of the Llandovery, up to the Lower *Pt. am. angulatus* Zone (*Pt. celloni* Superzone), is not present.
- the Llandovery/Wenlock boundary (= Telychian/Sheinwoodian boundary) is located within the short black shale interval between samples 12A–12B. Most of the Sheinwoodian is missing, since the graptolite *M. rigidus* was collected from this interval (JAEGER, 1975) and many conodont zones are not represented (sample 12B already belongs to the *K. patula* Zone).
- the Sheinwoodian/Homerian boundary cannot be precisely located. It occurs in the lowermost part of the *Oz. s. sagitta* Zone, tentatively around bed 13E.
- the Wenlock/Ludlow boundary (= Homerian/Gorstian boundary) cannot be precisely located because most of the upper Homerian is missing. However, it can be traced within the black shale level between samples 15A and 15B1 by the occurrence of *K. crassa* in the latter.
- the Gorstian/Ludfordian boundary can be traced only approximatively within the *A. ploeckensis* conodont Zone.
- the Ludlow/Pridoli boundary is located in the narrow black shale level just above sample 32, by the occurrence of *M. parultimus* (JAEGER, 1975). In terms of conodont stratigraphy it occurs in the upper part of the *Oz. crispa* Zone, since the index taxon is present up to sample 32A (CORRADINI et al., 2015a).
- the Silurian/Devonian boundary is placed in the uppermost part of the Alticola Fm., at the bedding plane between sample 47A and 47B, at which the first representatives of the index conodont *Icr. hesperius* occur.
References: WALLISER (1964), SCHÖNLAUB (1980), SCHÖNLAUB et al. (1994), HISTON et al. (1999a), BRETT et al. (2009), CORRADINI et al. (2015a).

3.2. Mt. Freikofel area (Day 2)

On the second day we will partly drive and walk to Mt. Freikofel, spanning the state boundary between Austria and Italy, mainly to observe the Devonian transitional facies. We will leave the minibus near Passo Cavallo/Rossbodentörl (1580 m). From there we will descend on the Italian side and move to the West flanking the southern part of the Mt. Freikofel from where we climb to the top (1756 m). This will allow to observe all the formations of the so called Devonian transitional sequence. From there we will descend on the western side and continue back to the Plöckenhaus (Fig. 10).

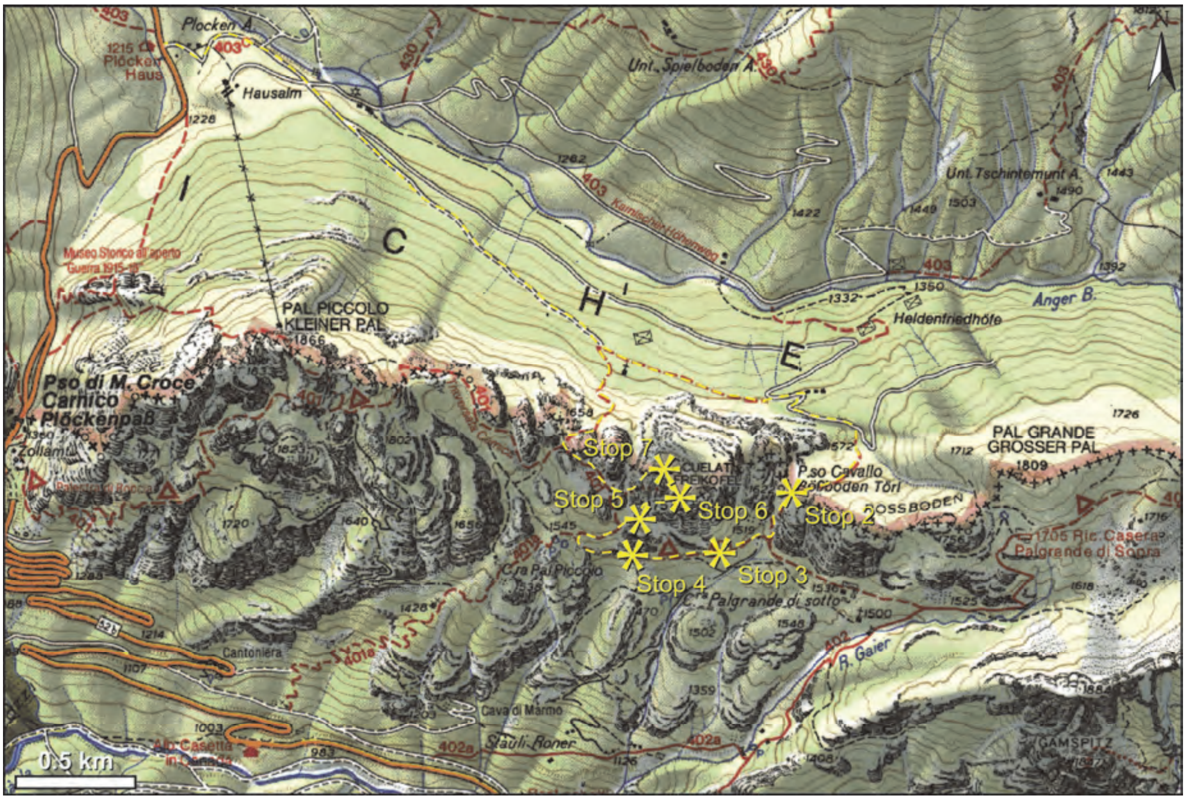

Fig. 10. Topographic map with indication of the itinerary and location of the stops of the second field trip day.

3.2.1. Stop 2 – Geological overview at Passo Cavallo/Rossbodentörl

The Angerbach valley is cut into siliciclastic rocks of the Hochwipfel Fm. which represents a syncline following the north-trending Kleiner Pal (Pal Piccolo) anticline to the south. The latter is 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). Farther 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.

We will walk along the northern flank of the huge anticline (Fig. 11). In the core that roughly corresponds to the valley south of the Mt. Freikofel, the oldest parts of the succession, including Upper Ordovician deposits of the Valbertad and Uqua Fms. and Silurian of the Kok and Alticola Fms., crop out, while the younger strata are exposed progressively (with some minor deformations) towards the top of the surrounding mountains. The Devonian starts with the Rauchkofel Fm. (Lochkovian) at its base followed by the whole succession of the transitional units: Kellerwand (Pragian-Emsian), Vinz (Emsian-lower Givetian), Cellon

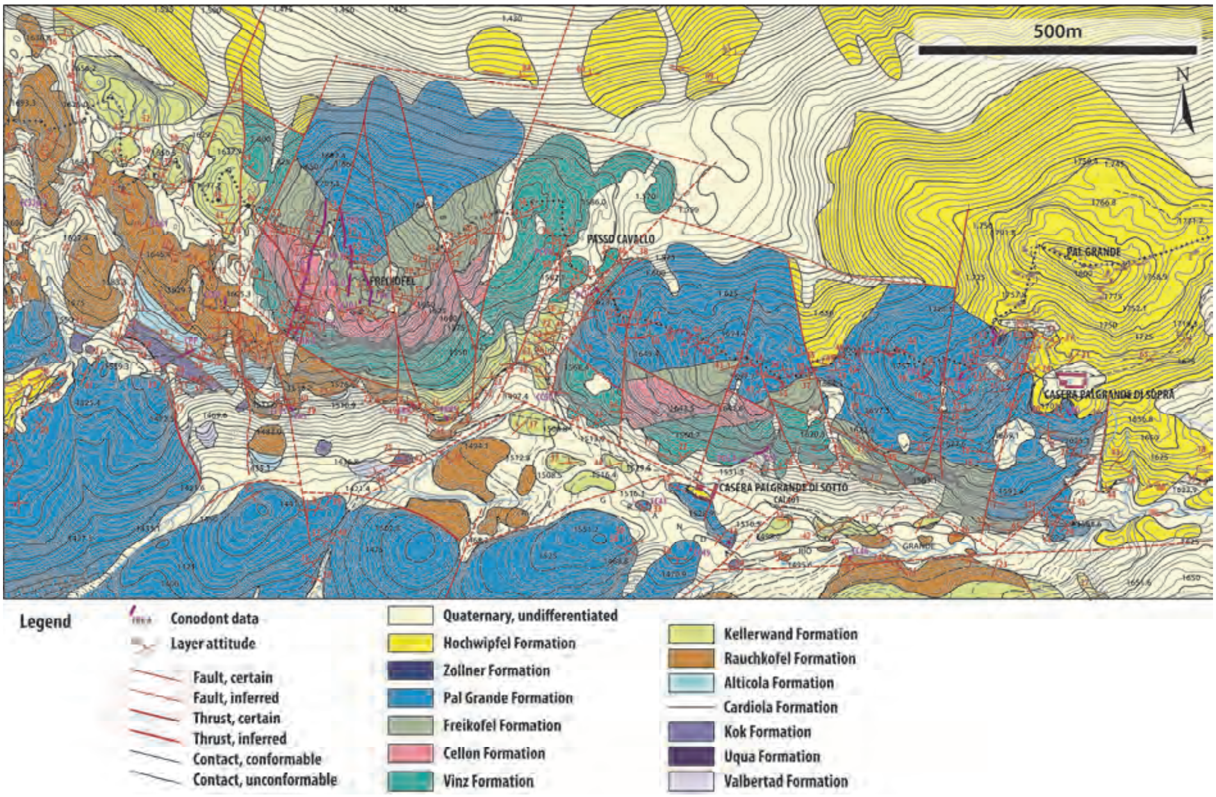

Fig. 11. Geological map of Mt. Freikofel and surroundings.

Fig. 12. View of the Mt. Freikofel from the East with the litostratigraphic subdivisions.

(Givetian) and Freikofel (Givetian-Frasnian) Fms (Fig. 12). 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.

This sequence is covered by the Pal Grande Fm. (Frasnian-Famennian and locally Tournaisian in this area) and, in disconformity, by patches of Plotta Fm. The Variscan sequence in this area terminates with the mostly turbiditic Hochwipfel Fm. (Visean-Bashkirian).

3.2.2. Stop 3 – Rauchkofel-Kellerwand formations transition

The limit between the Rauchkofel and Kellerwand Fms is exposed in correspondence of the FRKS section (Fig. 13), at the altitude of 1525 m and coordinates N 46°35'55.7" E 12°58'46.7".

Here the very dark grey packstone/grainstone to locally coral-bearing rudstone of the Rauchkofel Fm. are covered by medium dark grey mudstone and wackestone of the

Kellerwand Fm. This transition has been dated by scarce conodont data roughly referable to the Lochkovian-Pragian boundary (the index taxon *Icr. steinachensis* beta has been collected at the base of the Kellerwand Fm.).

Few tens of meters ahead along the path, the Kellerwand Fm. is better exposed and has been dated as lower part of the Pragian Stage (PERRI & SPALLETTA, 1998). Moving upward in the stratigraphic column, some lithoclastic horizons composed of grainstone and packstone become increasingly abundant. These levels might represent tempestites suggesting that the Kellerwand Fm. formed in the medium to distal part of a ramp-type margin (VAI, 1980).

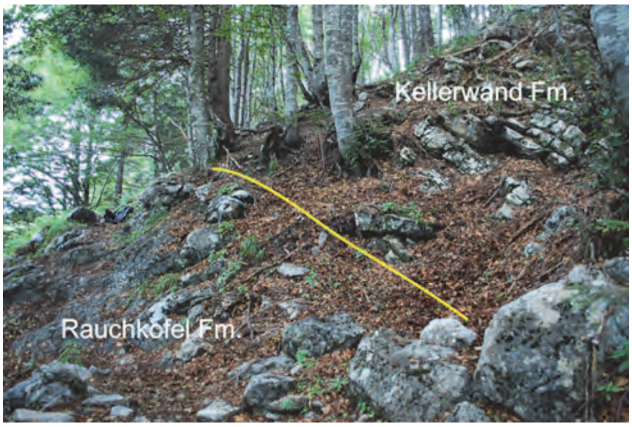

Fig. 13. Boundary between Rauchkofel Fm. and Kellerwand Fm. at the FRKS section.

3.2.3. Stop 4 – Alticola-Rauchkofel formations transition

The limit between the Alticola and Rauchkofel Fms is exposed in the FRS section (Fig. 14) at the altitude of 1552 m (coordinates N 46°35'54.9" E 12°58'32.3").

The grey pelagic *Orthoceras* bearing limestone of the Alticola Fm. pass into dark grey wackestone to grainstone of the Rauchkofel Fm. roughly corresponding to the Silurian-Devonian boundary.

The Rauchkofel Fm. consists of packstones to grainstones showing hummocky-cross stratification sometimes passing to wave ripples and interlayered with shales, which suggest deposition within the offshore transition. Immediately above in the section, a coarser grained very thick bed suggests a transition to shoreface conditions. This succession suggests that the basin profile at the base of the Devonian corresponded to a ramp-type margin.

Walking forward along the track, we will move down in the succession, reaching the Silurian Kok Fm. and then the Alticola Fm. In this area the Cardiola Fm. is covered by detritus and vegetation, although sometimes can be inferred by the dark color of the terrains. Starting to climb towards the top of Mt. Freikofel, the Rauchkofel Fm. is exposed. In particular, the breccia facies crops out widely. It consists of angular clast-supported cm-large clasts that suggest a limited sedimentary transport.

Fig. 14. Boundary between Alticola Fm. and Rauchkofel Fm. at the FRS section.

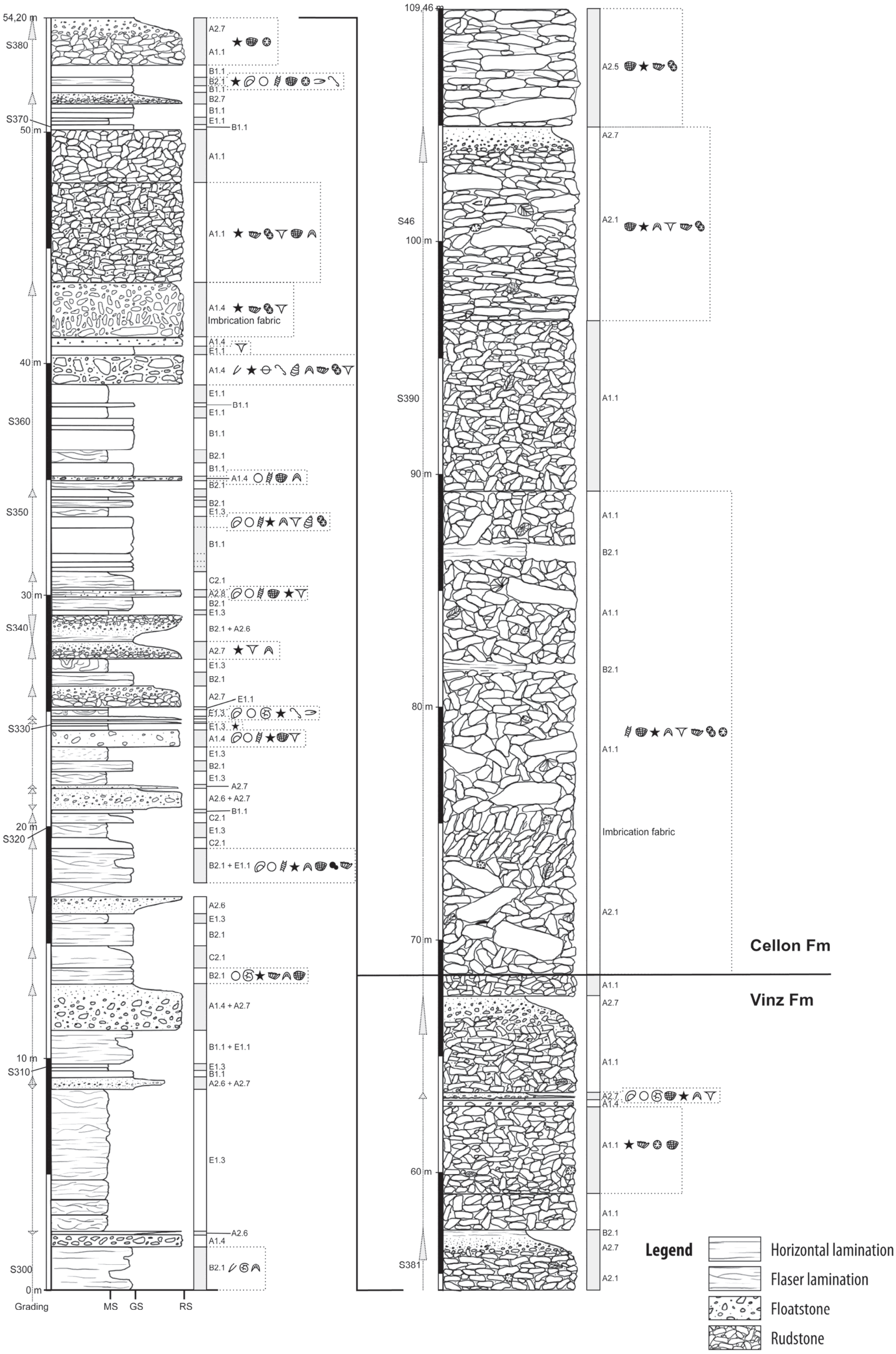

Fig. 15. Stratigraphic log of the lower part of the Freikofel section, correspondent to the upper part of the Vinz Fm. and the lower part of the Cellon Fm. (after SCHNELLBÄCHER, 2010).

3.2.4. Stop 5 – Vinz and Cellon formations

The ascent to Mt. Freikofel starts along a NW-SE trending fault, which marks the transition from the Rauchkofel Fm. to the Vinz Fm. After the fault, at an elevation of 1642 m and coordinates N 46°36'00.3" E 12 58'31.3", the upper part of the Vinz Fm. is exposed (Fig. 15). This unit consists of two interlayered facies (BANDEL, 1972; SCHÖNLAUB, 1985; KREUTZER, 1992; SCHNELLBÄCHER, 2010; PONDRELLI et al., 2015b): (1) medium dark grey, thin to medium bedded, wackestones to packstones and (2) medium dark grey, medium to thick bedded, poorly sorted coral- and stromatoporoid-bearing rudstones (more rarely floatstones) and grainstone matrix; sometimes rudstones shows a fining upward trend up to grainstones. The base of this succession, right after the fault, belongs to the Eifelian Stage (PERRI & SPALLETTA, 1998), but the base of the Vinz Fm., dated elsewhere as Emsian (PONDRELLI et al., 2015b), is not exposed here.

The succession shows a thickening and coarsening upward trend which characterises the transition to the following Cellon Fm. (Figs. 11, 12, 15), which has been dated as lower Givetian. The Cellon Fm. consists of medium dark grey, very thick bedded, poorly sorted, coral- and stromatoporoid-bearing rudstones and subordinate floatstones with clasts up to ~40 cm of diameter and grainstone matrix; sometimes rudstones show a fining upward trend up to grainstones. Locally the base of the bed shows inverse grading with laminated grainstones passing to floatstone/rudstones. However, the deposits are mostly disorganised. The Cellon Fm. deposed in correspondence of the maximum extension of the reefal facies (BANDEL, 1972; SCHÖNLAUB, 1985; KREUTZER, 1992; SCHNELLBÄCHER, 2010).

The wackestone to packstone facies represent a pelagic depositional setting, while the breccia deposits represent gravitative-driven flows reworking shallow water, mostly reef-derived materials. This in turn implies the establishment of a reef and a slope connecting the shallow water environment with the basin. The base of the Vinz Fm. probably corresponds to a physiographic change of the basin from ramp-type to a rimmed shelf margin (BANDEL, 1972).

3.2.5. Stop 6 – Top of Mt. Freikofel

Walking along the path to the summit of the mountain, we will cross the Cellon Fm. up to the Freikofel Fm (Figs. 11, 12, 16). The transition has been dated as lower Givetian (PONDRELLI et al., 2015c).

A phosphorite-rich horizon (BANDEL, 1972) is present about 9 meters below the top of Cellon Fm. The transition to the Freikofel Fm. is marked by a progressive decrease, although with some fluctuations, of the breccia facies. The Freikofel Fm. consists of three well-bedded facies: (1) medium dark grey, medium to thick bedded, lithoclastic rudstones (subordinately floatstones) sometimes showing fining upward grading; matrix consists of grainstone (subordinately wacke-/packstone); (2) medium dark grey, thin to medium bedded grainstones and subordinate packstones locally showing fining upward grading; planar and subordinate cross lamination is present; (3) very thin to thin bedded, moderate pink to grey mud-/wackestones (BANDEL, 1972; SPALLETTA & VAI, 1984; SCHÖNLAUB, 1985; KREUTZER, 1992; SCHNELLBÄCHER, 2010; PAS et al., 2014).

The Freikofel Fm. was formed at the slope of a carbonate apron (SCHNELLBÄCHER, 2010; PAS et al., 2014). Deposits of hyperconcentrated and concentrated density flows and turbidity flows predominate. Thin interbeds of pelagic sediments are rarely preserved.

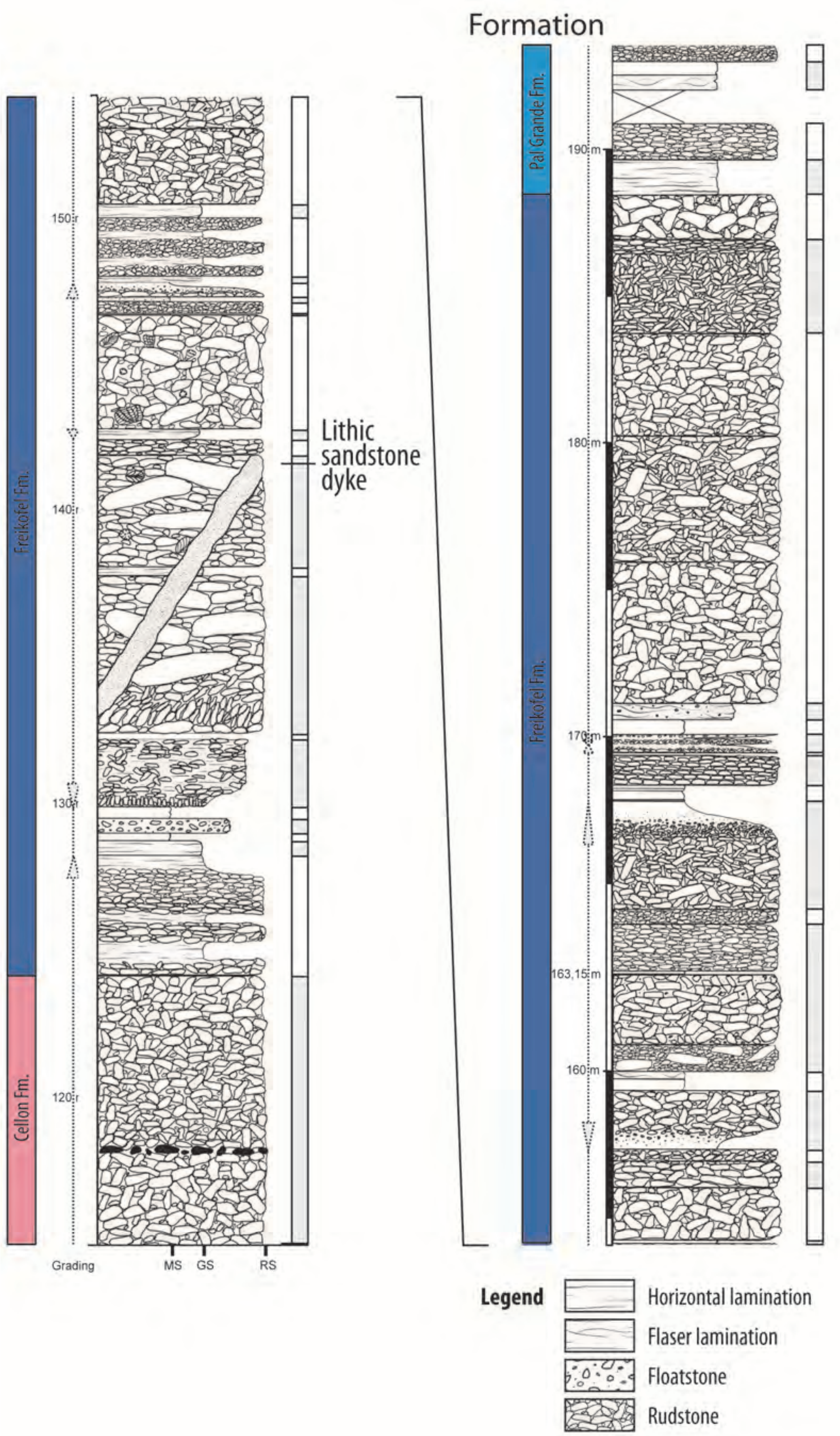

Fig. 16. Stratigraphic log of the upper part of the Freikofel section, correspondent to the upper part of the Cellon Fm., the Freikofel Fm. and the lower part of the Pal Grande Fm. (after SCHNELLBÄCHER, 2010).

Fig. 17. Panoramic view of the Creta di Timau area, with simplified stratigraphy and tectonic. The westward part of the complex shows the sharp boundary between the Rauchkofel and Kellerwand formations.

The top of Mt. Freikofel offers a spectacular panoramic view of the geology of this part of the Carnic Alps. To the southeast, the southern part of the anticlinal structure can be seen (Fig. 17), showing south-dipping beds of the Rauchkofel Fm. and the sharp transition to the Kellerwand Fm. The Rauchkofel Fm shows a clear thickening upward succession which reflects a shallowing upward trend abruptly interrupted at the base of the Kellerwand Fm. On the Eastern end of the cliff, the fault-bounded Creta di Timau represents part of the north-dipping flank of the anticline.

Toward the West (Fig. 18), the same succession of the Mt. Freikofel crops out in the Pal Piccolo and Cellon mountains. Instead in the Pizzo Collina, Mooskofel, Gamskofel and Polinik, the Devonian consists of shallow water facies.

Fig. 18. Panoramic view to the west from the Mt. Freikofel top. The Pal Piccolo and Cellon mountains consists of the same succession as the Mt. Freikofel. More to the west, the transition to the Devonian shallow water platform occurs.

3.2.6. Stop 7 – Freikofel and Pal Grande formations

Starting the descent from Mt. Freikofel in western direction, we will observe the gradual increase of thin-bedded grey and pink mud- and wackestones that will pass to the Pal Grande Fm. (Figs. 11, 12, 19). The formation boundary is assigned to the Frasnian according to conodont data (Spalletta et al., 2015a).

From the Lower Frasnian, the succession records low occurrences of reef-builder debris and/or shallow water-derived allochems compared to the high proportion of fore-reef-slope-derived lithoclasts (Pas et al., 2014). These data suggest a deposition during a period of low carbonate productivity within the shallow water settings, which in turn suggest 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). This appears to be related to the extensional or transtensional tectonic episode supposed by SPALLETTA et al. (1980, 1982) and SPALLETTA & VAI (1984). The progressive sea-level rise is marked by deposition of red nodular limestone overlying the thick sequence of reef and fore-reef ‘‘transitional’’ facies of the Devonian Carnic Alps carbonate platform (PAS et al., 2014).

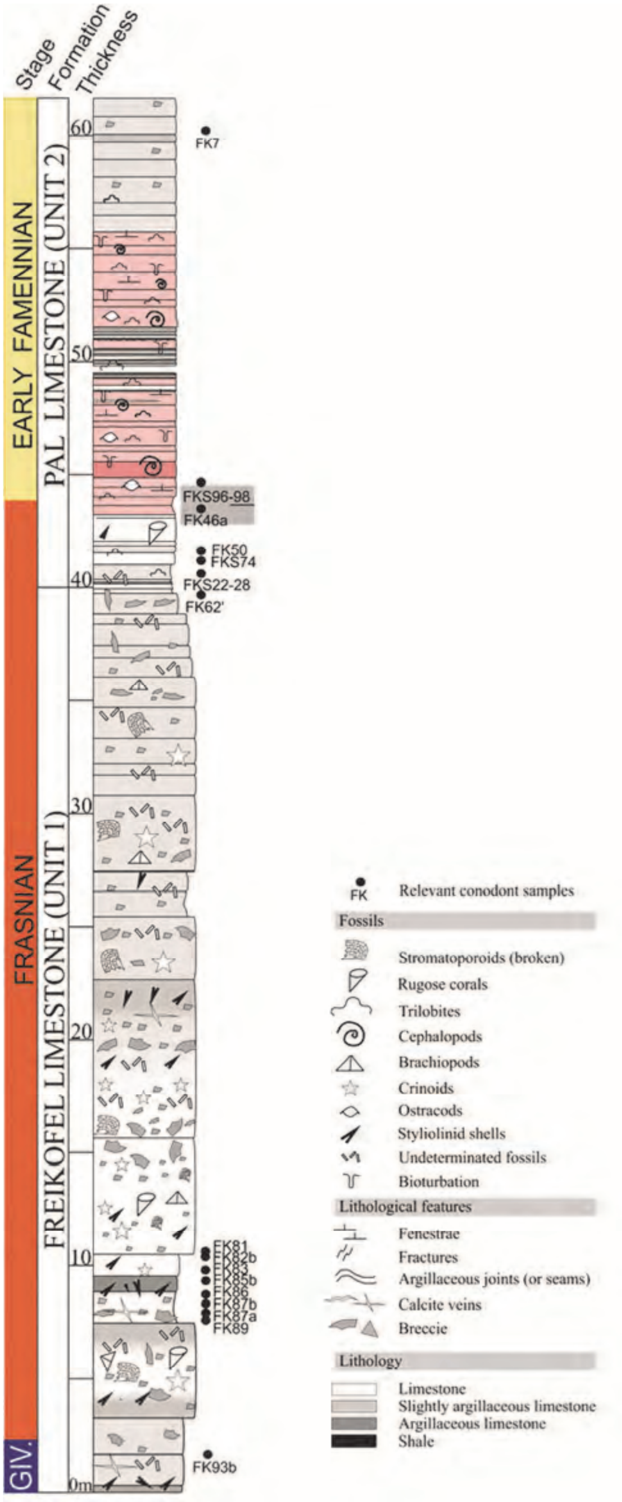

Fig. 19. Stratigraphic log of the Freikofel-Pal Grande Fms. transitions, (after PAS et al., 2014).

3.3. Lake Wolayer area (Days 3–4)

In the last two days of the field trip a hike to Lake Wolayer area is planned (Fig. 20). We will start at Untere Valentin Alm (1220 m) and walk through the Valentin Valley up to Valentintörl (2138 m). Then we will continue to Lake Wolayer (1951 m). Several sections will be shown along the trail, and geological overviews will be given, too. An overnight stay is scheduled at Rifugio Lambertenghi-Romanin.

On the next morning we will visit the Costone Lambertenghi/Seekopf Sockel section, and will walk along the Geotrail Lake Wolayer until the famous Rauchkofel Boden section. After that, we will walk back to Untere Valentin Alm, where the field trip will end.

3.3.1. Stop 8 – Geological overview along the Valentin Valley

The Valentin Valley formed in correspondence of a large strike-slip fault that represents the most recent deformational structure of this area. In the northern part of the Valley, following the Variscan and Alpine compressional and strike-slip phases, the Middle Devonian shallow water units of Mt. Mooskofel are thrusted by the Middle Devonian lagoonal units of the Mt. Gamskofel; both are referred to the Polinik Fm. A large NW-SE trending fault separates these units from the Mt. Rauckhofel where several tectonic repetitions from Upper Ordovician to Upper Devonian strata occur. The Devonian units here belong to the transitional facies.

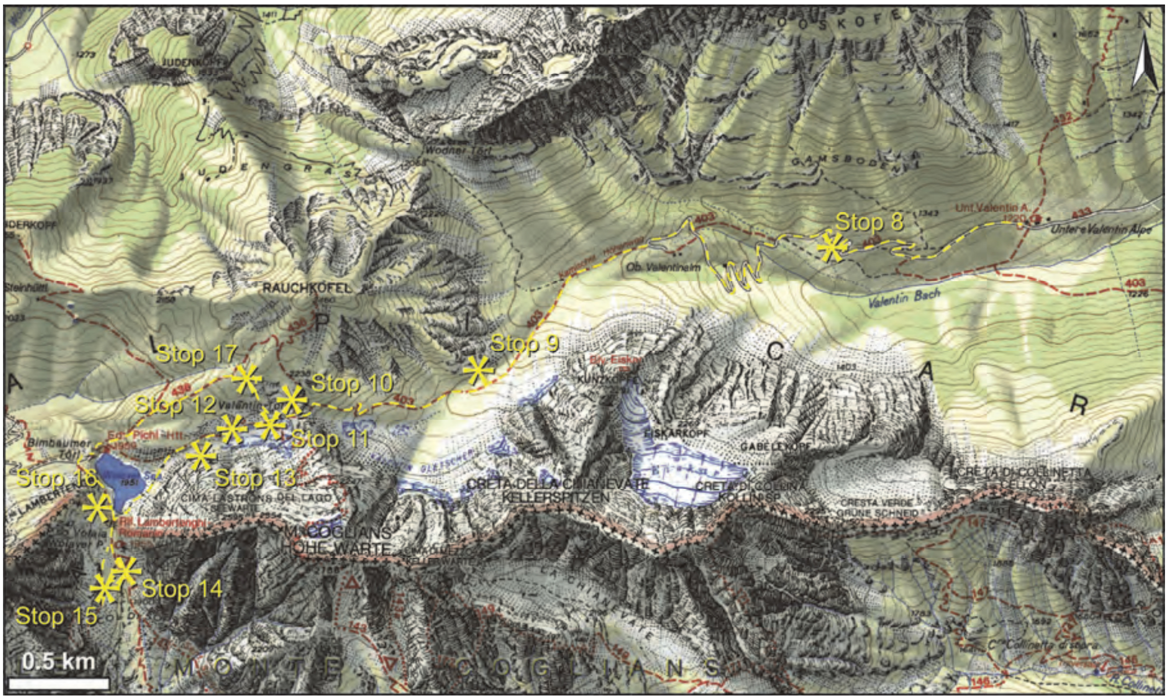

Fig. 20. Topographic map with indication of the itinerary of Days 3–4 and location of the stops.

The southern spectacular side of the valley, named the Kellerwand cliff, shows sub-horizontal layers of mostly Silurian to Upper Devonian age (Fig. 21). In particular, the Rauchkofel Fm. and the Devonian transitional units (Kellerwand-Vinz-Cellon-Freikofel Fms) are exposed.

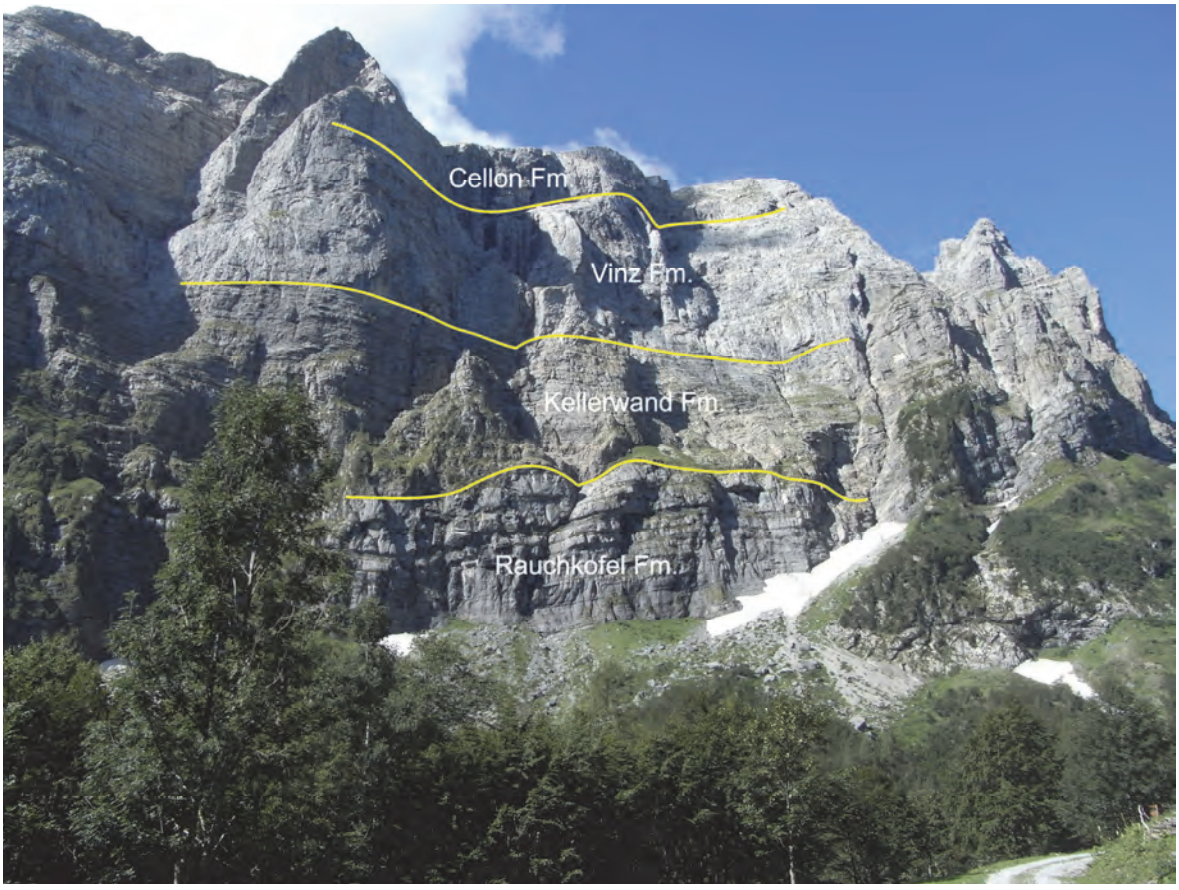

Fig. 21. Panoramic view of the northern wall of Mt. Kellerwand, with indication of the lithostratigraphic units.

Close to the Valentintörl the transition from the Devonian slope deposits characterising the Cellon section to the Devonian shallow water facies, with the Seekopf Fm. passing into the Hohe Warte and Seewarte Fms can be observed.

3.3.2. Stop 9 – Geological overview at the Rauchkofel South section

The Rauchkofel South section (Fig. 22) crops out in the northern side of the Valentin valley at an altitude of about 1990 m., at coordinates N 46°36'58.5", E 12°53'23.0". The section exposes rocks from Upper Ordovician to Lower Devonian, belonging to the following 7 formations: Valbertad Formation, Uqua Formation, Plöcken Formation, Kok Formation, Alticola Formation, Rauchkofel Formation and Kellerwand Formation.

Fig. 22. The Rauchkofel South section.

The Rauchkofel South section is the type section of the Rauchkofel Formation (CORRADINI et al., 2015c), that is here about 120 m thick.

References: SCHÖNLAUB (1970).

3.3.3. Stop 10 – Valentintörl section

The Valentintörl section (Fig. 23) has been measured in the prominent calcareous cliff, which separates the north and the south Valentin passes, at coordinates N 46°36'49.5", E 12°52'51.5", and altitude 2138 m. The area is tectonically complicated by faults and thrusts. Therefore, also in the Valentintörl section large parts of the sequence are missing or extremely condensed.

The sections starts with a few metres of the light grey encrinitic limestone of the Wolayer Fm. The Kok Fm. lies above, with an irregular basal contact. The Llandovery and Wenlock are missing, and the older Silurian bed belongs to the *K. crassa* Zone. The thickness of the Kok Fm. is here reduced to 4.3 m.

The Cardiola Fm. is not present and the section continues with the Alticola Fm., and the Lower Devonian units (Rauchkofel Fm., La Valute Fm. and Findenig Fm.), not yet studied in detail in this section.

References: SCHÖNLAUB (1971, 1980), HISTON et al. (1999b), BRETT et al. (2009).

3.3.4. Stop 11 – Base of Sewarte section

The Base of Seewarte section (Fig. 24) is exposed a few metres west of the southern pass of Valentintörl, at altitude 2100 m. Rocks from Upper Ordovician to Silurian in a transitional facies between the Plöcken and the Wolayer facies are here exposed.

The section starts with a few metres of badly exposed Valbertad Fm. grading into reddish carbonaceous sandstones and the greyish Katian Wolayer Fm.

The oldest Silurian beds belong to the *Pt. celloni* Superzone and are represented by dark grey shales, followed by grey to reddish siliceous mudstones and iron and manganese rich

Fig. 23. The Valentintörl section (view to the east).

carbonate beds. The rest of the Kok Fm., that has a total thickness of 12 m, varies from the typical brownish cephalopod-bearing Kok Fm. by its greyish color and its rich brachiopod and crinoid content. The accumulation of small brachiopods ("Pentamerids") has not been studied yet.

Above 3.3 m of Cardiola Fm. crop out, represented by dark grey to black shales with limestone intercalations.

The section continues with the Alticola Fm., constituted of massive cephalopod-bearing, grey to pinkish wackestones and packstones.

References: SCHÖNLAUB (1971, 1980), BRETT et al. (2009).

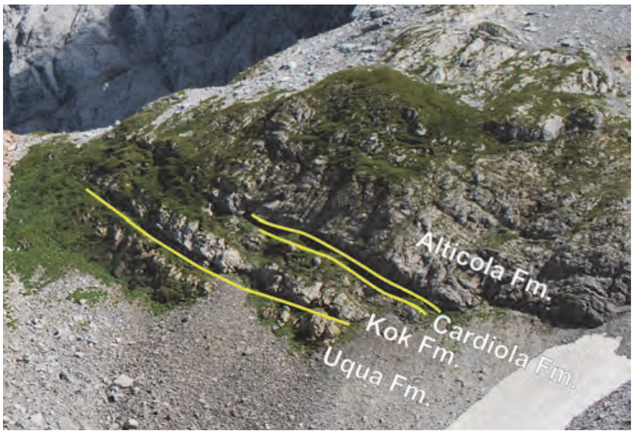

Fig. 24. The Base of Seewarte section (view to the south).

3.3.5. Stop 12 – Wolayer glacier section

The Wolayer glacier (Fig. 25) section is located in the northern side of the Wolayer valley at altitude 2080 m, about half distance between Valentintörl and Lake Wolayer, at coordinates N 46°36'48.8", E 12°52'34.9".

That section is the type section for the Valentin Fm. (SPALLETTA et al., 2015b), and also exposes limestones of the Pal Grande Fm. in the upper part. The section has been investigated

Fig. 25. The Wolayer glacier section (view to the northeast).

for conodont biostratigraphy, sedimentology, isotope geochemistry by SCHÖNLAUB (1980), GÖDDERTZ (1982), JOACHIMSKI et al. (1994) and HÜNEKE (2006).

The Valentin Fm. is represented by about 14 m of bioturbated greyish wackestone, and packstone, deposed in a pelagic environment, with very low sedimentation rate and erosion/re-deposition controlled by bottom currents.

Here, the Pal Grande Fm. is very condensed, being the interval between the Upper *hassi* and the Lower *crepida* Zone represented by about 2.5 m of limestone. A 6 cm thick black shale horizon between sample 89 and 90 is interpreted as an equivalent of the Lower Kellwasser Horizon (JOACHIMSKI et al., 1994), whereas well-oxygenated conditions with bioturbations are documented at the Frasnian/Famennian boundary. The Upper Devonian strata are overlain by siliciclastics of the Lower Carboniferous Hochwipfel Fm.

In terms of chronostratigraphy, the following boundaries have been recognised along the section:

- The Lower/Middle Devonian boundary (= Emsian/Eifelian boundary) is placed between beds 28 and 29, by the entry of the marker *Po. partitus* in bed 29 (SCHÖNLAUB, 1980).
- The Eifelian/Givetian boundary is located in the upper part of the Valentin Fm., between beds 70 and 71.
- The Middle/Upper Devonian boundary (= Givetian/Frasnian boundary) can be traced at the top of the bed marked by sample 72, where a distinct phosphorite layer separating limestones of Givetian (*varcus* Zone) and Frasnian (Lower *hassi* Zone) age occur (SCHÖNLAUB, 1985; JOACHIMSKI et al., 1994).
- The Frasnian/Famennian boundary is located about 1 m above the base of the Pal Grande Fm., between samples 91 and 92 (SCHÖNLAUB, 1980; JOACHIMSKI et al., 1994).

<u>References:</u> SCHÖNLAUB (1980, 1985, 1999), GÖDDERTZ (1982), JOACHIMSKI et al. (1994), HÜNEKE (2006).

Fig. 26. Panoramic view of Mt. Seewarte, with indication of the lithostratigraphic units. The Seewarte section has been measured at the base of the mountain, form north to south (left to right in the photo).

3.3.6. Stop 13 – Seewarte section

The Seewarte section (Fig. 26) is located along the northwestern and western base of Mt. Seewarte, starting from the western end of the Wolayer valley, and continuing south across the state border, at coordinates N 46°36'44.5", E 12°52'21.4" (base).

The section is the type section of the four formation of the shallow water sequence exposed:

- Seekopf Fm. (SUTTNER et al., 2015). Lithology: well-bedded nodular and lithoclastic limestone to dolostone in the lower part, and peloidal and crinoidal pack- grain and rudstones in the upper part. A megaclast horizon, dated at the base of the Pragian, occur in the central part of the unit. Thickness: about 120 m. Age: uppermost Silurian? to Pragian (Upper *Oul. el. detortus*-*Pel. serratus* zones).
- Hohe Warte Fm. (BANDEL et al., 2015). Lithology: thick-bedded echinoderm-rich grainstone and rudstone in the lower part and massive reefal limestone interbedded with crinoid grainstone and rudstone in the upper part. Thickness: about 250 m. Age: Pragian- ?lower Emsian.
- Seewarte Fm. (POHLER et al., 2015a). Lithology: dark grey fossiliferous limestone, slightly dolomitic in places. Thickness: about 40 m. Age: lower Emsian.
- Lambertenghi Fm. (POHLER et al., 2015b). Lithology: well-bedded grey fossiliferous limestones intercalated with laminated yellow-stained dolostone beds; meter-long red mudstone layers, birdseye structures, graded bedding, flat-pebble lithoclasts and cavities lined with fibrous calcite are common. Thickness: about 110 m. Age: Emsian.

In terms of chronostratigraphy, the following boundaries have been recognised along the section:

- The Silurian/Devonian boundary is located in the lowermost part of the section at the base of sample 01/03.
- The Lochkovian/Pragian boundary is traced in the central part of the Seekopf Fm., at the base of the megaclast horizon, where *Icriodus steinachensis* beta morph is present (SUTTNER, 2007).
- The Pragian/Emsian boundary is tentatively traced in the uppermost part of the Hohe Warte Fm., or at the transition between the Hohe Warte and the Seewarte formations.

References: BANDEL (1972), SUTTNER (2007).

3.3.7. Stop 14 – Rifugio Lambertenghi Fontana section

The Rifugio Lambertenghi Fontana (RLF) section (Fig. 27) is located about 100 m south of the mountain hut in the eastern side of the valley, along the path reaching Rifugio Lambertenghi Romanin from the south, at coordinates N 46°26'22.6" E 12°52'07.8". About 18 m of *Orthoceras* limestone belonging to the Alticola Fm. are here exposed.

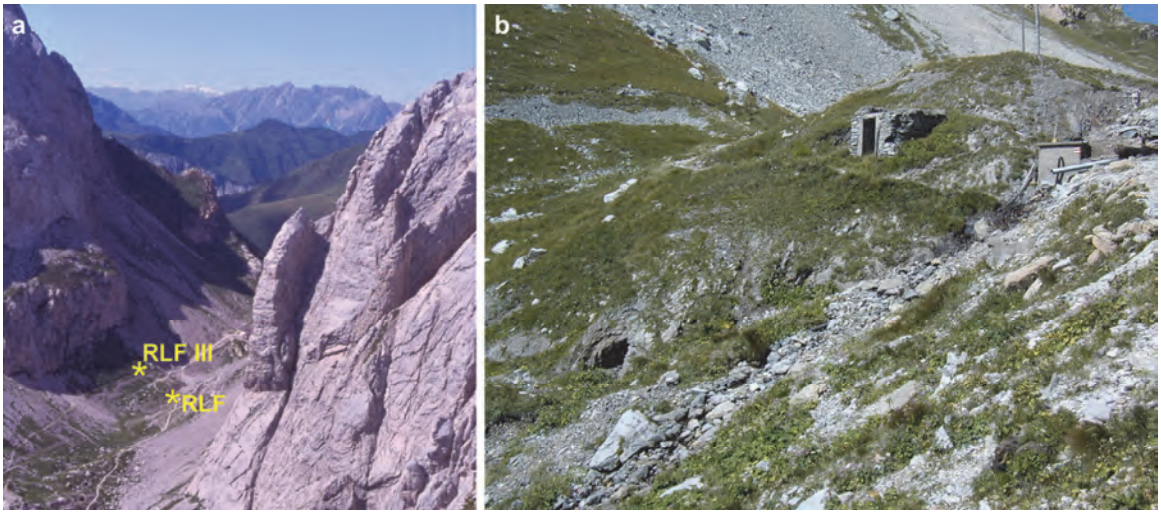

Fig. 27. a) Panoramic view of the valley south of Pass Wolayer, with location of Rifugio Lambertenghi Fontana (RFL; stop 14) and Rifugio Lambertenghi Fontana III (RLF III; stop 15) sections; b) View of the Rifugio Lambertenghi Fontana section.

The section starts with about three meters of highly fossiliferous reddish limestones, where fossil remains are mainly represented by crinoids, brachiopods, cephalopods and bivalves, often fragmented and packed together at the centimeter scale. A covered interval corresponding to a World War I trench is present in the lower part of the section. The central part of the section comprises grey micritic limestone rich in orthoceratid nautiloids; concentrations of small crinoidal debris are observable in some levels, as well as a few brachiopod casts. The fossiliferous content strongly decreases above sample RLF 6 and only a few poorly preserved cephalopods occur in the upper part of the section, where the colour of the rock frequently grades to red due to weathering. A mineralised horizon, bearing hematite and limonite, occurs just above sample RLF 9.

The age of the sections ranges from the *Ped. latialata/Oz. snajdri* interval Zone to the Lower *Oul. el. detortus* Zone. The Ludlow/Pridoli boundary is approximately traced around sample RLF 6, where the last occurrence of *Oz. crispa* is documented.

References: CORRADINI & CORRIGA (2010).

3.3.8. Stop 15 – Rifugio Lambertenghi Fontana III section

The Rifugio Lambertenghi Fontana III (RLF III) section (Fig. 28) is located about 100 m south of the mountain hut in the western side of the valley, along the path from Rifugio Lambertenghi Romanin to Mt. Capolago/Seekopf, at coordinates N 46°26'22.7", E 12°52'05.4". More than 15 meters of limestone crop out in a World War I trench, immediately west of the path. The section is subdivided into two parts, 5 and 10.5 m thick respectively, separated by a covered interval about 10 m thick.

The lower part of the section, up to sample RLF III 3A, is represented by grey micritic limestone, with a sparse crinoid remnants and scattered rare brachiopods. It represents a transitional facies between the Alticola and the Seekopf formations, still attributed to the former.

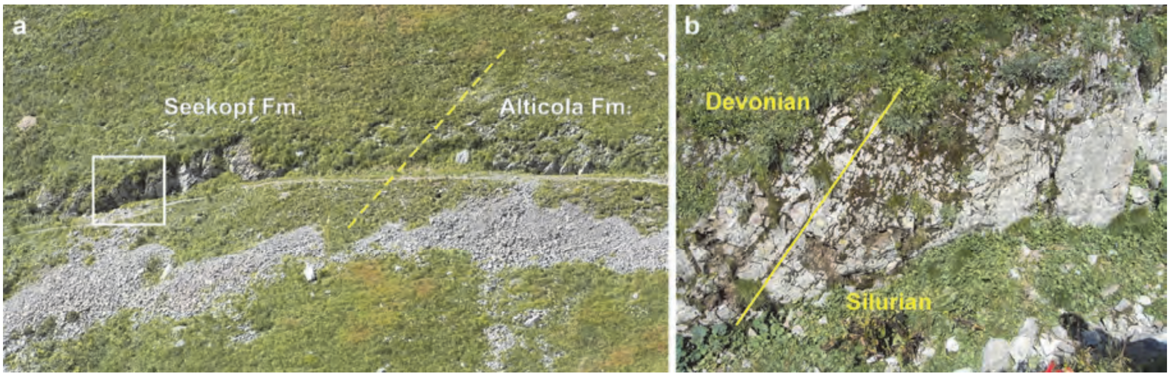

Fig. 28. The Rifugio Lambertenghi Fontana III section. a) Panoramic view of the section with indication of the lithostratigraphic units; b) Detail of the part of the section across the Silurian/Devonian boundary (box in fig. a).

The upper part of the section belongs to the Seekopf Fm. It is represented by a fossiliferous packstone and wakestone, with the fossil content increasing toward the top of the section. However, the state of preservation of the fauna is poor. Crinoids are always abundant and brachiopods often present, at places concentrated in centimeter-thick coquina-like levels. The fauna includes bivalves, nautiloid cephalopods, rare trilobites and solitary corals. In the uppermost part of the section, above sample RLF III 2, bedding planes are difficult to observe, due to heavy weathering and fracturing of the rocks.

The age of the section ranges from the Lower *Oul. el. detortus* Zone to the *Icr. hesperius* Zone.

The Silurian/Devonian boundary is located in the uppermost part of the section, at level of sample RLF III 1L, slightly above the entry of *Z. remscheidensis* and in the upper part of the prominent $\delta^{13}C$ shift typical of uppermost Pridoli.

References: CORRIGA et al. (2009), CORRADINI & CORRIGA (2010).

3.3.9. Stop 16 – Costone Lambertenghi/Seekopf Sockel section

The Costone Lambertenghi/Seekopf sockel section (Fig. 29) is located along the state border west of the Wolayer Pass, at coordinates N 46°36'33.6" E 12°51'58.5" (base), N 46°36'32.0" E 12°51'52.6" (top). Strata of Ordovician to Carboniferous ages are here exposed which are tectonically superimposed The lower and the upper parts belong to different sedimentary sequences, separated by a major thrust. The lower part of the section has been studied much more in detail than the upper part.

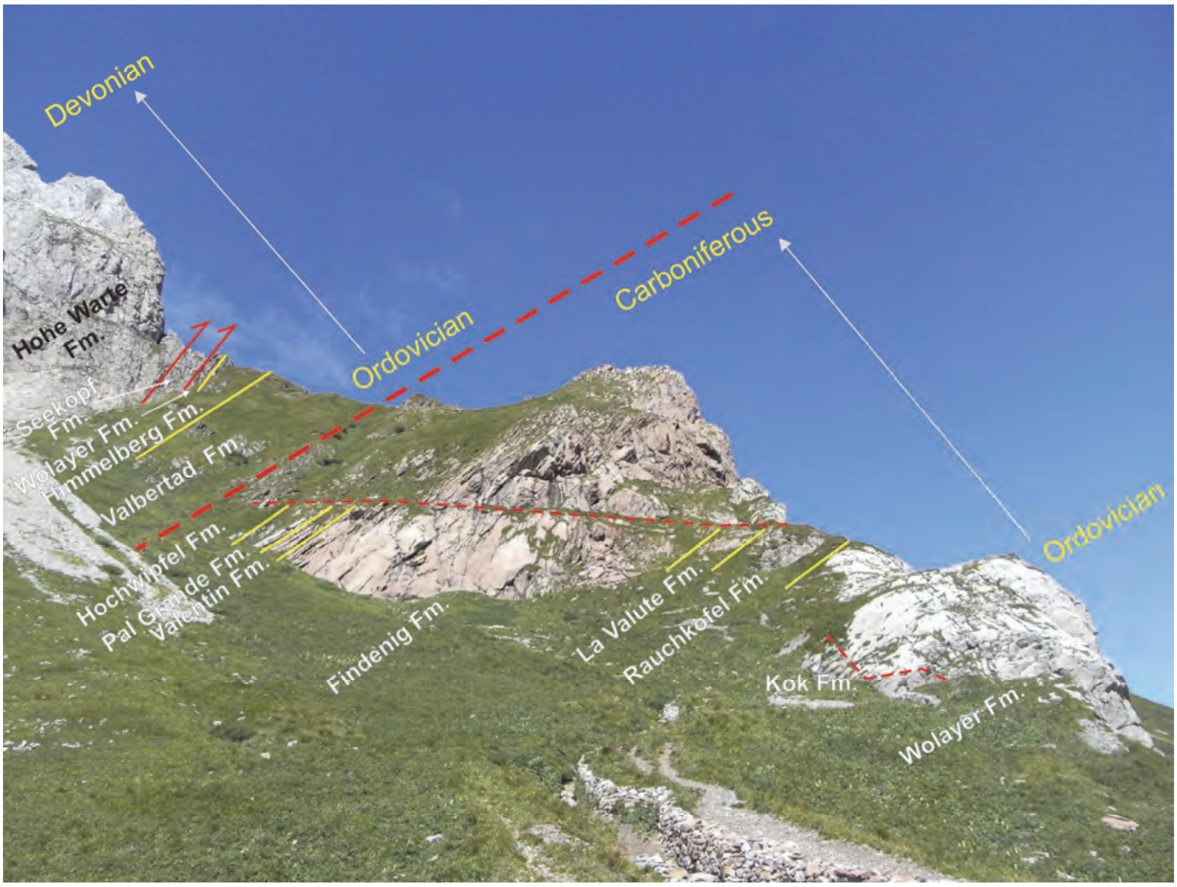

Fig. 29. Panoramic view to the northwest of the Costone Lambertenghi/Seekopf Sockel section, with indication of lithostratigraphic units and structural features.

The following lithostratigraphic units can be recognised (from base to top):

- Wolayer Fm.: coarse grained cystoid limestone. Thickness: about 15 m. Age: Katian-Hirnantian.
- Kok Fm.: red patchy laminated limestone with stromatolite-like structures and pink-colored wackestone/packstone with abundant trilobite remain resting disconformably upon the Wolayer Fm. Thickness: up to 1.1 m. Age: Wenlock-Ludlow (*Oz. s. rhenana-Pol. siluricus* zones, BRETT et al., 2009).
- Alticola Fm.: light grey limestone, also resting on the Wolayer Fm. Thickness: 80 cm. Age top Pridoli? to Lochkovian.
- Rauchkofel Fm.: dark grey platy limestone with centimetric black shale intercalation, followed by pinkish crinoidal limestone. Thickness: 13.90 m. Age: Lochkovian.
- La Valute Fm.: light grey flaser limestone. Thickness: 1.90 m. Age: Lochkovian.
- Findenig Fm.: red argillaceous tentaculite limestone. Thickness: estimated 30-40 m. Age: Pragian to Middle Devonian.
- Valentin Fm.: well bedded light grey micritic limestone. Thickness: 2 m. Age: No data available from this part of the section.
- Pal Grande Fm.: grey limestone. Thickness: 3 m. Age: Frasnian? (SCHÖNLAUB, 1980).
- Hochwipfel Fm: siltstone and shale. Age: Carboniferous.

In the upper part of the section, above the overthrust, the following formations crops out: Valbertad Fm., Himmelberg Fm., Wolayer Fm., Seekopf Fm. and Hohe Warte Fm. The latter forming the high white cliff of Mt. Seekopf/Capolago.

References: VAI (1967), SCHÖNLAUB (1970, 1980), BRETT et al. (2009).

3.3.10. Stop 17 – Rauchkofel Boden section

The Rauchkofel Boden section (Fig. 30) is located on the southwestern slope of Mt. Rauchkofel, at coordinates N 46°36'54", E 12°52'30", and altitude 2175 m. Rocks from Upper Ordovician to Lower Devonian in Wolayer facies are here exposed, but a significant gap in the lower Silurian is present. Various studies and monographic works have been carried out on this section (for a brief summary see FERRETTI et al., 1999). The conodont stratigraphy of the Silurian and Devonian parts has first been published by SCHÖNLAUB (1980) and is presently under revision by M.G. Corriga and C. Corradini.

The Rauchkofel Boden section is the type section of the Wolayer Fm. (SCHÖNLAUB & FERRETTI, 2015a) and of the La Valute Fm. (CORRADINI et al., 2015b).

The following lithostratigraphic units can be recognised (from base to top):

1. Wolayer Fm. Lithology: whitish cistoid massive limestone. Thickness: 8.6 m. Age: Katian-Hirnantian (*Am. ordovicicus* Zone).
2. Kok Fm. Lithology: Grey-brownish highly fossiliferous cephalopod limestone. The contact with the Wolayer Fm. is strongly irregular with basal pockets infilled with ooidal ironstone (FERRETTI, 2005); Thickness: 3.4 m. Age: Wenlock-Ludlow (*Pt. am. amorphognathoides-A. ploeckensis* zones), but several conodont biozones are not documented and probably missing.
3. Cardiola Fm. This unit is badly exposed in the war trench. Lithology: bituminous shale with dark limestone lenses. Thickness: 20-30 cm. Age: a Ludlow age can be inferred by the age of the adjacent units, because no direct data are available from the section.
4. Alticola Fm. Lithology: Grey-pink cephalopod packstone to wackestone in the lower part of the unit, grading to darker grey in the upper part; a level with abundant lobolith of scyphocrinitids occur in the uppermost part of the formation. Thickness: 16.50 m. Age: Ludfordian-Lochkovian (*Po. siluricus-Icr. hesperius* zones).

5 Rauchkofel Fm. This unit is poorly exposed in an almost covered interval at the base of the steep cliff, but was excavated for the field trip of the 2nd European Conodont Symposium (SCHÖNLAUB, 1980). Lithology: blackish platy limestone with shale intercalations. Thickness: 1.8 m. Age: Lochkovian (*Icr. hesperius-Ad. carlsi* zones).

6. La Valute Fm. Lithology: well bedded light grey cephalopod bearing limestone. Thickness: 18 m. Age: Lochkovian (*Ad. carlsi-P. gilberti*? zones).
7. Findenig Fm. Lithology: reddish flaser limestone. Thickness: about 20 m. Age: Pragian.

In terms of chronostratigraphy, the following boundaries have been recognised along the section:

- the Ordovician/Silurian boundary is drawn between the Wolayer and the Kok Fm. It should be noted that a large hiatus is present, corresponding to the whole Llandovery.
- the Sheinwoodian/Homerian boundary can be traced just above the thin ooidal infillings at the base of the Kok Fm.
- the Wenlock/Ludlow boundary (= Homerian/Gorstian boundary) can be tentatively traced just below sample 314, where *K. crassa* occurs.
- the Gorstian/Ludfordian boundary can be tentatively traced within the cephalopod rich bed referred to the *A. ploeckensis* Zone, about 1 m below the top of the Kok Fm.
- the Ludlow/Pridoli boundary can be tentatively located in the lower part of the Alticola Fm., in the uppermost part of the steep slope, where *Oz. crispa* has been collected.
- the Silurian/Devonian boundary occurs in the uppermost part of the Alticola Fm., just below sample 201, where *Icr. hesperius* first appears.

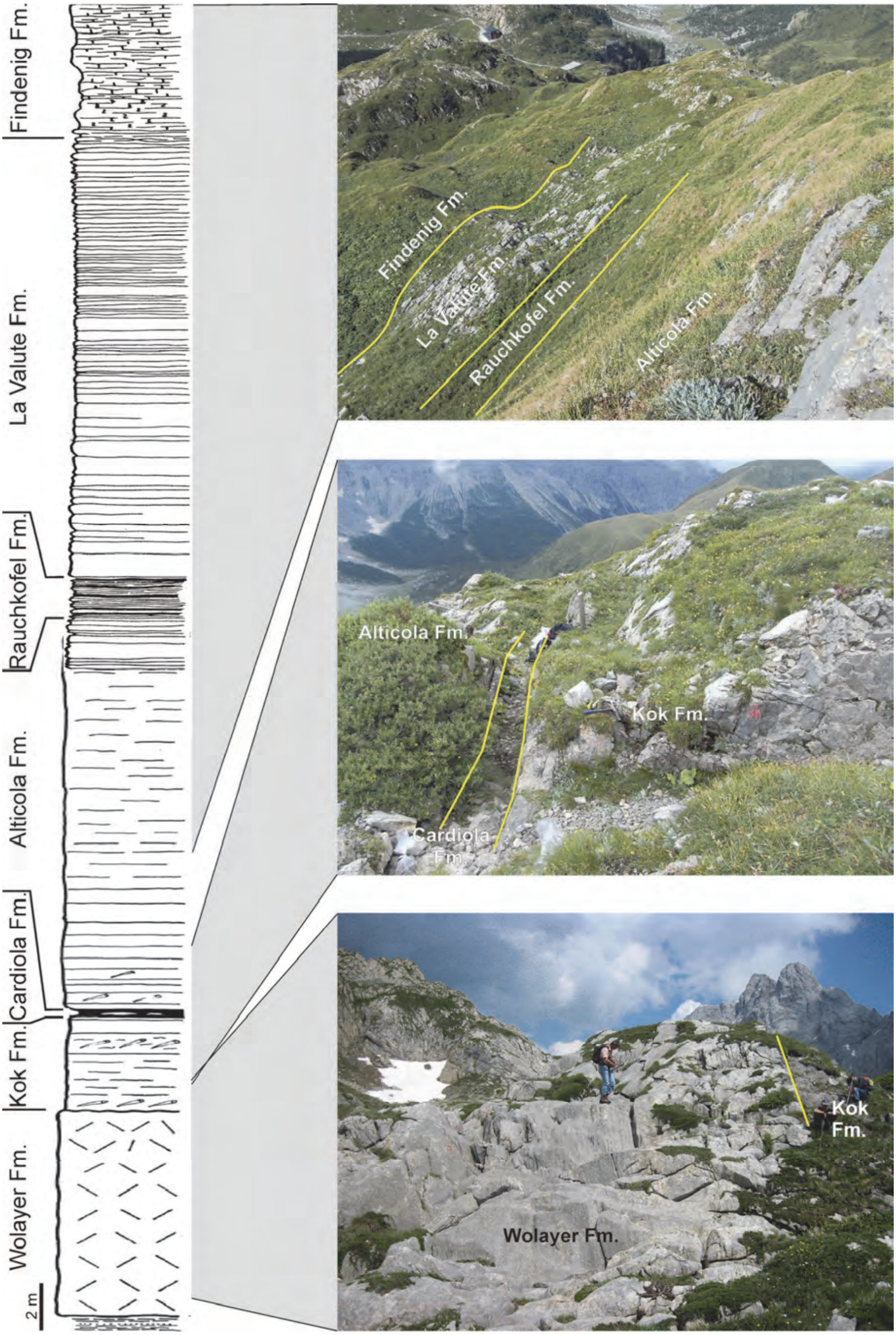

Fig. 30. The Rauchkofel Boden section. Stratigraphic log modified after SCHÖNLAUB (1980), with indication of lithostratigraphic units and selected views of the section.

- the Lochkovian/Pragian boundary can be traced just above the transition between the La Valute and Findenig formations, around sample 227, where *Nowakia acuaria* is reported (SCHÖNLAUB, 1980).

References: SCHÖNLAUB (1970, 1980), FERRETTI et al. (1999), BRETT et al. (2009).

Acknowledgements

We wish to thank all the participants to the working group on "Formal Lithostratigraphic Units in the Pre-Variscan Sequence of the Carnic Alps" for fruitful, open and enthusiastic discussions. The topographic maps with itinerary of the excursion days (Figs 7, 10, 20) have been based on the maps 1:25,000 printed by Tabacco (Tavagnacco, Udine).

This paper is a contribution to IGCP Projects n. 591 (*The early and middle Paleozoic revolution*) and 596 (*Climate change and biodiversity in the Mid-Paleozoic*).

Literature

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, 1–41, Heerlen.

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, Wien.

BANDEL, K. (1972): Palökologie und Paläogeographie im Devon und Unterkarbon der zentralen Karnischen Alpen. – Palaeontographica Abteilung A, **141**/1–4, 1–117, Stuttgart.

BANDEL, K., HUBMANN, B., KIDO, E., POHLER, S.M.L., SCHÖNLAUB, H.P., SIMONETTO, L. & SUTTNER, T.J. (2015): Hohe Warte Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 85–88, Wien.

BARTHEL, E.M., NEUBAUER, F., HEBERER, B. & GENSER, J. (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, Amsterdam.

BRETT, C., FERRETTI, A., HISTON, K. & SCHÖNLAUB, H.P. (2009): Silurian Sequence Stratigraphy of the Carnic Alps, Austria. – Palaeogeography, Palaeoclimatology, Palaeoecology, **279**/1–2, 1–28, Amsterdam.

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. – International Journal of Earth Science, **97**/6, 1213–1229, Berlin-Heidelberg.

CORRADINI, C. & CORRIGA, M.G. (2010): Silurian and lowermost Devonian conodonts from the Passo Volaia area (Carnic Alps, Italy). – Bollettino della Società Paleontologica Italiana, **49**/3, 237–253, Modena.

CORRADINI, C. & SUTTNER, T.J. (eds.) (2015): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 158 p., Wien.

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, Udine.

CORRADINI, C., CORRIGA, M.G., MÄNNIK, P. & SCHÖNLAUB, H.P. (2015a): Revised conodont stratigraphy of the Cellon section (Silurian, Carnic Alps). – Lethaia, **48**/1, 56–71, Oslo.

CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SCHÖNLAUB, H.P. & SIMONETTO, L. (2015b): La Valute Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 77–80, Wien.

CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SCHÖNLAUB, H.P., SIMONETTO, L., SPALLETTA, C. & FERRETTI, A. (2015c): Rauchkofel Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 73–76, Wien.

CORRIGA, M.G., CORRADINI, C., LEHNERT, O., JOACHIMSKI, M.M., PONDRELLI, M. & SIMONETTO, L. (2009): The Silurian-Devonian Boundary in the Rifugio Lambertenghi Fontana III Section (Wolayer area, Carnic Alps, Italy). – In: SUTTNER, T.J., HUBMANN, B. & PILLER, W.E. (eds.): Paleozoic Seas Symposium - Abstract Volume. – Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, **14**, 24–25, Graz.

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, Udine.

FERRETTI, A. (2005): Ooidal ironstones and laminated ferruginous deposits from the Silurian of the Carnic Alps, Austria. – Bollettino della Società Paleontologica Italiana, **44**/3, 263–278, Modena.

FERRETTI, A. & SCHÖNLAUB, H.P. (2001): New conodont faunas from the Late Ordovician of the Central Carnic Alps, Austria. – Bollettino della Società Paleontologica Italiana, **40**/1, 3–15, Modena.

FERRETTI, A., HISTON, K. & SCHÖNLAUB, H.P. (1999): The Silurian and Early Devonian of the Rauchkofel Boden Section, Southern Carnic Alps, Austria. – In: HISTON, K. (ed.): V International Symposium Cephalopods - Present and Past. Carnic Alps Excursion Guidebook. Berichte der Geologischen Bundesanstalt, **47**, 55–62, Wien.

FERRETTI, A., SCHÖNLAUB, H.P., CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SIMONETTO, L. & SERVENTI, P. (2015a): Kok Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 46–51, Wien.

FERRETTI, A., SCHÖNLAUB, H.P., CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SIMONETTO, L. & SERVENTI, P. (2015b): Cardiola Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 52–55, Wien.

FERRETTI, A., SCHÖNLAUB, H.P., CORRADINI, C., CORRIGA, M.G., PONDRELLI, M., SIMONETTO, L. & SERVENTI, P. (2015c): Alticola Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 56–60, Wien.

GÖDDERTZ, B. (1982): Zur Geologie und Conodontenstratigraphie der Rauchkofelböden und des Rauchkofel in den Zentralen Karnischen Alpen. – Diploma thesis, University of Bonn, 88 p., Bonn.

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 and Planetary Science Letters, **331–332**, 128–139, Amsterdam.

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, Birmingham.

HISTON, K. (2012): The Silurian nautiloid-bearing strata of the Cellon Section (Carnic Alps, Austria): Color variation related to events. – In: FERRETTI, A., HISTON, K., MCLAUGHLIN, P.I. & BRETT, C.E. (eds.): Time-specific facies: the colour and texture of biotic events. – Palaeogeography, Palaeoclimatology, Palaeoecology, **367–368**, 231–255, Amsterdam.

HISTON, K., FERRETTI, A. & SCHÖNLAUB, H.P. (1999a): Silurian Cephalopod Limestone sequence of the Cellon Section, Carnic Alps, Austria. – In: HISTON, K. (ed.): V International Symposium Cephalopods - Present and Past. Carnic Alps Excursion Guidebook. Berichte der Geologischen Bundesanstalt, **47**, 46–54, Wien.

HISTON, K., FERRETTI, A. & SCHÖNLAUB, H.P. (1999b): Upper Silurian sequence at the Valentintörl section. – In: HISTON, K. (ed.): V International Symposium Cephalopods - Present and Past. Carnic Alps Excursion Guidebook. Berichte der Geologischen Bundesanstalt, **47**, 64–68, Wien.

HUBMANN, B., POHLER, S., SCHÖNLAUB, H.P. & MESSNER, F. (2003): Paleozoic Coral-Sponge Bearing Successions in Austria. – Berichte der Geologischen Bundesanstalt, **61**, 1–91, Wien.

HÜNEKE, H. (2006): Erosion and deposition from bottom currents during the Givetian and Frasnian: Response to intensified oceanic circulation between Gondwana and Laurussia. – Palaeogeography Palaeoclimatology, Palaeoecology, **234**, 146–167, Amsterdam.

JAEGER, H. (1975): Die Graptolithenführung im Silur/Devon des Cellon-Profils (Karnische Alpen). – Carinthia II, **165**: 111–126, Klagenfurt.

JAEGER, H. & SCHÖNLAUB, H.P. (1977): Das Ordoviz/Silur-Profil im Nolblinggraben (Karnische Alpen, Österreich). – Verhandlungen der Geologischen Bundesanstalt, **1977**, 349–359, Wien.

JAEGER, H. & SCHÖNLAUB, H.P. (1980): Silur und Devon nördlich der Gundersheimer Alm in den Karnischen Alpen (Österreich). – Carinthia II, **1980**, 403–444, Klagenfurt.

JAEGER, H. & 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, Wien.

JOACHIMSKI, M.M., BUGGISCH, W. & ANDERS, T. (1994): Mikrofazies, Conodontenstratigraphie und Isotopengeochemie des Frasne-Famenne-Grenzprofils Wolayer Gletscher (Karnische Alpen). – Abhandlungen der Geologischen Bundesanstalt, **50**, 183–195, Wien.

KREUTZER, L.H. (1990): Mikrofazies, Stratigraphie und Paläogeographie des Zentralkarnischen Hauptkammes zwischen Seewarte und Cellon. – Jahrbuch der Geologischen Bundesanstalt, **133**/2, 275–343, Wien.

KREUTZER, L.H. (1992): Photoatlas zu den variszischen Karbonat-Gesteinen der Karnischen Alpen (Österreich/Italien). – Abhandlungen der Geologischen Bundesanstalt, **47**, 1–129, Wien.

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 Geologischen Bundesanstalt, **40**, 42–60, Wien.

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, Wien.

LÄUFER, A., HUBICH, D. & LOESCHKE, J. (2001): Variscan geodynamic evolution of the Carnic Alps (Austria/Italy). – International Journal of Earth Sciences, **90**, 855–870, Berlin.

PAS, D., DA SILVA, A.-C., SUTTNER, T., KIDO, E., BULTYNCK, P., PONDRELLI, M., CORRADINI, C., DE VLEESCHOUWER, D., DOIEN, 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). – International Journal of Earth Sciences, **103**, 519–538, Berlin-Heidelberg.

PERRI, M. & SPALLETTA, C. (1998): Updating of the conodont biostratigraphy in the Carnic Alps (Italy). – In: PERRI, M.C. & SPALLETTA, C. (eds.): Southern Alps Field Trip Guidebook, Seventh International Conodont Symposium held in Europe. – Giornale di Geologia, Special Issue, **60**, 116–119, Bologna.

POHLER, S.M.L., BANDEL, K., KIDO, E., PONDRELLI, M., SCHÖNLAUB, H.P., SIMONETTO, L. & SUTTNER, T.J. (2015a): Seewarte Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 89–91, Wien.

POHLER, S.M.L., BANDEL, K., KIDO, E., PONDRELLI, M., SCHÖNLAUB, H.P., SIMONETTO, L. & SUTTNER, T.J. (2015b): Lambertenghi Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 92–95, Wien.

PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., KIDO, E., MOSSONI, A., SIMONETTO, L., SPALLETTA, C., SUTTNER, T.J. & CARTA, N. (2015a): Depositional and deformational evolution of a Lower Paleozoic portion of the Southalpine domain: the Mt. Pizzul area (Carnic Alps, Italy). – International Journal of Earth Sciences, **104**, 147–178, Berlin.

PONDRELLI, M., CORRADINI, C., CORRIGA, M.G., SCHÖNLAUB, H.P., SPALLETTA, C., POHLER, S.M.L., MOSSONI, A., SIMONETTO, L., SUTTNER, T.J., PERRI, M.C. & KIDO, E. (2015b): Vinz Formation. – In: CORRADINI, C. &

SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 113–116, Wien.

PONDRELLI, M., CORRADINI, C., SCHÖNLAUB, H.P., SPALLETTA, C., POHLER, S.M.L., SUTTNER, T.J., KIDO, E., PERRI, M.C., CORRIGA, M.G., MOSSONI, A. & SIMONETTO, L. (2015c): Cellon Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 117–120, Wien.

RANTITSCH, G. (1992): Fazies und Diagenese devonischer Riffkalke des Seeberger Aufbruches (Kärnten, Österreich). – Jahrbuch der Geologischen Bundesanstalt, **135**/1, 273–285, Wien.

ROSSI, P.L. & 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, Cagliari.

SCHNELLBÄCHER, P. (2010): Stratigraphy, transport mechanisms and provenience of Devonian carbonate slope deposits (Freikofel, Carnic Alps). – Unpublished master thesis, Universität Greifswald. – 124 p., Greifswald.

SCHÖNLAUB, H.P. (1969): Conodonten aus dem Oberdevon und Unterkarbon des Kronhofgrabens (Karnische Alpen, Österreich). – Jahrbuch der Geologischen Bundesanstalt, **112**/2, 321–354, Wien.

SCHÖNLAUB, H.P. (1970): Vorläufige Mitteilung über die Neuaufnahme der silurischen Karbonatfazies der Zentralen Karnischen Alpen (Österreich). – Verhandlungen der Geologischen Bundesanstalt, **1970**, 306–315, Wien.

SCHÖNLAUB, H.P. (1971): Palaeoenvironmental studies at the Ordovician/silurian boundary in the Carnic Alps. – In: Colloque Ordovicien-Silurien Brest 1971. – Memoires du Bureau de Recherches geologique et minieres (BRGM), **73**, 367–377, Brest.

SCHÖNLAUB, H.P. (1979): Das Paläozoikum in Österreich. Verbreitung, Stratigraphie, Korrelation, Entwicklung und Paläogeographie nicht-metamorpher und metamorpher Abfolgen. – Abhandlungen der Geologischen Bundesanstalt, **33**, 1–124, Wien.

SCHÖNLAUB, H.P. (1980): Carnic Alps. Field Trip A. with contributions from JAEGER, H., HOUSE, M.R., PRICE, J.D., GÖDDERTZ, B., PRIEWALDER, H., WALLISER, O.H., KŘÍŽ, J., HAAS, W. & VAI, G.B. – In: SCHÖNLAUB, H.P. (ed.): Second European Conodont Symposium, ECOS II, Guidebook, Abstracts. – Abhandlungen der Geologischen Bundesanstalt, **35**, 5–57, Wien.

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, Wien.

SCHÖNLAUB, H.P. (1992): Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its implications for Plate Movements. – Jahrbuch der Geologischen Bundesanstalt, **135**/1, 381–418, Wien.

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, Wien.

SCHÖNLAUB, H.P. (1999): Wolayer "Glacier" section. – In: HISTON K. (ed.): V International Symposium, Cephalopods – Present and Past. Carnic Alps. Excursion Guidebook. – Berichte der Geologischen Bundesanstalt, **47**, 69–72, Wien.

SCHÖNLAUB, H.P. & FERRETTI, A. (2015a): Wolayer Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 34–37, Wien.

SCHÖNLAUB, H.P. & FERRETTI, A. (2015b): Uqua Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds,): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 38–41, Wien.

SCHÖNLAUB, H.P. & FERRETTI, A. (2015c): Plöcken Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 42–45, Wien.

SCHÖNLAUB, H.P. & 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 Bundesanstalt, **61**, 3–157, Wien.

SCHÖNLAUB, H.P. & 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, Wien.

SCHÖNLAUB, H.P. & KREUTZER, L.H. (1993): Paleozoic boundary sections of the Carnic Alps (southern Alps). – Erlanger geologische Abhandlungen, **122**, 77–103, Erlangen.

SCHÖNLAUB, H.P. & KREUTZER, L.H. (1994): Lower Carboniferous Conodonts from the Cima di Plotta Section (Carnic Alps, Italy). – Jahrbuch der Geologischen Bundesanstalt, **136**/1, 247–269, Wien.

SCHÖNLAUB H.P. & LAMMERHUBER A. (2009): Geologie und Zeit an Beispielen aus den Karnischen Alpen. - Edition Lammerhuber & Geologische Bundesanstalt, 1–48, Wien.

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, Berlin.

SCHÖNLAUB, H.P., KREUTZER, L.H. & PRIEWALDER, 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, Wien.

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. – Instituto Geológico y Minero de Espana, Cuadernos del Museo Geominero, **14**, 515–526, Madrid.

SPALLETTA, C. & VAI, G.B. (1984): Upper Devonian intraclast parabreccias interpreted as seismites. – Marine Geology, **55**, 133–144, Amsterdam.

SPALLETTA, C. & 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**/4, 637–647, Wien.

SPALLETTA, C., VAI, G.B. & VENTURINI, C. (1980): Il Flysch ercinico nella geologia dei Monti Paularo e Dimon (Alpi Carniche). – Memorie della Società Geologica Italiana, **20**, 243–265, Roma.

SPALLETTA, C., VAI, G.B. & VENTURINI, C. (1982): La Catena Paleocarnica. – In: CASTELLARIN, A. & VAI, G.B. (eds.): Guida alla geologia del Sudalpino centro-orientale. – Guide geologiche regionali Società Geologica Italiana, 281–292, Bologna.

SPALLETTA, C., PERRI, M.C., PONDRELLI, M., CORRADINI, C., MOSSONI, A. & SCHÖNLAUB H.P. (2015a): Pal Grande Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 137–140, Wien.

SPALLETTA, C., SCHÖNLAUB H.P., PONDRELLI, M. & CORRADINI, C. (2015b): Valentin Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 133–136, Wien.

ŠTORCH, P. & SCHÖNLAUB, H.P. (2012): Ordovician-Silurian boundary graptolites of the Southern Alps, Austria. – Bulletin of Geosciences, **87**/3, 755–766, Prague.

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 Bundesanstalt, **59**, 1–111, Wien.

SUTTNER, T.J., BANDEL, K., CORRADINI, C., CORRIGA, M.G., KIDO, E., POHLER, S.M.L., PONDRELLI, M., SCHÖNLAUB, H.P., SIMONETTO, L. & VAI, G.B. (2015): Seekopf Formation. – In: CORRADINI, C. & SUTTNER, T.J. (eds.): The Pre-Variscan sequence of the Carnic Alps (Austria and Italy). – Abhandlungen der Geologischen Bundesanstalt, **69**, 69-72, Wien.

VAI, G.B. (1963): Ricerche geologiche nel gruppo del M. Coglians e nella zona di Volaia (Alpi Carniche). – Giornale di Geologia, **30**, 137–198, Bologna.

VAI, G.B. (1967): Le Devonien inferieur biohermal des Alpes Carniques Centrales. Colloque sur le Dévonien inférieur (Rennes 1964). – Mémoires du Bureau de Recherches Géologiques et Minières, **33**, 28–30, Orléans.

VAI, G.B. (1976): Stratigrafia e paleogeografia ercinica delle Alpi. – Memorie Società Geologica Italiana, **13**/1, 7–37, Roma.

VAI, G.B. (1980): Sedimentary environment of Devonian pelagic limestones in the southern Alps. – Lethaia, **13**, 79–91, Oslo.

VENTURINI, C. (1990): Geologia delle Alpi Carniche centro-orientali. – Pubblicazioni del Museo Friulano di Storia Naturale, **36**, 222 p., Udine.

VENTURINI, C. (1991): Introduction to the geology of the Pramollo Basin (Carnic Alps) and its surroundings. – In: VENTURINI, C. (ed.): Workshop Proceedings on ‘Tectonics and Stratigraphy of the Pramollo Basin (Carnic Alps)’. – Giornale di Geologia, **53**/1, 13–47, Bologna.

VENTURINI, C. & SPALLETTA, C. (1998): Remarks on the Palaeozoic stratigraphy and the Hercynian tectonics of the Palaeocarnic Chain (Southern Alps). – In: PERRI, M.C. & SPALLETTA, C. (eds.): Southern Alps Field Trip Guidebook. Seventh International Conodont Symposium held in Europe. – Giornale di Geologia, Special Issue, **60**, 69–88, Bologna.

VON RAUMER J.F. & STAMPFLI G.M. (2008): The birth of the Rheic Ocean – Early Palaeozoic subsidence patterns and subsequent tectonic plate scenarios. – Tectonophysics, **461**, 9–20, Amsterdam.

WALLISER, O.H. (1964): Conodonten des Silurs. – Abhandlungen des Hessischen Landes-Amtes für Bodenforschung, **41**, 1–106, Wiesbaden.

WENZEL, B. (1997): Isotopenstratigraphische Untersuchungen an silurischen Abfolgen und deren paläozeanographische Interpretation. – Erlanger geologische Abhandlungen, **129**, 1–117, Erlangen.