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Modena, 3-6 September 2019

PRE-CONGRESS FIELD TRIP GUIDEBOOK

# Devonian reefs of the Carnic Alps and related environments

Dipartimento di Scienze Chimiche e Geologiche

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# Devonian reefs of the Carnic Alps and related environments

**30 August - 2 September 2019**

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## INTRODUCTION

The Carnic Alps, located at the Italian-Austrian border (Fig. 1), exposes one of the more complete and better preserved and investigated Palaeozoic sequence of the world. An almost continuous sequence ranging from the Middle Ordovician to the Permian/Triassic boundary up to the Middle Triassic, is exposed. Within this sequence, Devonian rocks are the most abundant and more differentiated. In fact, during the Lower Devonian huge reefs started to develop, and persisted until the Frasnian, generating the largest Devonian reef of Europe. They were mainly built by stromatoporoids, rugose and tabulate corals, calcisphaeres and populated by a variety of brachiopods, trilobites, crinoids, etc. Beside the reefs, all the deposits from back reef to fore reef and basin are preserved.
During this field trip most of these sediments will be visited in a complete transect from shallow to deep water deposits, as well as pre-and post-reef rocks.

## GEOLOGICAL OVERVIEW

The oldest part of the Carnic Alps ("Palaeocarnic Chain") is considered as a segment 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 from the Southalpine domains; towards the South 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 weakly metamorphosed limestones occur.
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. 3) (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.
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 compres-

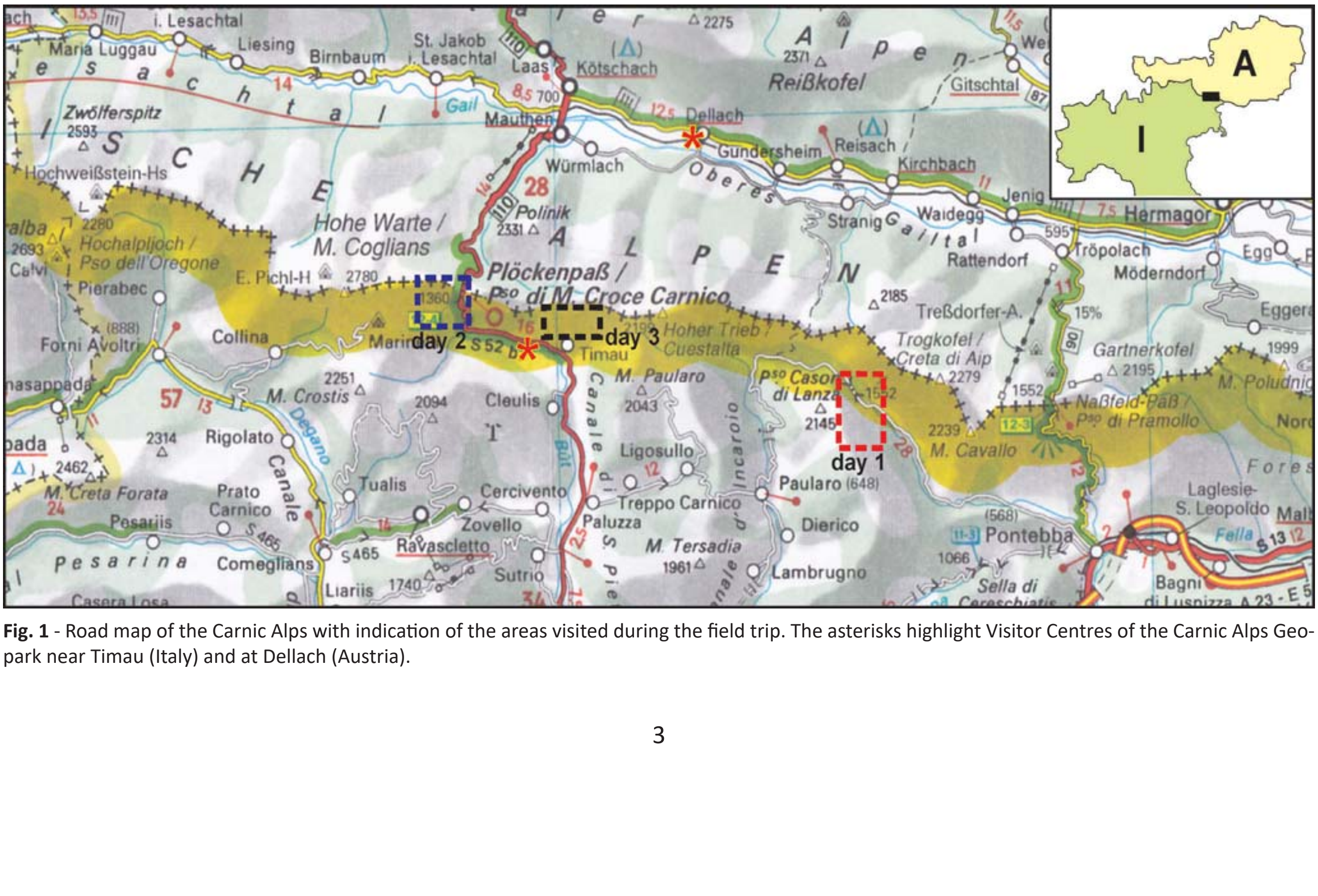


**Fig. 1** - Road map of the Carnic Alps with indication of the areas visited during the field trip. The asterisks highlight Visitor Centres of the Carnic Alps Geopark near Timau (Italy) and at Dellach (Austria).

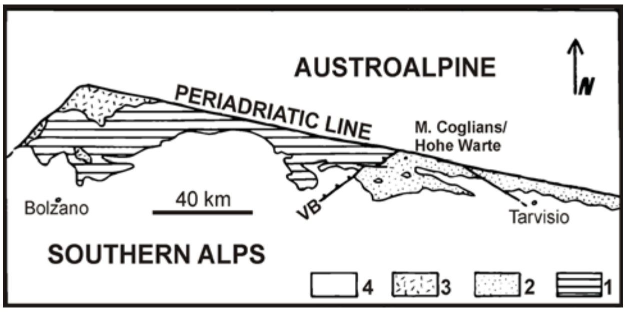


**Fig. 2** - Simplified geological map of the Southern Alps showing the partition of the Palaeocarnic Chain into a West and an East Zone (after Venturini & Spalletta, 1998, modified). VB: Val Bordaglia thrust; 1: low to middle grade metamorphic basement; 2: non- to anchi-metamorphic units; 3: Variscan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

sion; (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.

## Palaeogeographic context

During the early Palaeozoic the Carnic Alps belonged to a group of terranes that detached from the northern Gondwana margin within the Ordovician and moved northward faster than the main continent (Fig. 4a). 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. 4b). 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 clearly evident differences in litho- and biofacies 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 & Forke 2007) constitute the so-called 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 & Suttner, 2015).

The oldest rocks of the Carnic Alps are Middle Ordovician in age (Fig. 5) 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 represented by up to 100 m of shallow-water pelites, sandstones and rare conglomerates deposited at medium-high sou-

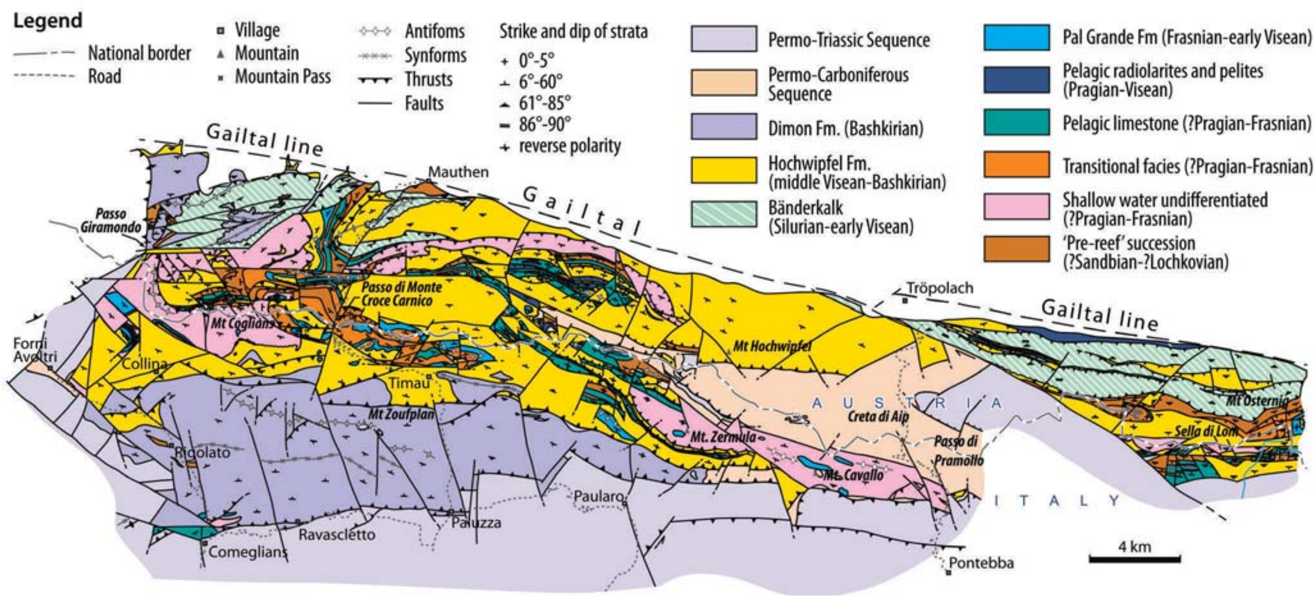


**Fig. 3** - Sketch of the geology of the Carnic Alps (after Brime et al., 2008, simplified).

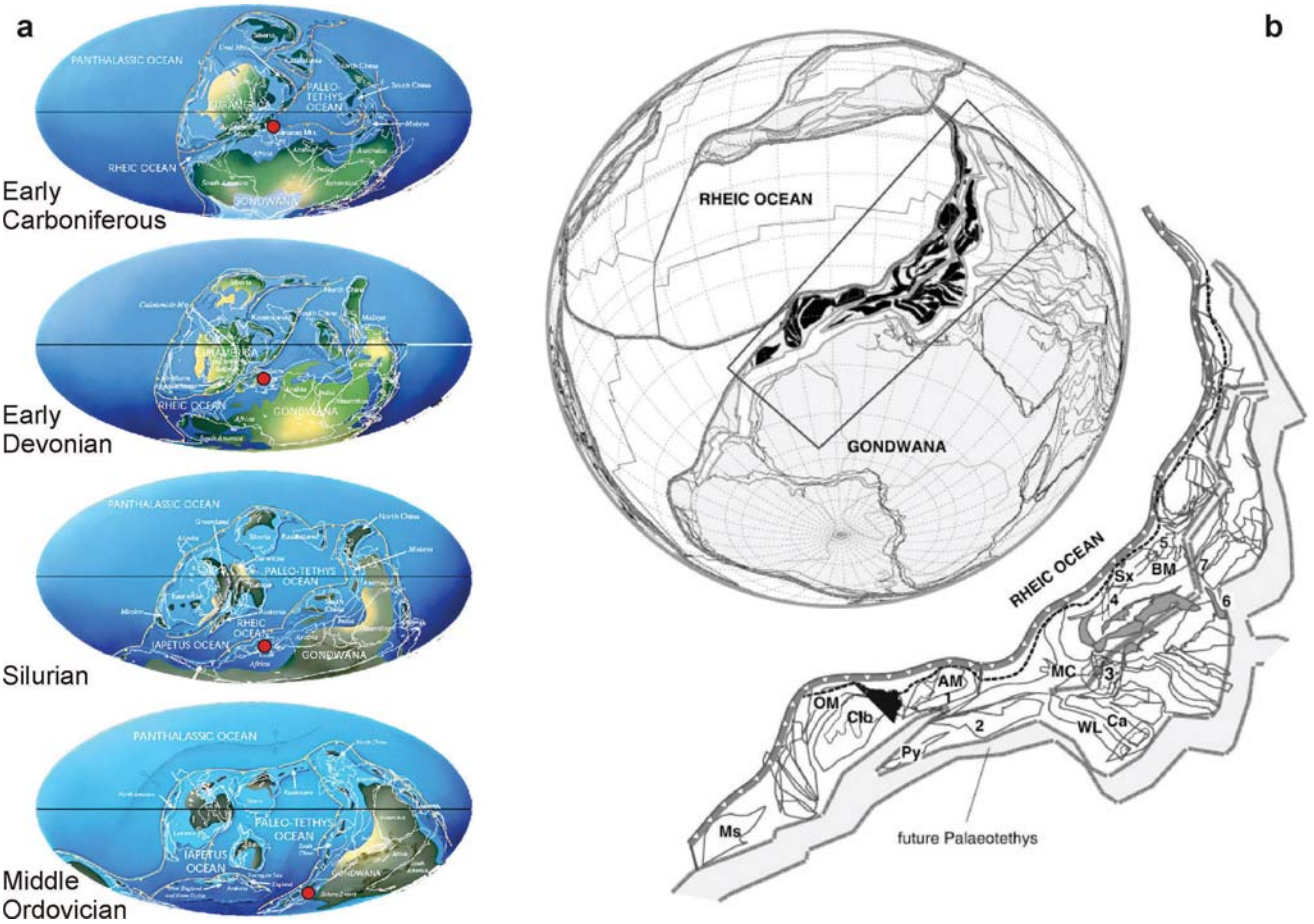


**Fig. 4** - Palaeogeography of the Carnic Alps. a: position of the Carnic Alps (red circle) from the Ordovician to the Lower Carboniferous (maps after www.scotese.com). b: Global tectonic situation at the beginning of the Devonian (After von Raumer & Stampfli, 2008) and detail of the Galatian terrane 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.

thern 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 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, 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).

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

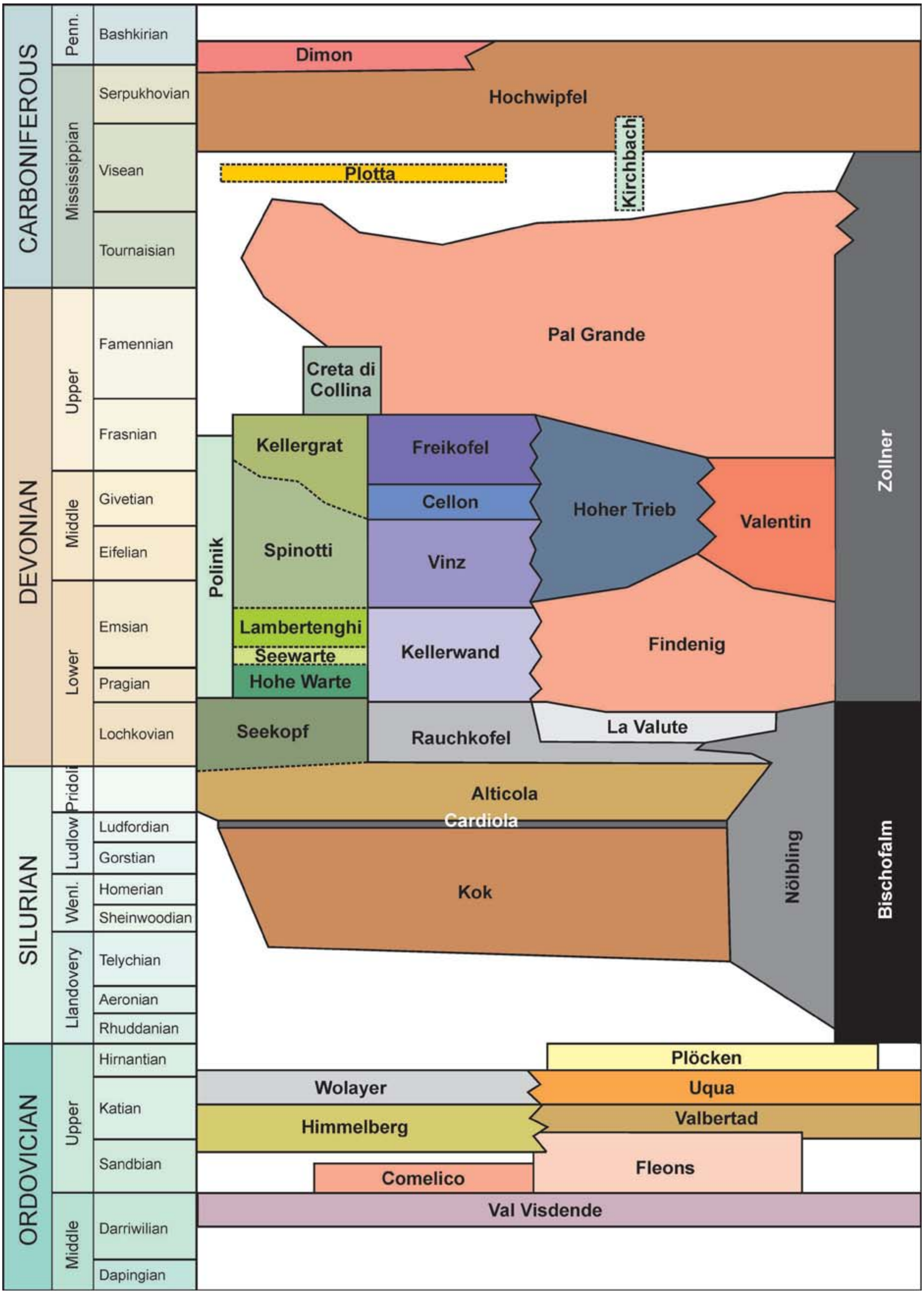


**Fig. 5** - General lithostratigraphic scheme of the Pre-Variscan sequence of the Carnic Alps (after Corradini et al., 2015b, modified).

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. was deposited. It consists of a tripartite succession, up to 60 m thick, of black siliceous shales, with interbedded cherts, clay-rich alum shales, and black graptolitic shales. 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).

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 characterized 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.

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., 2019). 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 late Lochkovian, 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 & 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. 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, Mt Cavallo/Roßkofel and Mt Osternig, beside several minor buildups. The fossil content (Fig. 6) 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).

Starting from the early Frasnian, the basin was subjected to a combination of extensional tectonic activity and eustatic fluctuations, which combined effects caused reefs

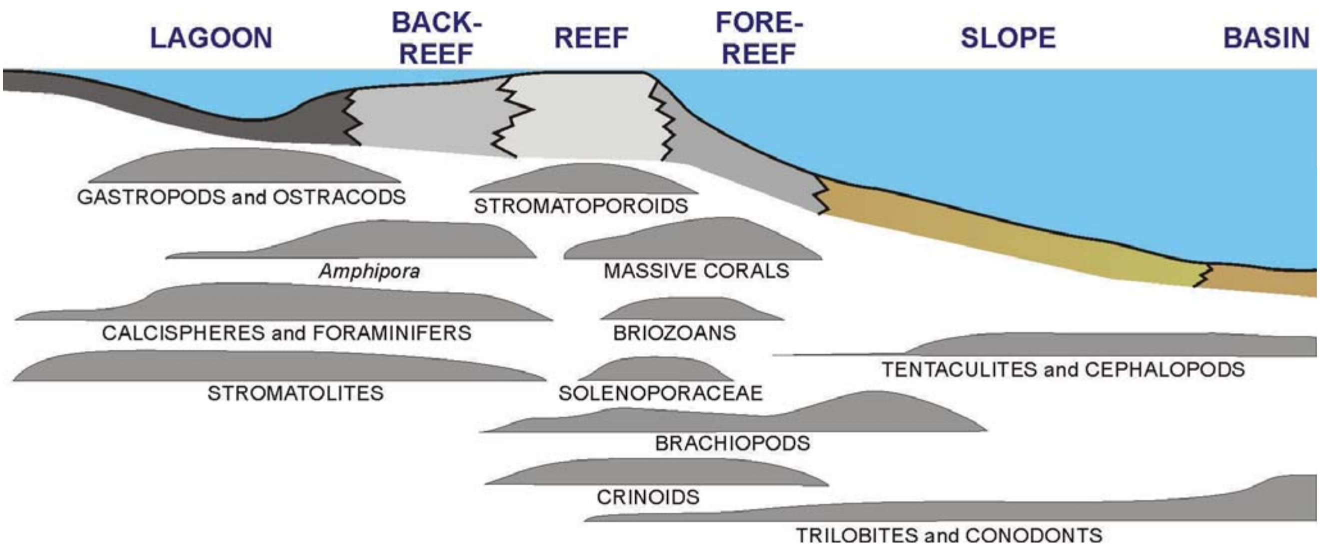


**Fig. 6** - The distribution of main fossil groups in the Middle Devonian of the Carnic Alps (modified after Vai et al., 2002).

extinctions. From the late Frasnian (Upper *rhenana* conodont Zone) a uniform pelagic environment developed, which continued up to the early Visean (Schönlaub, 1969; Schönlaub & Kreutzer, 1993; Perri & Spalletta, 1998; 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 a paleokarstic event in the early Carboniferous (Schönlaub et al., 1991; 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 & 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 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 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. 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).

### 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, where, because of subsidence related to a strike-slip tectonic system, the Permo-Carboniferous Sequence (Fig. 7) deposited in disconformity on top of the Pre-Variscan Sequence. It consists of alternating cycles of fluvio-deltaic and marine deposits, caused by frequent eustatic sea level changes due to the Permo-Carboniferous glaciation. The sequence starts with basal breccias and conglomerates, resulting from the erosion of the Paleocarnic Chain.

The basal conglomerates (attributed by Venturini, 1990 to the Bombaso Fm.) are overlaid by sediments subjected to frequent transgressive-regressive cycles, with alternating fluvio-deltaic clastic sediments and calcareous shallow water deposits. Different authors discriminate five formations belonging to the Pramollo Group (Venturini, 1990), or several members within the Auernig Fm. (Forke et al., 2006; Schönlaub & 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 with the Trogkofel Group (Venturini, 1990) (Trogkofel Fm., Forke et al., 2006), characterized 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 (Val Gardena Sandstones), and finally evaporitic, lagoonal and shallow marine water (*Bellerophon* Fm.). This sequence was deposited in an environment characterised by alluvial fans (Tarvisio Breccia

| CHRONOSTRAT. | | | Venturini (1990) | | Forke et al. (2006) | |
|---|---|---|---|---|---|---|
| PERMIAN | Cisuralian | Kungurian | | | | |
| | | Artinskian | Trogkofel Gr. | Coccau Lms. | Trogkofel Fm. | |
| | | | | Trogkofel Lms. | | |
| | | Sakmarian | Rattendorf Gr. | U. Pseudo. Fm. | Zweikofel Fm. | |
| | | Asselian | | Val Dolce Fm. | Grenzland Fm. | |
| CARBONIF. | Pennsylvanian | Gzhelian | | L. Pseudo. Fm. | Schulterkofel Fm. | |
| | | | Pramollo Gr. | Carnizza Fm. | Auernig Fm. | Carnizza Mb. |
| | | | | Auernig Fm. | | Gugga Mb. |
| | | | | Corona Fm. | | Corona Fm. |
| | | Kaisimovian | | Pizzul Fm. | | Watschig Mb. |
| | | | | | | Pizzul Mb. |
| | | | | Meledis Fm. | | Meledis Mb. |
| | | Moscovian | | Bombaso Fm. | Collendiaul Fm. | |

**Fig. 7** – Stratigraphic 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). Abbeviations: L. Pseudo. Fm.= Lower *Pseudoschwagerina* Fm.; U. Pseudo. Fm.= Upper *Pseudoschwagerina* Fm.

and Sesto Conglomerates), alternating with alluvial plains with irregular braided rivers 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 characterized by gypsum, graywackes and evaporitic dolostone in the lower part of the succession and by dolostone and black limestone in the upper part.

## HISTORY OF RESEARCH ON PORIFERA AND CNIDARIA IN THE CARNIC ALPS

Studies on the Palaeozoic of the Carnic Alps started in the fifties of the XIX century, and were mainly based on the rich fossil content, used as main stratigraphic tool to unravel the complex succession of the area. In that contest, corals and sponges played an important role in oldest studies.

Between 1895 and 1901, De Angelis D'Ossat published several papers on the Devonian and Carboniferous corals of the Carnic Alps (De Angelis D'Ossat, 1895, 1896, 1899a, 1899b, 1901) ascribing to the Devonian the limestones of Mt Zermula, north of Paularo, formerly considered as Triassic by Frech (1894) and recognizing the Carboniferous in the Rio degli Uccelli/Vogelbach, north of Pontebba. In these papers, De Angelis D'Ossat described also two new localities with Devonian corals: Val di Collina area, in the south-eastern slope of Mt Coglians massif, and the southern side of Mt Lodin/Findenig. At the beginning of the twentieth century, Michele Gortani and Paolo Vinassa de Regny studied the Paleozoic succession of the Carnic Alps in detail and published several papers on Palaeozoic corals and sponges, mainly from the Devonian limestones of the Mt Coglians massif and Mt Zermula (Vinassa de Regny, 1908, 1915, 1918, 1919; Gortani, 1912). These monographs, that are the last compiled on this topic in the Carnic Alps, provided an important contribution in the correct subdivision of the Palaeozoic sequence of the Carnic Alps, that was definitively established between the 1920's and the 1930's thanks to the studies of Michele Gortani, Paolo Vinassa de Regny, Franz Heritsch and Hans Rudolf von Gaertner. Later, due to the new research methods in biostratigraphy, studies were mainly focused on other fossil groups, and the Palaeozoic succession of the Carnic Alps is now one of the best known and deeply studied in Europe. Among the few exceptions, it worth to be mentioned the papers on Devonian corals from Mt Zermula (Ferrari, 1968) and carboniferous sponges from the Pramollo area (Bizzarrini & Muscio, 1992).

In the last years studies on fossil corals restarted, mainly due to their value in paleoecological researches (e.g., Pickett, 2007; Kido et al., 2011a, b; Rodríguez et al., 2018).

## INTRODUCTION TO CORALS IN THE CARNIC ALPS

The rugose and tabulate corals that have been described or listed from the Paleozoic deposits of the Southern Alps in Austria, Italy and Slovenia, are comprehensively listed in the *Catalogus fossilium Austriae* by Flügel & Hubmann (1994) and Hubmann (1995). Below, only rugose corals are summarized based on former publication. Although Flügel & Hubmann (1994) indicated the age and lithostratigraphic unit based on the original publication, we revised that for the Pre-Variscan sequence according to Corradini et al. (2015b). Without any amendment, corals from the post-Variscan sequence are summarized best by Flügel & Hubmann (1994).

### Ordovician and Silurian

The late Katian Wolayer Fm. yields some few broken specimens of rugose corals (Schönlaub & Ferretti, 2015). Silurian rugose corals occur in the Kok Fm., Cardiola Fm. and Alticola Fm. (Pickett, 2007; Ferretti et al., 2015a, b, c). Following species have been reported (Flügel & Hubmann, 1994; Pickett, 2007):

<u>Alticola Fm.</u>: *Petraia*? sp., *Petraia laevis*, *Petraia* sp. aff. *P. semistriata*, *Metriophyllum* sp.?, *Laccophyllum* sp. and *Lindstroemia* sp. aff. *L. laevis.*

<u>Cardiola Fm.</u>: *Spongophyllum coeni.*

### Devonian

During the Devonian more than 1000 m of shallow marine carbonates were deposited in the central Carnic Alps. Corals occur in the Rauchkofel Fm., Polinik Fm., Hohe Warte Fm., Seewarte Fm., Lambertenghi Fm., Spinotti Fm., Kellergrat Fm., Kellerwand Fm., Cellon Fm., Freikofel Fm. and Pal Grande Fm. (Flügel & Hubmann, 1994; Pohler et al., 2015a, b, c; Bandel et al., 2015; Kido et al., 2015; Pondrelli et al., 2015a, b, d; Spalletta et al., 2015c). The Creta di Collina Fm., Vinz Fm., Hoher Trieb Fm. and Valentin Fm. yield reworked fossils including corals (Spalletta et al., 2015a, b; Pondrelli et al., 2015c, e, f).

<u>Rauchkofel Fm.</u>: *Brachyelasma*? *alpina*.

<u>Lochkovian rugose corals of unknown lithostratigraphic unit</u>: *Tryplasma loveni* and *Arachnophyllum diffluens.*

<u>Hohe Warte Fm.</u>: *Tryplasma devoniana*, *Tryplasma vermiculare*, *Cystiphyllum*? *intermedium densum*, *Mesophyllum* (*Mesophyllum*) *cristatum*, *Mesophyllum* (*Mesophyllum*)

*vesiculosum vesiculosum*, *Favistella* (*Dendrostella*) *fluegeli*, *Zelophyllia tabulata*, *Pseudamplexus bohemicus*, *Pseudamplexus frechi*, *Amplexus frechi frechi*, *Amplexus irregularis*, *Syringaxon*? *zimmermanni*, *Endophyllum acanthicum*, *Endophyllum carnicum*, *Hallia*? sp., *Spongophyllum halisitoides*, *Battersbyia symbiotica*, *Battersbyia syringoporoides*, *Acanthophyllum* sp. cf. *A. heterophyllum heterophyllum*, *Acanthophyllum* sp. cf. *A. heterophyllum torquatum*, *Dohmophyllum helianthoides*, *Lyrielasma* sp., *Stringophyllum* sp., *Heliophyllum*? sp., *Cyathophyllum*? n. sp. ex aff. *dianthus*, *Cyathophyllum*? *hallioides*, *Cyathophyllum*? *macrocystis*, *Cyathophyllum*? *vermiculare carnicum*, *Cyathophyllum? Volaicum* and *Phillipsastrea ananas.*

Seewarte Fm.: *Tryplasma hercynica*, *Lyrielasma subcaespitosa carnica*, *Cyathophyllum*? *alpinum*.

Section at Mt Canale (Emsian): *Aspasmophyllum* sp.

Vinz Fm.: *Tabulophyllum* sp.

Silicified corals from the Hoher Trieb Fm. are collected in the breccia-levels of that unit. Eight species in seven genera have been reported from the formation at Mt Lodin/ Findenig by Vinassa de Regny, (1908, 1915) and Flügel & Hubmann (1994):
*Cystiphyllum*? *geyeri*, *Grewinglia*? *carnica*, *Barrandeophyllum carnicum*, *Entelophyllum*? *alpinum*, *Entelophyllum articulatum*, *Pycnactis mitratum*, *Sociophyllum torosum* and *Cyathophyllum*? *taramelli*.

Following rugose corals have been listed or described from stratigraphically undifferentiated Middle Devonian shallow water limestones of Mt Zermula (Ferrari, 1968) and Casera Monumenz (Vinassa de Regny, 1918). The corals from the Kellergrat Fm. in central Carnic Alps (Vinassa de Regny, 1918; Oekentorp-Künster & Oekentorp, 1992; Flügel & Hubmann, 1994) are Givetian in age, except for the *Pexiphyllum* sp. and *Tabulophyllum delicatum* which ranged until Frasnian (Flügel & Hubmann, 1994). *Scruttonia julli* occurs in the upper part of the formation, indicating Frasnian age (Küster, 1987).

Undifferentiated Middle Devonian of Mt Zermula: *Dendrostella trigemme*, *Dendrostella vulgaris*, *Pseudamplexus* sp. aff. *P. frechi*, *Tabulophyllum delicatum*, *Tabulophyllum heckeri giveticum*, *Battersbyia devonica*, *Stringophyllum schwelmense*, *Neospongophyllum primordiale*, *Cyathophyllum dianthus*, *Thamnophyllum coespitosum*, *Cyathophyllum* sp. cf. *C. volaicum* and *Disphyllum*? *recressum.*

Undifferentiated Middle Devonian of Casera Monumenz: *Pseudamplexus bohemicus*, *Cyathophyllum vermiculare*, *Cyathophyllum*? *conglomeratum pauciseptatum*, *Cyathophyllum spongiosum*, *Cyathophyllum*? *canavarii*, *Cyathophyllum*? *lindströmi* and *Disphyllum goldfussi.*

Other Middle Devonian localities (Vinassa de Regny, 1908, 1918; Assereto, 1962): *Tryplasma devonica*, *Cystiphyllum*? *cristatum*, *Zonophyllum* sp., *Dendrostella* sp. cf. *D. praerhenana*, *Amplexus frechi major*, *Amplexus hercynicus*, *Amplexus mutabilis*, *Endophyllum acanthicum*, *Dohmophyllum* sp. cf. *D. involtum*, *Acanthophyllum heterophyllum heterophyllum*, *Dohmophyllum philocrinum*, *Battersbyia petshorense*, *Disphyllum caespitosum caespitosum*, *Phacellophyllum conglomeratum*, *Pterorrhiza dubia*, *Cyathophyllum vermiculare*, *Cyathophyllum*? *lindströmi*, *Cyathophyllum*? *volaicum*, *Cyathophyllum*? *angustum*, *Peripaedium planum* and *Thamnophyllum caespitosum*.

Kellergrat Fm.: *Dendrostella trigemme*, *Amplexus gortanii*, *Endophyllum priscum*, *Acanthophyllum heterophyllum heterophyllum*, *Acanthophyllum concavum*, *Acanthophyllum* sp., *Grypophyllum* sp., *Dohmophyllum helianthoides*, *Battersbyia* sp., *Stringophyllum praecursor*, *Stringophyllum* sp., *Columnaria* sp., *Alaiophyllum jarushevskyi*, *Temnophyllum* sp. cf. *T. latum*, *Disphyllum goldfussi*, *Phillipsastrea hennahi*, *Scruttonia julli*, *Pexiphyllum heterophylloides*, *Pexiphyllum*? sp., *Thamnophyllum caespitosum*, *Thamnophyllum carnicum*, *Cyathophyllum vermiculare*, *Cyathophyllum dianthus*, *Cyathophyllum*? *bathycalyx*, *Cyathophyllum*? *collinense*, *Cyathophyllum*? *gortanii*, *Cyathophyllum*? *tinocystis carnicum*, *Cyathophyllum*? *lindströmi* and *Clisiophyllum*? *taramelli*.

**Carboniferous**

The Mississippian aged deposits of the Kirchbach Fm. (Schönlaub et al., 2015) yield solitary corals as well as crinoids and ooids. Just recently, one rugose coral, *Lonsdaleia carnica*, has been described from that unit (Rodríguez et al., 2018).

## DAY 1 - CASON DI LANZA AREA

Cason di Lanza Pass is located in the heart of the Carnic Alps, along the mountain road connecting Paularo and Pontebba (Fig. 8). The morphology of the area conforms to a typical high mountain morphology, controlled by lithology (massive Middle Devonian limestone constituting the highest and sharpest edifices), tectonic, mass wasting and with a glacial imprint.

The Pre-Variscan sequence is exposed south of the pass (Fig. 9), and is largely laterally uniform across the area with the exception of the Eifelian-Frasnian interval, when the basin was differentiated in a shallow water part, with the deposition of back reef and reef deposits, and a distal part, with pelagic deposits interlayered by gravity driven redeposited material coming from the shallow water units. In the Cason di Lanza Pass area the Variscan orogeny resulted in a top to the south detachment leading to the formation of a pluri-kilometric asymmetric NW-SE trending fold with an overturned flank which includes the Zermula and Pizzul mountains as well as the Malinfier gorge (Venturini, 1990) (Fig. 10). Centrimetric to decametric large parasitic asymmetric folds are superimposed to the pluri-kilometric fold where lithological characters allow such ductile deformation (Fig. 11). For a more exhaustive description of the Pre-Variscan sequence in the Cason di Lanza Pass area refer to Corradini et al. (2012) and Pondrelli et al. (2015a).

North of Cason di Lanza, deposits of the Permo-Carboniferous sequence are extensively exposed. They belong to the western part of the Pramollo Basin. The Carboniferous terms are represented by alternations of fluvio-deltaic and marine deposits (Meledis Fm.), whereas in the lower Permian units the marine calcareous facies are dominant.


**Fig. 8** - Location map and panoramic view of the Cason di Lanza Pass, from the top of Mt Pizzul. In front right the white cliffs of the Zuc della Guardia, constituted by Devonian reefal limestone. In the northern side of the valley, behind the hut, mainly Permo-Carboniferous rocks are exposed.

For a complete discussion of the Permo-Carboniferous sequence, refer to Venturini (1990) and Schönlaub & Forke (2007).

In the Cason di Lanza area, well exposed back- and fore-reef sediments coral and porifera bearing can be observed. They are represented by the “Amphipora limestone” and the Hoher Trieb Fm., respectively.

**Fig. 9** – Panoramic view of the Pre-Variscan sequence south of Cason di Lanza. The white rocks forming the cliffs of northern flank of Mt Zermula (right), Zuc della Guardia (centre) and Zuc di Malaseit (left) are constituted by Middle Devonian reefal limestone; the darker sediments on the back deposed in deeper environment during the Late Ordovician-early Carboniferous interval.

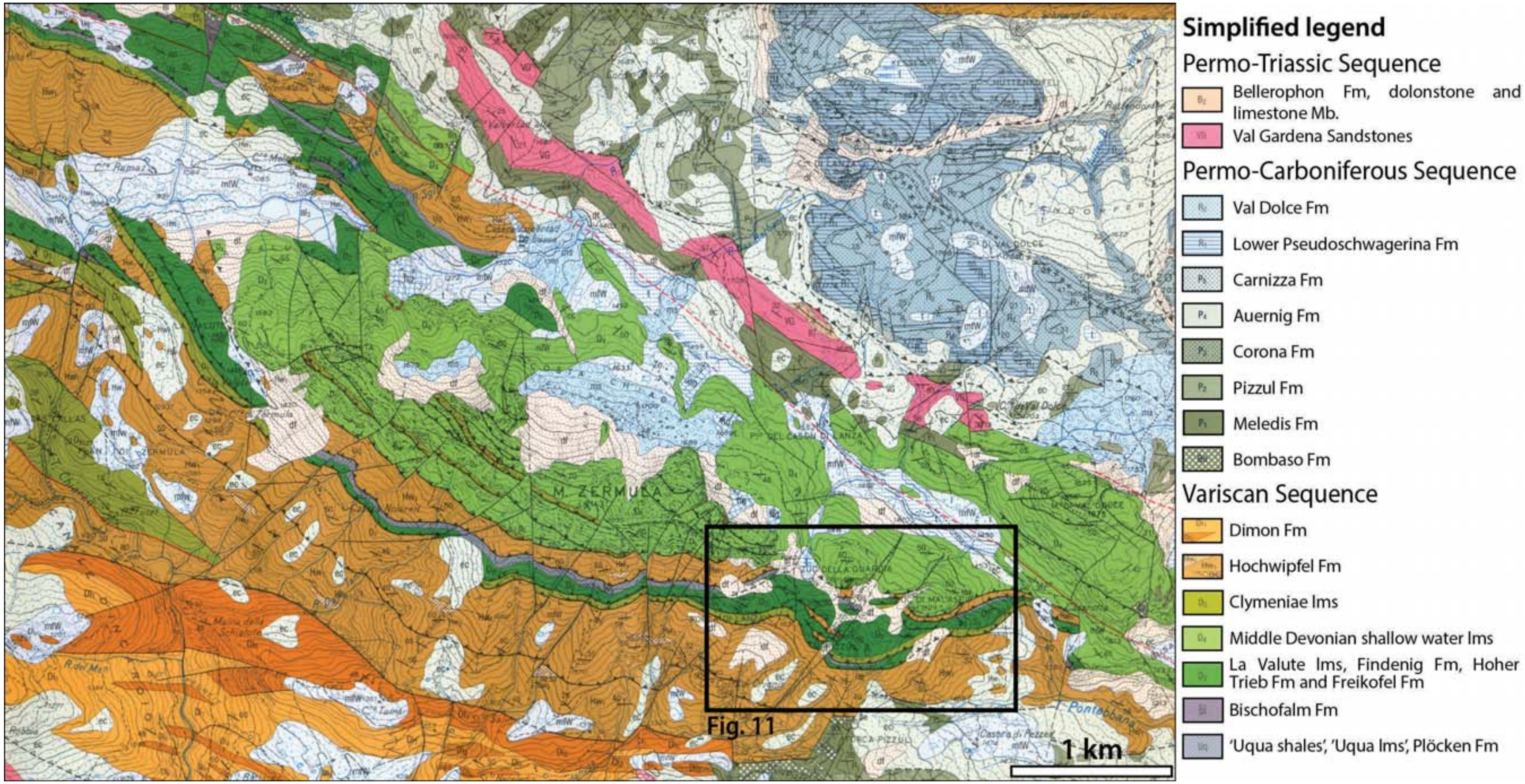


**Fig. 10** - Simplified geological map of the Cason di Lanza Pass area (after Venturini et al., 2001). See text for the description of the units. Light patterned yellow, blue and red represents Quaternary deposits. The box represents the location of the detailed geological map of Fig. 11.

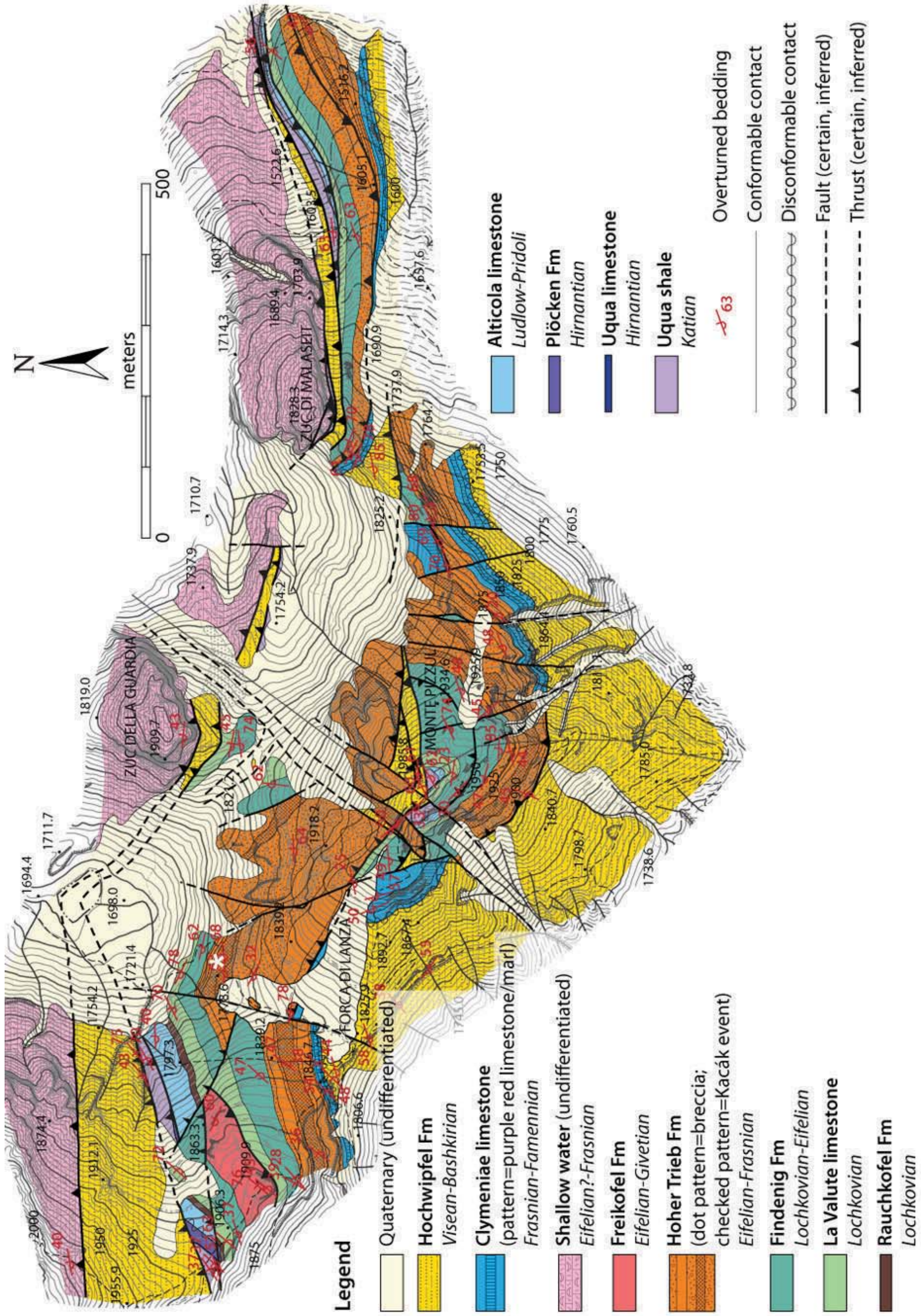


**Fig. 11** - Detailed geological map of the Mt Pizzul area (after Pondrelli et al., 2015a, mod.). The asterisk indicates the locality where silicified corals are exposed.

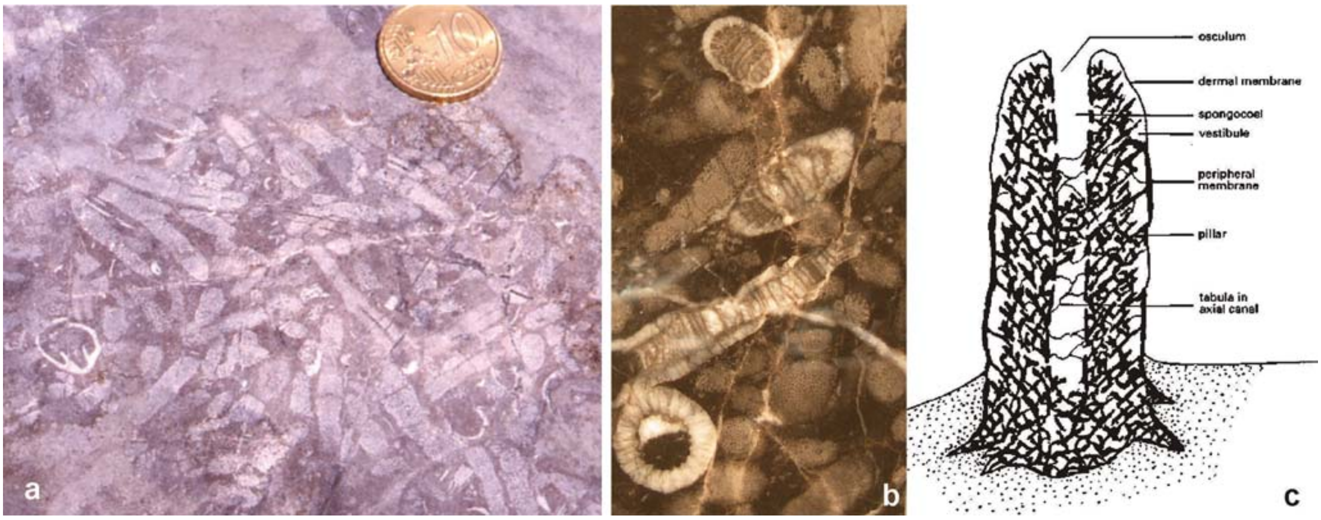


**Fig. 12** - a: The "Amphipora limestone" (Spinotti Fm.) at Cason di Lanza Pass. b: polished slab. c: reconstruction of *Amphipora* ramosa as a small sponge rooted in the substrate (after Stearn, 1997).

**The back reef ("Amphipora lms")**

On the southern side of the pass, right below the reefal cliffs of Mt Zermula and Mt Zuc della Guardia, sediments from the calm lagoonal back-reef environment crop out. They are better exposed around the old military house at the Cason di Lanza pass (Fig. 12).
These rocks of Givetian (Middle Devonian) age belong to the Spinotti Fm., and are informally known as "Amphipora limestones". They are constituted of "prairies" of *Amphipora ramosa*, trapping carbonatic mud. Additionally, it yields rugose corals predominately of the genus *Dendrostella*, which here consisting of 3 species. Within the unit darker levels bearing the brachiopod *Stringocephalus burtinii* are present here and there. This taxon confirms the Givetian age of the outcrop. In other areas of the Carnic Chain (Mt Coglians area) this unit spans a wider time interval (Eifelian-Frasnian, Middle-Late Devonian) and its thickness reaches 370 meters.
The Genus *Amphipora* is known from Emsian to early Famennian, with the most widespread distribution in Middle Devonian time. The amphiporoid animal was a small, cylindrical, branching, calcified sponge (Stearn, 1997). The stems are rods of a few millimeters in diameter and are composed of skeletal elements of fibrous calcite defining an irregular network of hard tissue in which concentric elements are obscure, and radial elements are hard to distinguish. The labyrintine canals between the elements

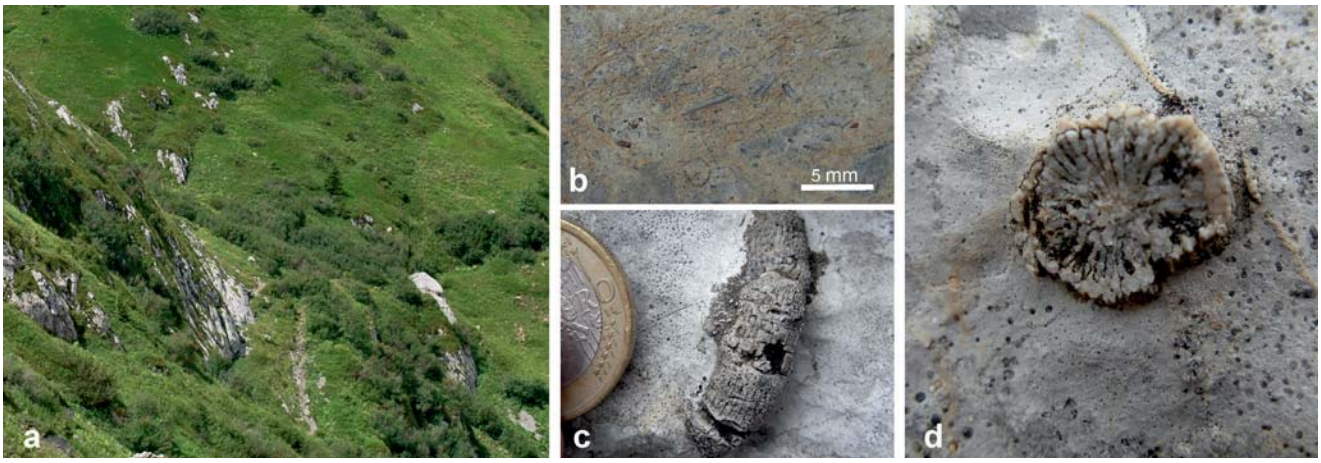


**Fig. 13** - The Hoher Trieb Fm. in the Cadin di Lanza Parete (CAD P) section. a: panoramic view of the section. b: tentaculitic limestone. c-d: silicified corals in the outcrop.

open on the periphery in apertures of irregular shape or are covered there by a thin hard tissue membrane. The peripheral membrane may be present on only some of the stems or only on some parts of individual stems. A prominent axial canal crossed by dissepiments may or

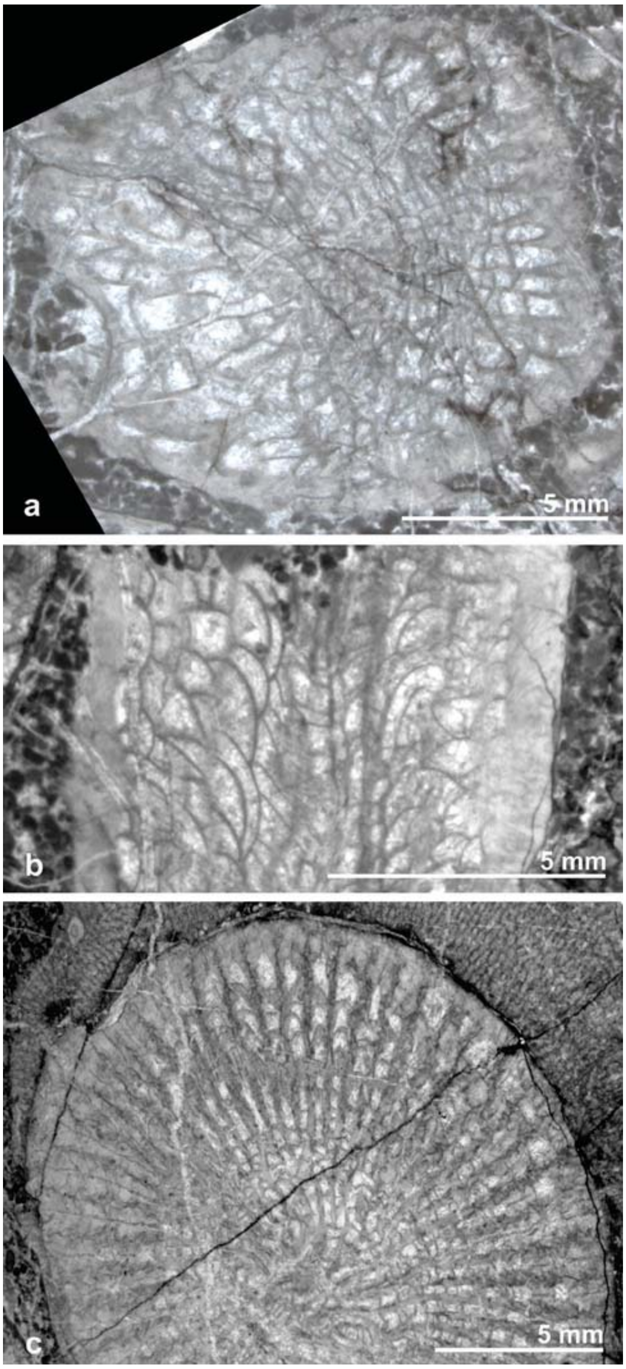


**Fig. 14** - Rugose corals from the Hoher Trieb Fm. of the CAD-P section. a-b: transverse and longitudinal section of *Grypophyllum*. c: transverse section of *Cyathophyllum*.

may not be present. Some specimens are branched, other remain as single tubes. Taxonomically, Amphiporidae (Silurian-Permian) are considered a family of the Class Stromatoporoidea, but their phylogenetic relationships with other representatives of the group are still unclear (Stearn, 1997).

*Amphipora* lived in shallow, calm waters. The stem was anchored inefficiently by irregular outgrowths at the base or cemented into the substrate; the latter hypothesis seems to be more probable (Stearn, 1997).

**The fore reef (Hoher Trieb Fm.)**

The Hoher Trieb Fm. crops out at Forca di Lanza, Mt Pizzul and Zuc di Malaseit (Figs. 11, 13). The overall thickness can be estimated about 45 meters. This unit consists of interlayered meter thick floatstone, centimetric and decimetric thick grainstone and packstone, centimetric thick black radiolarite and shales and rare sandstones. Breccia layers are characterized by the presence of silicified remains of corals (e.g. *Dendrostella* sp., *Grypophyllum* sp., *Temnophyllum* sp. and *Cyathophyllum* sp. under taxonomic study; Fig. 14) resedimented from shallow water. Grainstone and packstone are often laminated and normally graded, suggesting deposition from a waning flow. A black shales episode marks the Kačak Event (Kido et al., 2011b; Pondrelli et al., 2015a; Suttner et al., 2017). This unit is interpreted as transitional from slope to pelagic deposits. According to conodont data, the Hoher Trieb Fm. spans an interval from Eifelian through Frasnian, and is partly heteropic with the Freikofel Fm.

## DAY 2 - PASSO DI MONTE CROCE CARNICO/PLÖCKENPASS AREA

Passo di Monte Croce Carnico/Plöckenpass (Fig. 15) is a deep pass in the central Carnic Alps between Creta di Collinetta/Cellon to the west, and Pal Piccolo to the east. 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 'syn-reefal' 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), border the southern limit of the Creta di Collinetta/Cellon mountain right to the south-west of Passo di Monte Croce Carnico/Plöckenpass. 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 south-dipping (roughly 35°-40°) monocline while to the northeast of the fault a north-verging inclined pluri-kilometric fold is present.
The shallow water succession in this area consists of the Middle Devonian to Frasnian Spinotti and Kellergrat formations, representing lagoonal and reefal 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 Formation. 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 the Givetian.

### Val di Collina quarry

Val di Collina quarry is located at trail 149 via Rifugio Marinelli to Collina, approximately 1.5 km southwest of Passo di Croce Carnico/Plöckenpass, on the sotheastern slope of Mt Coglians/Hohe Warte massif at an elevation of 1520 m (Fig. 16a-b). 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 depo-


**Fig. 15** - Location map and panoramic view of the Passo di Monte Croce Carnico/Plöckenpass from south.

sitional phases are provided (Fig. 16c). Although the area was mentioned by several authors (e.g., Hubmann et al., 2003 and Schönlaub et al., 2004) detailed palaeontological studies are ongoing.
Regarding the rugose corals, diversified taxa have been described or reported from the shallow water limestone at the quarry and the area around, i.e., Casera Monumenz, (Vinassa de Regny, 1918; Oekentorp-Künster & Oekentorp, 1992; Flügel & Hubmann, 1994; see list above), they need taxonomic restudy according to modern publication. 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 limestone succession is designated to be Middle Devonian by microfossils. The conodont assemblage across the formation boundary includes species diagnostic for the *ensensis* and *hemiansatus* biozones (Suttner et al., 2017).
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 (Fig. 17). The sedimentary succession presents stromatoporoid/coral-breccia layers alternating with fine crinoidal

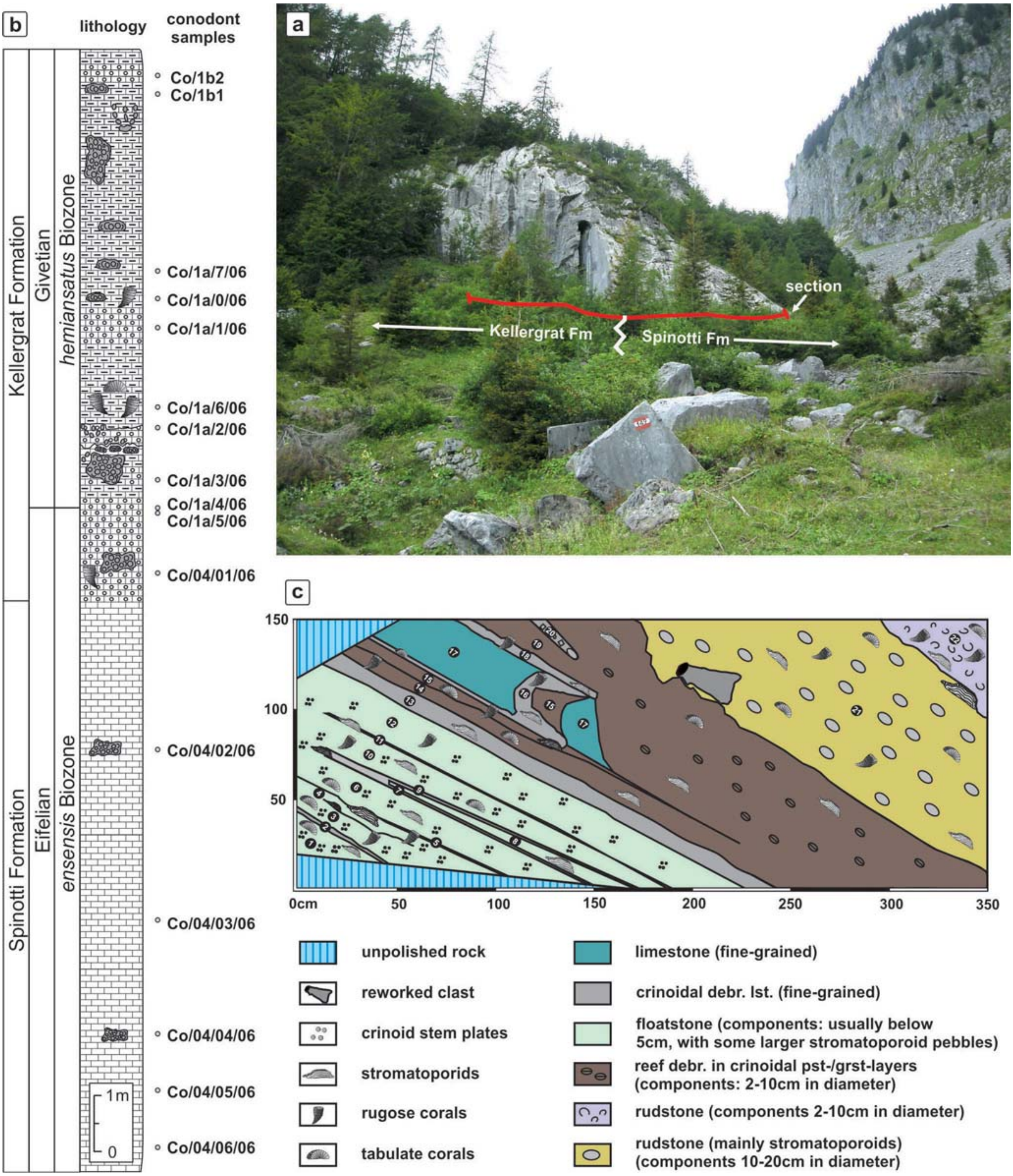


**Fig.16** - Shallow water section across the Eifelian-Givetian boundary at the abandoned Val di Collina Quarry (Italy). a: Large blocks of reef-debris limestones formatted for commercial purpose. b: Sedimentological log of the section ranging from the *ensensis* Zone to the *hemiansatus* Zone. c: Detailed facies documentation of one of the larger blocks (for fossil distribution see also Figure 18).

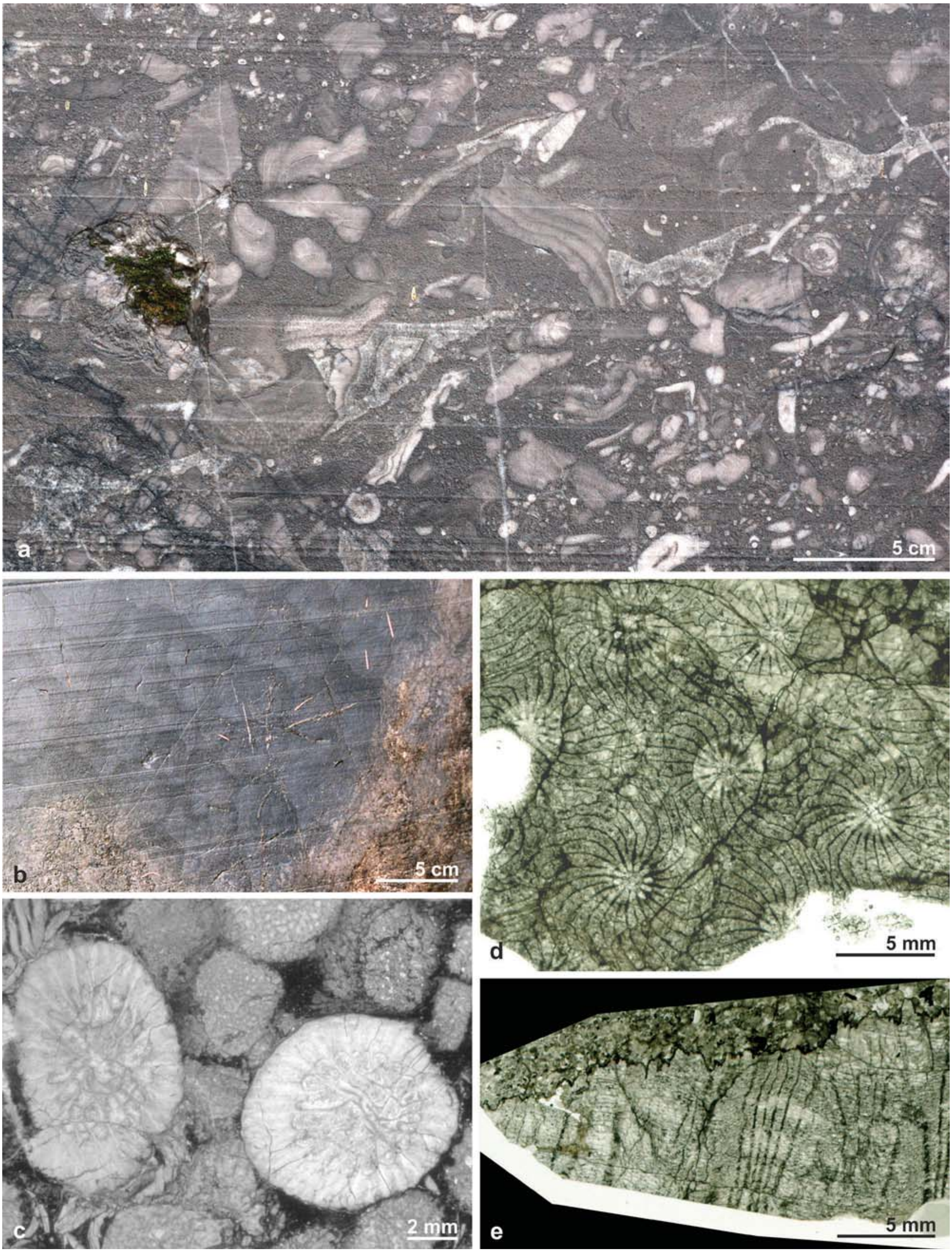


**Fig. 17** - Fossil cnidaria and porifera from the Val di Collina Quarry (Italy). a: Reef debris including large fragments of stromatoporoids, rugose and tabulate corals, crinoids and brachiopods. b: Large stromatoporoid colony. c: *Amphipora* and *Dendrostella*. d-e: transverse and longitudinal section of *Phillipsastrea*.

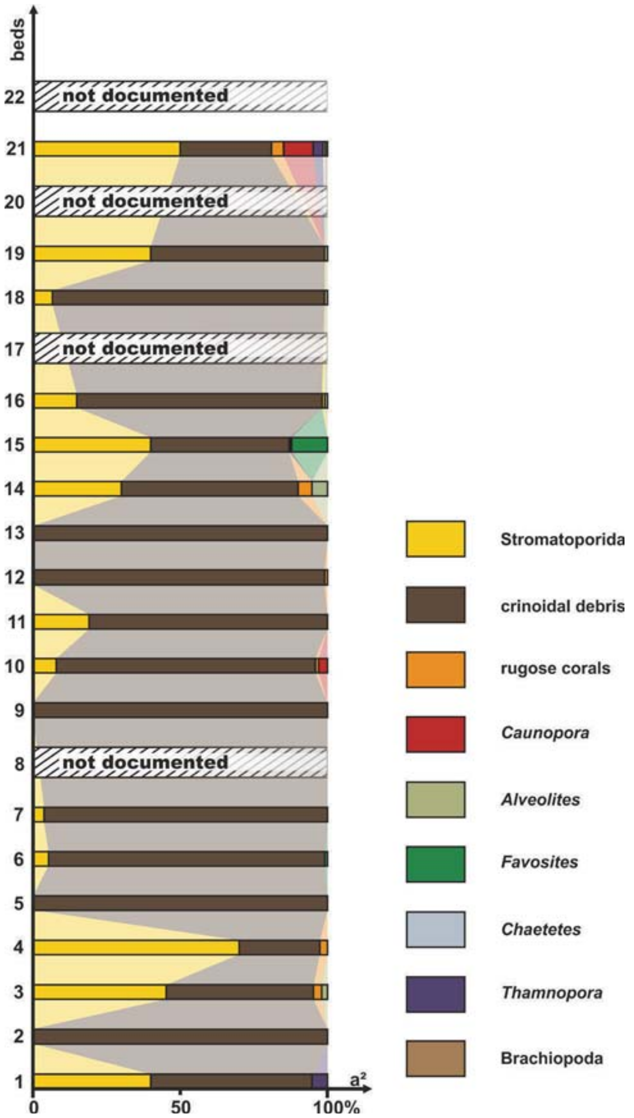


Fig. 18 - Distribution of fossils evaluated from one of the polished blocks at the Val di Collina Quarry (see Figure 16c).

debris layers. The surface of one of the larger polished blocks (approx. 5.5 m³) for example shows a distribution of stromatoporoids to corals of approximately 60% stromatoporoids, 5% rugose corals, tabulate corals (14% *Caunopora*, 5% *Favosites*, 5% *Alveolites*, 4% *Heliolites*, 3% *Thamnopora*) and 4% of coral clasts (Fig. 18).

## DAY 3 - PRAMOSIO AREA (POST REEF SEDIMENTS)

Pramosio is located north-east of Timau village (Fig. 19) and is a classical locality for studies on the Upper Devonian rocks of the Carnic Alps.

The Pramosio area is characterized mainly by Lower to Upper Devonian limestone disconformably capped by siliciclastic rocks of the Hochwipfel Fm. The Upper Devonian limestone of the Freikofel and the Pal Grande Fms constitute the major part of the calcareous sequence and were extensively studied by means of conodonts. The Pal Grande Fm. in this area is represented by almost all conodont biozones from Frasnian Zone 13a to the Famennian *Bispathodus ultimus* Zone, and its rich ammonoid (goniatites and clymenids) content was object of studies since the end of the XIX century.

This area is characterized by a km-large anticlinal structure of Chattian-Burdigallian age (Venturini, 1990). This structure folds the previously emplaced Variscan thrusts and is in turn faulted by the more recent Alpine mostly strike-slip structures of Tortonian-Serravallian and Plio-Pleistocene age. In the core of such folds the oldest part of the succession are preserved, starting, in this area, from the Eifelian deposits of the Vinz Fm. up to the Hochwipfel Fm. In this area the 'syn-reef' succession consists mostly of slope (fore-reef) deposits, fed by the shallow water, including reefal-bearing, successions. The uppermost part of the Freikofel Fm. and the Pal Grande Fm. represent the post-reef sedimentation in this part of the basin.


Fig. 19 - Location map and panoramic view of the Pramosio area. Almost all the light grey rocks in the back are limestones of the Pal Grande Fm., that are extracted for building purposes in the large Pramosio quarry.

**The "post-reef" pelagic limestones**

The Pramosio Bassa section (Fig. 20) is shown as example of the pelagic Upper Devonian limestones of the Pal Grande Fm. The section is especially interesting for documenting the Annulata Event.

The Pal Grande Fm. deposited in a pelagic environment from slope to open basin. It has to be highlighted that the depth of the Carnic basin during the Late Devonian was moderate, likely not exceeding a few dozens of meters. The pelagic character of the formation is mainly due to deposition in one area far away from coasts (Spalletta et al., 2017). The unit is highly fossiliferous, yielding conodonts, ammonoids, brachiopods, trilobites, and crinoids. Beside conodonts, the residues from acid-leaching yield also some vertebrate microremains.

The Pramosio Bassa section has a thickness of about 15 m, and is separate into two parts by a faint tectonic disturbance, corresponding to a cover interval about 5 m above the base. The age spans from the *Palmatolepis rugosa trachytera* Zone (= Lower *trachytera* Zone) to upper part of the *Bispathodus ultimus* Zone (= Lower *praesulcata* Zone) (Spalletta et al., 2017). The level in correspondence of sample PB5a is very rich in fossils of *Prionoceras* and others ammonoids (Hartenfels & Becker, 2016). The original bedding planes are mm-cm thick, but the stratification now appears in beds 10 to ca 100 cm thick, often separated by mm levels of ochraceous pelite, with laterally irregular thickness along the exposure (Spalletta et al., 2017). The limestone sequence is also interested by levels with stromatactis structures. Black shales levels equivalent to the *Annulata* Black Shales are not present.

In the Carnic basin a general transgressive tendency from the *Palmatolepis marginifera marginifera*–*Polygnathus styriacus* zones was inferred by Perri & Spalletta (2000) based on conodont biofacies analysis. Hartenfels & Becker (2016) report that the level yielding a mass occurrence of *Prionoceras* (bed of sample PB5a) can be considered as an equivalent of the "Wagnerbank" of Thuringia. According to Hartenfels & Becker (2016) the goniatite-rich limestone of the "Wagnerbank" represents a regressive phase in the highest part of the *annulata* Zone (UD IV-A).


Fig. 20 – a: View of the Pramosio Bassa section. The box indicates the area enlarged in b. b: detail of the ammonoid rich level corresponding to the *Annulata* Event.

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