The Rannach Facies of the Graz Palaeozoic (Eastern Alps, Austria)

By

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With 37 figures

Field Trip Guide

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Content

Abstract

The Graz Palaeozoic (?Silurian to Upper Carboniferous) belongs to the “classical“ non to only low grade metamorphic fossiliferous Austroalpine Palaeozoic units. The Eo-Alpine (Cretaceous) internal structure is composed of a Lower and an Upper Nappe System. Each of them is differentiated into individual facies domains which reflect basal pre-Devonian volcanoclastics and a pronounced platfom to basinal facies geometry during the Devonian. The excursion focusses to the most famous and best investigated Rannach Facies of the Upper Nappe System but some major lithologies of the Lower Nappe System will be presented beside as well. The sequence of the Rannach Facies begins with a volcanoclastic influenced environment (Reinerspitz Group; ?Ludlow to Lochkovian) followed by a Lochkovian to Frasnian carbonate shallow water environment (Rannach Group) which interfingers with basinal calcareous schists (“Kalkschiefer-Fazies“). During Frasnian the facies changed to a pelagic environment (Forstkogel Group) which continued until the Serpukhovian and is followed by limestones and slates of the Dult Group (Bashkirian). The concordant marine sequence which persists to the Bashkirian and is interrutped only by some erosion events stimulates a discussion about the extistence of Variscan deformations in the Upper Nappe Unit of the Graz Palaeozoic.

1. Topics and area of the Field Trip

At the SE margin of the Eastern Alps the Graz Palaeozoic comprises Silurian to late Carboniferous sediments that occur within a mid-Cretaceous thrust complex capped by Upper Cretaceous “Gosau“ sediments. In the west, north and east the Graz Palaeozoic exhibits tectonic contacts to basal Austroalpine metamorphic complexes. To the south and southeast the Graz Palaeozoic is covered by Neogene sediments of the “Styrian Basin“ marginal to the Pannonian Basin.

Internally the Graz Palaeozoic consists of several facies nappes. The Rannach Facies, in the uppermost tectonic position, indicates a sedimentation area changing from a passive continental margin with intra-plate volcanism to shelf and platform geometries during Silurian to Devonian time. During Early to Middle Devonian time deposition changed from near-shore facies to open platform environments, during the Late Devonian and Carboniferous the carbonate platform was drowned and pelagic limestones were deposited.

The basal nappes of the Graz Palaeozoic are made up of Late Silurian to Early Devonian sequences that were subjected to metamorphic overprint under upper greenschist to exceptionally occurring amphibolite facies metamorphic conditions. Meggen-type lead/zinc-barite Sedex mineralizations are remarkable for some Upper Silurian - Lower Devonian volcanisedimentary sequences; thick banded limestones for the Lower/Middle Devonian. Lower Silurian to Late Devonian pelagic limestones, shales and volcaniclastics are in the intermediate tectonic position, summarized as “Kalkschiefer Facies“.

The excursion is focussed on the stratigraphy and facies architecture of the slightly metamorphosed Rannach Facies at the upper structural level of the Grau Palaeozoic thrust complex, but also some representative outcrops of the deeper nappe systems will be visited. We will see:

- Basal pre-Devonian basaltic tuffs.
- Silurian initial sedimentary successions (nautiloid dolostones) at the top of a basaltic volcanic island.
- Lower Devonian tidal flats.
- Lower Devonian massive dolomite (Schlossberg) in the centre of Graz.
- Middle Devonian restricted lagoonal Stachyodes-biostromes, coral-stromatoporoid-carpets and initial growth stages of a reef.
- Upper Devonian to Moscovian pelagic conodont and cephalopod limestone showing stratigraphic gaps which include mixed conodont faunas due to karstification and resedimentation.
- Devonian-Carboniferous section proposed as a candidate for the international boundary stratotype.
- Lower Carboniferous radiolarite and phosphorite levels related to the Kellwasser event.
- Erosional contact between the Carboniferous cephalopod limestone and the overlying shallow-marine limestones and shales (Bashkirian/?Moscovian).

2. Palaeozoic in Austria

Low grade and non metamorphosed Palaeozoic successions are irregularly distributed in Austria (Fig. 1). Two major regions of Palaeozoic domains can be distinguished which are separated by the Periadriatic Fault, the most prominent Alpine fault system: the Eastern Alps with the Greywacke Zone, the Gurktal Nappe, the Graz Palaeozoic, some isolated domains in south Styria and Burgenland and the Southern Alps with famous fossiliferous Palaeozoic

Fig. 1: Austria and its disconnected Palaeozoic units (shaded areas). Position of the city of Schladming and area of the Graz Palaeozoic indicated in red. Major Palaeozoic domains in Austria belong to the Eastern Alps (Graz Palaeozoic, Greywacke Zone, Gurktal Nappe, South Burgenland) and the Southern Alps (Carnic Alps, South Karawanken Mts.).

sequences in the Carnic Alps and the southern Karawanken Mountains (Schönlaub & Heinisch 1993).
In the Eastern Alps the Palaeozoics belong to the Upper Austroalpine Nappe System (Schmid et al. 2004) in which non metamorphosed Palaeozoic sequences were primarily superposed unconformably by Late Palaeozoic to Eocene stratigraphic sequences most spectacularly exposed in the Northern Calcareous Alps. The nappe structure of the Upper Austroalpine System was triggered by the closure of the Meliata Ocean during Jurassic to Early Cretaceous times and sealed by Late Cretaceous to Eocene overstep sequences (Gosau Group). Later, during the indentation of the Apulian Plate to the north and the southward subduction of the Penninic units under the Apulian Plate, the Upper Austroalpine Nappe System was thrusted into the uppermost tectonic position of the Eastern Alps. Contemporaneous with the Apulian indentation uplift of the Penninic Tauern Window and other core complexes triggered lateral extrusion of the eastern parts of the Eastern Alps within the ALCAPA (**Al**pine-**Ca**rpathian-**Pa**nnonian) unit to the east (Ratschbacher et al. 1991, Neubauer et al. 2000).

3. The Graz Palaeozoic

The Graz Palaeozoic comprises an outcropping area of approximately 1.250 km^2 tectonically resting on metamorphic basement. Metamorphic units in the northwest, west, northeast and southeast belong to the Upper Austroalpine Silvretta-Seckau and Koralpe-Wölz Nappe Systems (Schmid et al. 2004). The boundary between metamorphic units and the Graz Palaeozoic is formed by distinct thrust planes and a significant NE-SW striking sinistral wrench corridor at the northwestern border (Fig. 2). The nappes of the Graz Palaeozoic are unconformably overlain by the Upper Cretaceous Kainach Group (“Kainach Gosau“; Ebner & Rantitsch 2000) in the west and by Neogene sediments of the “Styrian Basin“ in the south (Ebner & Sachsenhofer 1991, 1995, Gross et al. 2007). SW of Rothleiten Upper Cretaceous conglomerates are also included along the sinistral wrench corridor between the Graz Palaeozoic and the Austroalpine metamorphic units.

The Graz Palaeozoic represents a pile of Eo-Alpine (Cretaceous) nappes consisting of different facial developments. Fritz & Neubauer (1990) discerned a Basal, an Intermediate, and an Upper Nappe Group in respect to lithological similarities, tectonic position, and metamorphic overprint. This concept of a tectonic three-arrangement in the sense of Fritz & Neubauer (1990) is the conceptual base for the lithostratigraphic arrangement shown in the ASC 2004 (Piller et. al. 2004):

1) The Basal Nappe Group (Upper Silurian - Lower Devonian) comprises the Schöckel Nappe and the Anger Crystalline Complex. Besides the Alpine (Early to Late Cretaceous) deformation of the Graz Palaeozoic in this Basal Nappe System minor Variscan deformation under upper greenschist facies metamorphic conditions (with exceptionally occurring amphibolite facies) is detected.

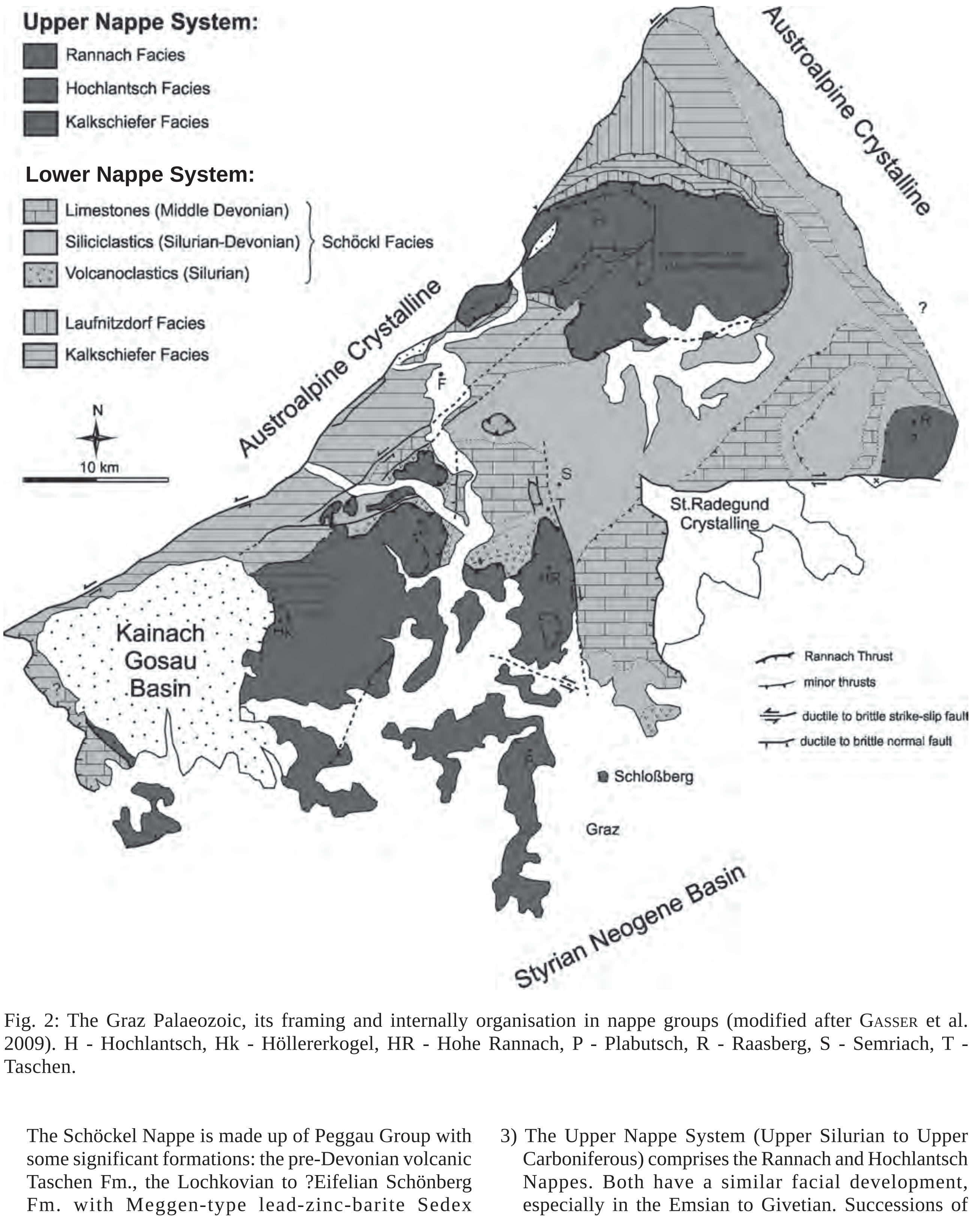


Fig. 2: The Graz Palaeozoic, its framing and internally organisation in nappe groups (modified after GASSER et al. 2009). H - Hochlantsch, Hk - Höllererkogel, HR - Hohe Rannach, P - Plabutsch, R - Raasberg, S - Semriach, T - Taschen.

The Schöckel Nappe is made up of Peggau Group with some significant formations: the pre-Devonian volcanic Taschen Fm., the Lochkovian to ?Eifelian Schönberg Fm. with Meggen-type lead-zinc-barite Sedex mineralizations (EBNER et al. 2000) and the 400-450 m thick Givetian Schöckel Fm. (FLÜGEL 2000).

2) The Intermediate Nappe Group includes the "Laufnitzdorf Nappe" (Lower Silurian to Upper Devonian pelagic limestones, shales and volcanoclastics) and the "Kalkschiefer Nappe" (Lower to Upper Devonian pelagic limestones and siliciclastics). Both nappes occur in different structural levels.

3) The Upper Nappe System (Upper Silurian to Upper Carboniferous) comprises the Rannach and Hochlantsch Nappes. Both have a similar facial development, especially in the Emsian to Givetian. Successions of the Rannach Nappe are composed of volcaniclastic rocks (Silurian to Lower Devonian; Reinerspitz Group), siliciclastics and carbonates rich in fossils (Lower to Middle Devonian; Rannach Group) of a litoral environment followed by the pelagic Forstkogel Group (Upper Givetian to Serpukhovian) and the shallow marine Dult Group (Bashkirian) (HUBMANN & MESSNER 2007, EBNER 1978) (Fig. 3).

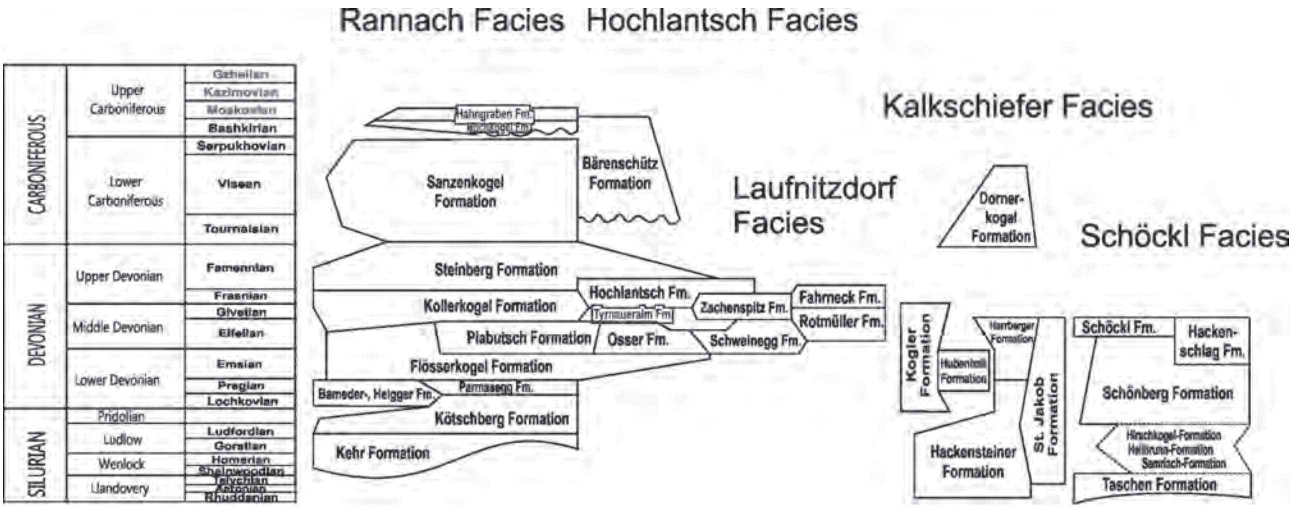


Fig. 3: Stratigraphic sequences of individual facies and nappe groups of the Graz Palaeozoic. Left column represents the sequence of the Rannach Facies. Together with the Hochlantsch Facies and parts of the Kalkschiefer Group it belongs to the Upper Nappe System (Hubmann et al. 2003).

According to a paleogeographical interpretation of the entire Palaeozoic succession, the groups/formations of the "Rannach-" and "Hochlantsch Facies" are interpreted to have developed nearest to shore, while the "Laufnitzdorf Facies" represents the furthest from shore. Successions of the "Schöckel Facies" occupy an intermediate position in this conception (Hubmann 1993).

The stratigraphic sequence indicates a sedimentation area changing from a passive continental margin with the continental breakup (alkaline volcanism) to shelf and

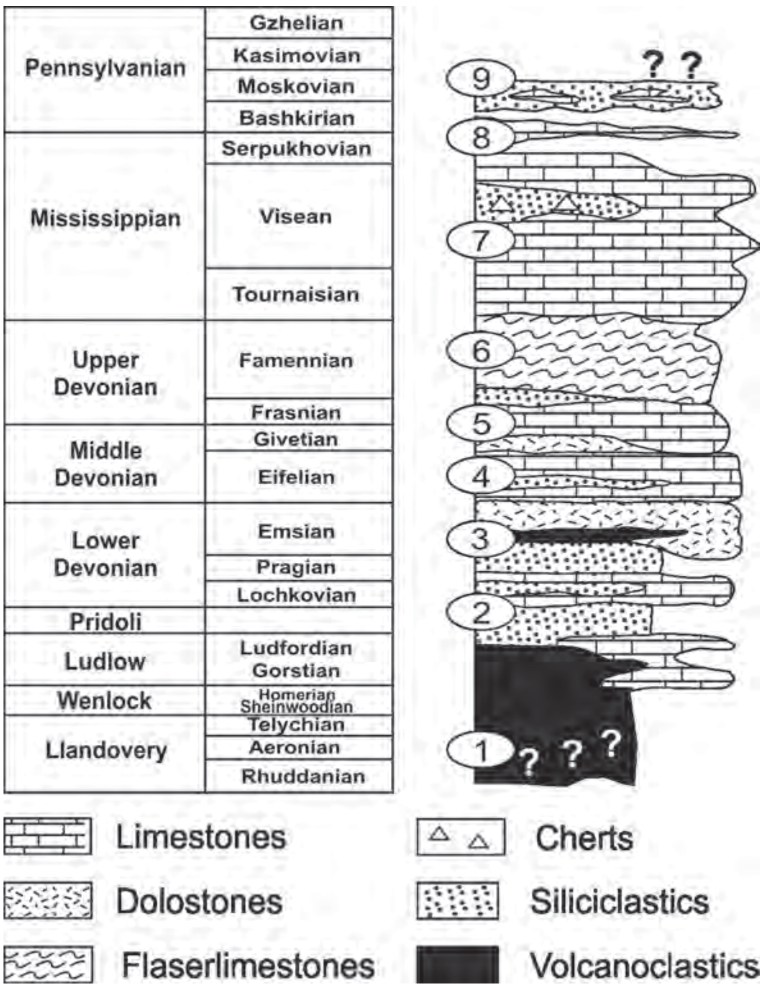


Fig. 4: Stratigraphic column of the Rannach Facies indicating main lithologies.
Reinerspitz Group: 1 - Kehr Fm., Kötschberg Fm.,
Rannach Group. 2 - Parmasegg Fm., 3 - Flösserkogel Fm., Bameder Fm.; 4 - Plabutsch Fm., 5 - Kollerkogel Fm.
Forstkogel Group: 6 - Steinberg Fm., 7 - Sanzenkogel Fm., 8 - Dult Group: Höchkogel Fm., 9 - Hahngraben Fm.

platform geometries during the Silurian to Devonian time span. Sea-level changes and probably synsedimentary tectonics had affected both, the lithologic development (i.e. alternations of dolostones and limestones) and in the Carboniferous the formation of stratigraphic gaps and mixed conodont faunas (Ebner et al. 2000).

Recently Gasser et al. (2009, 2010) published a new strutural sketch of the Graz Palaeozoic which gets along with only two nappe groups, a basal one characterized by intensely deformed units with penetrative foliation and pronounced stretching lineation and an upper one comprising less metamorphosed sequences (Fig. 2). In this conception the Lower Nappe System consists of sequences of the Laufnitzdorf Facies, the Kalkschiefer Facies (partly) and the Schöckel Facies whereas the Upper Nappe System comprises the Kalkschiefer Facies (partly), the Rannach Facies and the Hochlantsch Facies.

3.1. Review of stratigraphy and environmental architecture of the Rannach Facies

The architecture of the Rannach Facies is controlled by the specific tectonic and sedimentological history of the Noric Composite Terrane (Frisch & Neubauer 1989) and global environmental trends (sea level fluctuations, climatic changes etc.). The primary basement as well as the beginning of sedimentation in the Rannach Facies is still

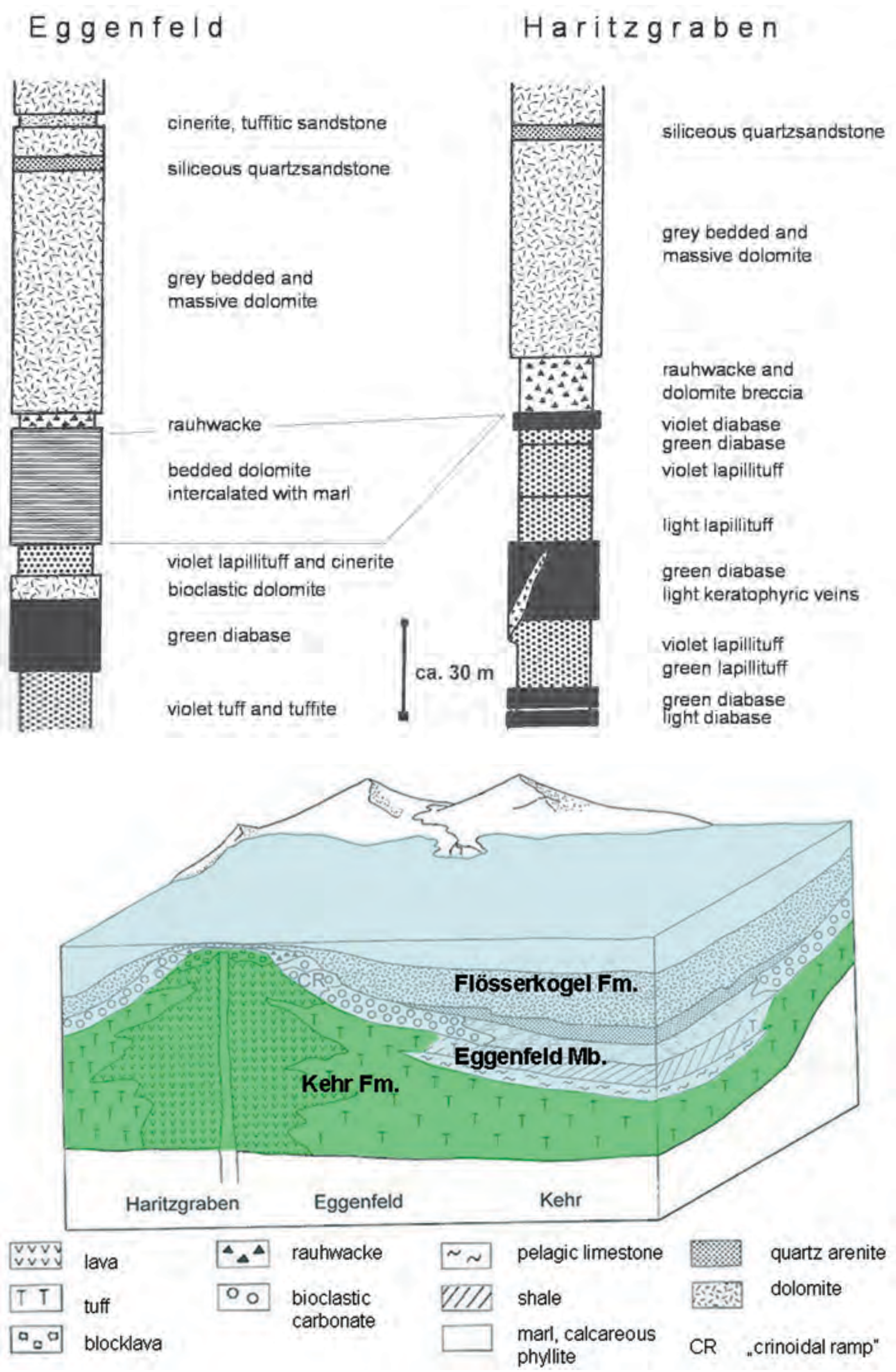


Fig. 5 A: Reconstruction of the sequence of the Late Silurian buried volcano of Harizgraben and Eggenfeld (top of Kehr Fm.) covered by dolomite of the Eggenfeld Mb. (modified after Fritz & Neubauer 1988).

B: Paleogeographic reconstruction of the Haritzgraben/Eggenfeld volcano island (top of Kehr Fm.) and the Late Silurian to Lower Devonian dolomite sequence of the Eggenfeld Mb. (modified after Fritz & Neubauer 1988).

unknown (Fig. 4). Nevertheless, the Reinerspitz Group (Flügel 2000) forms the stratigraphic footwall in which alkaline basic volcanism (Kehr Fm.; > 100 m; upper Ludlowium in its upper parts; Flügel 2000) and fine clastic and pelagic carbonatic sedimentation (Kötschberg Fm.; up to 30 m; Flügel 2000) reflect the evolution at passive margins of the separating terrane. Carbonate lenses/layers within the Kötschberg Fm. are distinguished as members (Thalwinkel Mb. Heritsch 1917; Genovakreuz Mb. Flügel & Schönlaub 1971), Lend Mb. (Flügel 2000) and Eggenfeld Mb. (Neubauer 1989) which fossils (conodonts, orthoceratides, brachiopods) indicate Ludlow to Lochkovian age of the Kötschberg Fm.

Some massive basic volcanics (diabase) at top of the Kehr Fm. (Haritzgraben, Eggenfeld) with lavaflows, block lavas lapilli and ash tuffs derive from volcanic islands with volcanic activity in shallow water and subaerial domains. Trace element analysis reveals weak alkaline affinities of the basaltic volcanics formed in an intracontinental rifting basin (Fritz & Neubauer 1988). Due to the morphology of the island, the superposition is herterochronous. On the slope (e.g. Eggenfeld) a several meters thick alternation of bedded dark fossil rich dolomite and fine grained tuffite (Ludlow - Lochkovian; Ebner 1976, Plodowski 1976, Fritz & Neubauer 1988, Hiden 1996) developed, whereas the top of the volcano (Haritzgraben) was still covered by dolomites of the basal Flösserkogel Fm. (Pragian).

During Pragian to Lower Emsian times intertidal to shallow subtidal deposits developed on a carbonate ramp which were comprised to the Parmasegg Fm. (Fritz 1991). Different facies resulted in the subdivision of three members (Flügel 2000): Greitnerkogel Mb. (blue-grey platy limestones and crinoidal limestones; less than 100 m in thickness), Oberbichl Mb. (brown platy silty limestones, flaser- and crinoid-limestones, and sand/siltstones; some tens of meters in thickness) and Stiwoll Mb. (yellowish marly sand/siltstones; about 80 m in thickness).

From the Lower Devonian, probably in causal connection with a gradual movement of the plate to which the depositional area of the Graz Palaeozoic belonged into lower latitudes (Fritz & Neubauer 1988, Fenninger et al. 1997), increase of carbonate production is obvious (Fig. 6). Thick successions of coarse-grained sandstones with layers of diabase tuff were deposited in a shallow marine, nearshore environment (Flösserkogel Fm., Heuberg Mb.). Due to different lithological characteristics Fenninger & Holzer (1978) distinguished four facial types which were considered as members by Flügel (2000), i.e., Göstinggraben Mb. (white to yellow sandy dolomites intercalated with quartzitic silt/sandstones and platy dolomites; some 100 m), Pfaffenkogel Mb. (white bio-laminated dolomites with birdseye-structures, thick bedded dolomites; up to 200 m), Treffenberg Mb. (grey to light-brown marly dolomites and flaserdolomites; up to 100 m, and Eichberg Mb. (interbeddings of black dolomitic *Amphipora* float/packstones and platy, sometimes laminated darkgrey dolomites; less than 100 m). Flügel (2000) added four further members, Admonterkogel Mb. (reddish-purple to green volcaniclastics within grey to bluish dolostones; about 50 m in thickness), Pleschkogel Mb. (well bedded dolomites in intercalation with darkblue biodetritic limestones; about 70 m), Schwarzkogel Mb. (massive to platy sand/siltstones with yellow weathering colour; some 100 m), and Sattler Mb. (darkblue, local biodetritic dolostones with subordinate dolomitic shales and sandstone intercalations; about 500 m). Hubmann (2003) supplemented the Kehlberg Mb. (brown cellular dolomites and shales; some 10 m).

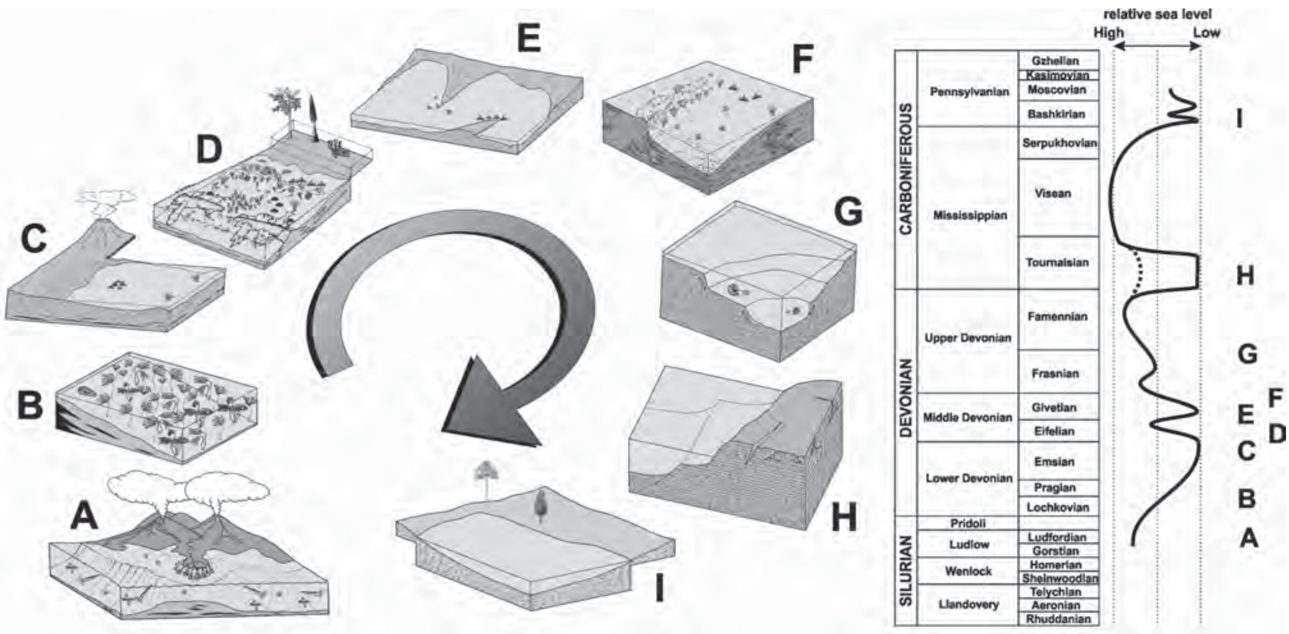


Fig. 6: Cartoon of the depositional environments of the Rannach Facies.
A - Kötschberg Fm., B - Parmasegg Fm., C - Flösserkogel Fm., D - Plabutsch Fm., E - Gaisbergsattel Mb., F - Kanzel Mb., G - Steinberg Fm., H - Sanzenkogel Fm., I - Höchkogel and Hahngraben Fms. (modified after Ebner et al. 2000). Note the relative sea-level curve through time estimated from sedimentological and palaeontological data.

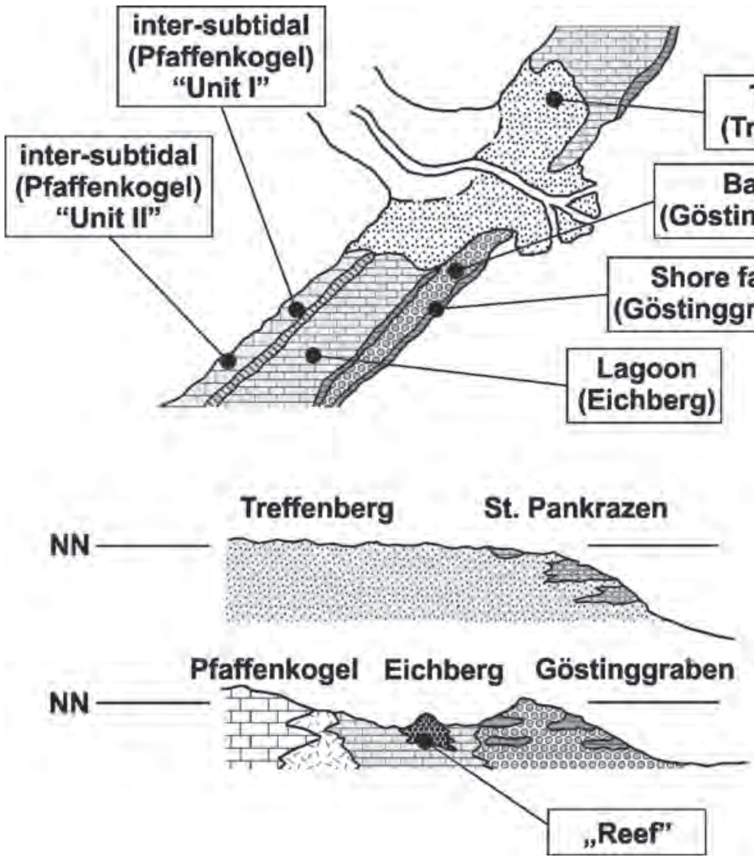


Fig. 7: Reconstruction of the depositional environment of the Flösserkogel Fm. (modified after FENNINGER & HOLZER 1978).

In general, the Flösserkogel Fm. comprises different kinds of dolostones, silt- to sandstones and subordinated dolomitic limestones which are interpreted as depositions of a supra- to shallow subtidal, barrier-surrounded lagoon, or tidal flats (FENNINGER & HOLZER 1978) (Fig. 7). Near Graz the lower parts of the succession are interpreted as sand bars whereas the upper parts which are separated by volcanic tuffs contain meadows of the spaghetti-like stromatoporoid *Amphipora* (HUBMANN et al. 2007, HUBMANN & SUTTNER 2007). Although conodonts are very rare they point to a (Lower?) Emsian age (cf. EBNER et al. 2000). Parts of the litoral Flösserkogel Fm. interfinger with more basinal environments which are characterized by more limy sediments (Pleschkogel Mb.; Emsian to ?Givetian) and calcareous schists and fine-grained siliciclastics respectively (Heigger Fm.; Lochkovian to Emsian; > 100 m; BUCHROITHNER 1978, EBNER 1998).
A highly fossiliferous sequence dominated by dark marly bioclastic limestones overlyies or rather interfingers the Flösserkogel Fm. This sequence, called Plabutsch Fm., exhibits in the lower parts especially at the boundary to the underlying Flösserkogel Fm. yellow to brownish shales occasionally blotched with moulds of chonetid brachiopods. In the upper parts of the formation intercalations of red marls and marly limestones are common phenomena.
Among the organisms typical "reefbuilders" are common (HUBMANN 1993, 2003) in all sectional sites. Nevertheless, there is no evidence in the field of a "true reef"; rather coral-stromatoporoid-carpets and lagoonal sediments are the dominant features. Environmental investigations indicate deposition on a differentiated and slightly inclined carbonate platform (HUBMANN 1993). The following features support the assumption that sedimentary conditions were unfavourable for reef formation: the rarity of in situ organisms, the intermittent high supply of clayey sediments (marl-limestone intercalations) and high supply of lime mud, temporary influx of high amounts of continental phytoclasts, storm impacts (several tempestite sequences within the profiles) and especially their effects on the biocoenosis (HUBMANN 1995a).
This phase of the Plabutsch Fm. is terminated by a repetition of tidal flat deposits similar to the Flösserkogel Fm. and obviously caused by an eustatic sea level fall (Fig. 6).
According to the information provided by the literature the dolomites stratigraphically above the Plabutsch Fm. are generally considered as late diagenetic, untextured and massive rocks that achieve only few meters in thickness. In contrast to that in the St. Pankrazen area they reach thicknesses up to 100 m and take over a prominent areal part (HUBMANN et al. 2008).
The succession, summarized as Gaisbergsattel Mb. (part of the Kollerkogel Fm., see below), comprises varied rocks, i.e. biolaminated dolomites, mudstones to bioclastic dolostones and clayey siltstones. Our investigations argue for a penecontemporaneous or early diagenetic origin rather than a late diagenetic formation.
Four microfacial types dominate: mudstones (25%), microbial bindstones (30%), crinoidal wackestones (28%), and brachiopod-tabulate packstones (17%). Laminated rocks, either stromatolitic layers (microbial mats) commonly composed of micrite laminae with laminoid

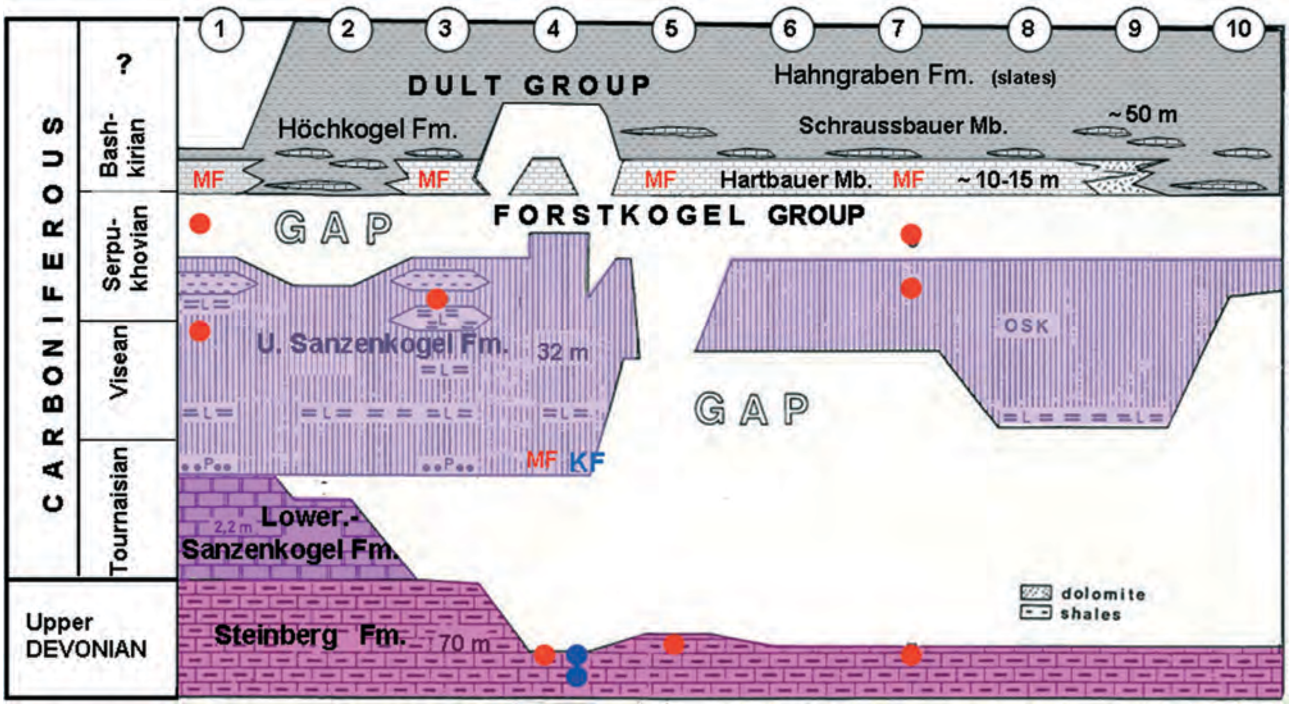


Fig. 8: The Forstkogel Group (Upper Devonian to Serpukhovian) and Dult Group (Bashkirian) in the Rannach Facies of the Graz Palaeozoic (modiefied after Ebner 1978).
Abbreviations
Sections - Western domains: 1 - Steinberg, 2 - Eichkogel, 3 - Gratwein/Au; Sections - Eastern domains: 3 - Gratwein Au, 4 - Hartbauer, 5 - NNE Dult Monastery, 6 - Schraußberg, 7 - Hahngraben, 8 - Hahngraben height 519, 9 - Höchkogel. Section 1 at Trolp quarry and section 4 are presented during the IAS excursion.
P - Trolp Phosphorite Bed; L - lydites; the lowermost level is the Hart Lydite Bed.
MF (red) levels with formation of conodont mixed faunas; red dots below indicate the age of components of the mixed fauna.
KF (blue) indicates the position of the erosion niveau and the filling time of karst fissures. The blue dots below indicate the age of the related Devonian components in the mixed faunas of the filling and the deepest position of the fillings in the section.

fenestrae and very fine grained intraclasts from desiccation, or varve-like rhythmic alternations of coarse and fine laminae are interpreted as intertidal mudflats (Hubmann & Brandner 2009).
Transgression resulted in a sequence with sharp (bio)facial contrasts between patch-reefs and monotonous mudstones of Givetian age (Rannach Facies: Kollerkogel Fm., Hochlantsch Facies: Tyrnaueralm Fm., Zachenspitz Fm.) in the Upper Nappe System. Grey dolomites with biolaminations, light bluish limestones (mostly mudstones), locally bioclastic limestones with chert nodules which are interpreted to have developed in major parts in an open platform setting are comprised to the Kollerkogel Fm. According to Flügel (2000) four members in the Kollerkogel Fm. are discernible: Gaisbergsattel Mb. (dark grey biolaminated dolostones; about 20 m), the basal part of the formation representing tidal flat deposits and sediments of a restricted lagoon, Kanzel Mb. (light grey to bluish limestones; mostly mudstones; up to 100 m), Platzlkogel Mb. (grey limestones with locally developed biohermal structures; about 75 m), Platzl Mb. (grey limestones intercalated with carbonatic argillaceous shales; about 50 m; reaches up to the Upper Devonian). In contrast to the Kanzel Mb. which is very poor in conodonts the conodont fauna of the Platzlkogel Mb. is much richer. The *Polygnathus-Icriodus* ratio indicates a higher energetic open platform environment (Ebner 1998).

In the Hochlantsch Facies tuffs, spilites and pyroclastic breccias (Zachenspitz Fm., 80-300 m; upper Givetian) indicate a second peak of the alkaline mafic volcanism, which possibly continues up to the Frasnium. In the Rannach Facies a thin volcanic intercalation in the Platzlkogel Mb. may be an equivalent to this volcanic event. It is the matter of debatte if this volcanism is responsible for increased Hg contents (up to 2 ppm) in parts of the Kanzel and Platzlkogel Mbs. The source for epigenetic cinnabar vein mineralization hosted in parts of the Kanzel Mb. and Hg anomalies in soils above the Kanzel and Platzkogel Mbs. (Ebner & Weber 1983, Ebner 1998) can also be interpreted in close connection with the volcanic activity. During uppermost Givetian to lower Frasnian the sedimentation of shallow platform carbonates was replaced by variegated micritic cephalopod limestones (Forstkogel Group) which continued until the Serpukhovian. The thickness of this pelagic group reaches in maximum 100

m. In the eastern parts of the Rannach Facies it is reduced to ~30 m by an intraformational stratigraphic gap across the Devonian/Carboniferous boundary caused by karstification (EBNER 1978, 1980). Colour (grey - yellowish brown - reddish - violet) and lithology (thin to thick bedded, flaser- to nodular marly limestones) are strongly changing. By means of conodonts the Forstkogel Group can be subdivided in the Upper Devonian Steinberg Fm. and the Carboniferous Sanzenkogel Fm. Locally, the Givetian parts of the Steinberg Fm. are separated as the 20-30 m thick Höllererkogel Mb. (EBNER 1978, 1980 a, b, 1985, EBNER et al. 1979, 2000, NÖSSING 1974, 1975, SURENIAN 1978, BUCHROITHNER et al. 1979). Marker beds within the Upper Sanzenkogel Fm. are the Trolp Phosporite Bed (up to 40 cm thick shale and lydite with phosphorite nodules) in the western and the Hart Lydite Bed (250 cm lydite; EBNER 1978, BOSIC 1998, 1999, FLÜGEL 2000) in the eastern parts of the Rannach Facies.

All known conodont zones from the *varcus* zone (latest Givetian) until the Serpukhovian *Gnathodus bilineatus bollandensis* zone were proved in the Forstkogel Group (FLÜGEL & ZIEGLER 1957, NÖSSING 1975, EBNER 1977 a, SURENIAN 1978, BUCHROITHNER et al. 1979, BOSIC 1998, 1999).

Generally continuous sequences across the Devonian/Carboniferous boundary occur in the western parts of the Rannach Facies. In the east this level is dominated by ersosional gaps which increase in their stratigraphic extent towards the east. In maximum the erosion phase includes the time span from early Famennian to early Visean. Therefore, the strongly condensed and only 220 cm thick Lower Sanzenkogel Fm. (Tournaisian, *Siphonodella sulcata-Scaliognathus anchoralis* zone) occurs only in the western domains.

Conodont mixed faunas related to the stratigraphic gaps provides detailed information due to the nature of the gaps. The mixed faunas constrain a Late Devonian regression, followed by karstification, isolation of conodonts during subaerial weathering and Carboniferous filling of the karst relief and fissures with residual sediments, mixed faunas and Carboniferous transgression sediments (EBNER 1978, EBNER et al. 1980 a, EBNER 1989, EBNER et al. 2000). Characteristics of the condont mixed faunas are:

Position of the mixed faunas: a) Stratigraphic admixtures (BRANSON & MEHL 1933, 1934) within an only a few cm thick calcareous microbreccia at the base of the Upper Sanzenkogel Fm. ("transgression sediment").

b) Stratigraphic leaks (BRANSON & MEHL 1933, 1934) in irregular karst fillings can reach as deep as 20 m in the Devonian limestones below the bottom of the Upper Sanzenkogel Fm.

Components of the mixed faunas: Devonian conodonts represent the age from the position of the mixed fauna until the top of the Steinberg Fm. in the investigated section. Carboniferous components indicate the transgression of the Upper Sanzenkogel Fm. after the erosion event. The interval not represented by conodonts of the mixed fauna determines the time span of the subaerial erosion event.

Since no evidence for a facial change is traceable it is assumed that the considered area remained in an off shore shelf position. Thus, to explain the condont mixed faunas the depositional environment must have been affected by synsedimentary tectonics and/or sea level fluctuations causing a shallowing of the sea with local desiccation followed by rapid deepening within the latest Tournaisian to early Visean time interval. The western domain with continuous sections remained always in marine, pelagic positions. Sedimentation of shales, lydites and phosporites (Trolp Posphorite Bed) may indicate upwelling zones at

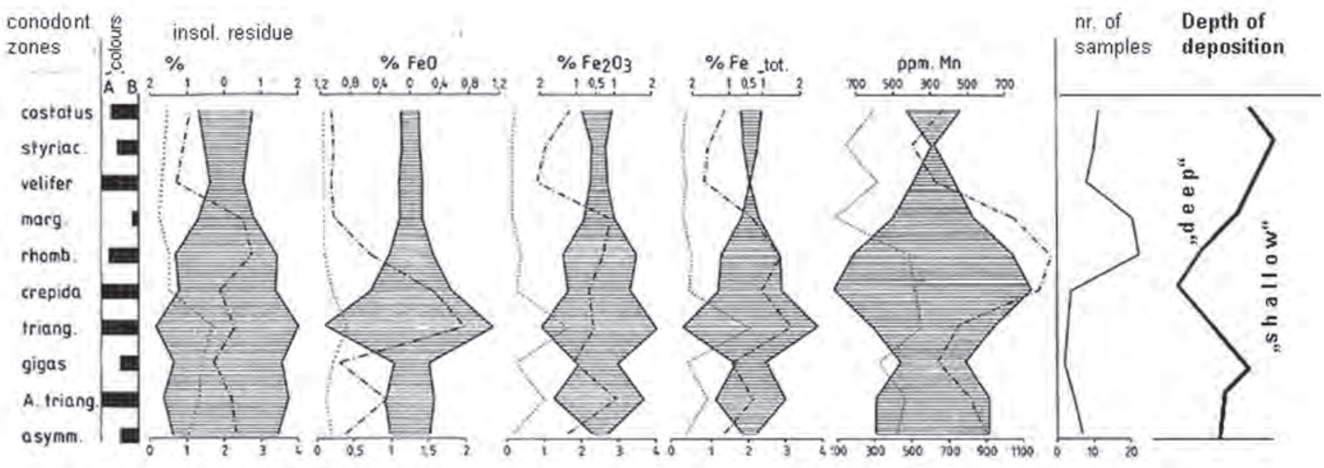


Fig. 9: Colour, insoluble residue, Fe and Mn content of limestones of the Upper Devonian Steinberg Fm. at the type locality (Fig. 21) within the individual conodont zones. The "bathymetric" curve is deduced from the Mn content. Stippled line indicates minimum contents; dashed-dotted line indicates maximum contents (BUCHROITHNER et al. 1979).
Colour groups:
A: greyish-greenish-bluish „cold" colour shades (Rock Colour Chart: N5, N6, N8, 5G6/1, 5 B5/1, 5Y6/1).
B: reddish-brownish-yellowish „warm" colour shades (Rock Colour Chart: 5R6/2, 5R6/6, 5YR4/4, 5YR4/2, 5YR6/1, 10YR4/2, 10YR5/4, 10YR6/2, 10YR6/6, 10YR7/4, 5Y4/1, 5Y5/2, 5RP4/2, 5 RP6/2).

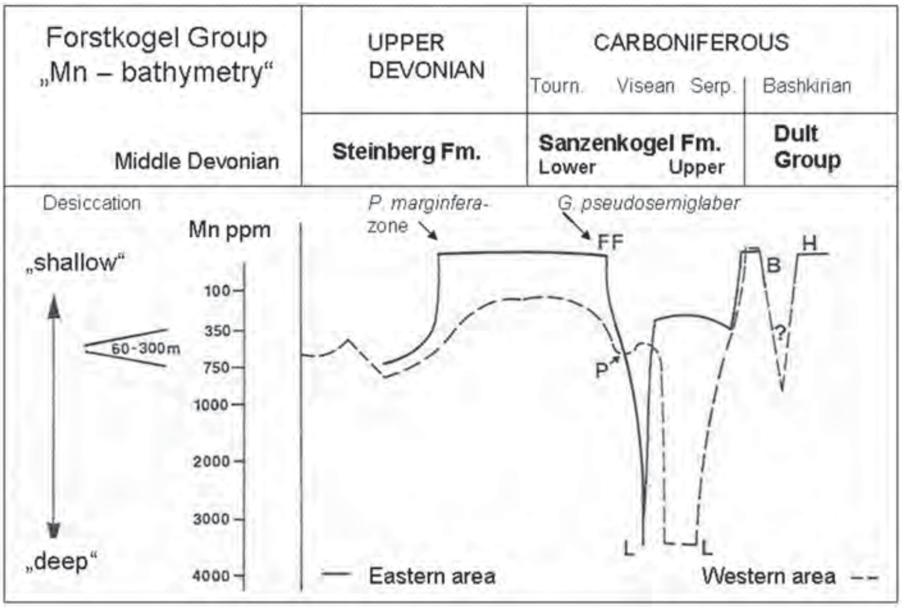


Fig.10: "Mn-bathymetry" of the Forstkogel Group and basal Dult Group deduced from the Mn contents and typical lithologies (Ebner & Prochaska 1989). FF: erosion level as the starting point of karst fissures filled with conodont mixed faunas, P: "phosphorite-event" (Trolp Posphorite Bed), L: lydites, B: limestone microbreccia (Hartbauer Mb.) at the bottom of the Dult Group, H: haematite crust.

the margin of the outer shelf just at the beginning the Carboniferous transgression (Ebner et al. 2000).

Tentatively the bathymetric path of the Forstkogel Group was interpreted from Mn contents (Buchroithner et al. 1979, Ebner & Prochaska 1989, Ebner et al. 2000). These data, calibrated with Mn contents of 400-1750 ppm for Palaeozoic cephalopod limestones (Buggisch 1971, Lütke 1976), suggest a depth of 60-300 m for the formation of phosphorite and cephalopod limestones in the Graz Palaeozoic (Nössing 1974a). Additionally increasing Mn contents indicate an environmental deepening.

During the Upper Devonian the western domains represent deeper and more open shelf conditions. A deepening trend until the early Famennian *crepida* zone was followed by shallowing until to the *styriacus* zone. The generic composition of the conodont biofacies of the *styriacus* zone indicates "shallow- to moderate deep-water on the continental shelf" (Sandberg 1976).The decreasing and low level Mn contents of the western domains reflect the uplift/shallowing of the eastern parts culminating in subaerial erosion and karistification (Fig. 9, 10). During late Tournaisian increasing Mn contents reflect the transgression of the Upper Sanzenkogel Fm. and a deepening of the environment in which lydite formation may indicate the deepest parts in both areas. Possibly the crossing of the bathymetric paths (Fig. 10) in the eastern and western domains after the phosphorite event indicates diverse synsedimentary tectonics of the two blocks. Decreasing Mn contents at top of the Sanzenkogel Fm. coincides with another erosion event between the Forstkogel and Dult Groups.

The **Dult Group** (Ebner 1978, Flügel 2000) began after an erosion gap at top of the Sanzenkogel Fm. (Ebner 1976, 1977a, b, 1978, 1998, Flügel 2000, Ebner et al. 2000). At its basal part the Höchkogel Fm. consists of dark coloured limestones (Hartbauer Mb.) which are interfingering/ superposed with/by an alternation of shales with black limestones. The latter sometimes contains birdseye-structures (Schrausbauer Mb.) indicating a shallow water deposition. At top of the Dult Group approximately 50 m thick black slates, sometimes with intercalations of silt- and sandstone with fine phytoclastic materials are comprised to the Hahngaben Fm.

The **Höchkogel Fm.** is dated by conodonts of the *Declinognathodus-Idiognathoiodes* group as Lower Bashkirian (Ebner 1977, 1980a, Zhi-hao & Yu-ping 2002). The boundary between the pelagic Forstkogel Group and shallow marine Dult Group is formed by an erosion surface. Locally at the very base of the Hartbauer Mb. 20 cm thick fine-grained limestone breccias contain mixed conodont faunas with autochthonous elements of the Lower Bashkirian and reworked condonts (Visean - Serpukhovian) from the Upper Sanzenkogel Fm. At one site (section 5 in Fig. 8) the entire Upper Sanzenkogel Fm. was eroded, thus affecting a direct superposition of Upper Devonian limestone (*velifer* zone) by the Bashkirian Hartbauer Mb. (Ebner 1978, 1980 a).

The **Hartbauer Mb.** interfingers and is superposed with/ by the Schraußbauer Mb. The latter is composed of calcareous schists, shales and layers of black limestones with birdseye structures (Fig. 11 f). The latter were primarily described as the coral genus *Cladochonus* (Heritsch 1930). The interfingering of both members is documented in the field by the intercalation of shales in the Höchkogel Mb., limestone-shale alternations and dolomite-shale breccias at some locations. The local absence of the Schraußbauer Mb. is explained by a further erosion event prior to the beginning of the fine clastic sedimentation of the Hahngraben Fm. In the Hartbauer section (excursion stop 6) this erosion plane is exposed between the Hartbauer Mb. and slates of the Hahngraben Fm. and is documented by pockets filled with hematite. The age of the Hahngraben Fm. is unknown due to the lack of age diagnostic fossils. However an upper Bashkirian or even younger age is possible.

Some lithologies of the Dult Group are known only as blocks in a sliding mass N of the Gratkorn highway tunnel

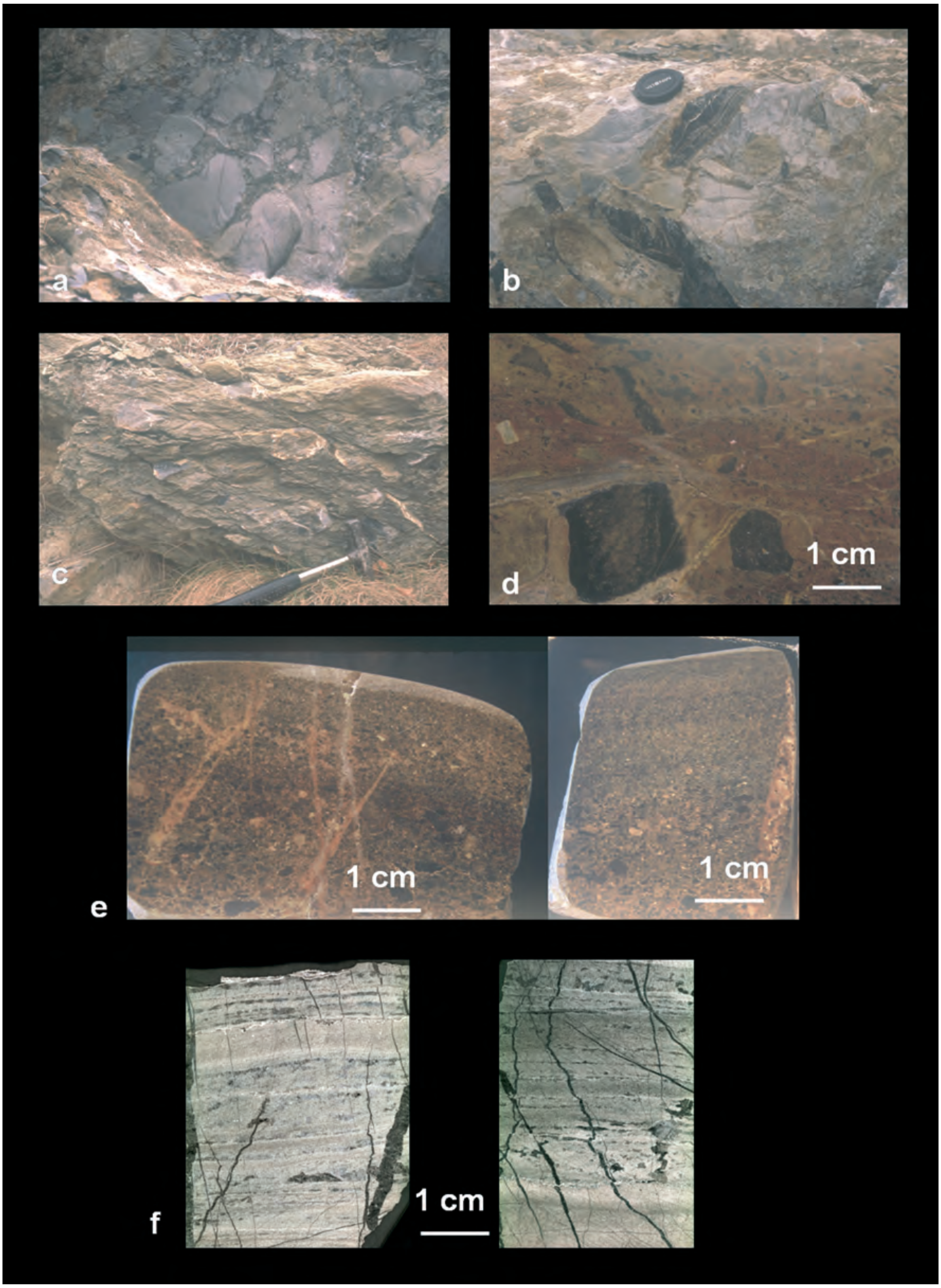


Fig. 11: Lithologies of the Dult Group found as blocks in a sliding mass N of the Gratkorn highway tunnel (Ebner et al. 2000).
a-e) Reworked limestones ? belonging to the base of the Höchkogel Fm.:
a) Limestone breccia with Visean clasts of the Upper Sanzenkogel Fm.
b) as 1 but additionally with black banded lydite
c) olistostrom with components of micritic limestones of Sanzenkogel Fm. in a matrix of greyish-green silty shales
d) detail with reworked limestone in a olistostromatic layer
e) 4 cm thick layer of fine grained graded allodapic limestone with hints of sole marks (above greyish-green pelite) at the footwall.
f: Birdseye structures in limestones of the ? Schraußbauer Mb.

(Ebner 1998, Ebner et al. 2000):
- limestone breccias with Visean clasts of the Sanzenkogel Fm. and black banded lydite (Fig. 11a, b),
- olistostroms with pebbles of micritic limestone in a greenish-grey shale matrix (Fig. 11c, d),
- a 5 cm thick fine grained graded layer of allopdapic limestone above greenish-grey shale (Fig. 1 e),
- intercalations of cm thick shale in dark grey limestone.

During the excavation of the northern Gratkorn highway tunnel black, platy limestones alternating with 10-20 cm thick shales (in the north of the tunnel) and shales with limestone intercalations (in the south of the tunnel) respectively were exposed. This intermixture of different facies types is interpreted as the interfingering of the Hartbauer and Schraußbauer Mbs.

3.2. Palaeobiogeographic and palaeogeographic implications

All non to weak metamorphosed Palaeozoic units of the Eastern Alps are part of the Noric Composite Terrane (Neubauer & Frisch 1989, Neubauer et al. 1997). Early Palaeozoic sequences, still located at the NW margin of Gondwana (Raumer et al. 2003), were deposited above the Celtic and Speik Terranes (Neubauer & Frisch 1989, Neubauer et al. 1997). After separation from Gondwana this unit became the Noric Composite Terrane. Its history is characterized by a Devonain drift stage and an Early Carboniferous accretion to the palaeo-European margin. The Noric Composite Terrane was included in this Variscan accretionary collage in different structural positions which is reflected also by the different Variscan tectonometamorphic overprint of this terrane (Ebner et al. 2008). Efforts to point out faunal relationships between the Graz Palaeozoic and other remnants of the Palaeozoic in Europe, especially the Prague Basin (for Silurian and Lower Devonian successions) and the Rhenohercynian Zone (during Middle to Upper Devonian periods) date back to the early beginning of the investigation history. More recent attempts to point out the degree of proximity among the Graz realm and other Palaeozoic remnants in Europe were made with metazoans (cephalopods, corals) and algae.

Results of a preliminary systematic study of the end-Silurian nautiloid cephalopod fauna (Histon et al. 2010) suggest faunal exchange between the Graz Palaeozoic, central Bohemia, the Carnic Alps, Sardinia, France (Montagne Noire), Spain (the Ossa Morena Zone) and Morocco. Detailed microfacies study of the "Silurian Cephalopod Limestone Biofacies" (i.e. Orthoceras-limestone in the old literature) in the Prague Basin by Ferretti & Kriz (1995) resulted in the identification of two distinct depositional environments: one by surface currents and one within a shallower setting affected by storm action. The cephalopod bearing limestone beds from the studied section also show diverse orientation of the nautiloid conchs on the bedding surface. Uni-directional orientation of conchs may indicate deposition by surface currents while the perpendicular orientation of conchs and distinct time-rich taphonomic features such as dissolution of shell material and disarticulation of septal chambers on the bedding surface may indicate deposition within a shallower setting and periods of non-deposition. According to Histon (2002) the more shallow-water, facies restricted, nautiloid species possibly reflect the closeness of the depositional environment of the Eggenfeld locality (excursion stop 8) to the Carnic Alps and to Bohemia (Histon et al. 2011) while the more pelagic faunas may reflect the exchange between the various North Gondwana terranes, Baltica and the Urals due to migration events related to the prevailing warm water currents (e.g., South Tropical Current).

The Lower to Middle Devonian coral fauna of the Graz Palaeozoic has been an investigation topic since the end of the 19th century (Flügel & Hubmann 1994, Hubmann 1995). Among more than 65 genera and almost 120 species known from the Graz Palaeozoic (Hubmann 2002) some show biogeographic connections with the Rhenohercynian Zone, the Moravian Karst and the Cantabrian Mountains (Flügel 1972, Hubmann 1991).

Similarly, the Lower to Middle Devonian (Emsian to Eifelian) calcareous green algal flora of the Graz Palaeozoic which contain halimedalean representatives of the genera *Pseudolitanaia*, *Pseudopalaeoporella*, *Zeapora*, *Maslovina* and a new lanciculoid taxon (Hubmann et al. 2008) indicate (mutual) relations to other regions. Identical taxa on species level are known from the Rhenohercynian Zone and the Cantabrian Mountains; in addition *Pseudopalaeoporella* is known from the Urals and Karakorum Mountains (Hubmann & Gaetani 2007) whereas *Maslovina* also occurs in Australia.

Halimedalean algae are of special interest for biogeographic consideration since their way of life remained unchanged during Earth's history and current palaeontological deductions can be readily applied. In summary the following is applicable to the Devonian of Graz:
- The occurrence of halimedacean green algae suggests a deposition inside the 25°C isotherm (matches approximately latitude 30°) within the "Rheic Ocean".
- The conspecific algal flora of the Devonian of Graz, Ardennes/Belgium, Rhenian Slate Mountains, Harz/Germany, Armorican Massif/France, and Cantabrian Mountains/Spain, and the palaeogeographic position mentioned above leads to assumption that the "Graz Terrane" and the Aquitaine-Cantabrian-Terrane occupied adjacent locations during Emsian and Eifelian times.
- Conspecific/comparable taxa of different organisms on both sides of the Rheic ocean suggest that no continuous and separating fold belt, or landmass acting as barrage between the Gondwanan north shelf areas and Laurussian south shelf areas existed (Hubmann et al. 2009).

The Carboniferous of Graz fits well in the facies pattern of the Alpine-Mediterranean domain. All over the Austro- and Southalpine domain continuous sections with pelagic cephalopod limestones across the Devonian/Carboniferous boundary and Lower Carboniferous shale-lydite-phosphorite intercalations occur in short distance to sections with stratigraphic gaps related to karstification (Ebner

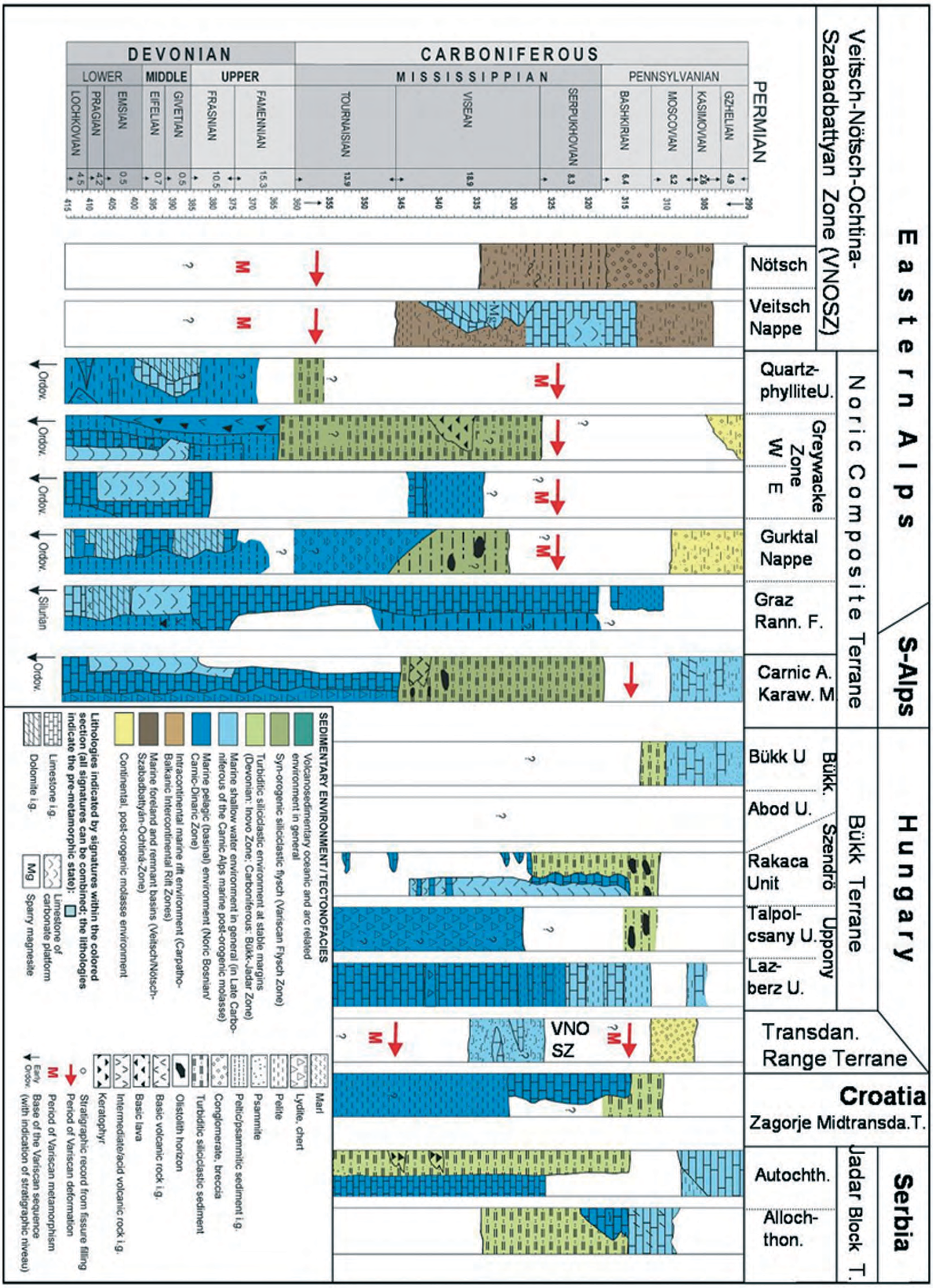


Fig. 12: Devonian to Carboniferous sequences of the Eastern and Southern Alps, Hungary and parts of Croatia and SW Serbia (modified after Ebner et al. 2008). Note that in some areas, e.g. the Rannach Facies, Hungary, parts of Croatia, SW Serbia) marine sedimendation continues up to the middle Pennsylvanian without Variscan angular unconformities.

1990, 1991a, b). In western parts of the Rannach Facies reddish to violet calcareous fissure fillings are exposed in the Givetian Platzkogel and Gaisbergsattel Mbs. (Ebner et al. 1979, Somers 1992). Although they are undated they might be correlated with Tournaisian/Visean fillings widely distributed in Alpine and Hungarian Palaeozoics (Ebner 1990, 1991a, b, Ebner et al. 2000, 2009). In the Graz Palaeozoic paleomagnetic investigations of the fillings and their host rocks indicate without any differentiation a primary position 10° south of the equator (Somers 1992). Palaeomagnetic data from the Admonterkogel Mb. (Fenninger et al. 1997) and the faunal characteristics of the Plabutsch Fm. (Hubmann 1992) point to a primary position of the Rannach Facies at the northern margin of Gondwana. This fits well to the suggested position of the Noric Terrane which includes all classical Palaeozoic domains of the Eastern and Southern Alps (Frisch & Neubauer 1989, Neubauer et al. 1998).

The findings of olistostroms, breccias and allodapic limestone in the Dult Group indicate a deepening of the environment after an event of desiccation and reworking. This conception fits with the supra-regional Carboniferous palaeogeography in which the Austroalpine domain occupies a position at a carbonate shelf which deepened to a flysch basin in the south (Herzog & Neubauer 1985, Ebner 1992, Ebner et al. 1998). Nevertheless we are far from interpreting the Dult Group as the beginning of the Variscan flysch stage. Ar-ages from detrial mica of the Dult Group reflect two groups of age data. The older ages

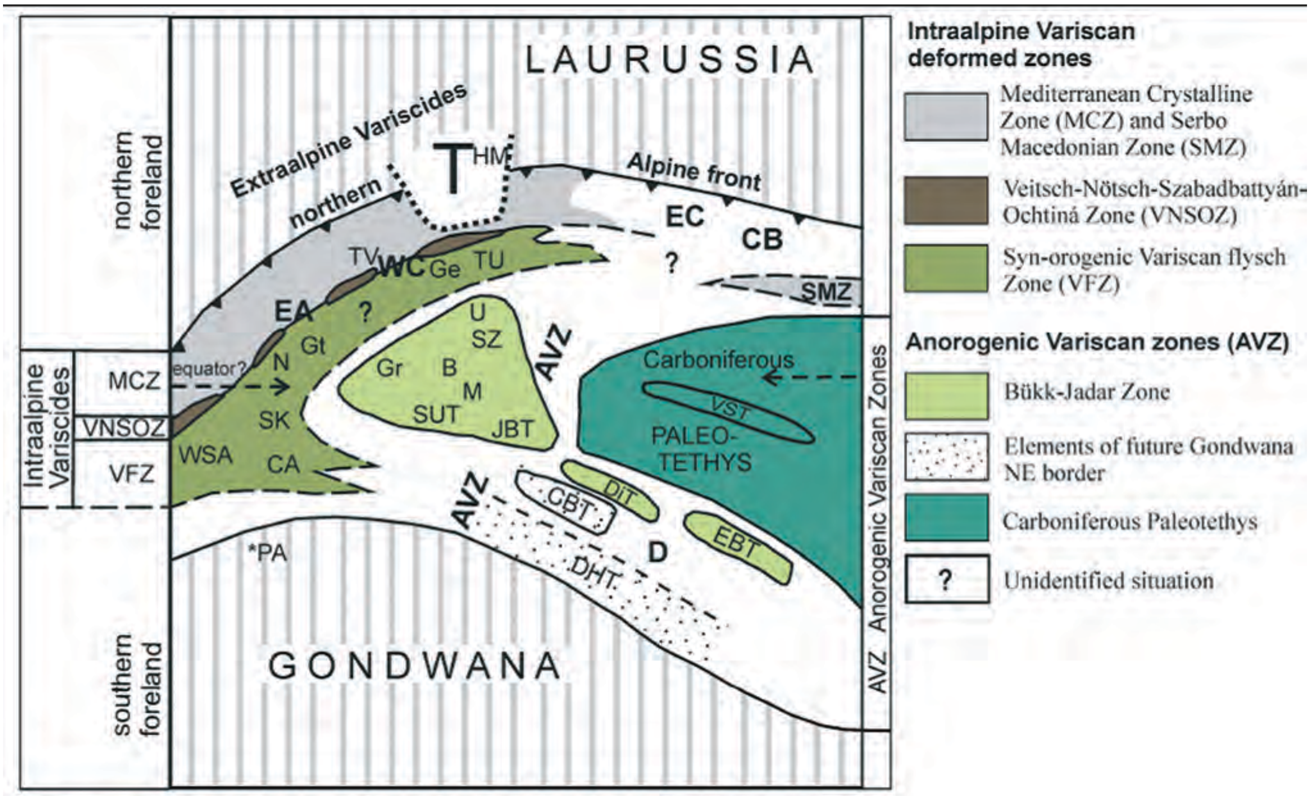


Fig. 13: Cartoon of the Visean/Serpukovian palaeogeographic restoration and Variscan orogenic zoning in the Circum Pannonian region (strongly schematized and not in scale; Ebner et al. 2008).
Extraalpine Variscides: HM - Helvetic Mountain Unit, T - segment of later Tisia Megaterrane.
Intraalpine Variscan deformed zones:
Upper Devonian to Early Carboniferous deformation and metamorphism. MCZ - Mediterranean Crystalline Zone, EA - Eastern Alps, WC - Western Carpathians, TV - Tatro Veporic Units, EC - Eastern Carpathians, CB - Carpatho-Balkanides, SMZ - Serbo-Mazedonian Zone. VNSOZ - Veitsch-Nötsch-Szabadbattyán-Ochtina-Zone.
Post-orogenic sediments in respect to MCZ.
VFZ - Syn-orogenic Variscan Flysch Zone: Deformation during ? Upper Visean - mid-Carboniferous
WSA - Western Southern Alps, CA - Carnic Alps, SK - South Karawanken Mts., N - Greywacke Zone, Noric Nappe, Gt - Gurktal Nappe, Ge - Gemeric Units, TU - Turna Unit.
AVZ - Anorogenic Variscan Zones:
No Variscan deformation and metamorphism. Gr - Graz Palaeozoic: R -Rannach Nappe, U - Uppony Mts., SZ - Szendrö Mts., B - Bükk Mts., M -Medvednica Mts., SUT - Sana Una Terrane, JBT - Jadar Block Terrane, DIT - Drina Ivanjica Terrane, EBT - East Bosnian Durmitor Terrane, D - Dinarides: CBT - Central Bosnian Terrane, DHT - Dalmatian Herzegovinian Terrane.
Paleotethys (remaining open oceanic domain): VST - Veles Serie
Gondwana: PA - Panafrican Basement at northern margin of Gondwana.

(367-415 Ma) may be deduced from an exhumed Silurian/ Devonian accretion complex. The younger age data (315-360 Ma) may be related to a basement complex which was either metamorphosed or rejuvenated during Early Carboniferous (NEUBAUER et al. 2007). Especially noteworthy is that in the Rannach Facies during the Early Carboniferous sedimentation was interrupted by intraformational erosion events only.

The marine stratigraphic sequence of the Rannach Facies continued until such time in which other Austroalpine units were affected by the Variscan event inducing an orogenic structure and metamorphic overprint followed by unconformably deposited continental molasse sediments (Fig. 12; EBNER et al. 1991, 1999, 2008). The Carboniferous sequence of the Rannach Facies was - if at all - affected by vertical tectonic movements. “Post-Variscan“ Upper Palaeozoic sediments are not known from the Graz Palaeozoic. Due to the sedimentary evolution and the lack of Permotriassic overstep sequences the existence, timing and thermal conditions of a Variscan event in the Rannach Facies of the Graz Palaeozoic is under discussion. According to RUSSEGGER (1992, 1993) and RANTITSCH et al. (2005) the weak metamorphic overprint is due to the Alpidic tectonics.

All these constraints may identify the Upper Nappe System of the Graz Palaeozoic with the Rannach- and Hochlantsch Facies as an exotic element among Austroalpine Palaeozoic units. In contrast to its position in Austria’s realm, it shows striking facial relationships to the Hungarian Szendrö and Uppony Mts. (EBNER et al. 1991, 1998) as well as to the Palaeozoic of the Jadar Block during the Late Devonian to Carboniferous (EBNER et al. 2009). These domains are characterized by pelagic carbonate sediments up to Bashkirian/Moskovian ages, the absence of Variscan angular unconformities and metamorphism and marine Upper Carboniferous and Permian sediments (Fig. 12). In this context exotic pebbles (Permian fusulinid limestones and limestones of Southalpine provenience; KAHLER 1973, GRÄF 1975) occurring in the Upper Cretaceous Kainach Group may be of particular importance (EBNER & RANTITSCH 2000).

The individual domains differ due to the tectonothermal impact of the Variscan orogeny, presence or absence of synorogenic flysch sediments and the heterochron beginning as well as the diverse character of the molasse sediments (Fig. 12). This is due to their individual positions either within or in the back the Variscan collision zone. Domains at the edges of the drifting terranes were included intensively into accretion and orogenic processes (flysch and molasses sedimenation, metamorphism, angular Variscan unconformity). In contrast, areas in the back of the colliding terranes were only affected by synsedimentary tectonics without penetrative deformation, metamorphism and typical flysch and molasse sedimentation. Such “anorogenic“ domains occur in the ALCAPA domain in the Rannach Facies and some Hungarian Palaeozoics (Szendrö, Bükk, Uppony Mts.) (Fig. 13). Their paleogeographic relation to the Graz Palaeozoic has also to consider the young dextral movements along the Periadriatic and Mid-Hungarian lineaments. An other domain featuring a similar Carboniferous stratigraphy and a comparable “anorogenic“ Variscan evolution is the Palaeozoic of the Jadar Block which was later separated from the Hungarian domains by Alpine rift and strike slip processes (EBNER et al. 2008, VOZÁROVÁ at al. 2009).

4. The Field Trip

4.1. Geological description of the route Schladming - Graz

From Schladming to the east the route follows the Enns valley, a segement of the SEMP (Salzachtal - Ennstal - Mariazell - Puchberg) Fault, which operated as a sinistral strike slip fault during Miocene extrusion tectonics. The present morphology of the Enns valley was formed during the Pleistocene by the Enns glacier. Geologically the Enns valley separates within the Upper Austroalpine Nappe System (SCHMID et al. 2004) the Northern Calcareous Alps (Late Permian to Eocene marine sediments) in the north from the metamorphic Silvretta-Seckau and Koralpe-Wölz Units (SCHMID et al. 2004) in the south. Due to the tectonic offset along the SEMP the Palaeozoic of the Greywacke Zone is reduced to a narrow stripe south of the Northern Calcareous Alps. Parts of the Austroalpine metamorphics underwent only greenschist metamorphic overprint (e.g. the complex of the Ennstal Phyllite S of the Enns valley). E of Liezen the highway follows another NW - SE oriented Tertiary fault zone along the Palten - Liesing valley. Generally domains NE of the valley belong to the Greywacke Zone which is thrusted above the Silvretta-Seckau Unit in the SW. In Styria, and also along the route, the Greywacke Zone displays an Alpine imbrication/nappe structure with the Veitsch Nappe at the structural base. At top the Noric Nappe exhibits a distinct Variscan angular unconformity to the Upper Permian basis of the Calcareous Alps.

Sedimentation of the Veitsch Nappe (fossiliferous shallow-water limestones, fine- to coarse-grained clastics) started after the Variscan tectonometamorphic climax during the Visean and continued until Moskovian (Westfalian) times. Tectonic activities and and metamorphic overprint (greenschist facies) were exclusively Alpidic (Cretaceous) (RATSCHBACHER 1984, 1987). The Veitsch Nappe hosts important magnesite, talc and graphite mineralizations (WEBER et. al. 1997). Some of them (e.g. sparry magnesite NW Wald/Schoberpass and graphite at Kaisersberg/W St. Michael) are still mined.

The sequence of the Noric Nappe starts with Middle to Upper Ordovician clastic sediments and up to some hundreds of m thick ignimbritic porphyroids. Silurian is made up of pelagic limestones, black shales and basic volcanics. During the Devonian 200-300 m thick platy, flaser/nodular and sometimes organdetritic limestones are developed. Some scattered findings of micro- and macrofossils provide a rough biostratigraphic subdivision. In the Eisenerz area Devonian limestones are disconformly overlain after an erosion hiatus during the upper Tournaisian by a thin layer of limestone breccias with conodont mixed faunas which is followed by 100-150 m

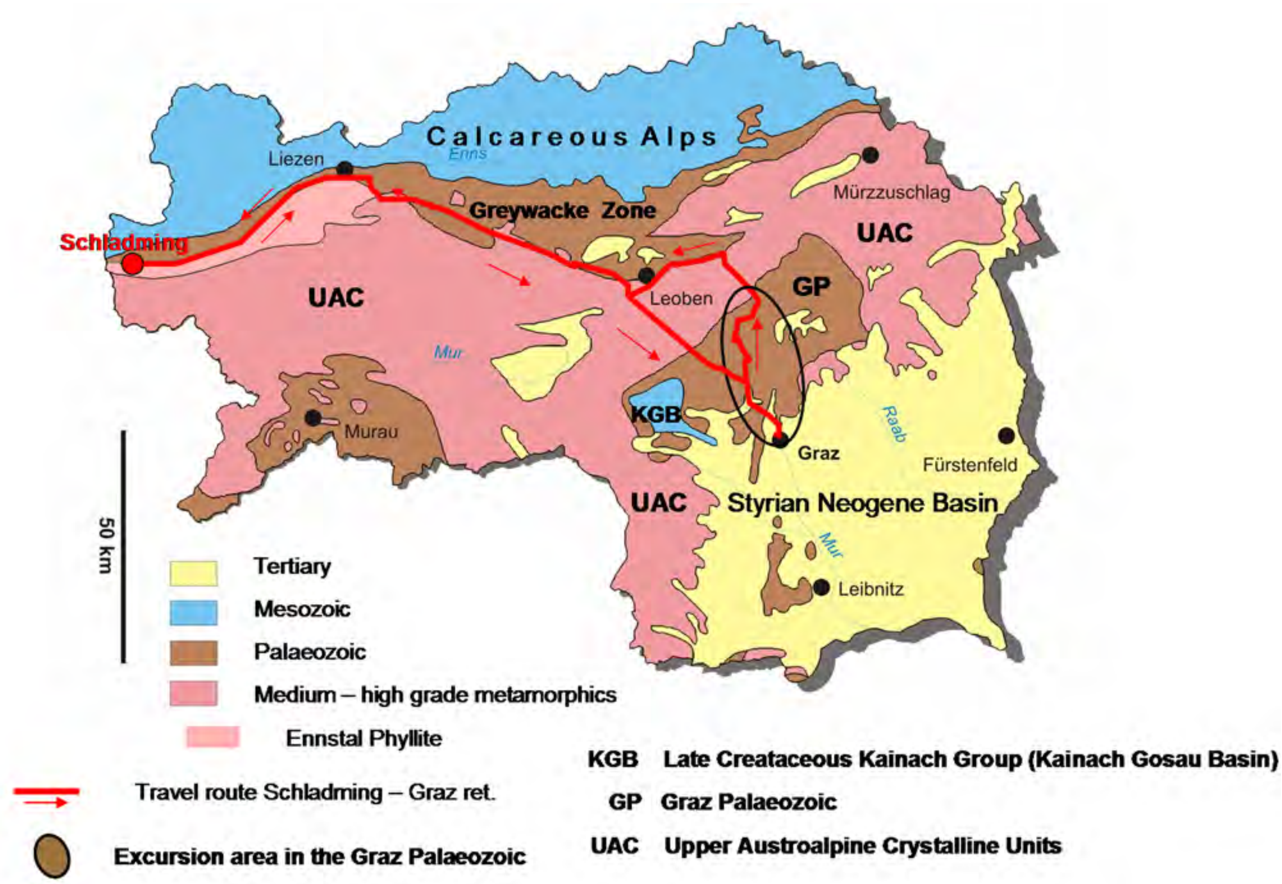


Fig. 14: Major geologic units of the Austrian federal state Styria. Schladming is the site of IAS 2012 conference. The travel route from Schladming to Graz and back and the field trip area within the Graz Palaeozoic is indicated.

thick fine-grained clastics (Schönlaub 1979, 1982, Schönlaub & Heinisch 1993). Major parts of the limestones (“ore bearing limestone“) were metasomatized to siderite/ ankerite ore (open pit mining at the “Styrian Erzberg“).
At St. Michael the highway crosses the Mur valley which follows in SW-NE direction the Mur-Mürz lineament, a fault system referring to sinistral strike slip movements during Miocene extrusion tectonics. Likewise in context with Miocene tectonics some small but relatively deep pull apart basins were formed, e.g. the Fohnsdorf Basin. These depressions accumulated Lower to Middle Miocene (Karpatian/Badenian) fresh-water sediments with occurrences of hard brown coal and layers of bentonite and vitric glass tuffs (Sachsenhofer et al. 2010).
South of St. Michael the highway crosses with its 8 km long Gleinalm highway tunnel the Silvretta-Seckau metamorphic complex which features a complex Variscan and Alpine tectonometamorphic history. The metamorphic rocks mainly comprise plagioclase gneiss and banded amphibiolite (Core Complex) which represent parts of a Lower Palaeozoic magmatic arc sequence of the Celtic Terrane (Frisch & Neubauer 1989, 1994). South of the tunnel the Core Complex is overlain by Palaeozoic marbles and micaschists and finally, about 6 km SE of the tunnel portal, the highway enters the Graz Palaeozoic which is separated from metamorphic complexes by a steep sinistral shear zone. Finally the route leads along the Lower Nappe Group of the Graz Palaeozoic into the Mur valley, where the highway is flanked by Devonian carbonate rocks belonging to the Upper Nappe Group (Rannach Facies) of the Graz Palaeozoic.

4.2. Field Trip in the surroundings of Graz

Stop 1: Plabutsch

After the incorporation of some municipalities in the year 1938 the Plabutsch with 754 m altitude became the highest elevation of the city Graz. The derivation of the name “Plabutsch“ is not clarified. Possibly Celtic roots of “pla“ indicate the meaning of iron smelt.
At the summit of the Plabutsch a little observation tower called „Fürstenstand“ is located more than 400 meters higher than the center of Graz and therefore provides a magnificent view over Graz and a panoramic view over the hilly landscape of the surrounding countryside, fair weather provided. The most important geologic units recognisable from here are illustrated in Fig. 16.
Already Rolle (1856:238) reported from the crest of the Plabutsch lots of fossils (i.e., rugosans, tabulates, stromatoporoids, crinoids, “bivalves“) occurring in dark grey limestones and assumed a reef structure. Since these limestones were used as building stones the walls of the

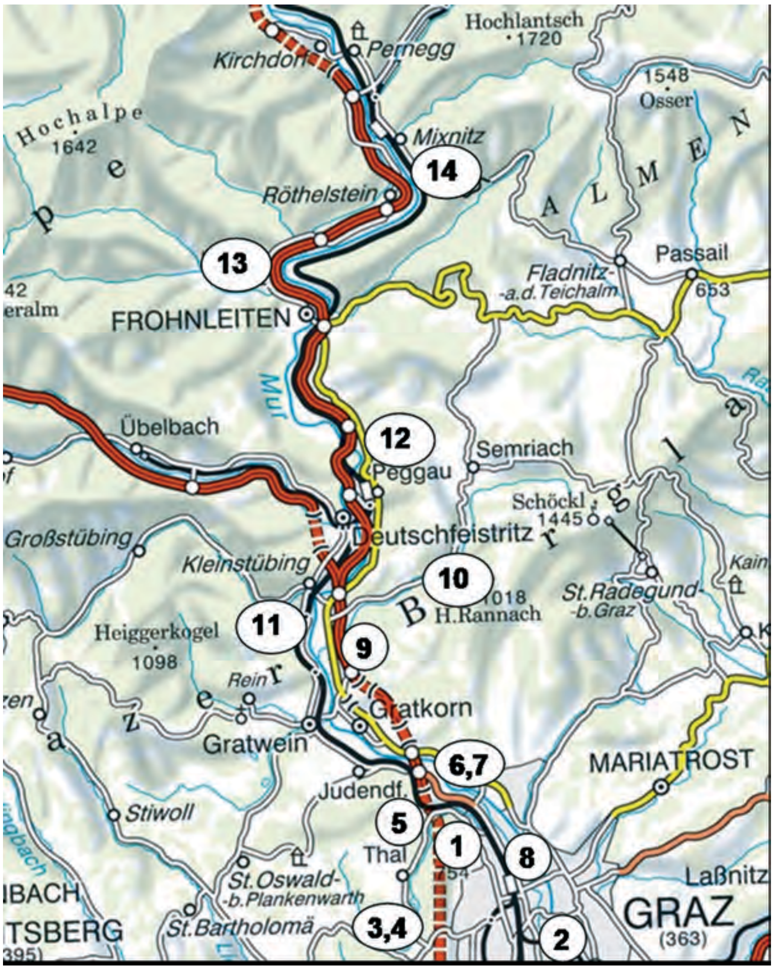


Fig. 15: Position of excursion stops. Stop 2 and Stop 8 in the center of Graz are “no hammer“ sites. 14 refers to an excursion point which will be explained form the passing bus/car only.

observation tower give an instructive insight into the organic composition of the environment (Fig. 17).

One and a half decade before ROLLE, Franz UNGER, a famous palaeobotanist at the Joanneum in Graz, published in 1843 taxonomic determinations of the following faunal content (UNGER 1843): *Gorgonia infundibuliformis* GOLDF., *Stromatopora concentrica* GOLDF., *Heliopora interstincta* Bronn (*Astraea porosa* GOLDF.), *Cyathophyllum explanatum* GOLDF., *Cyathophyllum turbinatum* GOLDF., *Cyathophyllum hexagonum* GOLDF., *Cyathophyllum caespitosum* GOLDF., *Calamopora polymorpha* a. var. *tuberosa* GOLDF., *Calamopora polymorpha* b. var. *ramoso - divaricata* GOLDF., *Calamopora spongites* a. var. *tuberosa* Goldf., *Calamopora spongites* b. var. *ramose* GOLDF., *Cyathocrinites pinnatus* GOLDF., *Pecten grandaevus* GOLDF., *Inoceramus inversus* MÜNST., *Orthoceras*, *Amonites*.

Today this listing of taxa is only of historical value. Nevertheless honor is due to UNGER having presented the first faunal list of Devonian fossils in Austria. The crest area of the Plabutsch from where the fossils originate is therefore the first area outside Great Britain and Germany where sediments were assigned to the Devonian system. Note that the Devonian period was established by MURCHISON and SEDGWICK only 4 years before in 1839.

Geology in the heart of Graz

The Graz Basin is flanked in the east and south by Neogene-Quaternary sediments of the Styrian Basin and by the Graz Palaeozoic in the west and north. Nevertheless two pre-Tertiary basement outcrops are forming spectacular sites of the city:

1) Schlossberg (castle mountain) in the centre (Lower Devonian dolomite of Flösserkogel Fm.),
2) Kalvarienberg (Mt. Calvary) made up of greenschists of uncertain age and tectonic position.

Within the 128 km^2 urban area of Graz varying lithologies of different geological epochs occur (Fig. 18):

(A) Successions of the Graz Palaeozoic

a) Non to low grade metamorphic Palaeozoic clastics and volcaniclastics (argillaceous schists, phyllites, clayey calcareous schists, greenschists and metadiabase) have their largest distribution in the northeast of the city (Rosegg, Platte) and in the Thalergraben (west of Graz); they are also located in some isolated basement outcrops (Reiner Kogel, Kalvarienberg, Stiftingtal).
b) Palaeozoic limestones, dolostones and sandstones of the Plabutsch-Buchkogel range form the western margin of the city. They also build up the hill of the Gösting castle, and on the eastern side of the river Mur, the Admonter Kogel, Kanzelkogel, Hauenstein, and areas in the vicinity of Mariatrost, as well as the Schlossberg in the center of Graz and the bed in the river Mur direct at the NW foot of the Schlossberg.

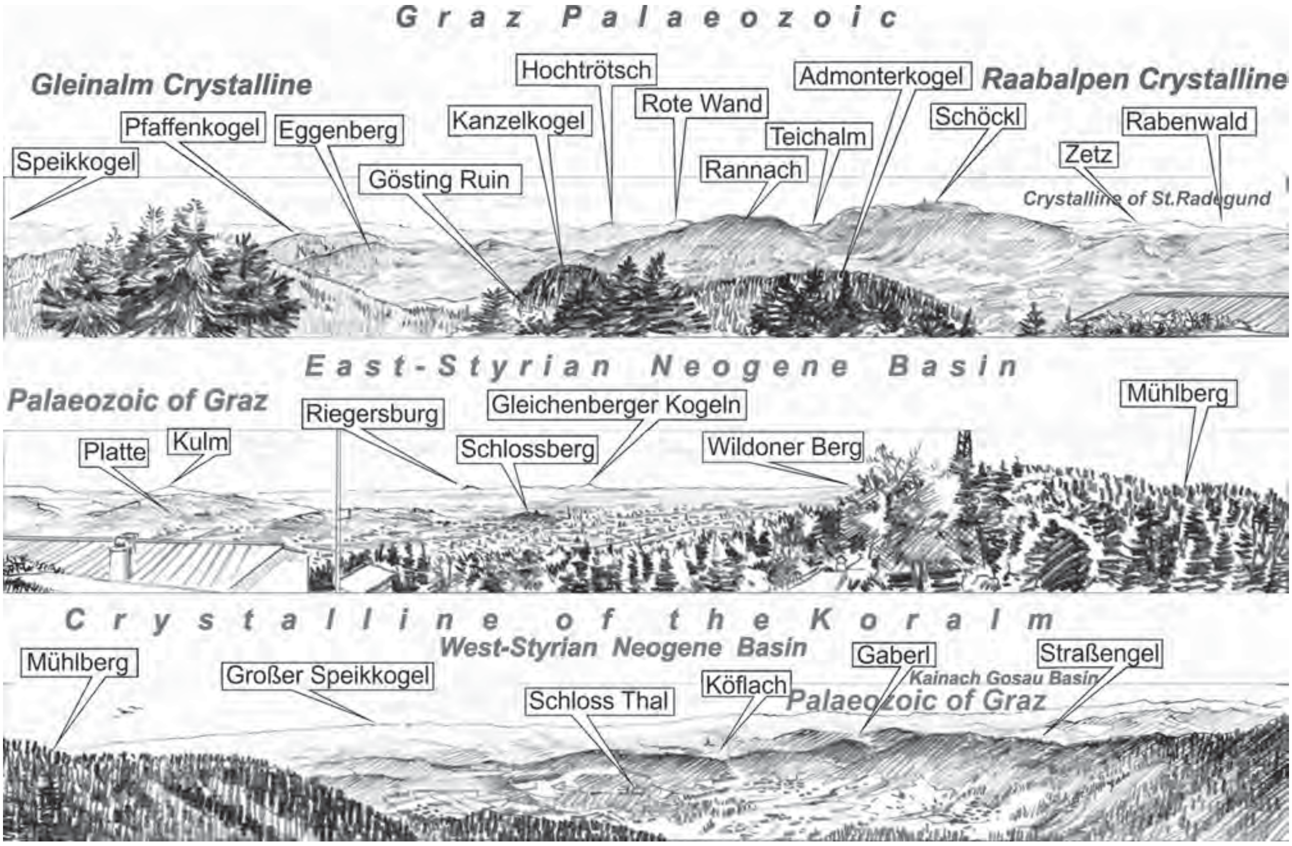


Fig. 16: Panoramic view from the "Fürstenstand". Main geologic units indicated. Drawing by Fritz MESSNER.

(B) Sediments of the Styrian Neogene Basin

a) The "Eggenberg Breccia", occurring at the eastern slopes of the Plabutsch-Buchkogel range, is composed of components of dolostones and limestones cemented by reddish marly matrix.
b) Badenian (?) to Lower Pannonian clayey to sandy sediments are developed in the lower to middle parts of the hills at the eastern border of the city. These sediments are also known from the Kehlberg area (Webling) in Straßgang southwest of Graz, and in the "Tertiary Basin of Andritz", in the northeastern part of Graz. In most cases, especially in the southern Graz Basin they are overlain by sandy gravels of Pleistocene terraces. Marine Badenian sediments were drilled below the Puntigam brewery in the southern parts of Graz.
c) In eastern and northeastern parts of Graz lower to middle Pannonian gravels and sands were deposited on crests of the hills (Petersbergen, Ries, Leechwald, Rosenberg) after geomorphologic activities during upper Peistocene to Paleogene times. Strongly weathered crystalline components are characteristic for these sediments.

(C) Quaternary sediments

a) Pleistocene terraces and Holocene
   - Terraces belonging to the Würm glacial stage are widely distributed within the Graz basin. They are mostly about 25 m in thickness.
   - Remains of the Riss terrace with slight clayey covers are not very prominent. They occur in a nearly 2 km distance parallel to the river Mur. The sandy gravels are very similar in their composition with those of the Würm glacial stage.
   - The Holocene terrain surface forms a stripe within the terrace of the Würm glacial stage along the river Mur.
b) Hillside weathered rocks and loess (aeolian silt deposits) are especially known from Frauenkogel and Plabutsch areas in the NW, and from the eastern parts of the Graz Basin in Waltendorf and St. Peter.

(D) Anthropogenic depositions

Very young deposits caused by housebuilding activities are apparently in the historic center (area of Sackstraße - Hauptplatz - Neutorgasse - Andreas-Hofer-Platz etc.) where thicknesses of dumps reach up 15 m. The plain of the "Stadtpark" is made up of waste deriving from the demolishing of the fortress at the Schlossberg after the Napoleonic War (Peace of Schönbrunn of 1809).

Stop 2: "Schlossberg and Mausoleum-Tour"

Schlossberg ("castle mountain")

Already more than 1000 years ago at top of the Lower Devonian dolomite cliff in the center of the city a small fort existed, which gave the city Graz its name (the Slavic word "Gradec" means little castle). Later, after 1544, it was extended to a huge Renaissance fortress planned by Domenico dell' Allio (1505-1563). Nowadays it is listed in the Guiness Book of Records as the strongest fortification

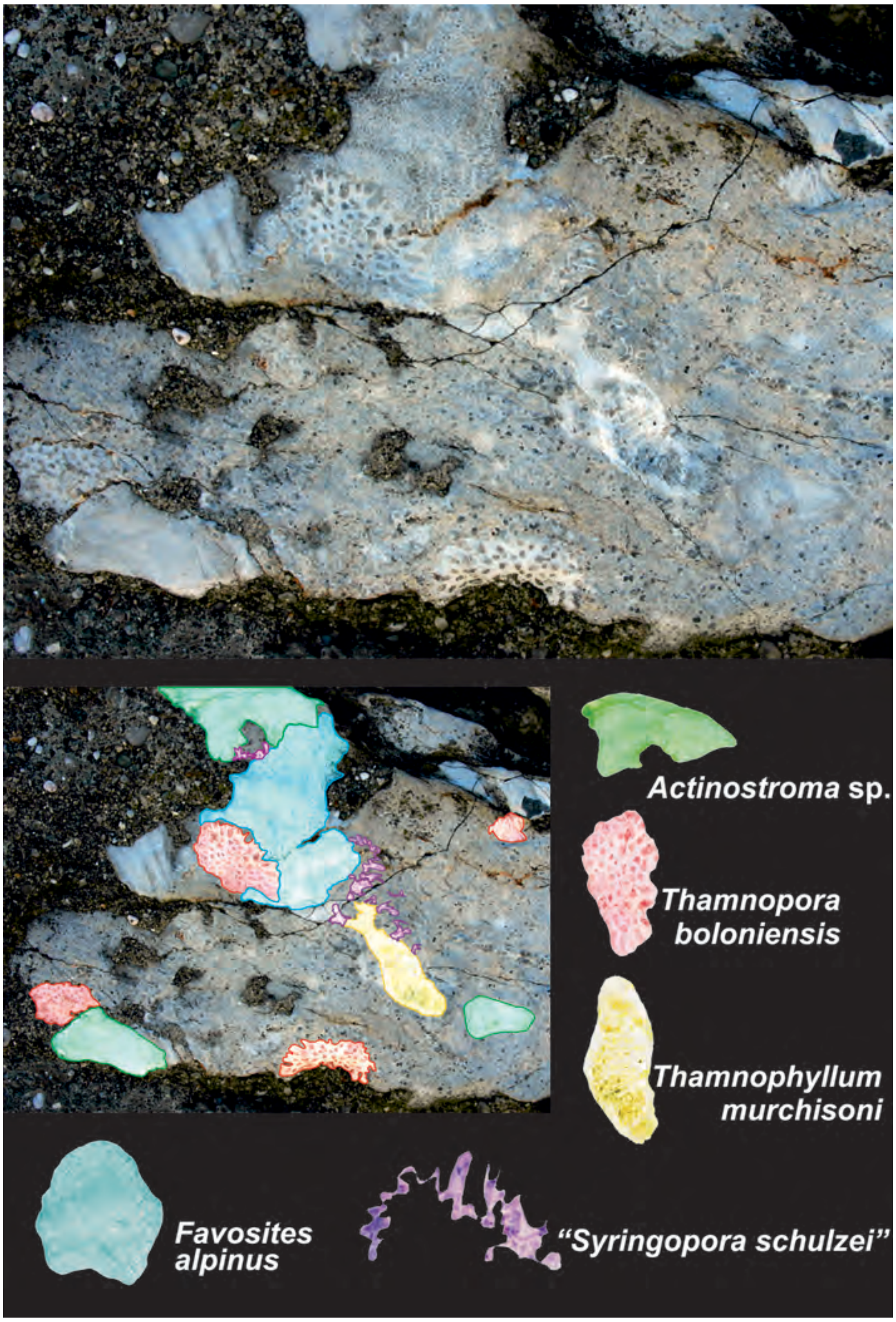


Fig. 17: A building stone from the observation tower “Fürstenstand“. Constituent fossils (tabulate and rugose corals and a stromatoporoid) highlighted in different colours.

of all time. Even Napoleon Bonaparte was impossible to capture it. Nevertheless in 1809 Graz was surrendered to the French otherwise the occupied Austrian capital Vienna would be destroyed. So most parts of the fortress were demolished. Only the clock tower (Uhrturm) and the bell tower (Glockenturm) with the famous bell “Liesl“ were ransomed by the citizens of Graz as a memorial and cultural heritage (GTI).

Beside some foot paths three spectacular possibilities to climb the top of the Schloßberg exist: The staircase (“Felsensteig“) with originally 260 steps was cut into the dolomite by French prisoners during the First World War. Another choice is a funicular railway which ascends the Schloßberg with an incline of 61% since over 100 years and finally a glass lift inside the mountain. The foot of the “Felsensteig“ is just at the Schlossbergplatz where there is also the entrance to a tunnel leading to the glass lift. Along another tunnel there is a footpath to the other side of the mountain (Karmeliterplatz). Altogether during the Second World War a 6.3 km long tunnel system with 20 entrances was mined into the mountain to serve as an air raid shelter for up to 40.000 people. Today the tunnelsystem is partly used as tourist attraction, e.g. the fairytale grotto railway (“Märchengrottenbahn“) for kids or as an underground event hall (“Dom im Berg“) (GTI).

The Lower Devonian massive dolomite of the Flösserkogel Fm. can be best observed when ascending the Felsensteig. Small karst caverns filled with reddish Pleistocene soil, sediment and spaelothems, some small scaled (cm thick) quartz veins and as absolute rarity branches of thamnoporid tabulate corals (HERITSCH 1936) are observable.

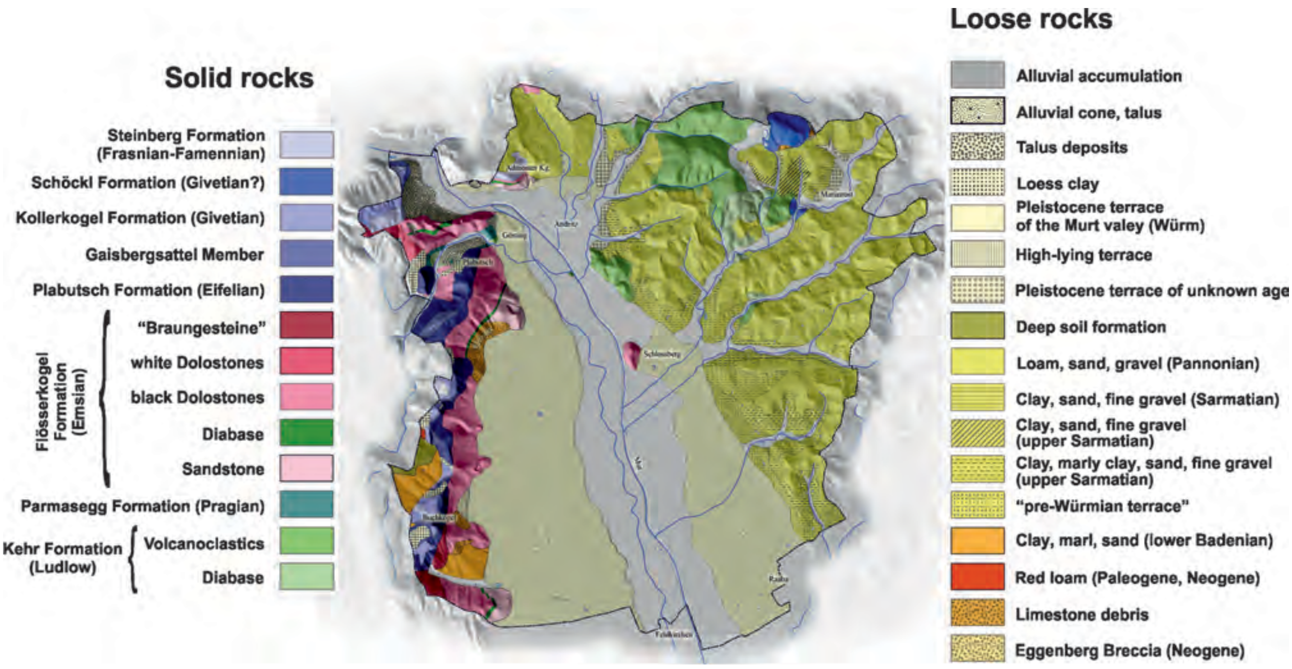


Fig. 18: Simplified geological map of the city area of Graz (modified after HUBMANN 2009).

Fig. 19: Left: The dolomite cliff (Lower Devonian dolomite of the Flösserkogel Fm.) of the "Schlossberg" in the center of Graz. The stairs ("Felsensteig") leads up to the clock tower (Uhrturm) the traditional landmark of the city. Right: Cartoon by Leo LEITNER with working and discussing condont scientists who visited the Graz Palaeozoic during an during ECOS II (2nd European Conodont Symposium 1980 Vienna-Prague) excursion .

Mausoleum

The so-called “Stadtkrone“ (= Crown of the Town) of Graz comprises important buildings of the downtown such as the cathedral, the “Burg“ (= seat of the government during medieval and Renaissance times) the “Old University“ and today’s Seminary (former Jesuit College).

In 1614 Ferdinand commissioned his Italian court painter and architect Pietro de Pomis (1569/70-1633) to erect a mausoleum and an adjacent St. Catherine’s Church next to today’s cathedral. It was to become one of the most important buildings of the early 17th century in Austria. The oval dome above the tomb chapel was the first of its kind built outside Italy. The facade of St. Catherine’s is composed with rich small details and demonstrates the taste of time at the threshold of Renaissance and Baroque. As a gable statue, St. Catherine of Alexandria is looking to the former Jesuit College opposite, where in 1585 Graz University was founded (she is worshipped the patron saint of universities!).

In 1619 Ferdinand was elected emperor and left Graz for Vienna and construction work at the Mausoleum came to a standstill. So in 1637 Ferdinand was laid to rest in a half-finished, “draughty“ tomb. Only his grandson, Emperor Leopold I, commissioned a young Graz artist to make the interior. The young artist later on became the famous Austrian Baroque architect Johann Bernhard Fischer von Erlach (1656-1723).

For the facade design of the mausoleum Pietro de Pomis used construction stones of the closer vicinity of Graz and/or Styria. At present the weathering degree of the building material shows the fossils as well as their internal structures almost optimally. That concerns even the stone which were replaced during the last renovation phase from the stairways leading to the portal.

Regarding the arrangement of different rocks used in the west frontage, the following ‘stratification’ results from an earthscientific view (Hubmann 2003b; Fig. 20):

(a) In the base area of the building stones were used, which were broken at the Plabutsch hill at the western city boundary of Graz. This rock was well-known during the 18th-19th century under the name “Gaisberg Marble“ as a popular building material. The term “marble“ points to a typical trade name used by stonemasons for all rocks which are able to become polished. Today the limestones are subsumed under the name Plabutsch Fm., a Middle Devonian (Eifelian) lithostratigraphic unit of the Graz Palaeozoic. Typically the very low grade to anchizonal metamorphosed, dark grey to almost black coloured limestones with their well preserved whitish fossils “come alive“ when they are cutted. Although the “Plabutsch Limestones“ represent no valuable construction material because of varying clay content, finely dispersed pyrite, and remarkable high amounts of organic matter enforcing decomposition processes, numerous organic remains enable an insight into a reefal ecosystem with tabulate (especially thamnoporids and favositids) as well as rugose corals (thamnophyllids dominating) and stromatoporoids. Reef dwelling thick-vavled brachiopods (*Zdimir*) are very common and sometime build up major parts of the rock.

(b) The stairways leading into the mausoleum are paved with beige limestones containing rudist bivalves in rock forming frequences. Comparable limestones have been quarried in northern Italy about 15 kilometres off Trieste since the Roman period. The common name “Aurisina Marble“ derives from a quaint village from which it is quarried. Lots of the bivalves which realised abnormal coral-like growth habits and constructed “rudist-reefs“ in tropical flat seas during upper Cretaceous times can be seen in various sections on cutted rock surfaces. Particularly cross sections through cup and tubular shaped shells resemble flower-like structures. The latter led to the famous trade name “Fior di Mare“. The jagged external delimitations of the valve attached to the substrate point to radiolitid rudists.

(c) The third type of building stone used for the mausoleum concerns the middle Miocene (Badenian) “Leitha Limestone“ (designated after the Leitha Mountains southeast of Vienna) which was used very commonly for building purposes in Austria (e.g., the Stephansdom in Vienna). In different facial characteristics Leitha Limestones were used in numerous historical buildings in the area of Vienna and Graz. For the frontage of the mausoleum a typical Styrian variety of Leitha Limestone was used, which is known as “Aflenz Stone“ among stonemasons. This type is also found at the Graz Landhaus (most important Renaissance building in the centre of Graz where the federal state parliament of Styria resides), the old main building of the Technical University, the “Herz-Jesu Church“, etc. Name-giving for the designation “Aflenz Stone“ or “Aflenz Sandstone“ is the mining area around Aflenz near Leibnitz (45 km south of Graz). Due to the outstanding suitability as component the rocks in Aflenz were cutted in subsurface quarries already during the time of emperor Vespasian (9-79).
Although the limestone is sensitive to weathering, it was besides aesthetic ascepts its high water absorbtion capacity which is favourable in hygienic aspects (Török et al. 2004). Today these limestones were also used as raw material for production of cement. Most of the rocks prove to be detrital foraminiferal-rhodoid limestones. Coralline algae are the dominating rock forming biota, whereas various molluscs (bivalves and gastropods) are recognisable mostly as molds however some like oysters and pectinids can thoroughly be observed. Accompanying fossils are mainly foraminifera, bryozoans, corals and sponges.

Due to the - although coincidental, but nevertheless opportune - combination of the different sorts of building material in the frontage the mausoleum is suitable in the best way to offer tourists a simple view on stratigraphy. But also the different ways how life in shallow marine areas at different geological times could develop and create organisms which became extinct at certain times (e.g., Rugosa, Tabulata, Stromatoporida, Hippuritacea) can be demonstrated to laypersons (Hubmann et al. 2007, Hubmann & Moser 2009).

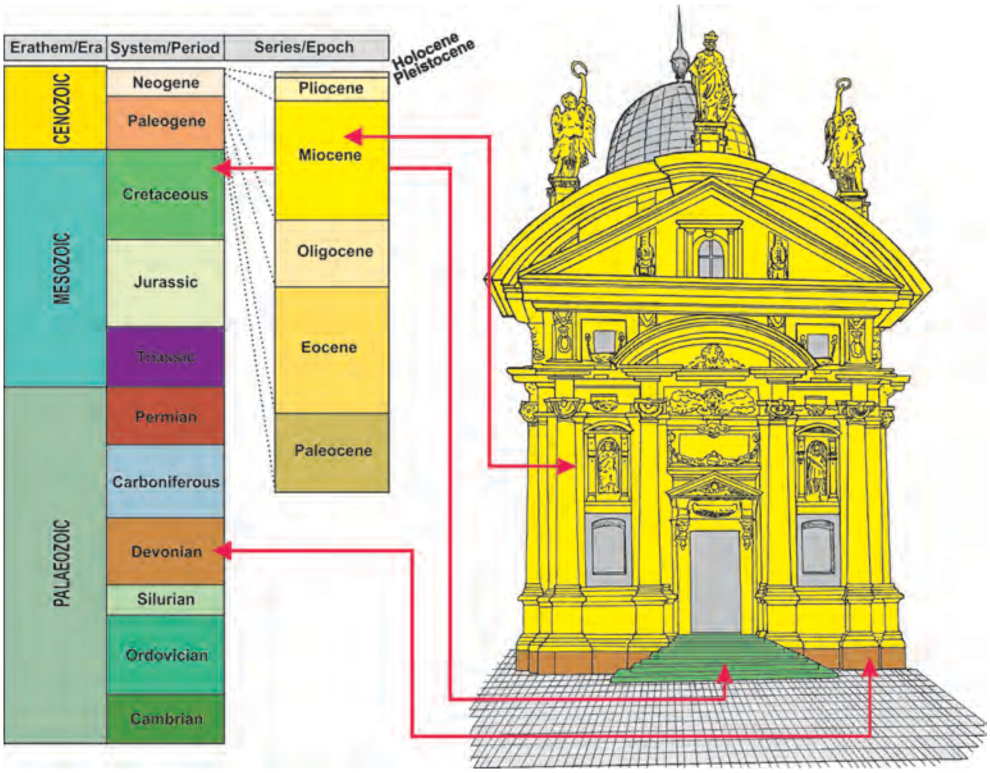


Fig. 20: Lithology and "Stratigraphy" of the western facade of the Graz Mausoleum (Hubmann et al. 2007). Basement area of the building: Middle Devonian Plabutsch Fm., stairways: upper Cretaceous Rudist limestones; west frontage; Miocene Leitha Limestone.

Forstkogel, Steinberg and Sanzenkogel (W of Graz) the type locality of the Forstkogel-Group

W of Graz the Forstkogel Group is made up of micritic coloured flaser limestones rich in cephalopods and conodonts. They were quarried as construction material and decoration stone around the type locality of the Steinberg Fm. since the middle ages (Fig. 21). First all these limestones were attributed to the Upper Devonian (Steinberg Fm.) until condont findings (Flügel & Ziegler 1957) identified also Lower Carboniferous ages in these limestones. Nomenclatorialy they were separated as "*Gnathodus* Limestones" from the Steinberg Limestones until Nössing (1974) recognized that limestones are also occurring in the lowermost Carboniferous prior to the first occurrence of the conodont genus *Gnathodus*. Therefore all Carboniferous limestones were integrated to the Sanzenkogel Fm. (Nössing 1975). Later, detailed stratigraphic investigations were carried out in all abandoned quarries of the Forstkogel, Steinberg and Sanzenkogel area (Surenian 1978, Buchroithner et al. 1979, Ebner 1980). The tectonic structure is complicated by a huge isoclinal fold with upright and inverse limbs which tectonic position can only be recognized by the succession of the conodont zones. Due to intensive stratigraphic research it was possible to

- identify Tournaisian limestones (Lower Sanzenkogel Fm.) of very reduced thickesses (220 cm; Nössing 1974),
- reconstruct a section across the Devonian-Carboniferous boundary which was for long time one of the favoured candidates for the international Devonian-Carboniferous boundary stratotype (Sandberg et al. 1983, Ziegler & Sandberg 1984),
- find a distinct 20-40 cm thick shale-lydite-phosphorite horizon (Trolp Phosphorite Bed) at the bottom of the Upper Sanzenkogel Fm. (Nössing 1974, Flügel 2000),
- find dark Bashkirian limestones and shales of the Dult Group stratigraphically above the Sanzenkogel Fm. (Ebner 1978).

Stop 3: Forstkogel ("Open air theater")

The Forstkogel with numerous abandoned quarries is the type region of the Forstkogel Group which is made up of variegated micritic limestones of Upper Devonian (Steinberg Fm.) and Carboniferous (Sanzenkogel Fm.) age. The thickness of the Steinberg Fm. is about 70 m (Fig. 21, Fig. 22).

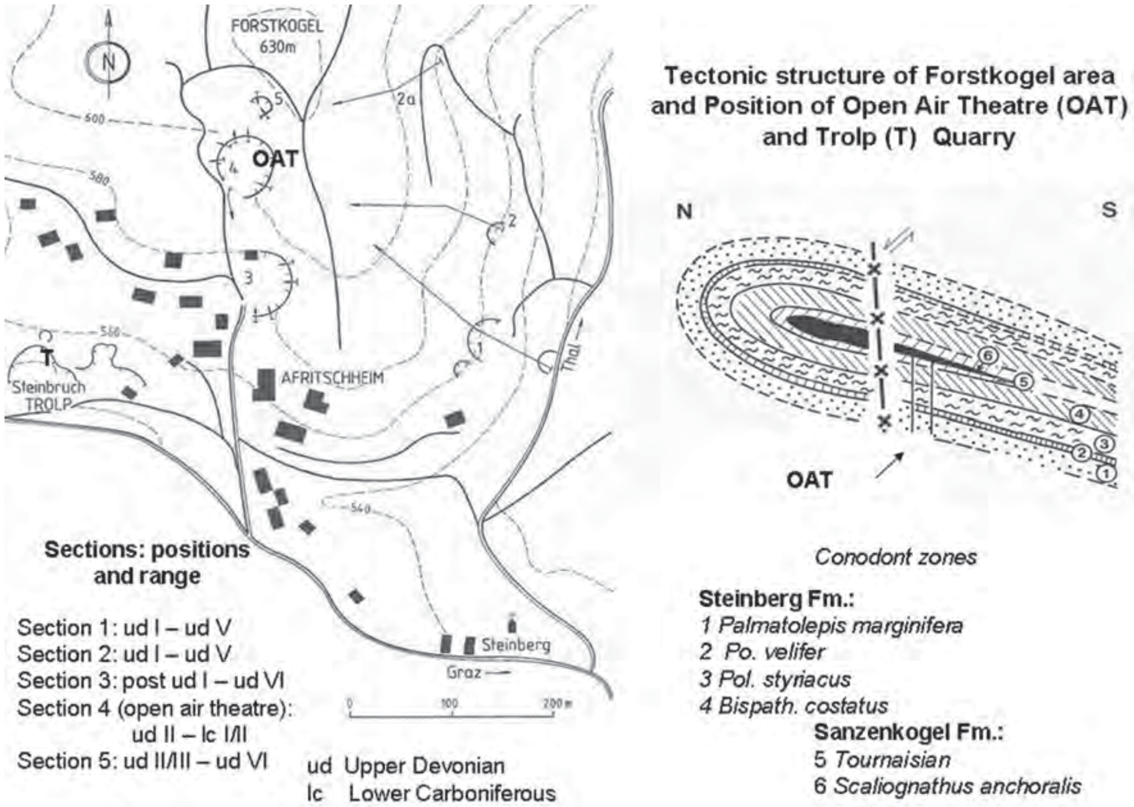
In the northern face of the quarry the following condont zones were recognized in an upright succession of light grey to yellow-brownish micritic limestones (Surenian 1977, Buchroithner et al. 1979):

top
- *Gnathodus typicus* zone
- horizons with Tournaisian condonts; the *Scaliognathus anchoralis* zone includes a thin layer of shales with phosporite nodules
- *Bispathodus costatus* zone (300 cm)
- the interval of the *velifer* to *styriacus* zones was not found in this but in other sections of the quarry
- *Palmatolepis marginifera* zone (> 600 cm).

bottom

The entrance area to the quarry exposes micritic limestones of the *Bispathodus costatus* zone in the south and *Polygnathus stryiacus* zone in the northern part. Caused

A



B

Fig. 21: A: Type locality of the Forstkogel Group with sections of the Upper Devonian Steinberg Fm. and Carboniferous Sanzenkogel Fm. (BUCHROITHER et al. 1979). The tectonic structure of this area is dominated by a N-verging isoclinal fold with upright and inverted limbs (stratigraphic successions). B: Section of a *"Clymenia*"; Steinberg Fm., Forstkogel area (collection of the Universalmuseum Joanneum, Graz).

by Plio-Pleistocene karstification the limestones are deeply corroded and cavernous and filled with reddish to brown residual clays. Conodonts dissolved by weathering processes from the limestones are enriched in the soil. A sample of 3 kg soil yields about 70 single elements of conodonts. The time span of the mixed fauna ranges from the basal Famennian to the Lower Carboniferous and reflects the total stratigraphic range of the surrounding area (SURENIAN 1977).

Stop 4: Trolp Quarry

The Trolp quarry with its overturned stratigraphic sequence is the type section of the Lower Sanzenkogel Fm. (NÖSSING 1974) and the type locality of the conodont taxon *Polygnathus styriacus* (ZIEGLER 1957).

In the eastern face of the quarry an overturned section from the latest Devonian *Bispathodus costatus* zone to the *Gnathodus typicus* zone is exposed. This section includes the site which was discussed as a favourite for the international Devonian-Carboniferous boundary stratoytpe (SAND-

Stratigraphic subdivision				Conodont zones	thickness of zones in m 1	2	3	4	5
Upper Devonian	FAMENNE	Wock.	do VI	*Protognathodus-Fauna*					?
			do V/VI	*costatus*			>3	>2,5 (>9; 3;1;>7,5)	>2,4
		Gon.	do V	*styriacus*	>20	>4 (10)	3,5 (2)	3,7 (>5,5; * * >4,5)	2,0
		Platy-clym.	do IV do IIIβ	*velifer*	3,4	4,5 (>15)	2	3,7 * *	1,2
			do IIIα	*marginifera*	14	12	3 (6; 3,5)	>3 (>6;>4)	>2,8
		Cheilo-ceras	do IIβ	*rhomboidea*	24	7	* (2,5;1,5)		
			do IIα	*crepida*	>0,8	11	*		
	FRASNE	Manticoceras	post do Iδ do Iδ	*triangularis*	>1,6	*	>3,5		
			do Iγ	*gigas*	1,8	>7			
			do Iβ?	*A. triangularis*	2,2	(>5)			
			do Iα	*asymmetricus*	0,9				
				hermanni cristatus					
Middle Devonian				total thickness in m	~70	~55	~15	~13	~9

Fig. 22. Stratigraphic range and thickness of the individual conodont zones (according to Ziegler 1971) in sections of the Upper Devonian Steinberg Fm. at the type locality. The numbers of sections correspond with the site numbers in Fig. 21.

berg et al. 1983, Ziegler & Sandberg 1984), the type section of the 220 cm Tournaisian Lower Sanzenkogel Fm. and a 20 cm thick horizon with shale, lydite and phosphrite nodules (Trolp Posphorite Bed) at the bottom of the Upper Sanzenkogel Fm. (Fig. 23).

The sparsity of macrofossils and siphonodellid conodonts excluded this section as international boundary stratotype. In the section (Fig. 23) the beginning of the Carboniferous is indicated by the first occurrence of *Protognathodus kuehni*. *Siphonodella sulcata* as the international index condont for the base of the Carboniferous was not yet found in the lowermost 20 cm of the Lower Sanzenkogel Fm. (Ebner 1980, Sandberg et al. 1983, Ziegler & Sandberg 1984, Kaiser 2005).

The boundary section is part of a 220 cm intensively investigated (conodonts, microfacies, stable isotope

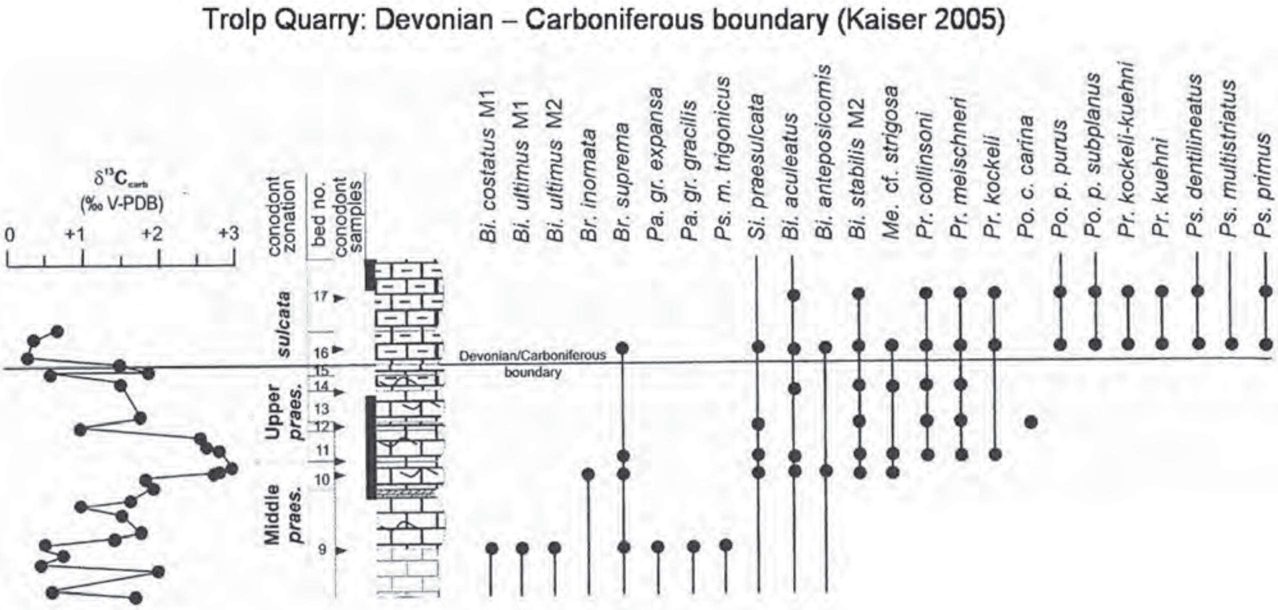


Fig. 23: Detail section across the Devonian-Carboniferous boundary (Steinberg Fm. - Lower Sanzenkogel Fm.) in the Trop Quarry with the range of the conodonts and $\delta^{13}C_{carb}$ values (Kaiser 2005). Note the isotopic excursion in bed 10 and 11 and that in nature the section is inverted.

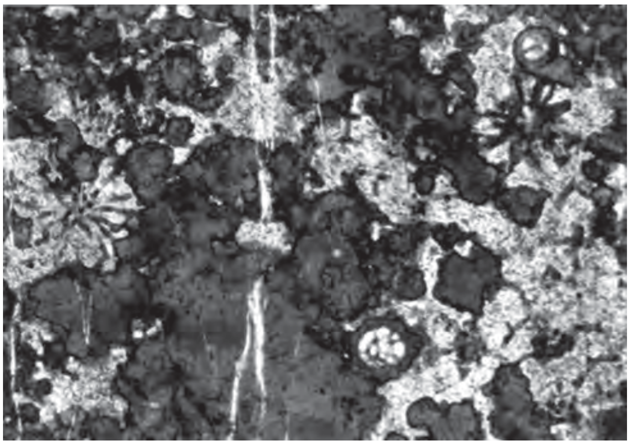


Fig. 24: Thin section of lydite with radiolarians from the Trolp Posphorite Bed at the type locality (Trolp Quarry).

geochemistry) section (KAISER 2005). The light-grey to ochre sometimes nodular and flaser-bedded marly cephalopod limestones are rich in conodonts (CAI ~ 4.5) and represent a complete succession from the latest Famennian *Siphonodella praesulcata* to the Tournaisian *Siphonodella sulcata* zone. At top of bed 9 (Fig. 23) there is a lithological change in form of a 1 cm thick argillaceous layer followed by thin bedded (~ 1-2 cm) marly limestones (mud- and wackstones) above which the base of the Carboniferous was recognized by the occurrence of *Protognathodus kuehni*. Due to the poor conodont fauna the marly bed is correlated with the main extinction phase of the Hangenberg event at top of the middle *Siphonodella praesulcata* zone. This level is characterized by a positive $\delta^{13}C$ isotope excursion which coincides also with a main extinction phase during the deposition of the Hangenberg blackshale in Germany and indicates a global perturbation of the carbon cycle during a period of warm seawater (KAISER 2005).

Stable isotope ($\delta^{18}O$, $\delta^{13}C$) and trace elements investigations highlighted Ir-anomalies and a $\delta^{18}O$ isotope excursion in micritic limestones of the *Siphonodella sulcata* and *duplicata* zones of the Lower Sanzenkogel Fm. These anomalies were interpreted as the evidence of a meteoritic impact (BOJAR & NEUBAUER 2003).

The Tournaisian Trolp-Phosphorite Bed at the base of the Upper Sanzenkogel Fm. includes lydite with fragments of radiolarians (Fig. 24). It indicates the deepening of the

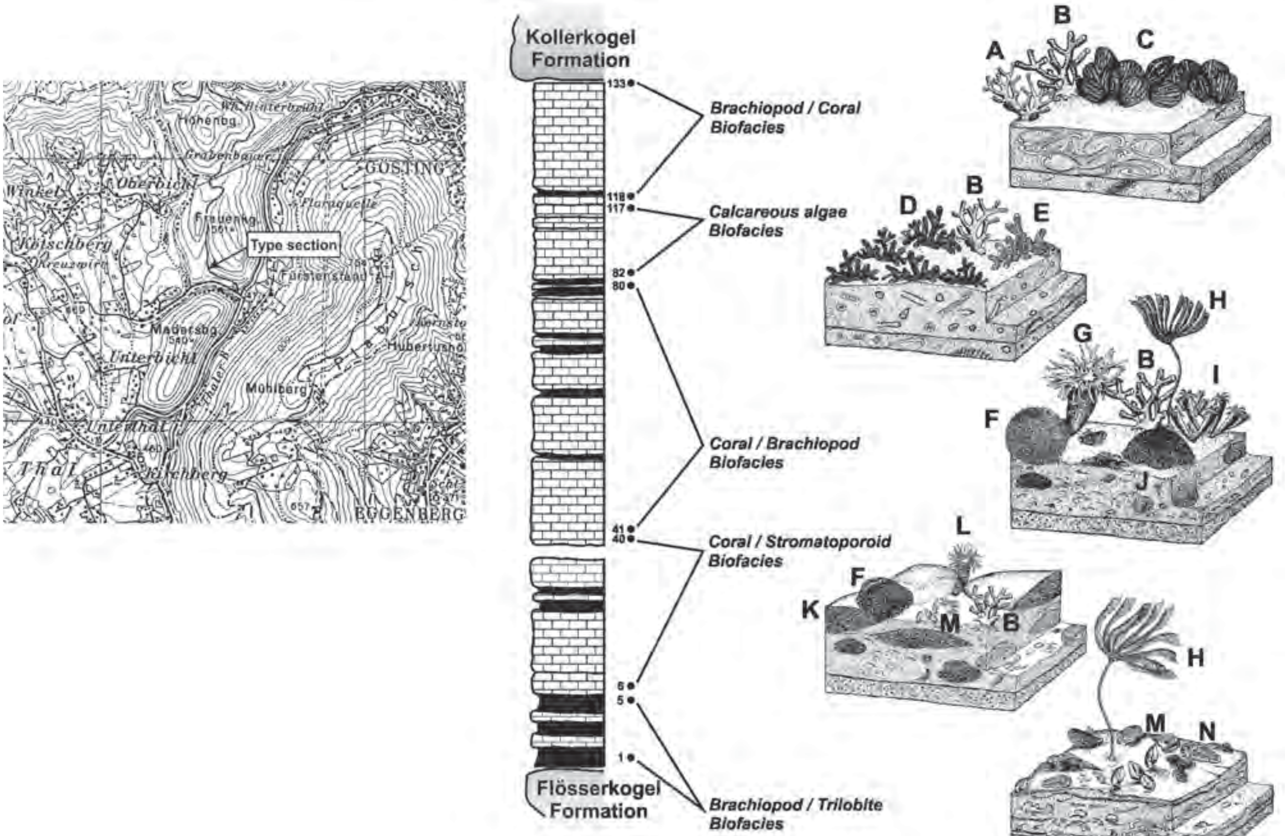


Fig. 25: Forest road Attems. Section of the Plabutsch Fm. subdivided into 5 biofacial sections: a) Siliciclastic brachiopod-trilobite-biofacies ("Chonetenschiefer" = Gaisberg Bed) with: *Chonetes* sp., *Maladaia* sp., and crinoids; b) Coral-stromatoporoid-biofacies with: *Actinostroma* sp., *Thamnophyllum stachei*, *Thamnophyllum murchisoni*, *Favosites styriacus*, *Thamnopora* sp., *Striatopora* sp., *Pachycanalicula barrandei*, *Heliolites* cf. *peneckei*, Crinoids; c) Coral-brachiopod-biofacies with *Thamnophyllum stachei*, *Thamnophyllum murchisoni*, *Thamnopora reticulata* ?, *Thamnopora* sp., *Striatopora* (?) *suessi*, *Favosites* sp., *Chonetes* sp., "Spiriferids", Crinoids; d) Algae-biofacies with *Pseudopalaeoporella lummatonensis*, *Pseudolitanaia graecensis*; e) Brachiopod-coral-biofacies with: *Zdimir* cf. *hercynicus*, *Thamnopora* cf. *reticulata*, *Striatopora* (?) *suessi* (modified from HUBMANN 2003a).

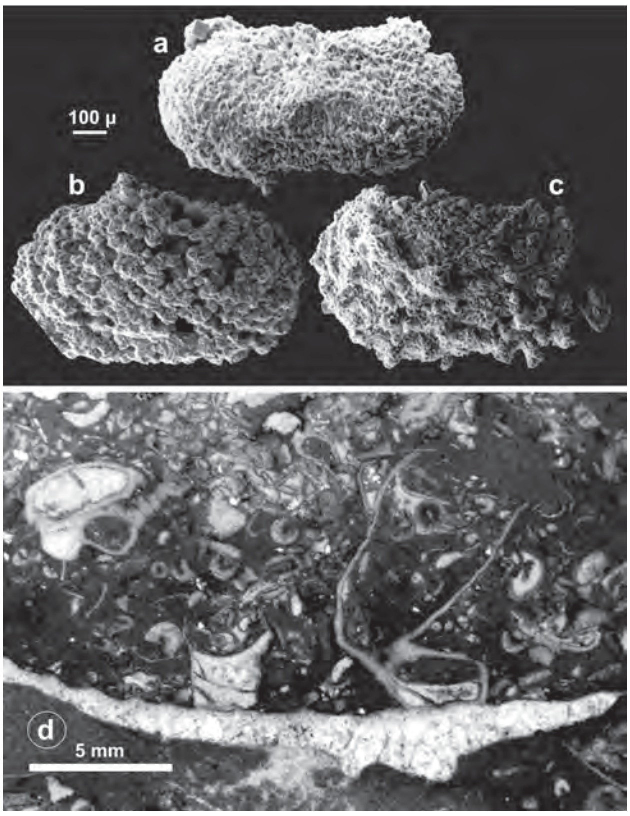


Fig. 26: Silicified micro fossils (a-c) of the Gaisberg Bed. (a) indeterminable smooth valved ostracod, (b) *Cryptophyllus* sp. (c) *Eridoconcha papillosa* and overgrowth of *Aulostegites* colonies on a chonetid shell (d).

environment resulting in the formation of phosphorite nodules along upwelling zones of the Carboniferous shelf margin (Buchroithner et al. 1979, Ebner 1980a, Ebner et al. 2000).

Stop 5: Forrest road Attems

Plabutsch Fm. (?Upper Emsium to Eifelium to ?Lower Givetium)

The forest road Attems is located on the southern slope of the Frauenkogel in the western vicinity of Graz (Fig. 25). Along the road the Flösserkogel Fm., Plabutsch Fm. (including marly shales and marly limestones of the Gaisberg Bed) and Kollerkogel Fm. (dark grey dolomites of the Gaisbergsattel Mb.) are exposed.

The outcrop along the road starts with whitish sandy dolostones of the Flösserkogel Fm. (Emsian) which passes into laminated dolomitic limestones (tidal flat deposits) in the uppermost part of the formation.

Separated by a fault brownish to yellow marly shales with moulds of chonetid brachiopods and very rare trilobites (*Maladaia* sp.) on bedding planes follow. At the base of this succession the shale is intercalated by marly limestone-beds less than 10 cm in thickness. The yellow to reddish-brown limestones are densely packed brachiopod or Eridostraca shell accumulations, containing also rare findings of icriodontid conodonts, placoderm plates and teeth of other fish. Some brachiopod shells were used by auloporid tabulates (*Aulostegites* sp.) as substrat for anchorage (Fig. 26d). Partly the ostracods (unidentifiable smooth valved individuals) and eridostracs (*Eridoconcha papillosa* and *Cryptophyllus* sp.) are silicified (Fig. 26a-c) in contrast to other fossil remains. The succession described reaches up to 8 to 10 meters in thickness and is assigned to the Gaisberg Bed of the Plabutsch Fm.

The uppermost part of the Gaisberg Bed is characterised by the settlement of mound shaped favositid tabulates (*Favosites styriacus*) with diameters of colonies up to 80 cm. The occurrence of corals coincides with a rapid lithological change from orange marls and marly limestones to greyish blue limestone beds.

The first few meters of these limestones are dominated by a stromatoporoid-coral faunal association which passes into a coral-brachiopod biofacies. This community includes *Favosites*, *Thamnophyllum*, *Thamnopora*, *Zelophyllia* and other corals. Approximately at the middle part of the unit this community is replaced by a biofacies which is dominated by calcareous green algae (e.g., *Pseudopalaeoporella*, *Pseudolitanaia*) and thamnoporids. In the upper part of the Plabutsch Fm. thick valved brachiopods which are assigned to *Zdimir* cf. *hercynicus* occur. Together with "*Striatopora*" and *Thamnopora* they compose the brachiopod-coral biofacies (Fig. 25).

Within the entire sequence along forest road Attems, conodonts are sparsely distributed. Mainly icriodontids were found which suggest an Emsian to Eifelian age for the lower part of the Plabutsch Fm. Despite a very rich fauna (Fig. 28) the age of this formation remains problematic because distinctive age-constraining fossils are rare (Hubmann & Messner 2005). Generally the faunal association indicates an uppermost Emsian to lowermost Givetian age.

For an interpretation of the depositional environment of the Plabutsch Fm. confer to the figure and text below (Fig. 27).

Stop 6: View to Kanzel Quarry

Two quarries S of the road to the Hartbauer section expose limestones (Kanzel Mb.) and dolostones (Gaisbergsattel Mb.) of the mainly Givetian Kollerkogel Fm.

The northern Pailgraben quarry is made up of thick bedded to massive micritic limestone of the Kanzel Mb. Remarkable are karst cavities with spaeleothems and fillings of red soils and Pliocene gravels with quartz pebbles.

The southern Kanzel quarry (STRABAG; Fig. 29) is the type locality of the Kanzel Mb. (Givetium to Lower Frasnian) of the Kollerkogel Fm. In the west the footwall of the quarry and a coulisse in front of the quarry is formed by the Eifelian Plabutsch Fm. (black fossiliferous limestones containing corals and brachiopods and calcareous shales with reddish-violet bedding planes). In the quarry limestones and shales of the Plabutsch Fm. are followed to the NE by massive grey dolostones (Gaisbergsattel Mb.) and thick bedded to massive limestones of the Kanzel Mb. Karst fillings (red soils,

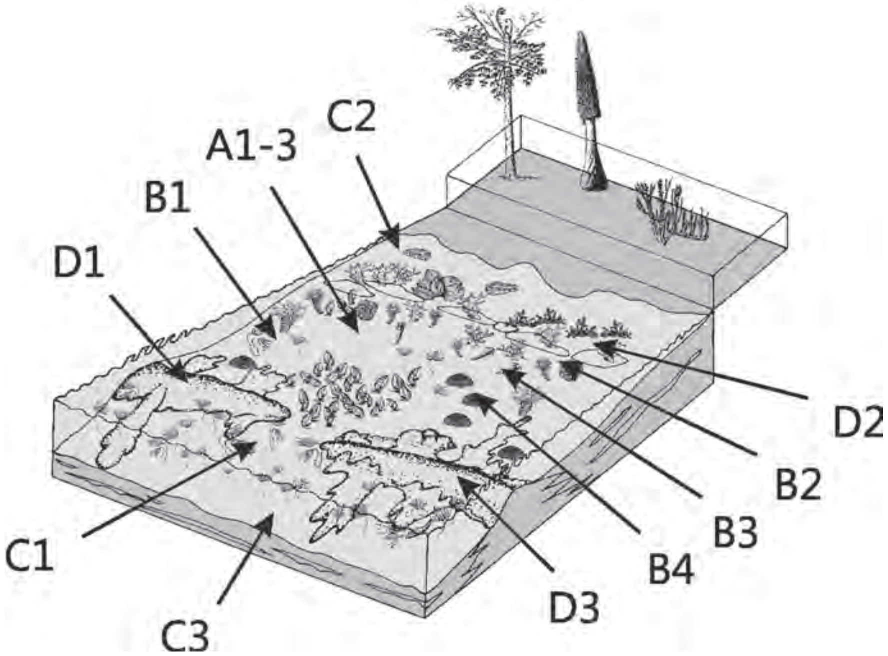


Fig. 27: Facies model of the Plabutsch Formation (after HUBMANN, 1993, 1995, EBNER et al. 2000).
A Low-energy mud facies: Micritic (to microsparitic) rocks with locally dominant fecal pellets and bioturbation structures. High mud content, as well as totally preserved, easily disarticulated skeletons (i.e.: articulated crinoid stems) suggest a low turbulence hydrodynamic regime.
A1 Mudstone-subfacies: Light grey to blue, yellowish, usually dark grey to black (finely distributed pyrite and/or organic substance), few fossils.
A2 Calcisphere-wackestone-subfacies: Dark blue to black, micritic limestones with concentrations of calcispheres (and ?spicula) and biogens/biomorpha of small size. Calcispheres and the rarity of macrofossils indicate deviations from a normal marine environment.
A3 Gastropod-pellet-wacke/grainstone-subfacies: Usually small (size up to 3 mm), trochospiral gastropods with apex upwardly oriented in pelmicritic to pel(pseudo)sparitic matrix. "Fecal pellets" frequently elongate due to pressure in the still unconsolidated sediment. Frequent bioturbation.
B Higher energetic mud facies: Bigger (allochthonous) biogens indicate higher hydrodynamic energy setting during deposition. General lack of rounding indicates short transport (parautochthonous to autochthonous). "Typical reef-building" organisms are characteristic.
B1 Crinoid-Brachiopod-wacke/floatstone-subfacies: Layers with isolated crinoid stems and thin-shelled brachiopods, frequently with micritic envelops are widely distributed. Thinshelled Brachiopods (Chonetids?) usually double-valved.
B2 "Amphiporid"/"Thamnoporid"-floatstone-subfazies: Accumulations of branching tabulata of *Thamnopora* und *Striatopora*-type with dendroid stromatoporoids of *Amphipora*-type with calcispheres and crinoids.
B3 Coral-stromatoporoid-floatstone-subfacies: Rugose, *Thamnophyllum*-dominated and tabulate corals with branching growth-form of coralla, as well as lamellar or tabular stromatoporoids in general parallel to layers. Also echinoderms, brachiopods, gastropods und broken shells. Frequent epoecic stromatoporoids on rugose (rarely on tabulate) corals. Orientation indicates directed currents; lack of abrasion indicates short transport.
B4 Brachiopod-coral-floatstone-subfacies: Characterized by thick-valved brachiopods and massive (*Favosites*, *Alveolites*, *Heliolites*) as well as dendroid corals (*Thamnophyllum*, *Thamnopora*, *Striatopora*). May be developed as *"Zdimir-*coquina". Lack of imbrication and frequent double-valved brachiopods indicate that at least brachiopods are autochthonous. The corals have no indication for live position.
C High-energy debris facies: Rounded, oriented components, graded fossil debris characteristic.
C1 Crinoid debris-subfacies: Echinoderms-, peloids- and gastropods in sparitic limestones frequently at the bases. Well rounded and sorted biogens with frequent micritic envelopes.
C2 Coarse silt-pellet-subfacies: Besides a high contribution by coarse silt (grain size from 60-125 µm, up to 78%) in micritic to microsparitic or pseudosparitic matrix, also pellets, in particular quartz-silt-grains rhythmites. Bioturbate structures.
C3 Eventstone(tempestite)-subfacies: Erosion base (not always evident) followed by shell debris and biodetritic layers, usually normal gradation. In two-valved organisms the ratio stable to unstable position is about 1:1, geopetal fillings are characteristic; "muddying-upward"-sequences.
D „Reef" facies: This facies unites genetically different organismal carpets (algae, stromatopores, corals (HUBMANN 1995a).
D1 "Coverstone"-subfazies: The "coverstone" facies according to TSIEN (1984) characterizes initial reef growth, but is also similar to the tempestite facies. Macroscopic allochthonous components are characteristic, they are covered by autochthonous lamellar organisms. Crinoids, dendroid tabulata, rugosa, heliolitida, brachiopoda and gastropoda are found as detritic (allochthonous) components. Lamellar and tabular stromatoporoids (type *Actinostroma*), as well as favositides with lamellar corallum act as stabilizers.
D2 Algae wacke/float to bafflestone subfacies: Halimedacean lawns = "algae-baffle/boundstones" (MAMET et al. 1984). This facies is found in alternation with red marly shales (HUBMANN 1990, 2000). This subfacies has residue values which are far elevated above values given in the literature for algal limestones.
D3 Coral-baffle(frame)stone-subfacies: Massive favositid patches of 0.5 m in diameter.

Fig. 28: Typical fossils of the Plabutsch Formation
(1) *Thamnophyllum stachei* Penecke 1894, x 1
(2) *Tamnophyllum murchisoni* Penecke 1894, x 1
(3) Fragment of a calyx of *Tryplasma devonica* (Penecke, 1894), x 1
(4) Fragment of a calyx of *Zelopyllia cornuvaccinum* (Penecke, 1894), x 0.5
(5) *Disphyllum caespitosum* (Goldfuss 1826), x 1
(6) *Pachycanalicula barrandei* (Penecke 1887), x 1
(7) *Thamnopora reticulata* (Blainville 1830), x 1.4
(8) *Thamnopora vermicularis* (M'Coy, 1850), x 1.4
(9) „*Striatopora*" *suessi* Penecke ,1894, x 1.4
(10) *Thamnopora boloniensis* (Gosselet, 1877), x 1.4
(11) *Favosites styriacus* Penecke, 1894, x 1
(12) *Atrypa reticularis* Linne, x 1
(13) *Zeapora gracilis* Penecke, 1894, x 2
All specimens are from the private collection of Fritz Messner.

Fig. 29: The Kanzel quarry (type locality of Kanzel Mb.) is made up of the Kollerkogel Fm. (Givetian to lowermost Frasnian). At the top of the Eifelian Plabutsch Fm. (PF) in the SW, massive dolostones of the Gaisbergsattel Mb. (GSMb) and micritic limestones of the Kanzel Mb. are exposed. Rocks of the Kanzel Mb. (KMb) were followed at top in the NE sector of the quarry by limestones of the Forstkogel Group (Kodsi 1967) but they were already mined away 40 years ago.

gravels, spaeleothemes) cause problems during mining the carbonate rocks which are used for construction purposes and as aggregates.
45 years ago the hanging wall of the quarry exposed flaser limestones of the Upper Devonian Steinberg Fm. and the Tournaisian Upper Sanzenkogel Fm. Conodont mixed faunas provided evidence that the boundary between these two formations was developed as stratigraphic gap (Kodsi 1967). Due to the intensive mining this site was destroyed and presently the topographic highest parts of the quarry consist of limestones of the Kanzel Mb.

Stop 7: Hartbauer Section
Type section of the Upper Sanzenkogel Fm. (upper Tournaisian to Serpukhovian); Dult Group (Bashkirian)

The section along the road and the adjoining northwestern escarpment exposes a sequence from the top of the Kanzel Mb. (lowest Frasnian) up to the Bashkirian Dult Group. Between micritic cephalopod limestone of the Steinberg Fm. and bedded micritic limestone of the Upper Sanzenkogel Fm. there is a stratigraphic gap caused by desiccation and karstification within the time interval of Famennian *Palmatolepis marginifera* zone and upper Tournaisian *Scaliognathus anchoralis* zone. Related to this gap conodont mixed faunas and fissure fillings in the Devonian limestones occur. An erosion surface at top of the Sanzenkogel Fm. (uppermost Serpukhovian) forms the boundary to the Dult Group (Bashkirian) which base is formed by the Hartbauer Mb. of the Höchkogel Fm. (Bashkirian). Another erosion surface indicated by hematite filling is situated above the Hartbauer Mb. just at the contact to the slates of the Hahngraben Fm. (Ebner 1978, 1980a, Ebner et al. 1980b, 2000, Neubauer et al. 1992, Bosic 1998, 1999, Flügel & Hubmann 2000).
All formations are fully concordant to each others. Originally the superposition of the limestones by the slates of the Hahngraben Fm. (originally named “Schiefer der Dult“) was interpreted as the Variscan unconfomity (Clar 1933), because the limestones of the Sanzenkogel Fm. were not identified as Carboniferous and the black limestone of the Lower Bashkirian Höchkogel Mb. at the base of the Dult-Group were assigned as Middle Devonian limestone.

Kanzel Member: Massive and thick bedded light grey biomicritic limestone locally enriched are crinoidal fragments. Scarce findings of conodonts indicate that the facies change of the shallow water Kanzel Mb. to the pelagic Steinberg Fm. occurred within the Lower Frasnian.

Steinberg Formation: 20 m thick variegated (grey to intensively brownish-yellow), partly flasered micritic and biomicritic (cephalopodes, trilobites, indet. filaments) limestones. In this section the top of Steinberg Fm. is within the Famennian *Palmatolepis marginifera* zone due to the erosion before the transgession of the Upper Sanzenkogel Fm.

Fissure fillings with condont mixed faunas: Pockets with Upper Famennian and latest Tournaisian conodont mixed faunas are irregularly distributed within the uppermost Kanzel Mb. and in the basal parts of the Steinberg Fm. along and just above the road. These karst fillings are hardly to recognize in the field. They are composed either of a reddish-brown, ironoxide rich microsparitic carbonates rich in organic remains (crinoidal fragments, ?foraminifera, e.g., *Umbellina*) or carbonates with sparry yellowish-brown matrix. Additionally some micritic pockets occur which can not distinguished visually from the Upper Devonian host rock. Their conodonts (pure Tournaisian faunas or Famennian-Tournaisian mixed faunas) however identify these pockets as Carboniferous fissure fillings within the Steinberg Fm. A mapping and

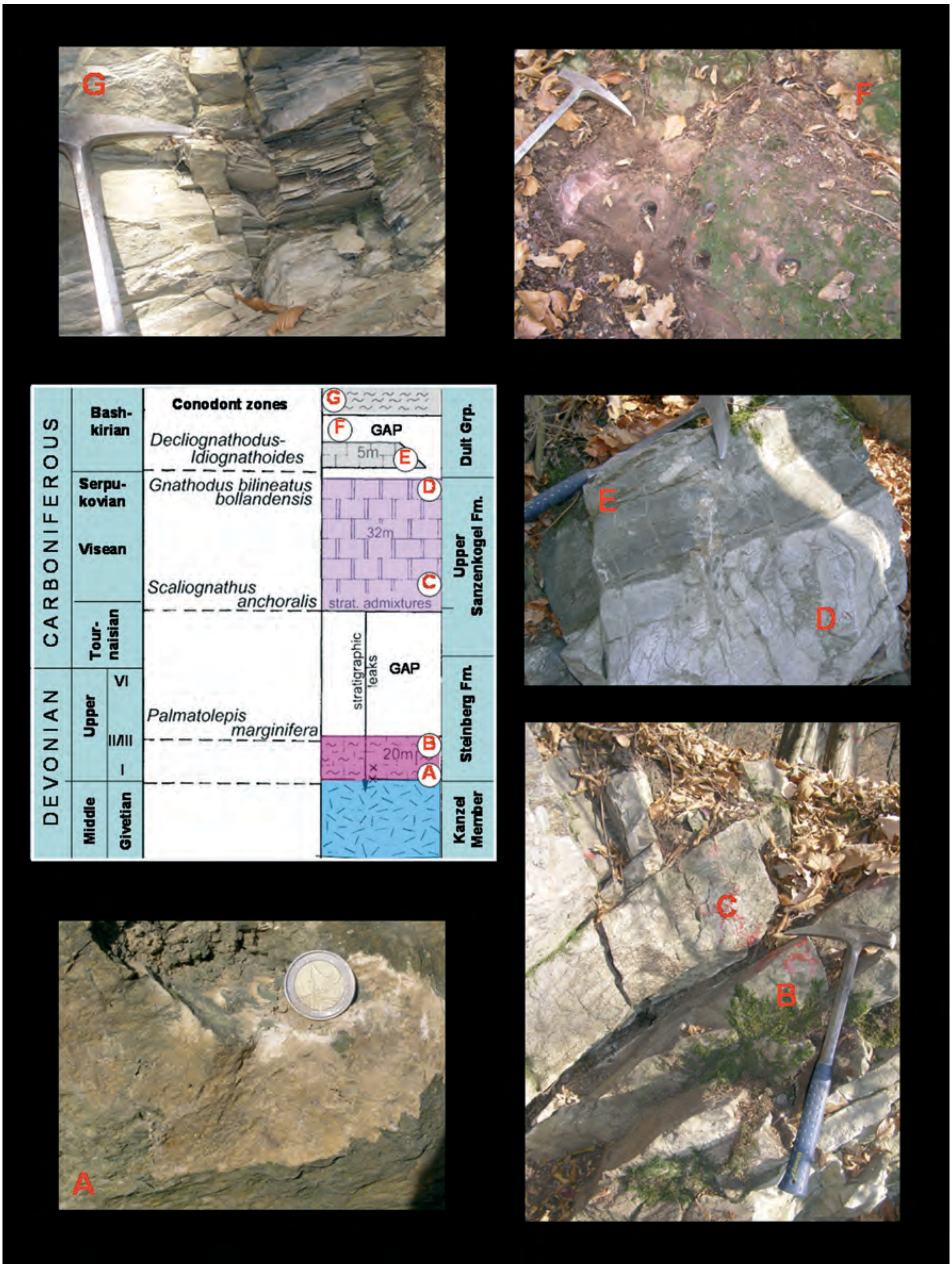


Fig. 30: Stratigraphic scheme of the Hartbauer section (Upper Devonian Steinberg Fm., Carboniferous Upper Sanzenkogel Fm., Dult Group) with the position of intraformational erosion levels, the position of karst fillings and conodont mixed faunas (Ebner et al. 2000).
A: Yellowish-brownish fissure filling with condont mixed faunas from lower parts of the Steinberg Fm.
B: Top of the Steinberg Fm. (Upper Devonian *Palmatolepis marginifera* zone) superposed by C the base of the Upper Sanzenkogel Fm. (uppermost Tournaisian). Between B and C there is a 2 cm thick carbonate microbreccia with conodont mixed faunas. From this niveau the karst fissures reach down to the level signed with A.
D: Top of the Upper Sanzenkogel Fm. (Serpukhovian) is cut by an ersosion level. E: Bottom of the Dult Group (Bashkirian dark limestone of Hartbauer Mb.).
F: Hematite crust and pockets indicate another erosion event between the top of limestones of the Hartbauer Mb. at the slates of the Hahngraben Fm. (G).

delineation of the karst fillings is hampered by bad outcrop conditions and the negligible lithological differences between Steinberg Fm. and Sanzenkogel Fm.

Upper Sanzenkogel Formation: At the bottom of this formation a 2 cm thick limestone miccrobreccia ("transgession sediment") is developed in which micritic components, crinoids and ?*Umbellina* are embedded in an ironoxide rich matrix containing corroded quartz grains. The microbreccia yields Famennian to Tounaisian conodont mixed faunas which identifys this level as the erosion surface. From this erosional level fissure fillings are reaching down to the Kanzel Mb. 20 m below.
The Upper Sanzenkogel Fm. is made up of 32 m thick well bedded limestones (partly flasered, spotty, micritic limestones with echinoderms, trilobites, cephalopods, radiolarians and indet. filaments) which are dated by conodonts of the latest Tournaisian (*Scaliognathus anchoralis* zone) to Serpukhovian (*Gnathodus bilineatus bollandensis* zone). The 250 cm thick Hart Lydite Bed (thin bedded lydite with four distinct limestone beds; late *Gnathodus pseudosemiglaber* to early *Gnathodus praebilineatus zone*) appears approximately 180 cm above the Devonian-Carboniferous boundary.
The following conodont zones were proved within the Upper Sanzenkogel Fm. from the late Tournaisian up to Serpukhovian:
Scaliognathus anchoralis zone: 97 cm
Gnathodus pseudosemiglaber zone: 176 cm
Gnathodus praebilineatus zone: 646 cm
Lochrieda commutata zone: 1511 cm
Gnathodus bilineatus bollandensis zone: 293 cm

Dult Group: In this section the Dult Group is composed of the Hartbauer Mb. (5 m thick dark grey to black micritic limestones and coarse sparry dolomites) superposed by black slates of the Hahngraben Fm. The boundary to the underlaying Upper Sanzenkogel Fm. is formed by an erosion surface above which the black limestone contains some reworked clasts of the Upper Sanzenkogel Fm. In some parts fine laminated limestones and lines of hematite or chert occur. Scarce conodonts of the *Idiognathoides sulcata* group indicate a Lower Bashkirian age.
Pockets and crusts with hematite (F_2O_3 contents up to 21,39%) as the result of intraformational karstification occur in light grey coarse sparry calcareous dolomitic limestone at top of the Hartbauer Mb. just below the overlaying slates of the Hahngraben Fm. The age of the fossil free Hahngraben Fm. is supposably Upper Bashkirian or even younger. The thickness may reach 50 m in this section.

Outcrops to see:
1. Section along the road from top to bottom:
approximately 2 m below the lydites of the Hart Lydite Bed (thin bedded lydite, some few cm thick limestone beds) the bedded limestones of the Upper Sanzenkogel Fm. are crosscut by a fault at the border to yellowish-brown limestone of the Steinberg Fm. The latter is underlain in the footwall by thick bedded grey limestone of the Kanzl Mb. Around this boundary level yellowish-brown karst fillings and pockets containing a Devonian-Carboniferous conodont mixed fauna are developed.
2. Climbing up the hill the hiatus between the Steinberg Fm. and Upper Sanzenkogel Fm. with formation of conodont mixed faunas can be studied.
3. At top of the section lithologies of the Dult Group (limestone of the Hartbauer Mb., slates of Hahngraben Fm.) and the intraformational erosion surfaces can be observed.

Stop 8: Kalvarienberg (Mt. Calvary)
Pre-Devonian greenschists

Green spotty basic metavolcanics occur at this isolated outcrop inside the Pleistocene terraces of the Graz Basin. The thin bedded chloritic greenschists (tuffs and tuffite) are intensively folded in mico scale and interlayered by thin layers and nodules of quartz (Fig. 31). Due to their isolated position the stratigraphic age and tectonic position of these greenschists is not clear. They belong either to the pre-Devonian Taschen Fm. of the Lower Nappe Group or to the volcanic successions of the Silurian Kehr Fm. of the

Fig. 31: Pre-Devonian fine laminated greenschists at Mt. Calvary showing polyphase deformation and formation of quartz veins followed by isoclinals folding and backfolding.

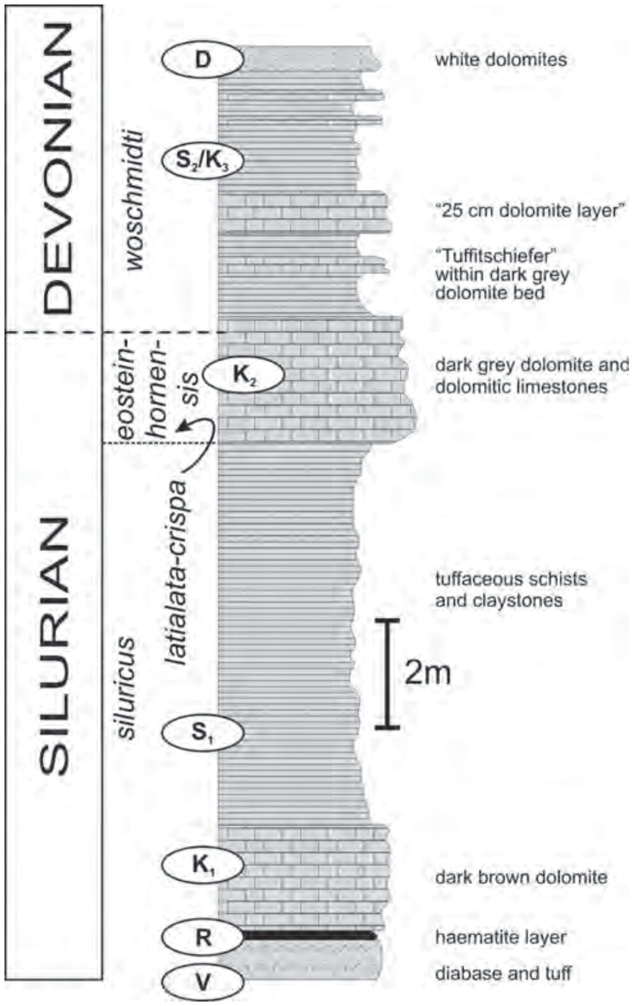


Fig. 32: Stratigraphy of the Eggenfeld Section. The hematite layer (R) separates rocks of the Kehr Fm. (below) from the Kötschberg Fm. (above). V - diabase and tuffs, K - carbonates, S - tuffaceous schists, D - dolomite.

Upper Nappe Group. Along the ways up to the top of the cliff various lithologies of the Rannach Fazies (e.g., sandstone of the Göstinggraben Mb. of the Flösserkogel Fm., fossiliferous limestone of the Plabutsch Fm., yellowish-brown and violet flaserlimestone of the Steinberg Fm.) were used as construction materials.
The church was built in 1629 by Johann Stengg around the altar carved into the greenschists. The calvary is the most important and largest scenic portrayal of the Passion of Christ in the open air. Some of the sculptures date back to the second half of the 17th century (Gti).

Stop 9: Eggenfeld section (Eggenfeld Mb.)
Ludfordian to Lochkovium

The Eggenfeld section belongs to the Eggenfeld Mb. (Flügel 2000) of the Kötschberg Fm. (Ludfordian to Lochkovian). The Silurian succession of the section (Fig. 5, 32) at Eggenberg (hill north of the village of Eggenfeld) consists of greenish, massive diabase (V) at the base, which is followed by approximately 2 m thick violet and greenish-grey unlayered tuffs, as well as thin bedded ash tuffs (Ebner 1976a). Some concretionary horizons with haematite occur. A moderately well preserved specimen of *Bohemograptus bohemicus tenuis* was recorded (Hiden 1995) from one of the ash tuff horizons. Above the volcaniclastic horizon which marks the boundary between the volcanic Kehr Fm. and the overlying Kötschberg Fm. (Eggenfeld Mb.) a layer of haematite (R) is developed at the contact between the diabase and dolomite. This haematite level passes into a 1 m thick succession of bedded dark grey dolostones which is overlain by fossil free tuffaceous schists and claystones (S1). Carbonate rocks K1, K2 and K3 of the section are dark grey, bedded dolomites and/or dolomitic limestones that are locally rich in fossils. They can be differentiated on the basis of their microfacies into: bioclastic dolosparites to biodolosparites, biodolosparites and biomicrites (microsparites). The bioclastic content (mainly crinoids, orthocerids, brachiopods, rare solitary rugose corals; Fig. 32) is fluctuating, however, generally amounts are up to 15%. The fossil content of the biodolosparites likewise reaches 15% but comprises exclusively crinoidal remains. Biomicrites contain up to 20% shell fragments, brachiopods, crinoids, trilobites and subordinate orthoconic nautiloids. The brachiopods are mostly preserved with both valves. The occurrence of macrofossils varies throughout the carbonate horizons (Ebner 1976a): K1 - crinoids, orthocerids (*Kionoceras* cf. *bronni*, *Cyrtocycloceras* cf. *urbanum*, *Oonoceras*? sp.), small sized undeterminable brachiopods, *Cardiolinka* sp., gastropods, *Favosites* sp. K2 - crinoids, orthocerids, *Septatrypa subsecreta*, *Syringaxon* frame. K3 - crinoids, orthocerids, *Septatrypa subsecreta*, frequent loboliths of *Scyphocrinites* (Ø about 10 cm) occur. Brachiopods appear as pavements (Plodowski 1976, Hubmann & Suttner 2007). Preservation of conodonts is excellent within the dolomites (see Ebner 1976a) and these indicate a range from the *P. siluricus* conodont zone (upper Ludlow) to the *I. woschmidti* conodont zone (Lochkovian).
Recent results of a preliminary systematic study of the nautiloid cephalopod fauna (Histon et al. 2010) indicate the presence of representatives of the families Oonoceratidae and Lechritrochoceratidae and subfamilies Michelinoceratinae, Kionoceratinae and Leurocycloceratinae with at least 7 genera: *Michelinoceras*, *Merocycloceras*, *Plagiostomoceras*, *Parakionoceras*, *Orthocycloceras*, *Oonoceras* and *Lechritrochoceras*.

Stop 10: "Weisse Wand"
Biostrome of the Kanzel Mb., Givetian

Overlying the Plabutsch Fm. a sequence with dolomites and micritic limestones is developed in which locally biostromes (Rannach area) and patch-reefs (St. Pankrazen area) may occur. In the Rannach Facies this sequence is called Kollerkogel Fm. whereas time-equivalent strata in the Hochlantsch Facies are comprised under Tyrnaueralm Fm. and Hochlantsch Fm. (Flügel 2000).
The basal parts of the Kollerkogel Fm. consist of biolaminated dolostones (Gaisbersattel Mb.). Overlying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2b
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Fig. 33: Typical fossils of the Kötschberg Formation (Eggenfeld Mb.) from the Eggenfeld section.
(1) *Kionoceras* cf. *bronni* (Barrande, 1886), x 1.5
(2) Orthocerida indet. x 0.75
(3) *Cyrtocycloceras* cf. *urbanum* (Barrande, 1866), x 1.5
(4) *Oonoceras*? sp. x 1.5
(5) *Naticopsis* sp. x 1.5
(6) *Loxonema* sp. x 1.5
(7) Platyceras sp. x 1.5
(8) *Syringaxon* sp. x 1.5
(9) *Cardiolinka* sp. x 1.5
(10) ? Fisch remain, x 1.5
(11) Echinoderm debris, x 1.5
(12) Scyphocrinites lobolith x 0,75
(13) *Bohemograptus bohemicus tenuis* (Boucek, 1936) x 1.5
(14) Brachiopod pavement with *Septatrypa subsecreta* Plodowski, 1976, x 1.5
1-12, 14: specimens from the private collection of Fritz Messner; 13: collection of the Universalmuseum Joanneum.

limestones (Kanzel Mb., "Kanzel Limestone") of the *varcus* zone locally start with *Amphipora* or *Stachyodes* meadows (Hubmann & Weber 2010).
During the Givetian renewed transgression resulted in sequences with sharp (bio)facial contrasts between patch-reefs and monotonous mudstones (Kollerkogel Fm.). The mentioned Givetian transgression is obviously indicated by litho-facial changes from rauhwacke (cellular dolomite) to micritic limestones. Due to the lack of age-diagnostic fossils - the coral fauna points only to a Givetian age, and rare conodont findings refer only to *varcus* zone but do not permit further age restriction.

Especially the "Weisse Wand" section at a steep slope of the Rannach Hill some 20 km north of Graz exhibits spatiotemporal ecological successions with certain community replacements (Hubmann & Holzer 2011) (Fig. 34). The latter comprise a basally developed 'reef pioneer settlement' dominated by densely packed stachyodes and auloporids in a black bituminous limestone matrix (*Stachyodes-Aulopora*-community). This well-bedded sequence passes into dark-grey fossil-rich limestones built up by thickets of small branching stromatoporoids (*Amphipora-Stachyodes*-community). This succession is followed by grey bioclastic limestones (*Thamnopora-Amphipora-Actinostroma*-community). A thin horizon (approximately 30-50 cm) with small colonies of the phaceloid *Thamnophyllum* and subordinate solitary *Mesophyllum* (*Thamnophyllum-Mesophyllum*-community) terminates the 'pioneer sequence', which is overlain by approx. 35 m thick, white and slightly dolomitized massive limestones. The latter contain accumulations of various reef-building organisms (stromatoporoids, rugose and tabulate corals) (Fig. 35).

Stop 11: Stübing

Pfaffenkogel Mb. of Flösserkogel Fm. (?Pragium to Lower Emsium)

At the southeastern slope of the Pfaffenkogel between Gratwein and Klein-Stübing, an approx. 220 m long section through early diagenetic and late diagenetic dolomites of the Flösserkogel Fm. is exposed (Fenninger & Holzer 1978, Ebner et al. 1980b, Ebner et al. 2000, Hubmann & Messner 2005).
The profile (Fig. 36) starts approximately 15 m above the railroad with a sequence of laminated to bedded dolomites with stromatolitic layers (= unit I). Subsequently coarsely bedded to massive dolomites follow (= unit II). The change from unit I to unit II is morphologically traceable in stair-like gradations whereby unit I prones to enlarge plains, unit II to develop walls.

a) Biodetritic dolostones

Typical are grainstones with corroded surfaces. Bioclasts can particularly be allocated to echinoderms and lumps of stromatolithic structures, udoteaceans, dasycladaleans (?), tabulate corals, gastropods and brachiopods. In some layers particles show misaligned internal geopetal structures and coatings in "normal" growth direction thus suggesting a frequent shifting before lithifying processes were completed. Meteoric vadose meniscus and microstalactitic calcite cements are common; fenestral voids contain crystal silt. Occasionally biodetritic dolostones show cross-bedding.

b) Peloidal mudstones with fenestral fabrics

Laminoid-fenestral fabrics are arranged as LF-A-fabrics (elongate horizontal, distinct laminoid fenestrae within fine-grained and grain-supported sediment) and LF-B-fabrics (irregular laminoid fabrics) with subtypes LF-B-I (low-detrital fabrics with voids within micritic matrix) and LF-B-II (high-detrital fabrics with voids in a grain-supported matrix). In some layers reworked pisoids occur (Fenninger & Holzer 1978).

c) Stromatolites and layers with stromatolitic autoclasts

Stromatolites occur as 1 to 3 cm thick horizons which often taper out laterally. Internally stromatolitic layer show either no internal structures or are arrangend by irregular thick dark/light laminae. Between stromatolite horizons layers of stromatolitic autoclasts may occur. These autoclasts are in dimensions of mm to cm and often in a rotated position.

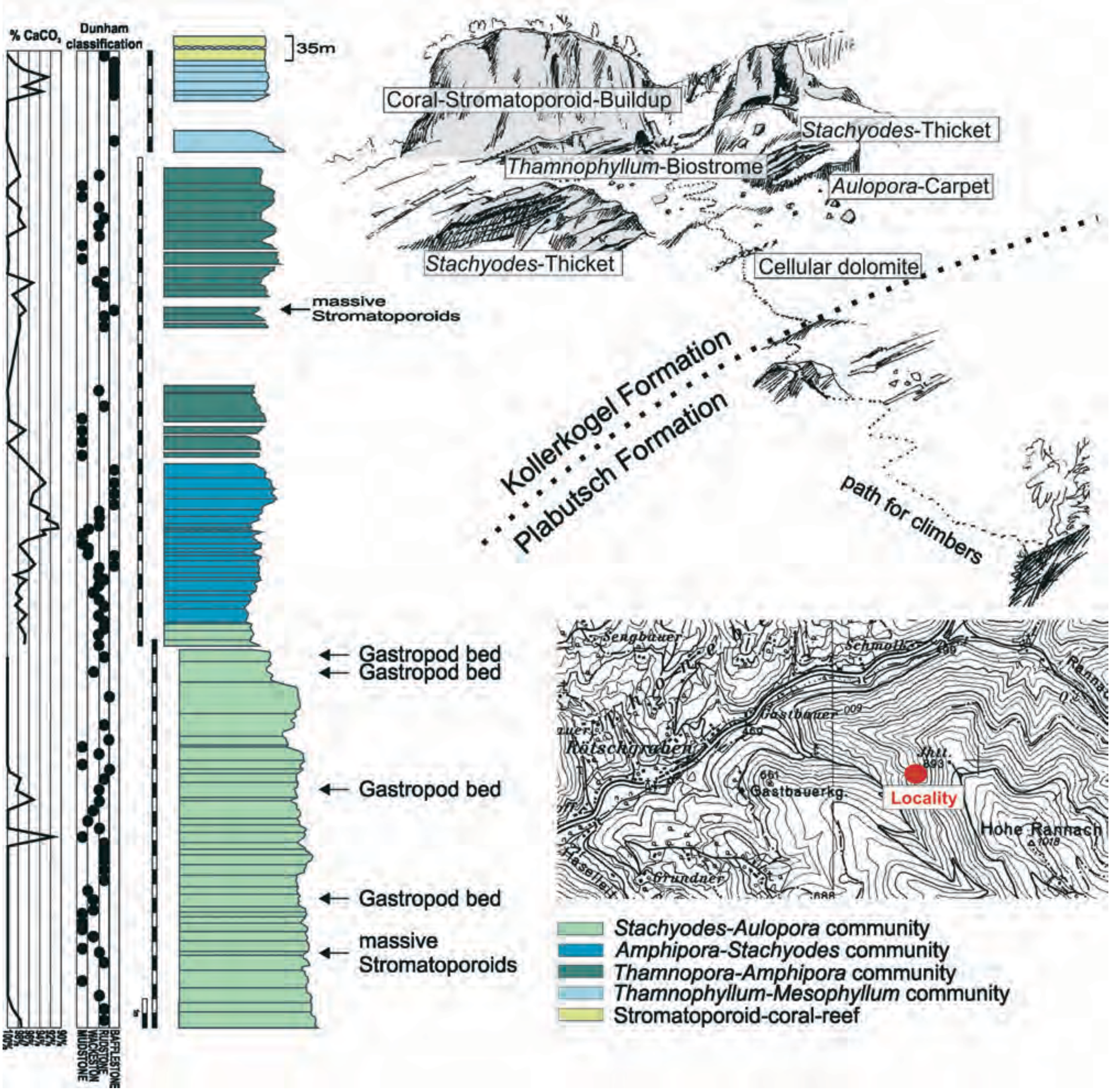

Fig. 34: Section of the "Weisse Wand" 20 km north of Graz exhibiting fossiliferous bedded limestones passing into a massive stromatoporoid-coral reef at its top (modified after HUBMANN & HOLZER 2011).

d) Layers containing "vadose pisoides"

These mostly very thin layer show inverse graded components and microstalactitic calcite cement. Pisoids lack grain to grain contacts in thin sections and frequently form aggregates.

e) Dolomitic sandstones

The section exhibits some rare thin horizons of dolomitic sandstones which are characterized by badly sorted and poorly rounded quartz grains. All the microfacies features, e.g. laminoid-fenestral fabrics co-occurring with stromatolitic layers, pisoids, infilling of crystal silt, etc. argue for a depositional environment within the intertidal zone.

Stop 12: Old road N of Peggau

Limestone of the Schöckel Fm. (?Givetium) Lower Nappe Group

Along the Mur valley the tectonic contact of the Upper Nappe Group (with successions of the Rannach Facies) to the Lower Nappe Group is impressively visible S of Peggau. In contrast to formations of the Upper Nappe System rocks of lower tectonic system feature a greenschist metamorphic overprint and penetrative foliation with pronounced stretching lineation (GASSER et al. 2010). Significant formations are the pre-Devonian volcanogenic Taschen Fm. (greenschists), the Lower Devonian calcareous-sapropelitic Schönberg Fm. (? Lochkovium - Eifelium) with numerous stratiform Sedex (Meggen-type) Pb/Zn-baryte deposits/

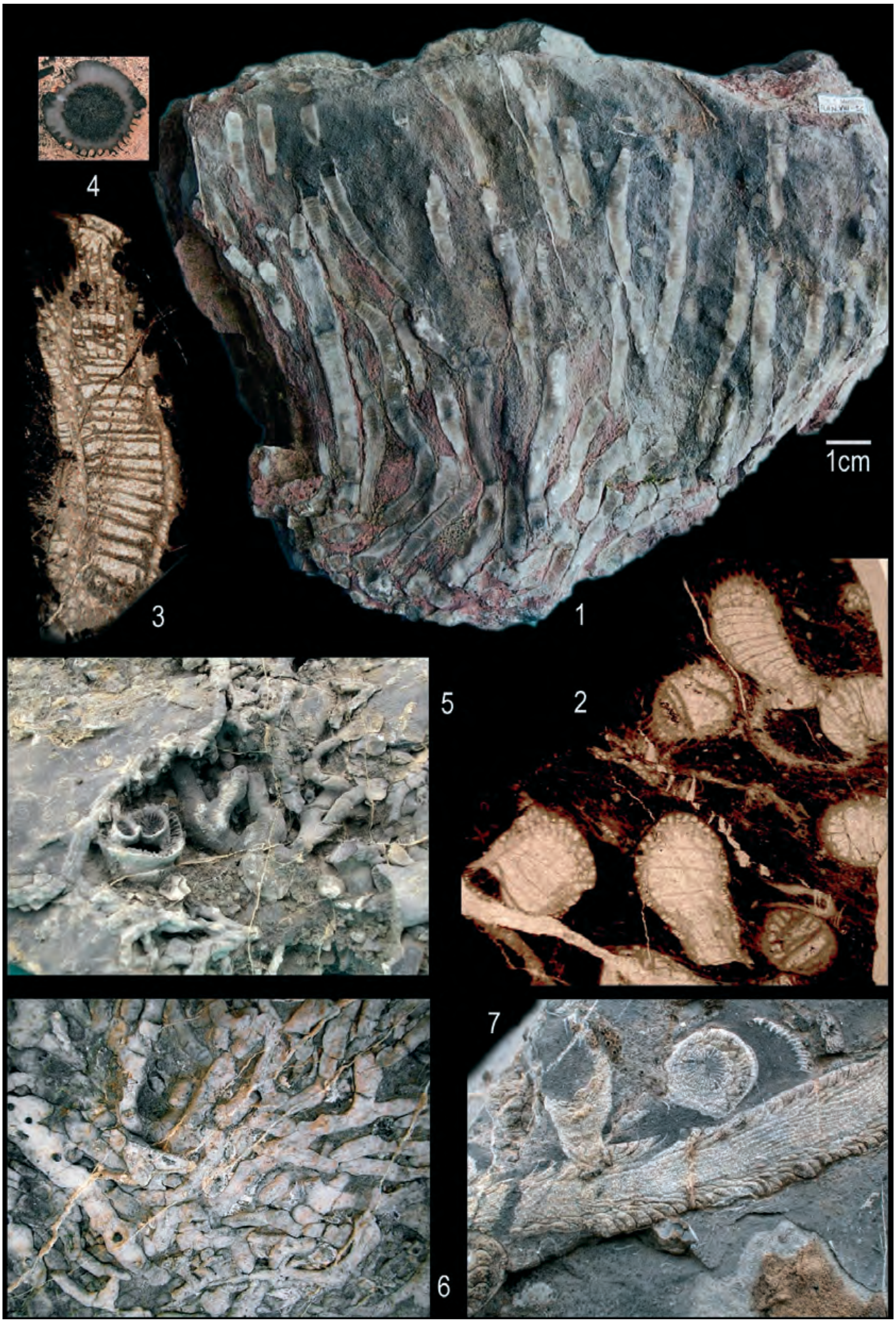

Fig. 35: Typical fossils of the Kanzel Member (Kollerkogel Formation)
(1) *Thamnophyllum caespitosa minus ?* (ROEMER, 1855), part of a colony
(2) *Thamnophyllum caespitosa minus ?* (ROEMER, 1855), thin section 1:2.5
(3) *Thamnophyllum caespitosa minus ?* (ROEMER, 1855), thin section 1:2.5
(4) *Thamnophyllum caespitosa minus ?* (ROEMER, 1855), cross section, polished section, 1:2.5
(5) „*Amplexus*", width of photo 11 cm
(6) Bedding plane with *Stachyodes*, width of photograph 15 cm
(7) *Stringophyllum* sp. width of photo 10 cm
All specimens are from the private collection of Fritz MESSNER.

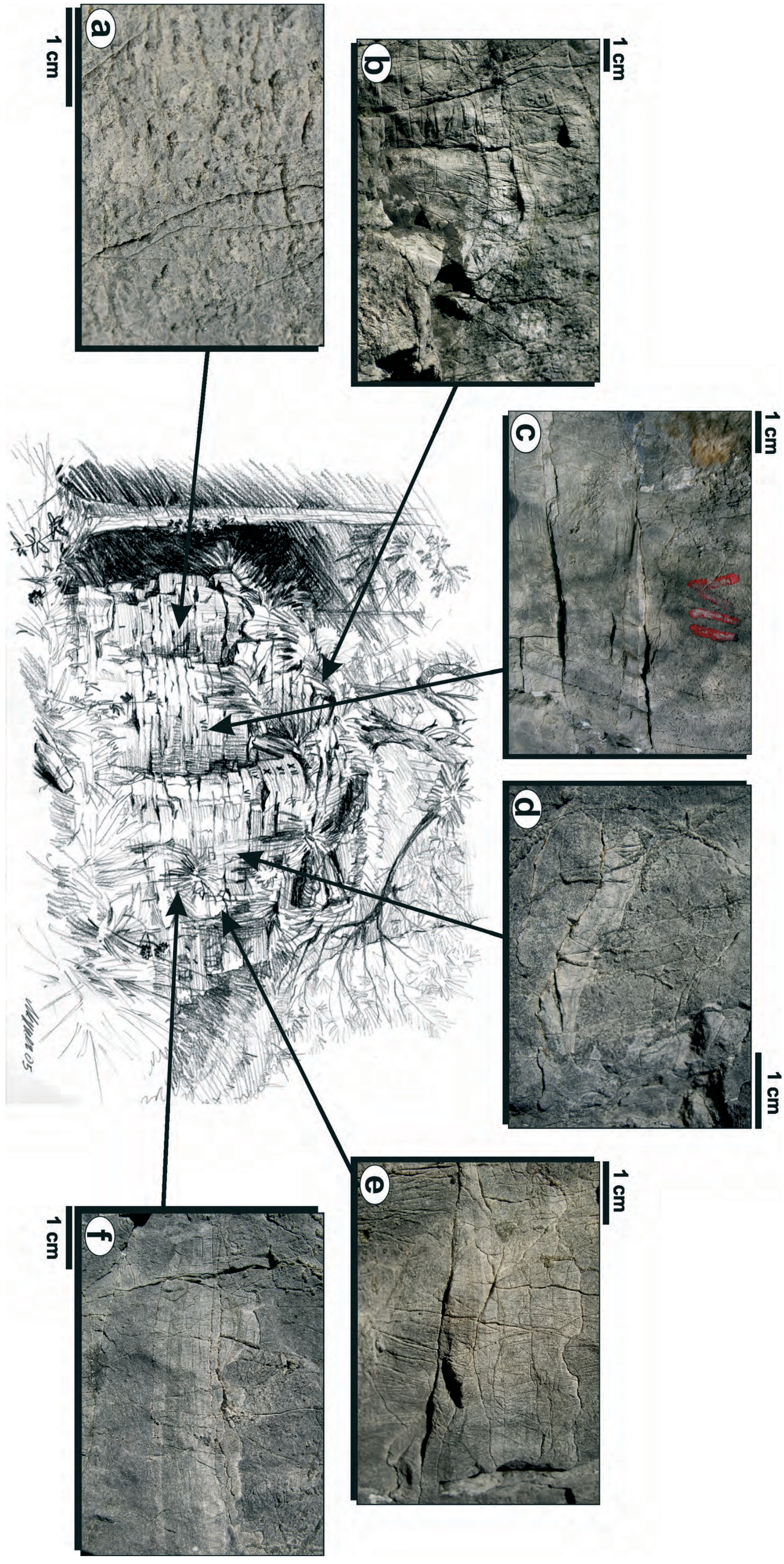

Fig. 36: Sketch of the section at Pfaffenkogel illustrating the main features:
(a) laminoid fenestral fabrics,
(b) tepee structure,
(c) low angle erosional surface of a stromatolithic layer,
(d) stromatolithic autoclast in rotated position,
(e) undulating surface of a stromatolite layer,
(f) erosional surface of a stromatolite layer.

occurrences and the 200 m thick banded limestones of the Schöckel Fm. (?Givetium; Flügel 2000, Ebner et al. 2000). This limestone is mined in two quarries in close vicinity of Peggau and used as raw material for cement production. The rock face east of Peggau exhibits lots of caves, which were inhabited during Neolithic ages. The famous "Lurgrotte" system situated at the bottom of the karst stock is an actively water bearing horizontal cave system with a length of about 4.5 km. The famous spaeleothems can be visited by guided tours. Banded limestones of the Schöckel Fm. (Fig. 37) crop out along the old road N of Peggau.

Stop 13: Rothleiten
Calcareous schists (Lower and Middle Devonian), Lower Nappe Group; Upper Cretacous ("Gosau") conglomerate

Along the NW margin of the Graz Palaeozoic the Upper Nappe Group with sequences of the Rannach and Hochlantsch Facies is tectonically resting on nappes of the Lower Nappe Group (Gasser et al. 2010). The Lower Nappe Group includes the Peggau Group (Schöckel Facies) and especially SE of the border to the Upper Austroalpine Crystalline Units some other thrust sheets, each of them characterized by individual Palaeozoic facies. The Laufnitzdorf Facies includes pelagic Silurian to Upper Devonian volcaniclastics and pelagic limestones, ?Carboniferous clastics and the Breitenau sparry magnesite deposit. The socalled "Kalkschiefergruppe" (= "Calcareous Schists Facies") is poor in fossils and forms a very monotonous basinal sequence of grey calcareous schists with intercalations of siltstones of Lower to Middle Devonian ages. Structurally the "Kalkschiefergruppe" occurs in two tectonic and facial positions: 1. within the Lower Nappe Group a nappe in the Rothleiten area and 2. in the NW part of the Upper Nappe Group the "Kalkschiefer" are interfingering with sequences of the Rannach Facies (Ebner 1998, Ebner et al 2000, Gasser et al. 2010). At Rothleiten a small outcrop gives insight in the lithology of the monotonous "Kalkschiefergruppe".

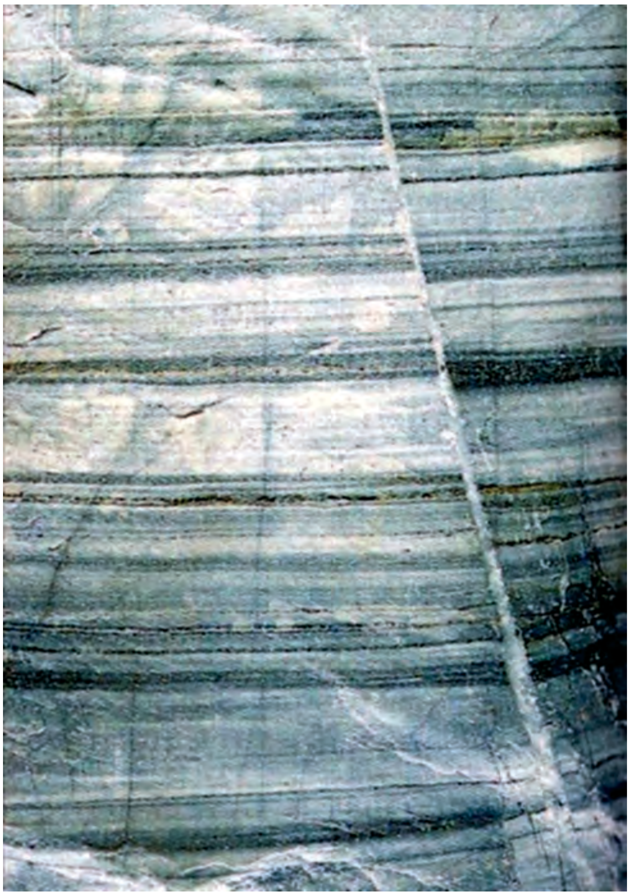

Fig. 37: Banded "Schöckel Limestone".

Some 100 m northwards an outcrop alongside the eastern slope of Rothleiten hill exhibits Upper Cretaceous carbonate conglomerates which are incorporated as a tectonic sheet in the sinistral shear corridor along the boundary zone of the Graz Palaeozoic to the Upper Austroalpine Crystalline Units. The conglomerates can be correlated with the Gaistthal Fm. occurring some 10 km westwards in the Upper Cretaceous "Kainach Gosau". There the conglomeratic Geisthal Fm. forms the basal unit of the Upper Cretaceous Kainach Group ("Kainacher Gosau") which seals the Alpine nappe structure of the Graz Palaeozoic. The basal conglomerates are characterized by "exotic" pebbles (Neubauer et al. 1995, Ebner & Rantitsch 2000).

Stop 14: Route between village Röthelstein and Mixnitz
Sight from the car/bus to Mt. Röthelstein

The Hochlantsch Facies is a further facies of the Upper Nappe Group and features similarities with the Rannach Facies concerning the composition of formations and faunal content (Ebner et al. 2001). As visible in the steep rocky faces of Mt. Röthelstein (E of the Mur valley) the Givetian to Frasnian is made up by 800 m thick massive limestones (Hochlantsch Fm.). At the top of the mountain the limestones of the Hochlantsch Fm. which are interpreted as depositions of a back reef environment are cut by an erosion surface and followed by up to 100 m thick pelagic limestones (Bärenschütz Fm.) of upper Tournaisian to lower Bashkirian age. At the bottom this formation includes limestones and dolomite breccias (Nadelspitz Bed) with conodont mixed faunas (containing lower Famennian and uppermost Tournaisian components). The overlaying Bärenschütz Fm. is composed of variegated bedded cephalopod limestones with the intercalations of nodular reddish cherts. The sedimentation continues without any break up to the lower Bashkirian (Zier 1981, 1983, Gollner & Zier 1985, Flügel 2000).

4.3. Geological description of the route Mixnitz - St. Michael

North of Mt. Röthelstein the Upper Nappe Group of the Graz Palaeozoic is thrusted above the Laufnitzdorf Nappe of the Lower Nappe Group which is directly situated along the sinistral shear corridor at the boundary to the Silvretta-Seckau Unit of the Upper Austroalpine Crystalline Complex (Schmid et. al 2004). Various metamorphic rocks, especially plagioclase gneiss and amphibolite of the "Core Complex" (Neubauer & Frisch 1993) can be observed from the bus/car along the highway to Bruck/Mur.

N of Kirchbach serpentinite and banded amphibolite of the ophiolitic Speik Terrane (Neubauer & Frisch 1989) occur resting on metamorphics of the Core Complex. These mafic to ultramafic rocks of Kirchbach area form the continuation of the Kraubath Ultramafic Massif situated 30 km to the WSW. There the serpentinite is quarried for crushed stone and hosts subeconomic chromite and "Kraubath-type" crypotcrystalline magnesite (Thalhammer et al. 2010). The excavation of the highway tunnel N of Kirchberg was problematic regarding safe working conditions because of asbestos serpentinite along the tunnel roadway.

At Bruck/Mur the route following the Mur vally turns its direction to the SW and follows the Mur-Mürz Fault till St. Michael. Some small Miocene basins (e.g. Bruck/Mur, Leoben) with hard brown coal are situated along the Mur valley. The N-dipping basement is formed by the Core Complex of the metamorphic Silvretta-Seckau Unit tectonically underlaying the Greywacke Zone. The thrust between both units is situated in the slopes S of the road. The road also passes Leoben, the home town of the Montanuniversität Leoben the organizing university of the 29th IAS Meeting of Sedimentology.

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WHY DO PLANES FLY SO HIGH?