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Earth Sciences

The Paleozoic of Austria – An Overview

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During Variscan and Alpine orogeneses several Paleozoic remnants were dismembered and are incorporated into the complicated Alpine nappe system. The primary geographic positions and mutual bio(geo)graphic relations of these isolated developments are only poorly understood. A possible arrangement of Paleozoic areas south of the Alpine front, including high grade metamorphosed Paleozoic parts within crystalline complexes, see below.

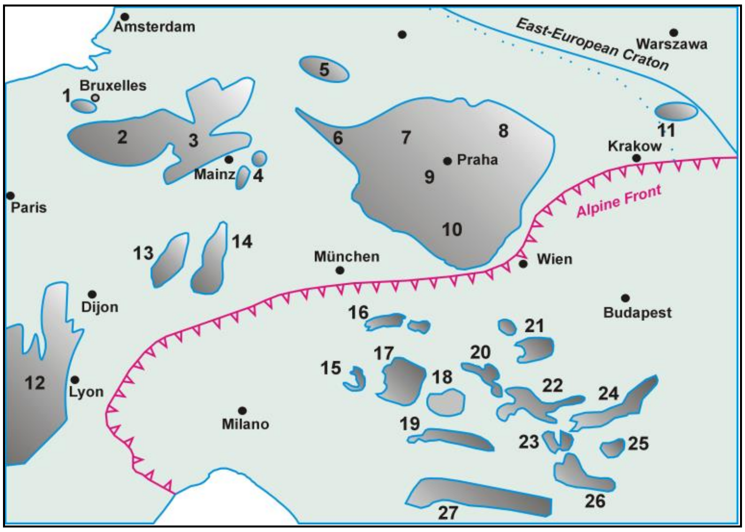


Fig. 1: Variscan regions in Europe. The geographic positions of Paleozoic areas of the Eastern and Southern Alps (15-27) are reconstructed after palinspastic subtraction of alpidic tectonic movements. Redrawn and modified after FAUPL (2000) and RATSCHBACHER & FRISCH (1993). 1 Brabant Massif, 2 Ardennes, 3 Rhenish Slate Mountains, 4 Spessart, Odenwald, 5 Harz, 6 Thüringerwald, Frankenwald, 7 Erzgebirge, 8 Sudetes, 9 Barrandian, 10 Bohemian Massif, 11 Holy Cross Mountains, 12 Massif Central, 13 Vosges, 14 Schwarzwald, 15 Err-Bernina, 16 Hohe Tauern, 17 Silvretta, 18 Ötztal, 19 Cristalline south of the Hohe Tauern, 20 Quartzphyllites of Innbruck, Radstadt, Ennstal, 21 Wechsel, 22 Seckau and Wölzer Alps, 23 Koralpe, Saualpe, 24 Greywacke Zone, 25 Graz Paleozoic, 26 Gurktal Nappe System, 27 Carnic Alps, Karawanken Mountains.

Austria's anchizonal to lower greenshist metamorphosed Paleozoic successions are irregularly distributed (Fig. 2). Two major regions of Paleozoic developments are distinguished which are separated by the most prominent alpine fault system, the Periadriatic Line (PL). Variscan sequences north of the PL form parts of the "Upper Austroalpine Nappe System" whereas sequences south of the PL belong to the Southern Alpine System.

The Carnic Alps and the Karawanken Alps of Carinthia belong to the Southern Alps.

Austroalpine Paleozoic areas are the Greywacke Zone of Tyrol, Salzburg, Styria and Lower Austria, the Nötsch Carboniferous, the Gurktal Nappe System, the Graz Paleozoic and some isolated outcrops in south Styria and Burgenland.

The differences between Austroalpine and Southalpine areas are the result of paleolatitudinal settings, subsidence rates and source areas for clastic sediments.

Fig. 2: Main regions of anchizonal to lower greenshist metamorphosed Paleozoic strata in Austria. The Periadriatic Line (P.L.) separates the Carnic Alps and the Karawanken Mountains (Southern Alps) from other Alpine Paleozoic remnants belonging to the Eastern Alps.

The Paleozoic of the Carnic Alps

Hans Peter SCHÖNLAUB, Kathleen HISTON, Susanne POHLER

The Carnic Alps of Southern Austria and Northern Italy represent one of the very few places in the world in which an almost continuous fossiliferous sequence of Paleozoic age has been preserved (Fig. 2). They extend in a W-E-direction for over 140 km from Sillian in Tyrol to Arnoldstein in central Carinthia. Continuing into the Western Karawanken Alps the Variscan sequence is almost completely covered by rocks of Triassic age. Further in the east, however, Lower Paleozoic rocks are excellently exposed in the Seeberg area of the Eastern Karawanken Alps south of Klagenfurt, the capital of Carinthia. Differing from the Carnic Alps, in this region the Lower Paleozoic strata are distributed on either side of the Peri-adriatic Fault (Gailtal Fault) which separates the Southern and the Central or Northern Alps. These rocks have been subdivided into a northern and a southern domain, respectively. The latter extends beyond the state border to northern Slovenia.

In both the Carnic and Karawanken Alps systematic research started soon after the foundation of the Geological Survey of Austria in the middle of the last century. The equivalents of the Lower Paleozoic were first found in the Karawanken Alps and not in the more fossiliferous Carnic Alps (SUESS, 1868; TIETZE, 1870). In this latter area main emphasis was drawn on marine Upper Carboniferous and Permian rocks. At the end of the 19th century this initial phase was followed by the second mapping campaign carried out by the Geologi-cal Survey of Austria and detailed studies by FRECH. During the first half of the 20th century HERITSCH and his research group from Graz University revised the stratigraphy on the Austrian side while GORTANI from Bologna University and others worked on the Italian part of the mountain range. One of the outstanding contributions of that time focusing on the Lower Paleozoic was provided by VON GAERTNER (1931). The detailed knowledge of Upper Carboniferous and Permian rocks resulted mainly from studies by KAHLER beginning in the early 1930s. Since that time many students of geology started to visit both regions. During this third campaign study of various microfossil groups began and other techniques were also applied. This research culminated in the publication of detailed maps, a new stratigraphic framework, and revisions of old and discoveries of new faunas and floras (see e. g., SCHÖNLAUB, 1971, 1980, 1985, 1997; SCHÖNLAUB & KREUTZER, 1994).

Review of Stratigraphy

Ordovician

In the Austrian part of the Southern Alps the Ordovician succession comprises weakly metamorphosed fine and coarse clastic rocks named the Val Visdende Group. This more than 1000 m thick sequence is well exposed in the westernmost part of the Carnic Alps on both sides of the Austrian-Italian border on the topographic sheets Obertilliach and Sillian. The lithology ranges from shales and slates to laminated siltstones, sandstones, arkoses, quartzites and greywackes. They are overlain by more than 300 m thick acidic volcanites and volcanoclastic rocks named the "Comelico Porphyroid" and "Fleons Formation" respectively, and their lateral equivalents comprising the Himmelberg Sandstone and the Uggwa Shale. Locally, the latter contain rich fossils such as bryozoans, trilobites, hyoliths, gastropods and cystoids indicating a Caradocian age (HAVLICEK et al., 1987; SCHÖNLAUB, 2000). According to DALLMEYER & NEUBAUER (1994) detrital muscovites from the sandstones are characterized by apparent ages ($^{40}Ar/^{39}Ar$) of circa 600 to 620 Ma and may thus be derived from a source area affected by late Precambrian (Cadomian) metamorphism.

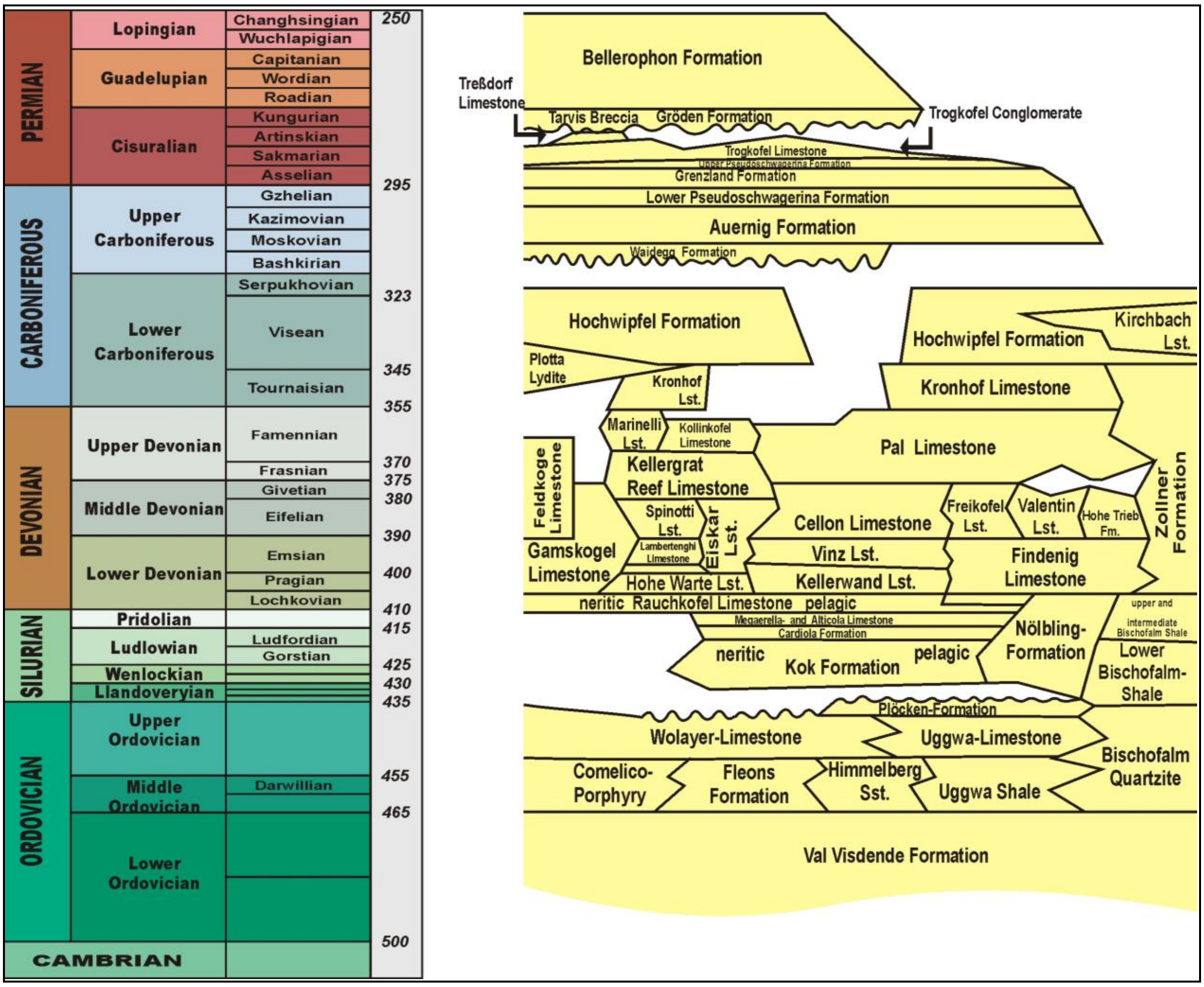


Fig. 3: Biostratigraphic scheme of the Paleozoic sequence of the Carnic Alps.
After SCHÖNLAUB, 1985, modified.

This basal clastic sequence is capped by an up to 20 m thick fossiliferous limestone horizon of early Ashgillian age. It displays two lithologies, namely the massive "Wolayer Limestone" composed of parautochthonous bioclasts (cystoids and bryozoans) which laterally grades into the bedded wackestones of the "Uggwa Limestone" representing a more basinal setting with reduced thicknesses.

In the Carnic Alps the global glacially induced regression during the Late Ashgillian Hirnantian Stage is documented by marly intercalations and arenaceous bioclastic limestones of the Plöcken Formation which presumably corresponds to the graptolite Zone of *Gl. Persculptus* (SCHÖNLAUB, 1996). If so it may have lasted during the early and middle Hirnantian Stage for not more than 0.5 to 1 million years. It resulted in channeling, erosion and local non-deposition. In fact, the succeeding basal Silurian strata generally disconformably rest upon the late Ordovician sequence.

Initiation of the fore-mentioned rifting and subsequent movements from higher to lower latitudes may be marked by basic volcanism occurring at various places in the Eastern Alps in pre-Llandeillian strata (for references see SCHÖNLAUB [1992]). In the Southern Alps such rocks have not yet been recognized. The Upper Ordovician faunal affinities, e.g. brachiopods, nautiloids, cystoids, ostracods, conodonts and vertebrate remains indicate links with Bohemia, Thuringia, Baltoscandia, Sardinia and the British Isles (SCHÖNLAUB, 1992; FERRETTI & BARNES, 1998; FERRETTI, 1997; BAGNOLI et al., 1998; BOGOLEPOVA & SCHÖNLAUB, 1998). Moreover, the appearance of carbonate rocks in the Upper Ordovician suggests a position within the broader carbonate belt for this time. However, also a temporary cold-water influx from northern Gondwana may have existed as can be concluded by certain elements of the Hirnantia fauna. Based on the available evidence from the Ordovician of the Southern Alps SCHÖNLAUB (1992) inferred a paleolatitudinal position at roughly 50°S.

Silurian

The Silurian of the Carnic Alps is subdivided into four lithological facies representing different depths of deposition and hydraulic conditions suggestive of a steadily subsiding basin and an overall transgressional regime from the Llandovery to Ludlow (Fig. 4). Uniform limestone sedimentation during the Pridoli suggests that more stable conditions were developed at this time (SCHÖNLAUB, 1997). Silurian deposits range from shallow water bioclastic limestones to nautiloid-bearing limestones, interbedded shales and limestones to black graptolite-bearing shales and cherts with overall thicknesses not exceeding 60 m. The available data for the Carnic and Karawanken Alps suggest a complete but considerably condensed succession in the carbonate-dominated facies and a continuous record in the graptolite-bearing sequences.

In the Carnic Alps the Silurian transgression started at the very base of the Llandovery, i.e. in the graptolite zone of *Akidograptus acuminatus*. Due to the disconformity separating the Ordovician and the Silurian at many places a varying pile of sediments is locally missing, which corresponds to several conodont zones of Llandoverian to Ludlovian age. Even uppermost Pridolian strata may disconformably rest upon Upper Ordovician limestones.

The Rauchkofel Boden section is one of the best known and most fossiliferous Upper Silurian sections of the Carnic Alps corresponding to the "Wolayer Facies", an apparently shallower marine environment. The contact with the underlying massive cystoid Wolayer Limestone (Upper Ordovician) and the Mid Wenlock bioclastic limestones with a rich fauna of nautiloids, bivalves, brachiopods and trilobites representing the neritic Kok Formation is marked by an iron-oolitic concentration. Development of microstromatolites is also evident in the lower levels of the sequence. In the Wenlock/Ludlow transition thinly developed cyclic micritic limestone beds of bioclastic accumulations are separated by stylolites and sometimes iron-oolitic concentrations which may mark the end of depositional regimes. Concentrations of apparently juvenile and equidimensional articulate brachiopods, nautiloids and gastropods alternate with the dominantly nautiloid beds (the classic Orthoceras Limestone) in the lower Ludlow demonstrating the changing energy and oxygen levels of the formation while the preservation and orientation of the fauna indicate many accumulated levels with intermittent changes in sea level particularly towards the top of the sequence. The overlying Cardiola Fm., Ludlow in age, comparable with the well-known cephalopod limestone deposited in Bohemia and along the North Gondwana margin is represented by a thinly developed dark limestone showing lateral variation in its outcrop. Nautiloids and bivalves are the dominant fauna in this micritic limestone which represents more current-ventilated conditions. The Alticola Limestone, Pridoli in age, is a fine grey micritic limestone with abundant micritised bioclasts, frequent stylolites and an abundant nautiloid fauna throughout the formation. The associated shallow water fauna is similiar to the Kok Formation except for the presence of rugose corals. A Scyphocrinites Bed bearing complete specimens caps the formation and marks the Silurian/Devonian boundary and the shallowest level of the sequence (FERRETTI et al., 1999).

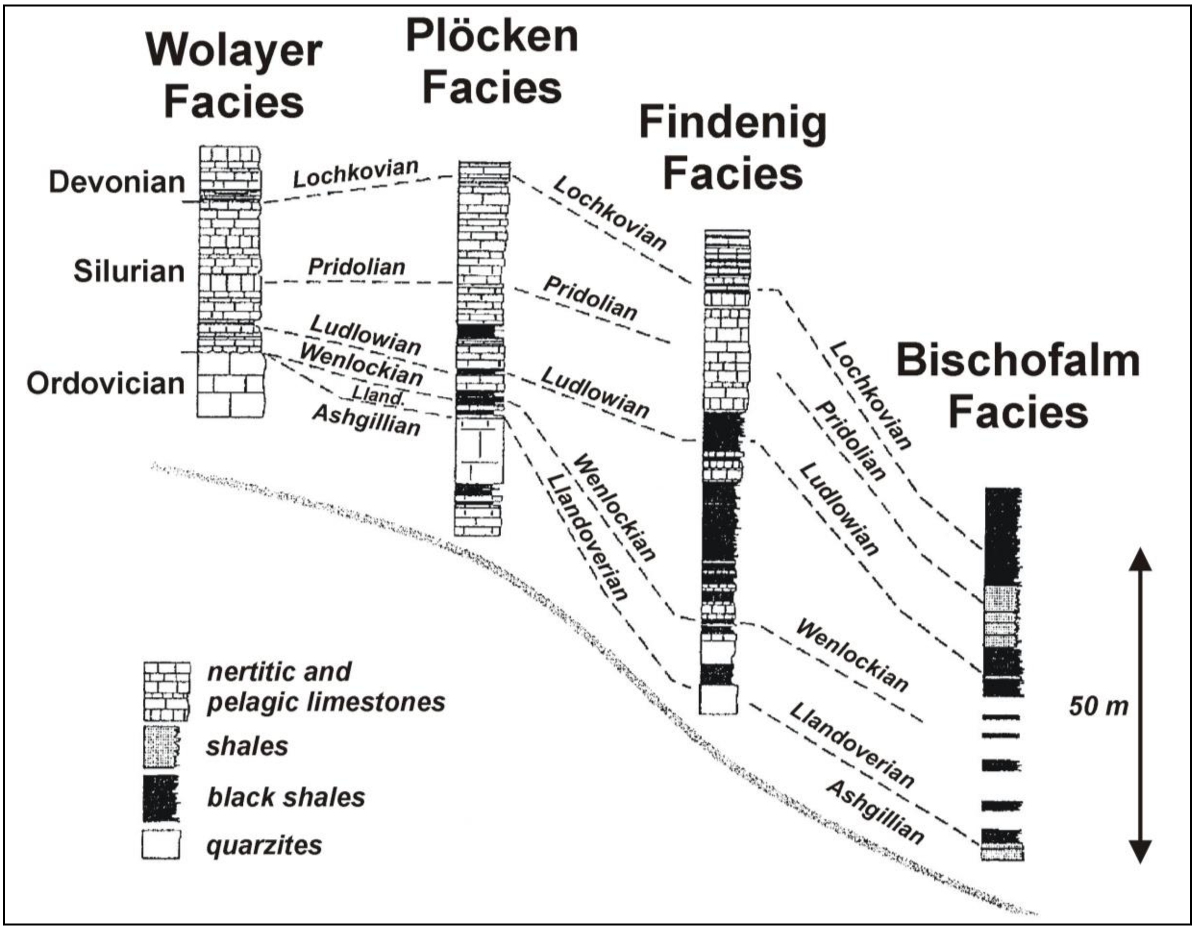


Fig. 4: Lithology of Silurian sediments of the four different lithofacies of the Carnic Alps. Brickstone: carbonates; black: C_{org} rich graptolite-bearing shales and cherts and C_{org} rich carbonates of the Wolayer Facies; light grey: C_{org} poor shales.
Columns from left to right show the sections Rauchkofel Boden, Cellon, Oberbuchach 1-2 and Nölblinggraben-Graptolithengraben. In the latter composite section Lower Silurian sediments are not continuously exposed. After WENZEL, 1997.

The Cellon section represents the stratotype for the Silurian of the Eastern and Southern Alps (WALLISER, 1964) and the "Plöcken Facies" is developed here as a shallow to moderately deep marine carbonate series (FLÜGEL et al., 1977). The condensed nature of the sequence of the Cellon section is clearly demonstrated when correlated with the thicknesses of the same intervals of the more basinal facies of mainly graptolitic shales of the Oberbuchach section and the even more condensed Rauchkofel Boden section. Underlain by the Uggwa Limestone and the clastic Plöcken Fm. the carbonate sequence of the Plöcken Facies was deposited in a relatively shallow environment, periodically effected by storm currents, with intervals of reduced depositional rates and non-sedimentation in an overall transgressive sequence. The pelagic Kok Formation consists of a transgressive carbonate series with alternating black shales and dark grey to slightly red micritic lenticular limestones occurring at the base of the formation in the upper Llandovery and brown-red ferruginous limestones with abundant nautiloids and frequent stylolites in the Wenlock - lower Ludlow. Two deepening events are documented within the formation: at the transition between the Llandovery and Wenlock and between the Wenlock and Ludlow (SCHÖNLAUB, 1997).

The alternating rapid deposition of black shales and laminated micrites with more time-rich light grey nodular micrites with an abundant nautiloid fauna of the Cardiola Beds (Ludlow) indicates a slightly deeper offshore environment with probable contemporary non-depo-sition taking place.

A more stable pelagic environment is developed in the Alticola and Megaerella Limestones from the upper Ludlow continuing into the Pridoli (SCHÖNLAUB, 1997) represented by a transgressive carbonate series of grey to dark pink micritic limestones with a variety of bed thickness and frequent stylolites The beds decrease in thickness in the Pridoli and alternate with interbedded laminated micrites with a dominant nautiloid and brachiopod fauna. Several deepening events marked by the development of black shales have been documented within the uppermost levels of the Pridoli. An offshore setting frequently ventilated by currents of varying energy is envisaged for the upper Ludlow and Pridoli sequences of the Alticola Limestone. The Megaerella Limestone (Pridoli in age) comprises the upper Pridoli and Silurian/Devonian boundary transgressive sequences of biodetritus-rich carbonates, lenticular micrites and black shales. The boundary between the Silurian and Devonian is drawn based on conodonts with the first occurrence of *Icriodus woschmidti* (WALLISER, 1964). However, the first evidence from graptolites of Lochkovian age is found in bed 50 with the occurrence of *M. uniformis* (JÄGER, 1975). PRIEWALDER (1997, 2000) indicates a rich chitinozoan fauna from the Pridoli-Lochkovian interval, therefore the depositional environment was of a low hydrodynamic regime, favorable for their preservation.

There appears to be a distinct gradation of beds upwards towards the Silurian/Devonian boundary indicating that the hydrodynamic regime is constantly changing with the shallowest point being reached at the base of the Rauchkofel Limestone (Lochkovian) with the occurrence of a bryozoan fauna (HISTON et al., 1999). A recent taphonomic study of the Silurian of the Cellon section has highlighted in more detail the faunal and environmental changes during this time interval (HISTON & SCHÖNLAUB, 1999).

The large oxygen isotope ratio excursion shown by WENZEL (1997) at the boundary may be supported by the more ventilated setting implied by the bryozoan fauna.

The intermediate "Findenig Facies" occurs between the shallow water condensed sequences outlined above and the starving basinal facies. It consists of the interbedded black graptolitic shales, marls and blackish carbonates which is locally underlain by a quartzose sandstone.

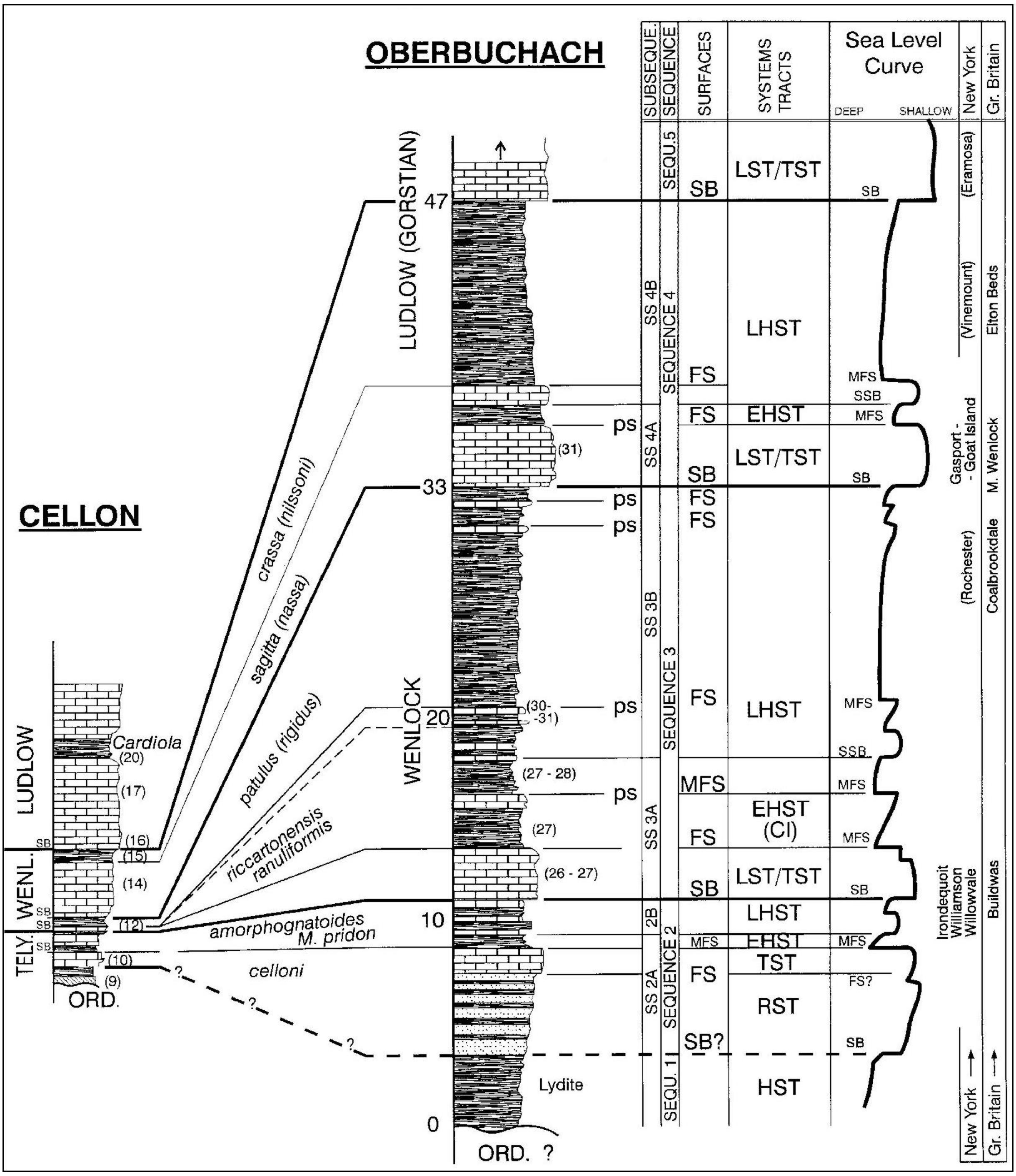


Fig. 5: Correlation and sequence interpretation Llandovery - Lower Ludlow, Carnic Alps. (BRETT & SCHÖNLAUB, 1998).

The stagnant water graptolitic "Bischofalm Facies" is represented by black siliceous shales, lydites and clayish alum shales.

The evidence from the Silurian indicates faunal affinities, e.g. conodonts, trilobites, brachiopods, molluscs, chitinozoa and acritarchs with Baltica and Avalonia as opposed to loose relationships with Africa and southern Europe. In addition, first occurrences of rugose and tabulate corals, ooids and stromatolites indicate a moderate climate. An overall island setting may be inferred by a generally condensed and reduced sedimentary pattern without significant clastic imput. These data suggest an ongoing drift towards lower latitudes and consequently a paleolatitudinal position between 30 and 40°S. In the central Alps rifting-related basic volcanism underpins these inferred plate movements (SCHÖNLAUB & HISTON, 1999).

A sea-level curve for the Llandovery/lower Ludlow interval of the Cellon (Plöcken Facies) and Oberbuchach (Findenig Facies) sections of the Carnic Alps has been elaborated by BRETT & SCHÖNLAUB (1998) based on a sequence stratigraphy study of the sections (Fig. 5). The variations in sea-level compare quite well with those inferred by JOHNSON (1996) and LOYDELL (1998) for the global sea-level changes during the Lower Silurian. For correlation and sequence interpretation see Fig. 5.

Devonian

Sequence Stratigraphy, Platform Evolution and Paleoecology
of Devonian Carbonates in the Central Carnic Alps

The Mid Paleozoic limestones exposed in the Central Carnic Alps preserve the whole range of carbonates encountered on a shelf to basin transect, a scenario rarely encountered in the geologic record. This provided an opportunity to investigate the consequences of sea level changes, shelf sedimentation and margin architecture on a Devonian carbonate system covering a time period close to 50 million years.

Devonian carbonates were investigated in an area extending from Giramondo Pass in the west to Findenigkofel in the east and from Pizzo di Timau in the south to the Gamskofel-Mooskofel Massif in the north. This area encompasses the majority of well-preserved Devonian carbonates in the Carnic Alps. A NNW-SSE oriented differentiation of facies can be recognized with backreef sediments in the south, separated by reef complexes from slope (or ramp) and basin sediments in the north. Tectonic shortening brought the different facies into close proximity and the various depositional environments of the Devonian carbonates are now located in different structural units.

In the Central Carnic Alps numerous sections were measured through reef- and backreef facies (Kellerwand-Hohe Warte Nappe), forereef-, ramp- and/or slope facies (Cellon Nappe) and through pelagic and hemipelagic facies with common gravity flow deposits and interbedded fine-grained siliciclastic units (Findenig Nappe). A pelagic facies with few or no gravity flow deposits occurs in the vicinity of Mount Rauchkofel, and at Zollner Lake cherts and siliceous shales of deep water aspect are exposed (Rauchkofel and Bischofalm Imbricate Nappe Complexes respectively).

The successions reflect the development of a carbonate ramp which was slowly drifting into low-latitudinal warm waters to a tropical carbonate shelf platform with shelfbreak and segmented slope. Masswasting is extensive on the slope and characterizes slope sedimentation. Upper Devonian strata are characterized by overall deepening of the water and backstepping of the shelf edge assembly. The Famennian carbonates of deepwater aspect dominate in all depositional environments and platform drowning is implied.

Depositional Environments of the Devonian Carbonates in the Central Carnic Alps

The Carnic Alps are an east-west striking mountain chain at the border between Southern Austria (Carinthia) and Northern Italy. They represent the Paleozoic basement of the Southern Alps with sequences ranging from Caradoc to Late Carboniferous. The late Paleozoic series were first affected by late Variscan tectonism and later by intense Alpine deformation, which resulted in formation of several thrust sheets, imbricate nappe systems, and dislocations in both, Variscan and post-Variscan Series (SCHÖNLAUB, 1979). Paleogeographically, sediments of the Carnic Alps were deposited in the vicinity of the northern margin of the ancient Gondwana continent. A position removed from a continental or volcanic source area enabled the formation of an almost pure carbonate system.

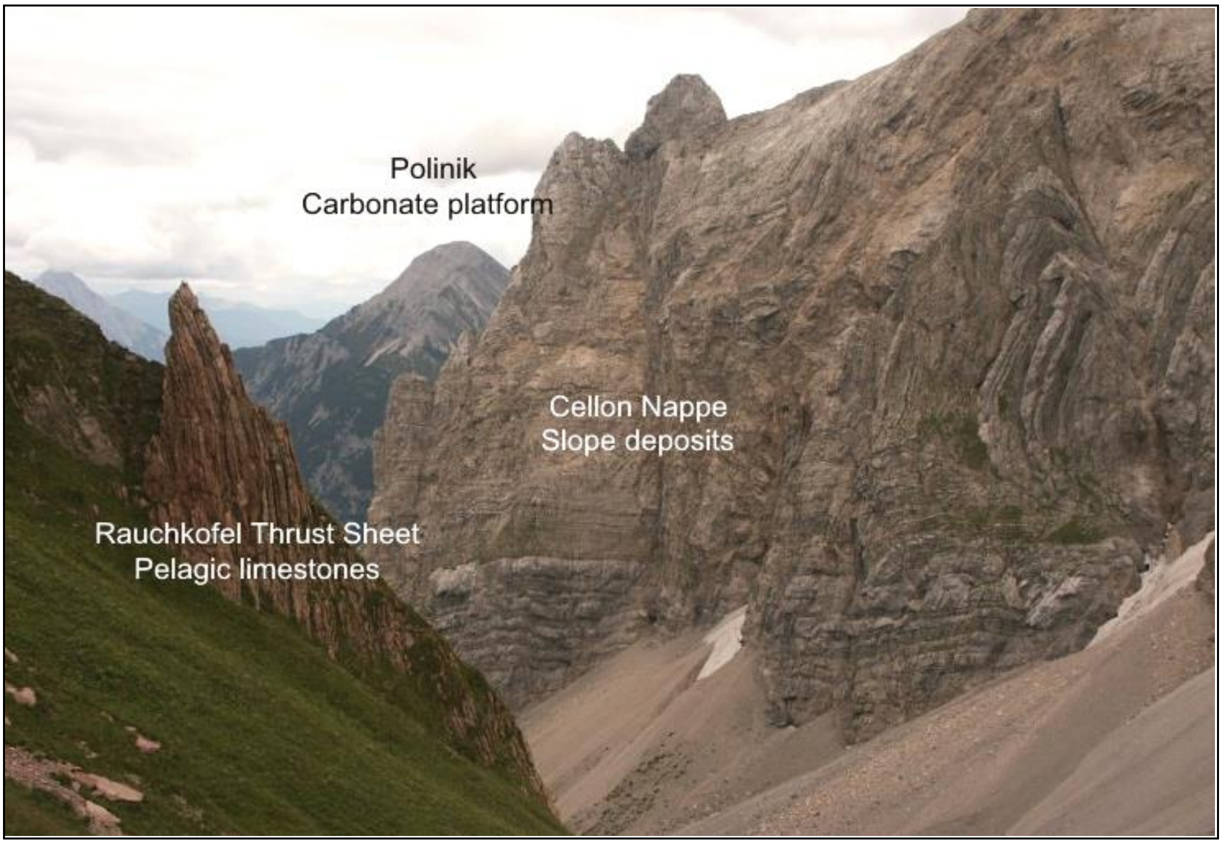


Fig. 6: View from Valentin Törl to the mountainous area in the east showing the proximity of the different depositional environments preserved in the Feldkogel, Cellon, and Rauchkofel Nappes.

The area extending from the Giramondo Pass in the west to the Findenigkofel in the east and from the Gamsspitz in the south to the Gamskofel-Mooskofel Massif in the north (Fig. 7) encompasses the majority of well-preserved Devonian carbonates in the Carnic Alps. KREUTZER (1990, 1992) recognized a NNW-SSE oriented differentiation of facies, and proposed a paleogeographic model with backreef sediments to the south, separated by reef complexes from slope (or ramp) and basin sediments to the north. Tectonic shortening brought the different facies into close proximity and the various depositional environments of the Devonian carbonates are now located in different structural units (see Fig. 6). In the Central Carnic Alps reef- and backreef facies of a carbonate platform complex are confined to the Kellerwand Nappe encompassing Gamskofel Massif, Biegengebirge and Kellerwand-Hohe Warte Complex.

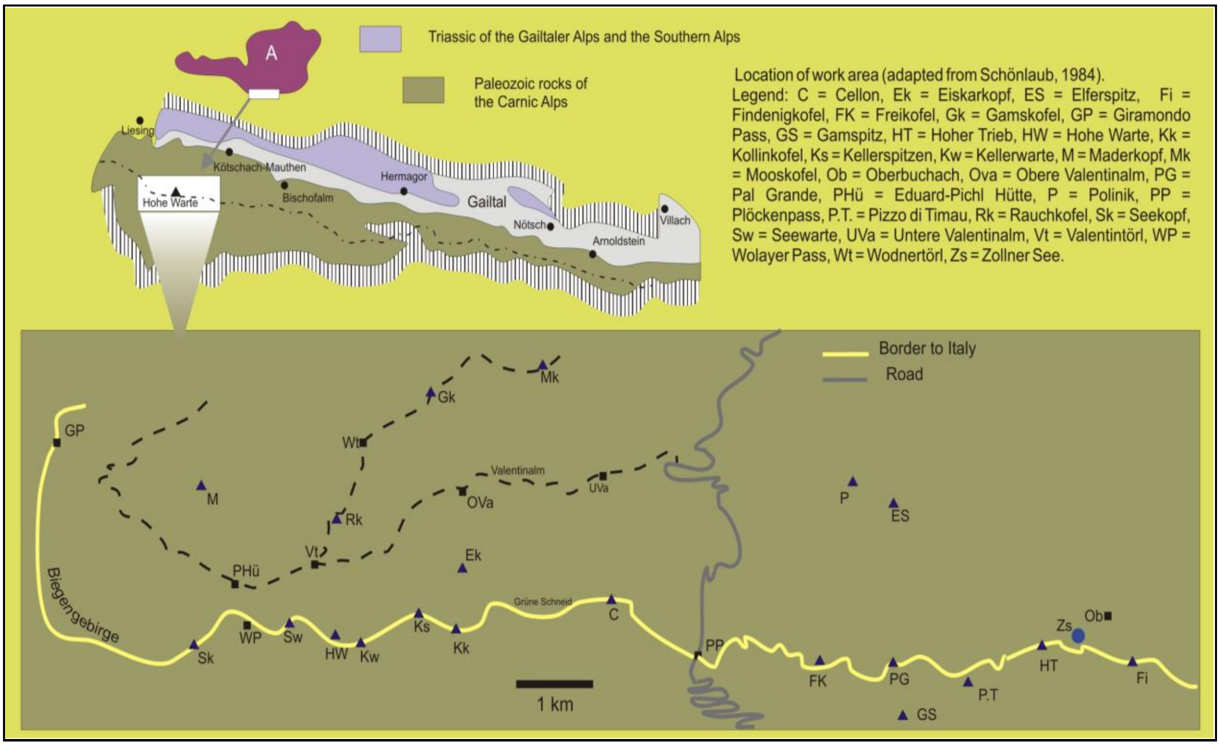


Fig. 7: Location of sections and localities discussed in the text.

The tectonically lower Cellon Nappe contains Silurian to Lower Carboniferous carbonates of forereef-, ramp- and/or slope facies. To the northeast along the Cellon Nappe pelagic and hemipelagic limestones occur with common gravity flow deposits and interbedded fine-grained siliciclastic units. A pelagic facies with few or no gravity flow deposits occurs in the vicinity of Mount Rauchkofel and is referred to as Rauchkofel Facies. In the region of the Zollner Lake cherts and siliceous shales occur with graded beds of the Bischofalm Facies. These are interpreted as basin deposits. Sediments of Rauchkofel and Bischofalm Facies display complex imbricated structures and are referred to as Rauchkofel- and Bischofalm Imbricate Nappe Complexes respectively. According to KREUTZER (1992) the intertidal and pelagic zones were spaced about 8-9 km apart with the intervening reef belt about halfway between both zones. Consequently at a few degrees inclination of the slope, the basin floor would have been at about 300 m, at 15°°inclination at over 1000 m water depth (Fig. 8).

Although most strata belong to various imbricate thrust slices and nappes that characterize the tectonic style of the Carnic Alps, the internal structure of the allochthonous units is coherent and sections can be correlated based on the biostratigraphy established particularly for slope and pelagic deposits (e.g. BANDEL, 1972, 1974; GÖDDERTZ, 1982; PÖLSLER, 1969; SCHÖNLAUB, 1982). The correlation with the shelf sequences poses more of a problem. The stage boundaries are only loosely defined due to sparse conodont and other biostratigraphically useful faunas and the difficult access to some sections (KREUTZER, 1990, 1992; VAI, 1973).

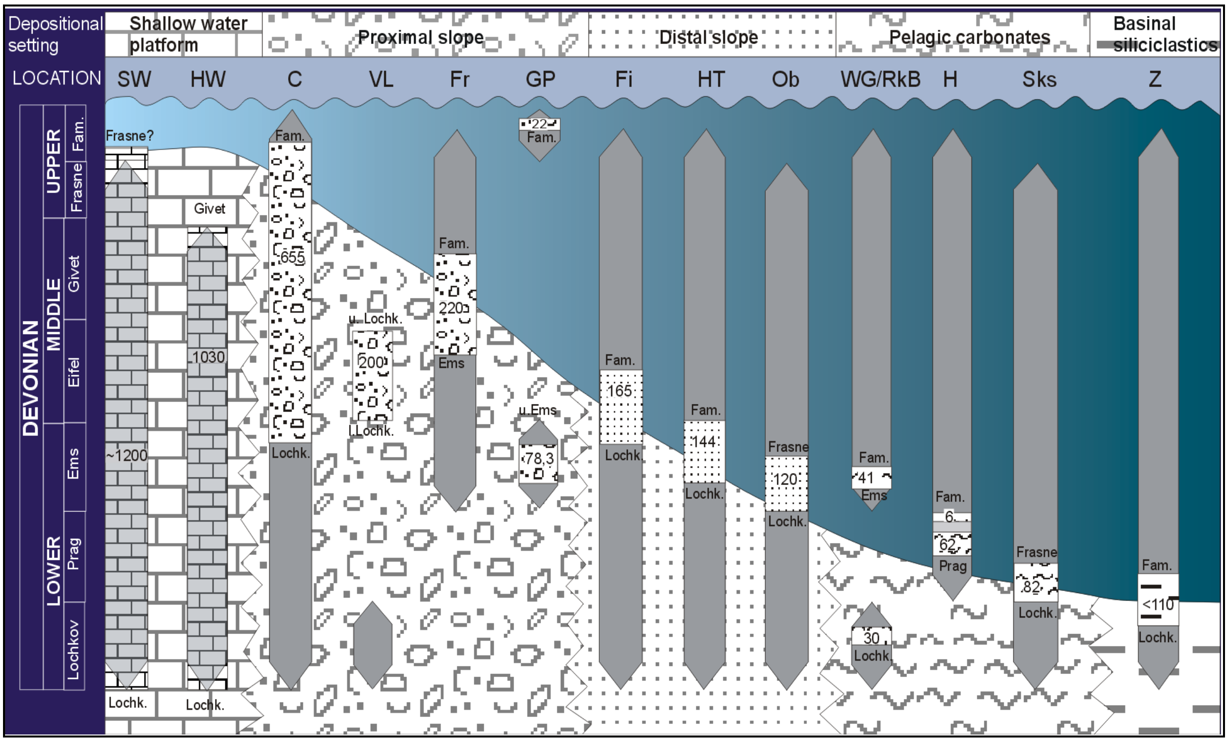


Fig. 8: Thicknesses and ranges of measured sections through the various sedimentary realms.
SW = Seewarte, HW = Hohe Warte, C = Cellon, VL = Valentintal, Fr = Freiko-fel, GP = Großer Pal, Fi = Findenigkofel, HT = Hoher Trieb, Ob = Oberbuchach, WG/RkB = Wolayer Glacier/ Rauchkofel Boden, H = Hütte, Sks = Seekopfsockel, Z = Zollnersee. For locations see Fig. 7.

Conodont Biostratigraphy

Conodont biostratigraphy of sections of the Rauchkofel Facies are well documented from Oberbuchach II, Wolayer Glacier, base of Seekopfsockel and Rauchkofelboden (Fig. 9; SCHÖNLAUB, 1981; GÖDDERTZ, 1982; SCHÖNLAUB, 1982). The sections at Findenigkofel were studied by PÖLSLER (1969) and numerous samples collected by BANDEL from various sections were dated by SCHÖNLAUB (in BANDEL, 1972). The latter are kept at the Geological Survey in Vienna and faunas need to be revised because much progress has been made in conodont taxonomy and stratigraphy. This is particularly true for the samples from sections of the Cellon Nappe which are not well constrained by conodonts.

Southern Shallow Water Facies (Kellerwand Nappe)

The Devonian carbonates of shallow water aspect are preserved in the Kellerwand Nappe Complex and are exposed in the Gamskofel-Mooskofel Massif, Biegengebirge (with Giramondo Pass), and Seewarte-Hohe Warte Massif. Best access and preservation are found at Seewarte, Hohe Warte, and at the base of the Seekopf (BANDEL, 1969, 1972; POHLER, 1982; KREUTZER, 1990, 1992). These sections also show the highest degree of facies differentiation in the region. A section through the southern shallow water facies is accessible at Mount Seewarte (Fig. 10).

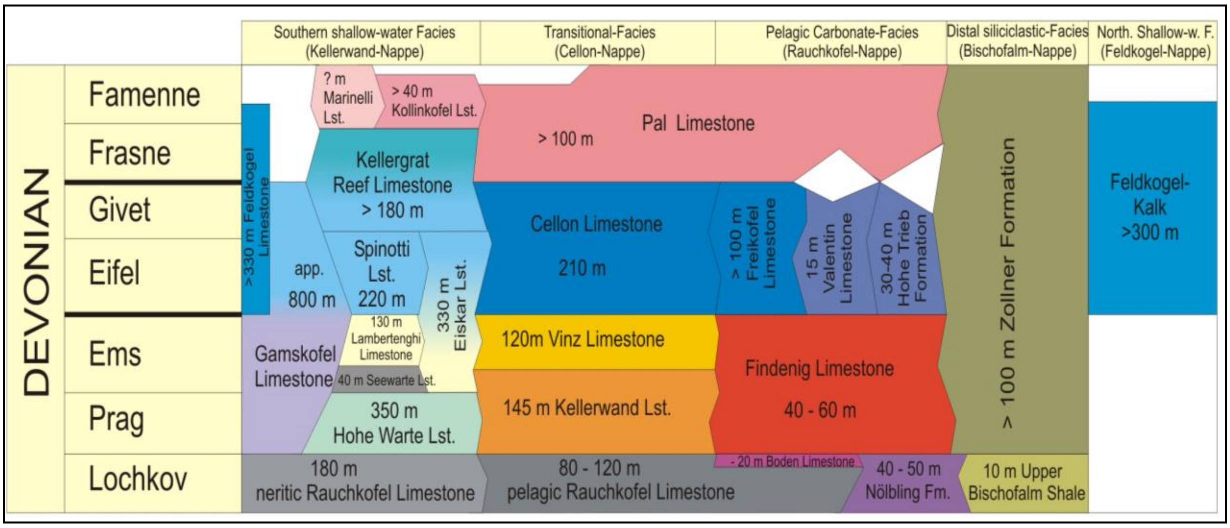


Fig. 9: Stratigraphy of the different Devonian lithofacies on a proximal (left) to distal (right) transect. To the right the northern shallow-water facies of the Feldkogel Nappe is indicated.
Adapted from SCHÖNLAUB, 1992.

Lochkovian limestones of the Rauchkofel Limestone are 152 m thick here and can be subdivided into two distinctive units: the lower 96 m consist of dark, thin-bedded finegrained limestones and shales interbedded with three dolomitized conglomerate and mega-conglomerate horizons. The mega-conglomerates contain boulders measuring up to 10 m in diameter. The upper 56 m of the Lochkovian limestone consist of crinoidal limestone with dolomitized groundmass. Graded beds with aligned crinoid debris are interbedded with disorganized massive crinoidal limestones.

The Pragian is represented by 350 m of Hohe Warte Limestone with coarse crinoidal limestone and well developed patch reefs particulary in the upper part (VAI, 1967; JHAVERI, 1967; BANDEL, 1969). It was measured and sampled in detail by BANDEL (1969) at the base of Mount Seewarte. Both Rauchkofel and Hohe Warte Limestone grade laterally into periplatform deposits composed of interbedded pelagic and detrital carbonates (KREUTZER, 1990). This facies is characteristic of the Lower to Middle Devonian sections in the Cellon Nappe and their presence in the shallow water Kellerwand Nappe shows that both sedimentary realms were closely related.

The succeeding Seewarte Limestone is up to 40 m thick and probably early Emsian in age (ERBEN et al., 1962; KREUTZER, 1990; SCHÖNLAUB, 1985). It is characterized by darkgrey colour, large molluscs (*Hercynella*), and abundant algae (PALLA, 1967; JHAVERI, 1969). The limestones are only locally developed and are interpreted as backreef or lagoonal facies. The following, up to 130 m of Emsian Lambertenghi Limestone comprises numerous shoaling upward sequences of 0.5-3 m thick grey limestone beds capped with yellow laminated dolomite (10-30 cm thick layers). Characteristic components are oncoids and other coated grains, algal lumps, bored and enveloped skeletal grains, and algae. Fibrous calcite crusts, algal laminites, open space structures (birdseyes), flat pebble limestone conglomerates and grading are conspicuous elements of the Lambertenghi Limestone. Dolomitization was probably early diagenetic. The sediments are interpreted as peritidal carbonates deposited on a shallow open to semi-restricted marine platform with a water depth ranging from shallow subtidal to supratidal (POHLER, 1982).

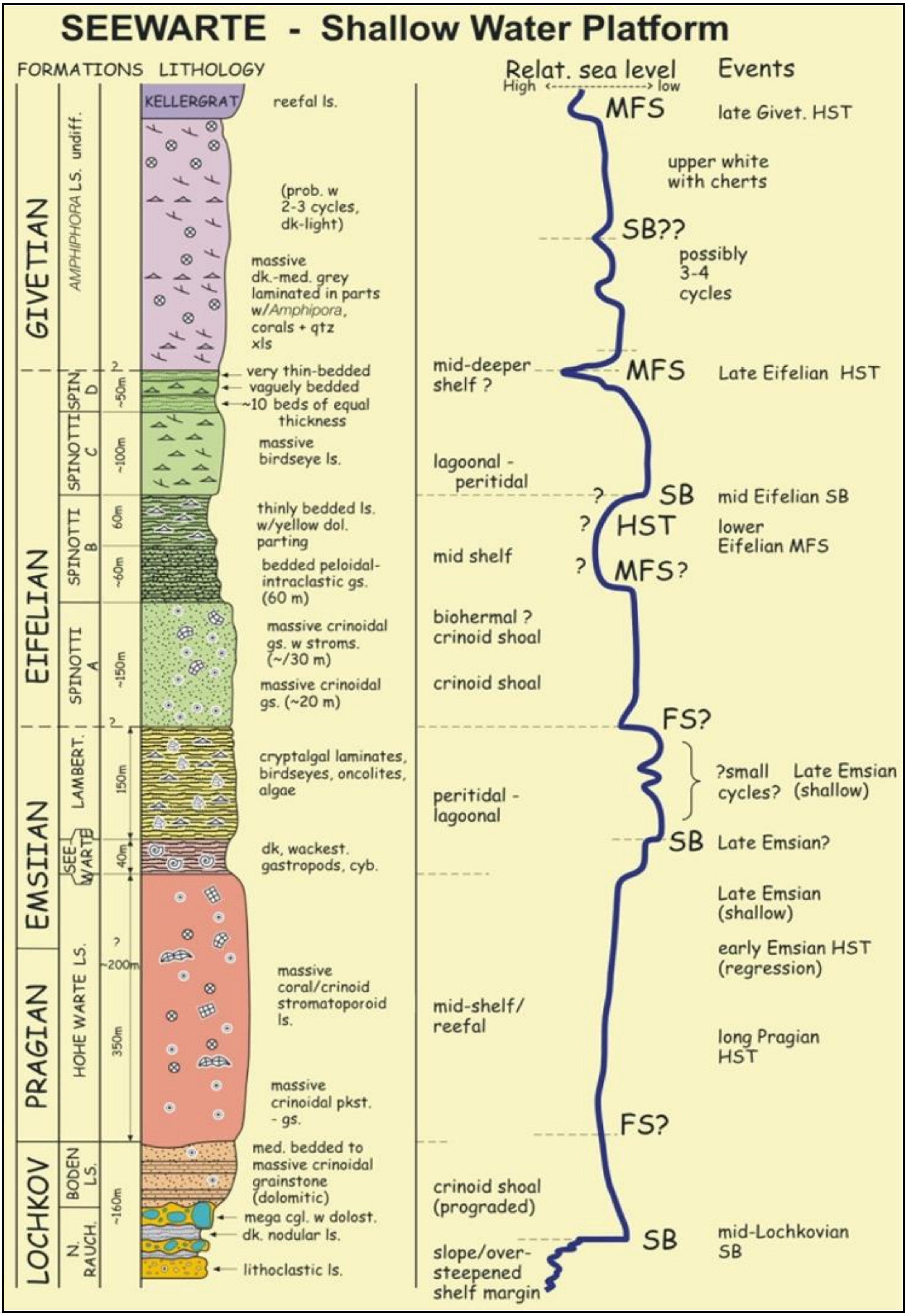


Fig. 10: Section through the southern shallow water facies (Kellerwand Nappe) measured at Mount Seewarte. Sequence stratigraphic interpretation by C. BRETT.

The nature of the Lambertenghi Limestone (Emsian) with shallowing upward carbonate-dolomite cycles indicates deposition in arid climate.

The overlying Spinotti Limestone is composed of basal crinoidal and bioclastic limestone (90 m thick) and upper "birdseye limestone" with *Amphipora* (approximately 130 m thick, Fig. 11). The lower unit is probably already Eifelian in age (VAI, 1967; KREUTZER, 1992).

The Spinotti Limestone Formation begins at the metal ladder at the base of the Sentiero Spinotti (Track # 145 to Rifugio Marinelli).

Above the massive stromatoporoid debris limestones of the lower Spinotti Limestone follow thickly-bedded unfossiliferous peloidal limestones. They represent 2-3 m thick beds with thin (25-30 cm thick) dolomitic interbeds. This succession is about 60 m thick and is succeeded by about 30 m thick vaguely bedded limestones (0.5-1 m thick beds) followed by 25 m of more distinctively bedded limestones. Characteristic are the dark veining and the laminitic inter-beds. Unfortunately thin sections yield little information of this upper part of the succession because of tectonic overprinting. This limestone sequence forms the initial steep part of the Sentiero Spinotti which ends at the ridge at an elevation of 2020 m.

Fig. 11: The succession with the basal Spinotti Limestone at the Sentiero Spinotti.

The track crosses a wide valley that opens to the SW where birdseye limestones are exposed between the 2020 m and the 2200 m ridge (Costone Stella). According to BANDEL (1972) and VAI (1963) they still fall into the Eifelian. In our opinion, however, these strata are equivalent to the basal portion of the Givetian.

A yellow limestone bed is exposed above the trail (Fig. 12) at elevation 2120 m, yielding abundant stringocephalid brachiopods.

The trail passes through birdseye limestones with limonitic crusts and intraclasts interbedded with fossiliferous dark Amphipora Limestones containing large gastropods, amphipores, stromatoporoids and stringocephalid brachiopods.

The beds dip with 36º to the south and are overlain by bedded limestones with dolomitic layers (Fig. 13). The determination of the brachiopods awaits confirmation, however, it is possible that these beds are already Givetian in age. On Fig. 10 this lithological change is indicated between the Spinotti D unit and the Amphipora Limestone.

The track to Costone Stella (2200 m) crosses poorly preserved birdseye limestones with few *Amphipora*-rich horizons. In the following karst terrain dark Amphipora Limestones are exposed in places associated with solitary rugose corals.

They appear to be interfingering with light coloured birdseye limestones. Their thickness is difficult to estimate due to tectonic complications.

The hitherto undescribed birdseye and overlying *Amphipora* limestones are informally referred to as Costone Stella Limestone.

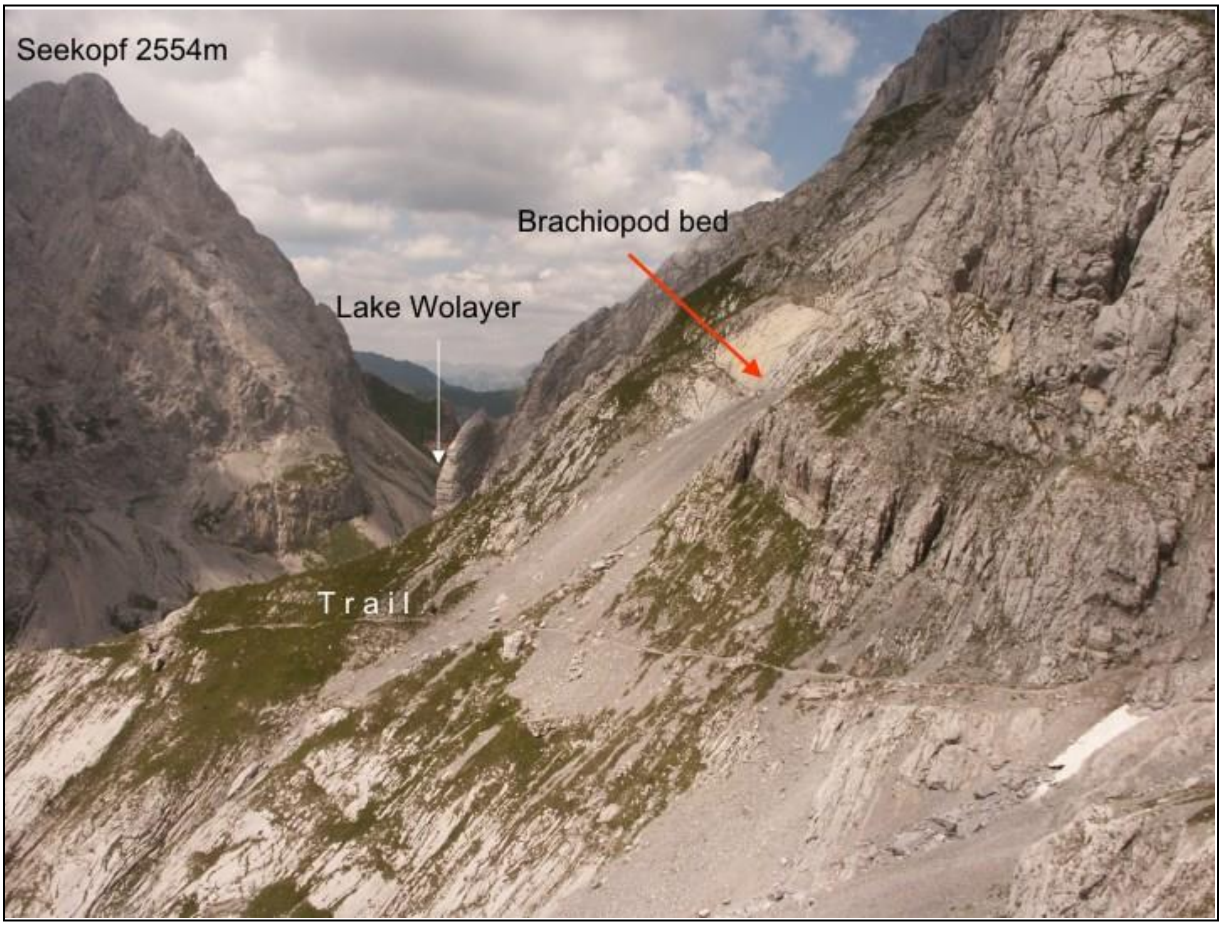


Fig. 12: The yellow bed above the Sentiero at elevation 2120 m.

The karst terrain ends at the track to the south side of Mount Hohe Warte (track # 143a) and here the first reefal limestones of the Kellergrat Limestone Fm. occur. *Amphipora rudis* was determined from this succession and indicates a Givetian to Frasnian age (E. FLÜGEL, pers. comm., 1981). The corals recovered from this area include *Scruttonia julli* (PEDDER) which also suggests a Frasnian age (ÖKENTORP-KÜSTER & ÖKENTORP, 1992). However, both authors caution that the total coral fauna contains elements characteristic of Givetian as well as Frasnian associations.

Along the trail to Hohe Warte *Amphipora* limestones are exposed to the west of the trail and coral limestones to the east. It is likely that a facies transition is present here; however, the rugged terrain and tectonic complications make this relationship difficult to assess.

The succession ends at an unconformity which separates birdseye limestones of unknown age from lower Carboniferous (anchoralis Zone) deep water limestone with goniatites.

To the north, in the upper Kellerwand Nappe both Lambertenghi and Spinotti Limestones grade into Eiskar Limestone, composed of algal-rich grainstones with interbedded "birdseye limestones". This facies ranges from Emsian into middle Givetian and is about 320 m thick. KREUTZER (1990) regarded it as backreef facies (crinoid-cortoid facies).

The Kellerwand Nappe was probably thrust over a segment of the Devonian shelfbreak and upper slope, whose nature is therefore not known. Hints of this facies are reflected in the composition of calciturbidites and other gravity flows which originated at the (now buried) shelfbreak and/or foreslope.

Fig. 13: Birdseye and Amphipora Limestones exposed along the upper part of the trail "Sentiero Spinotti".

Discussion

The term carbonate platform is used herein as a general term for a thick sequence of shallow-water carbonates (TUCKER & WRIGHT, 1990).

Prerequisites for the development of a carbonate platform are
1. Presence of plants and animals which produce carbonate minerals rapidly.
2. A shallow illuminated seafloor in tropical to subtropical seas.
3. Warm water (T >18ºC).

Indicators for shallow warm water in Devonian time include
1. Abundance of massive and branching stromatoporoids (*Amphipora, Stachyodes*).
2. Colonial rugose corals and tabulozoans (chaetetids and tabulate corals).
3. Calcareous green and bluegreen algae (e.g. Dasycladales and Udoteacean algae).
4. Ooids, oncoids, aggregate grains and common pellets.

Most of these organisms and components occur in the carbonates of the Kellerwand Nappe and the presence of these climate sensitive lithologies in the Carnic Alps indicates deposition in a tropical marine environment (30º or less). In recent oceans cool water carbonates accumulate at depths down to 350 m or more, from carbonates produced by non-photo-trophic organisms such as benthic forams, molluscs, bryozoa and red algae (foramol or bryomol assemblages). In the Devonian, crinoids feature prominently in cool water (as well as warm water) assemblages. The condensed Silurian and Ordovician sediments underlying the Devonian carbonate platform show all the hallmarks of cool water carbonates and indicate drifting of the Carnic Alps depositional system from high to low latitudes in the Paleozoic.

Geotectonic settings of shallow marine environments can be
1. Passive continental margins
2. Intracratonic basins
3. Failed rift basins
4. Arc-related basins
5. Oceanic islands
6. Foreland basins.

The lack of volcaniclastic and siliciclastic sediments excludes arc-related and foreland basins as environment for the Carnic Alps carbonates. Deposition in a rift-related basin was suggested by SPALLETTA et al. (1983) and also KREUTZER et al. (1997) proposed an extensional regime of enhanced mobility for the CA depositional system.

Several types of carbonate platform are known, including rimmed shelf, ramp, epeiric platform, isolated platform and drowned platform.

A rimmed shelf is a shallow water platform with a pronounced shelf break and slope into deeper water. Along the shelf margin reefs or shoals may develop, which restrict circulation on the shelf. Some rimmed shelves have deep intrashelf basins behind the shelf rim. Widths of rimmed shelves can vary from a few to 100 km. Accretionary, bypass and erosional types of rimmed shelves can be distinguished.

A carbonate ramp is a sloping surface with a low gradient (a few metres per kilometre) where shallow water carbonates pass gradually into deeper water and then basinal deposits. In contrast to a rimmed shelf there is no distinct break of slope in shallow depth. Two types of ramp can be distinguished. Homoclinal ramps have relatively uniform slopes whereas distally-steepened ramps have an increase in slope gradient in the outer deep ramp region (READ, 1985). The latter are characterized by gravity flow deposits and slumps similar to accretionary shelf margins but differ in the location of the slope break, which is in deeper water. As a consequence the resedimented deposits on the lower slope (or in the basin) consist of outer ramp and upper slope deposits.

Ramp facies are controlled by ocean currents and waves and distinctive sediments are carbonate sands and tempestites. In the shallow ramp region patch reefs, beach barriers and sandy shoals can form and provide sheltered back-ramp areas where lagoonal, shallow subtidal to supratidal flats occur, frequently associated with evaporites and/or paleokarsts and paleosols.

Epeiric carbonate platforms are extensive areas of negligible topography and gradient which covered extensive areas of cratons. Water depth rarely exceeded 10 m and vast areas covered by shallow subtidal to supratidal carbonates are characteristic. Deep intraplatform basins surrounded by ramps or slopes were sometimes present. The influence of tides on these platforms is under debate and a tidal island model is contrasted with a model proposing dampened or no tides and storm domination (JAMES & PRATT, 1986; IRWIN, 1965).

Epeiric carbonate platforms have no recent counterparts but were present particularly in the Paleozoic and in the Triassic-Jurassic in times of lengthy drift phases after plate separation.

Isolated carbonate platforms are shallow water platforms surrounded by deep water. Their size is variable but most are of small size and characterized by steep slopes. Frequently they develop on structural blocks in regions where renting and rifting occurred or on submerged volcanic seamounts. Sedimention on and around isolated platforms is controlled by prevailing wind and storm directions. Reefs are particularly developed at the windward side of isolated platforms and adjacent platform slopes receive little fine grained sediment from the platform interior. Off-platform transport is concentrated on the leeward side of the platform where much sediment is redeposited on the platform slope. Drowned platforms typically have deep-water carbonates overlying the shallow-water facies.

The areal extent of a carbonate platform is governed by the size of the platform and amount of siliciclastic sediment. In the CA siliciclastic influx is virtually absent in relation to the large amount of carbonate sediments. The existence of an extensive carbonate platform is indicated by the wide areal extent of the shallow water facies and KREUTZER et al. (1997) calculated a ratio of 12:1 for thicknesses of shallow water versus pelagic carbonates. However, occurrences of shallow water facies are disjunct and it is to date not known whether one continuous or several smaller platforms were present.

The stratigraphic succession investigated at Mt. Seewarte is composed of shallow water carbonates except for the lower Lochkovian interval which consists of allodapic and pelagic limestones and shales. The lateral change to the west is to date not known. To the east the Lower Devonian succession was documented at Hohe Warte (SCHÖNLAUB & FLAJS, 1982; KREUTZER, 1992) and deepening in this direction is indicated. The lithological changes seen in the basal Seewarte section imply that the shallow water facies prograded over a carbonate ramp or slope and suggests that either an accretionary shelf margin or a distally steepened ramp existed in this time interval. The clasts in the lower Lochkovian debris flow deposits are largely slope lithologies.

The overlying mid- to upper Lochkovian limestones are composed of crinoidal grain- and packstones with frequent graded beds interbedded with massive disorganized beds. The lithology suggests deposition at or near crinoid shoals with frequent remobilisation of skeletal debris presumably through storms or gravity flows. The overlying Pragian sediments also contain abundant well preserved crinoids but in contrast to the Lochkovian they are massive carbonates without any graded or other indication of hydraulic sorting. The good preservation of the crinoidal debris indicates deposition close to their original habitat. In addition, stabilization of seafloor sediments permitted local development of carbonate buildups (mounds). The sediments are well washed with little mud and much fibrous calcite. The high diversity of accessory skeletal components indicates good living conditions for organisms in well aerated shallow subtidal marine environment for most of the Pragian. The observed shallowing upward trend implies progradation of shallow platform sediments over the crinoidal storm beds deposited in the Lochkovian.

During late Pragian and early Emsian stromatolites and stromatoporoids became prolific and small patch reefs developed. The succeeding Seewarte Lst. is dark grey with numerous molluscs and stromatolitic bindstone. Deposition in a lagoonal setting is inferred and suggests that for a short time interval restricted circulation occurred at least locally. The reasons could be the formation of lagoonal environments behind substantial Emsian buildups or in an intra shelf basin which became restricted due to a sea level fall.

The succeeding Lambertenghi Limestone (Emsian) was deposited in shallow subtidal to supratidal environments, and hence in shallower water than the previous sediments. Further progradation of the platform is indicated. This continuous trend of shallowing ends with deposition of the Spinotti Limestone (Eifelian), beginning with muddy reefal limestone succeeded by crinoidal packstone.

Initial sediment composition on a platform is largely determined by its carbonate-secreting biota; resultant lithofacies, however, are determined by energy spectrum and sediment binding. In general terms lithofacies on rimmed platforms are dominantly muddy while those on open unrimmed platforms are grainy. On the CA platform grainy facies are dominantly found in the upper Lochkovian to Pragian, whereas lagoonal and muddy facies are found in the dark Seewarte Limestone and (to a lesser degree) in the Lambertenghi Lst. where an oscillation from muddy to grainy to dolomitic facies occurs. This pattern suggests, that a rimmed platform began to form in the mid-Emsian.

The balance between sediment production and sediment transport determines the growth potential of the platform; sea level fluctuations and subsidence cause changes in environmental conditions reflected in vertical accumulation of platform sediments.

Foreslope/Slope Facies (Cellon Nappe)

Several peaks and massifs belong to the Cellon Nappe including Cellon, Freikofel, Großer Pal, Gamsspitz, Pizzo di Timau (Fig. 7). BANDEL (1972) and KREUTZER (1990) both interpreted the Devonian sediments of the Cellon Nappe as remains of forereef, foreslope and slope. KREUTZER (1992) subdivided the transitional Devonian facies into several formations based largely on sections at Cellon and Kellerwand. For this study sections located at the Cellonetta avalanche cut (Cac) and along the Steinberger path at the eastern side of Mount Cellon (Pragian to Emsian) are considered (Fig. 14).

The Lochkovian Rauchkofel Limestone is well exposed at Cac and begins above sample number 47 of WALLISER (1964) just above the Silurian/Devonian boundary. The Lochkovian is 65 m thick here and two units can be distinguished: the lower unit (35 m thick) consists of alternating dark grey to black bituminous platy limestones with subordinate intercalations of black calcareous shales or shaly limestones. The limestones are commonly calcisiltites with coarser bioclastic material at the base of thin laminae. Grading and convolute bedding is common, fine laminations are characteristic. Limestone beds grade upward into shales. In some layers intraformational breccias occur. Dark chert nodules and concretions are common; dolostone beds and patchy dolomitization is characteristic. Bioturbation and ichnofossils are rare in this lower part of the succession. The fauna consists of nektonic, planktonic and benthic organisms. Trilobites and thin-shelled bivalves are abundant and crinoid debris features prominently in most samples. Graptolites are rather sparse in the lower Loch-kovian.

Fig. 14: View of Mount Cellon with location of Cellonetta Avalanche Cut.

The upper Lochkovian unit (30 m thick) consists of massive, grey nodular limestone units interbedded with thin-bedded grey limestones (Figs. 14, 15). The nodular limestone typically is bioturbated calcisiltite with numerous peloids and some crinoid debris in a matrix of lime mud. The main difference to the lower Lochkovian is the presence of bioturbation. The interbedded platy and vaguely laminated limestones are fine-grained calcisiltite with dark-brown lamination. Trilobite and other shell debris is oriented parallel to the bedding planes. Bioturbation is reduced. The lithological change from dark platy limestones and shales to dominantly nodular and lumpy limestones can be seen from afar because the latter form prominent steep ribs in the succession, not only at Mount Cellon but also at the inaccessible Kellerwand section to the east.

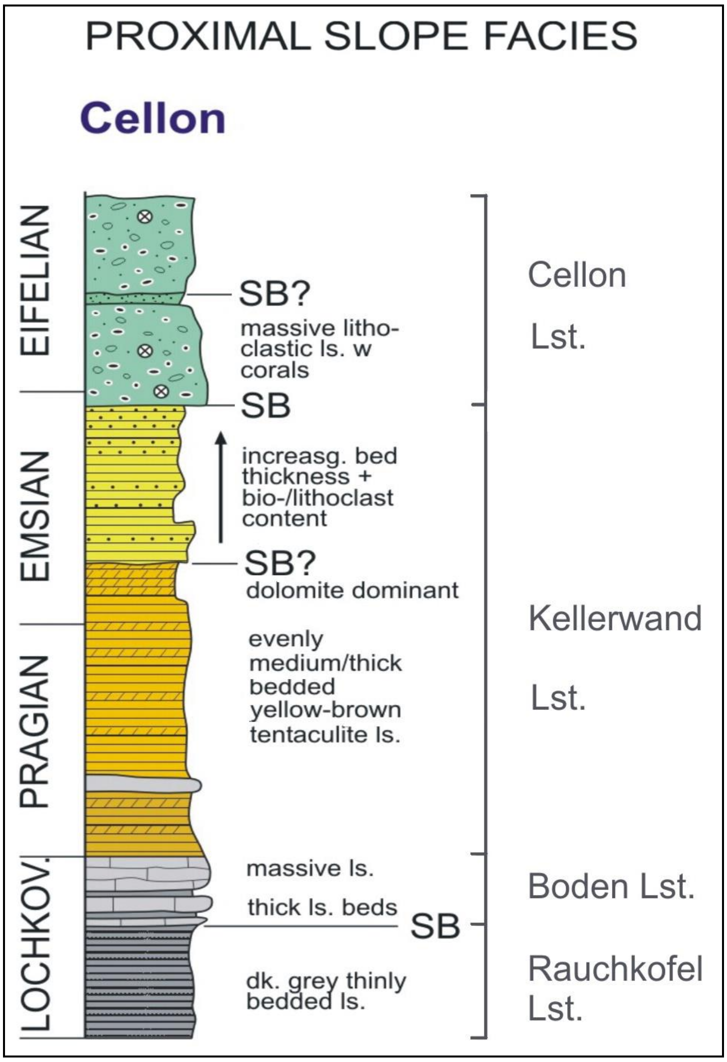


Fig. 15: Generalized section through the proximal slope facies (Cellon Nappe) measured at Mount Cellon.

The Lochkovian/Pragian boundary may coincide at Mount Cellon with the lithological change from grey nodular and platy limestone to yellow dolomitic tentaculite-bearing limestone referred to as Kellerwand Lst. (~145 m thick). At the Steinberger Path this unit is poorly exposed and recessively weathering. The Kellerwand Limestone is largely composed of fine-grained limestone intercalated with muddy calcarenite and calcisiltite beds. The fine-grained lithology is a microskeletal peloidal wackestone interbedded with very abundant broken and complete tentaculites. Skeletal debris of trilobites, crinoids and brachiopod shells is also common. Dolomite crystals are dispersed throughout in variable amounts ranging from numerous xenomorph and idiomorph crystals to pervasive dolomitization. Stylolites and their surroundings are particularly affected by dolomitization. Most of the fine-grained sediment is thoroughly bioturbated.

The coarser calcisiltites and calcarenites are composed of medium sand-sized crinoid debris in a matrix of peloidal grainstone to packstone. In some beds grading can be seen with medium sand-sized crinoid debris grading upward into peloidal grainstone to packstone with few crinoid fragments. Accessory skeletal material is derived from brachiopods and trilobites. In some cases the silty matrix is completely replaced by dolomite. The contacts between grainy beds and muddy lithologies are not sharp but vague and uneven due to the activities of burrowing organisms.

The Kellerwand Lst. is succeeded by the 120 m thick Emsian Vinz Limestone which is characterized by decreasing dolomite content, and increasing bed thickness and lithoclastic content. The Pragian/ Emsian boundary is not clearly defined based on litho- or biostratigraphy. The succession consists of thick bedded bioclastic wackestone intercalated with peloidal/bioclastic pack- and grainstones. The Lower Devonian ends at the transition to grey massive bioclastic wackestones, pack- and grainstones of the Cellon Lst. Fm., averaging 210 m in thickness and forming the peak massif of Mount Cellon.

Discussion

BANDEL (1972) measured and dated several sections through sediments of this "transitional facies" of the Cellon Nappe and also considered the "pelagic limestones with common redeposited beds" (his sections at Woderner Törl, Valentin Alm, Cellon, Cresta di Collinetta, Freikofel, Gamsspitz, Pal Grande, Pizzo di Timau, Elferspitz) transitional between the basin floor and the shallow water platform (BANDEL, 1974). The Lower Devonian interval of this "transitional facies" is characterized by bioturbated thinly bedded to lumpy wackestones and packstones interbedded with thin, fine-grained graded horizons. BANDEL (1972) interpreted the graded beds with abundant shallow-water derived skeletal material as turbidites and the intervening fine-grained beds as pelagic background sedimentation.

BANDEL (1972) noticed, that the composition of resedimented beds reflects the environment of shallow water deposition, where echinoderm fragments were most abundant in the Lower Devonian. KREUTZER (1990: 308) pointed out that debris derived from the backreef travels further downslope than the relatively coarse reefal debris. This may be reflected in the proximal to distal trend from Cellon (proximal) to Gamsspitz (intermediate) to Woderner Törl (distal) postulated by BANDEL (1972).

HLADIL et al. (1996) proposed a turbidite origin for Pragian lime mudstones of the Prague Basin on the basis of graded bedding, abundance of calcisiltite components and imbrication of tentaculite shells. The indistinct outline of the turbidite beds is here ascribed to dewatering after deposition.

To understand the geometry of the carbonate depositional system in the Carnic Alps it is necessary to take into consideration mechanisms of carbonate accumulation.

The surface slope that is maintained by carbonates is determined by the combined effects of (1) rate of *in situ* carbonate accumulation and (2) the depositional angle of the sediment shed from the bank or reef crest as talus and turbidite. Commonly the slope will be steep when most of the carbonate accumulates on the shelf. If carbonate accumulation does not vary much with water depth, then carbonate accumulation will maintain a uniform slope which parallels the underlying surface. This slope may be steepened with time by sediment shed as talus and turbidite from the reef or bank crest.

Distal slope facies at Mt. Findenig, Hoher Trieb and Oberbuchach

Sections through the distal slope facies were measured at Hoher Trieb, Oberbuchach and Findenigkofel. The sections at Hoher Trieb and Oberbuchach were previously documented in terms of lithofacies and biostratigraphy by SCHÖNLAUB (1970, 1985). The succession at Findenigkofel was mapped and studied in detail by PÖLSLER (1969). Limestones of the distal slope environment were measured at Oberbuchach, Findenigkofel and Hoher Trieb (Fig. 16). Between 13 and 31 m of section belong to the Lochkovian.

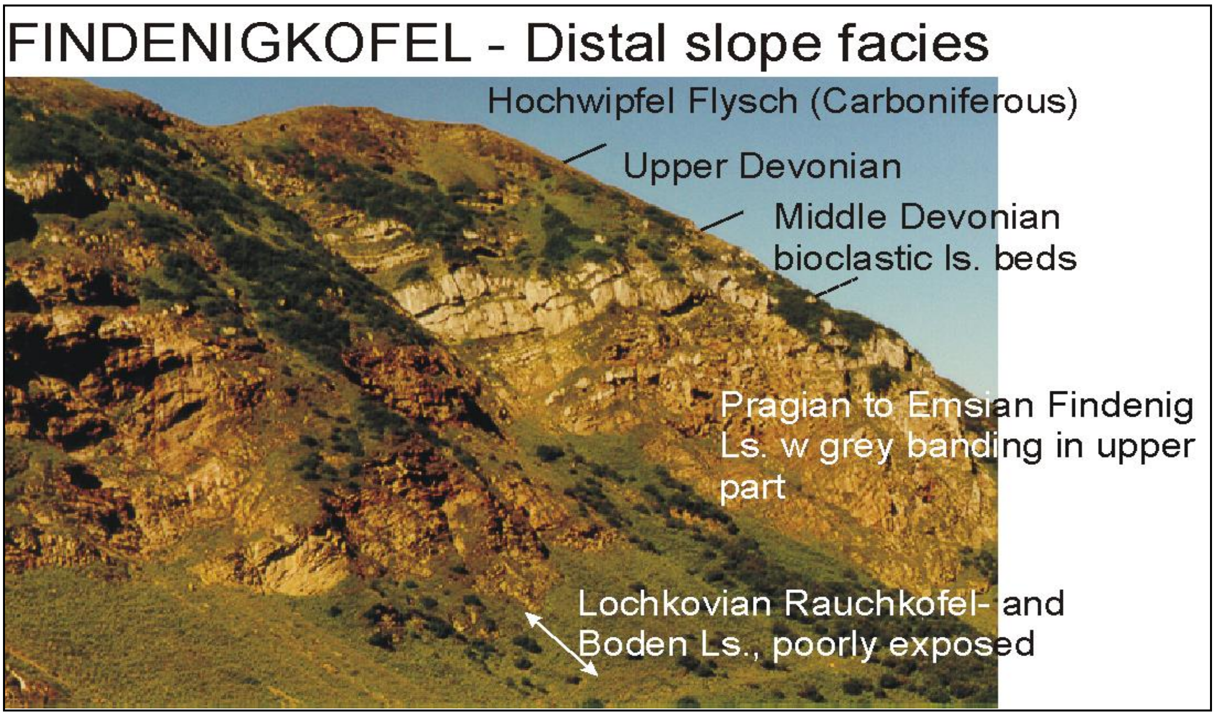


Fig. 16: View of distal slope sediments exposed at Findenigkofel from the Waidegger Alm.

At Oberbuchach and Findenigkofel, the characteristic lithological change from dark platy dolomitic and cherty limestone with graded beds to lighter grey nodular and "flaser" limestones can be observed. Pragian and Emsian limestones are red "flaser" and nodular limestones, both belonging to the Findenig Limestone. The Pragian is well constrained based on conodonts at Oberbuchach II (OB II) and about 30 m thick (Figs. 17a, b).

The Emsian segment at OB II is about 32 m thick and characterized by higher limestone content and thin light-grey calcilutite and calcarenite beds intercalated with red "flaser" limestones. Calciclastic beds increase in thickness and coarseness up-section. At Findenigkofel a 100 cm thick grey bed is exposed consisting of 50 cm thick grey lumpy limestone composed of lime-mud with numerous tentaculites with smooth walls, trilobite fragments and few ostracods. Parting material between lumps consists of mm-thick brown material (unresolvable by light microscopy) with silt-sized xenomorph dolomite crystals. This bed is overlain by five centimetres of graded and laminated limestone, composed of fine sand- to silt-sized peloids, crinoid debris (with syntaxial overgrowth) and thick-shelled dacryoconarids (?), followed by seven centimetres of wavy laminated calcisiltite. A six centimetre thick laminated shale unit concludes the succession. It is overlain by three beds of wavy laminated limestone (20 cm thick together) and finally 20 cm of grey lumpy limestone follows, similar to that at the base.

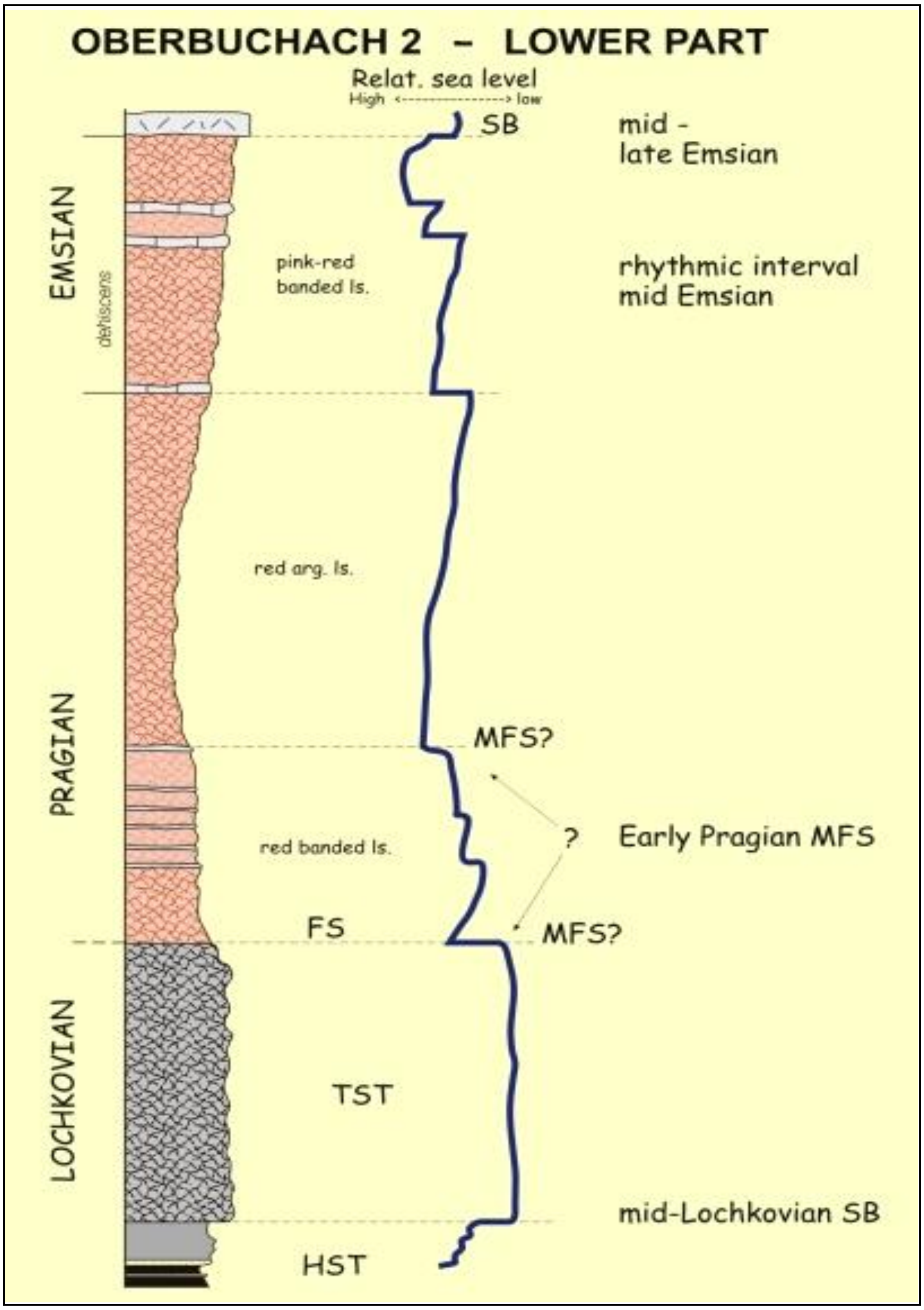


Fig. 17a: Section through the distal slope facies measured at Oberbuchach II, lower part. Adapted from SCHÖNLAUB, 1985. Sequence stratigraphic interpretation by C. BRETT.

Discussion

The succession observed at Findenigkofel is characteristic of turbidites deposited from low-density flows. Calciturbidites of such small grain sizes show structures similar to siliciclastic turbidites and the succession described above shows Bouma sequences T_a (graded calc-arenite), T_b (lower horizontally-laminated division), T_c (cross-laminated division) and T_d (upper horizontally-laminated division). The pelite interval (T_e) is missing. According to STOW (1986) fine-grained turbidites are characteristic of distal slopes or ramps and with increasing distality the T_b and T_c divisions may be missing.

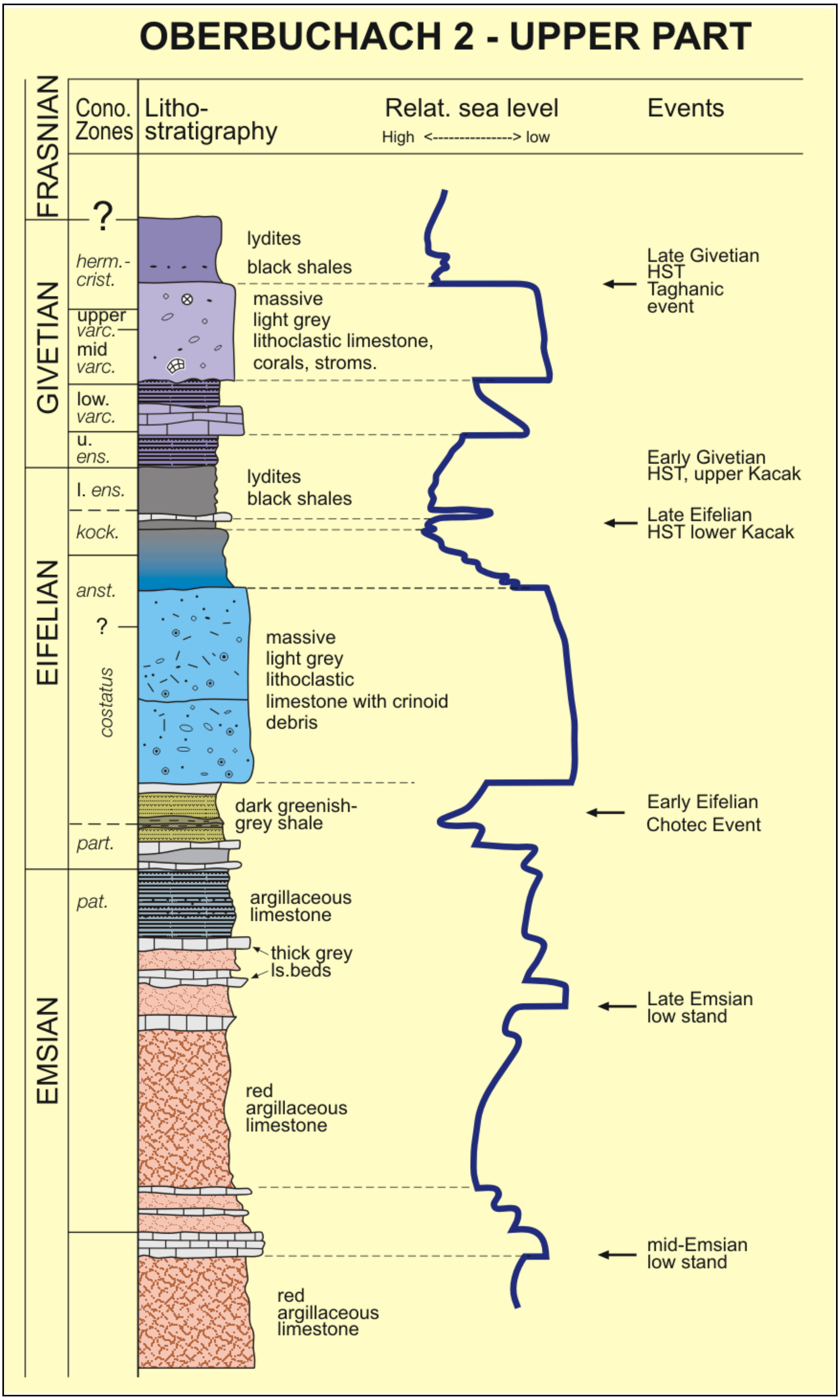


Fig. 17b: Section through the distal slope facies measured at Oberbuchach II, upper part. Adapted from SCHÖNLAUB, 1985. Sequence stratigraphic interpretation by C. BRETT.

VAI (1980) discussed the sedimentary environment of Devonian pelagic limestones from the Stua Ramaz section north of Paularo in the vicinity of Monte Zermula. VAI (1980: 80) noted the abundance of "grey allodapic limestone beds intercalated with red, partly nodular pelagic beds" which he described in detail. His description suggests that these limestones belong to the Findenig Facies which occurs also to the west at Findenigkofel and Oberbuchach. The colour change from grey to red, associated with increasing siliciclastic/carbonate ratio, is interpreted as lowered sedimentation rate by VAI (1980).

He discussed two different types of events that could account for the grey allodapic beds with redeposited shallow water material: (1) storms affecting the carbonate platform could stir up turbid clouds which drifted seaward and settled out of the water column over slope and basin. (2) Turbidity currents resulting from sediment overloading at the platform margin or on the upper slope. The grey limestone bed described above shows all indications of turbidite deposition, however, many of the grey limestones are very fine-grained and deposition from turbid clouds cannot be discounted. It is a well-known mechanism for deposition of fine-grained carbonates on recent carbonate slopes.

Condensed Pelagic Limestone Facies (Rauchkofel Facies)

Lower Devonian carbonates of the Rauchkofel-, Boden-, and Findenig Limestones were assigned to the Rauchkofel Facies (SCHÖNLAUB, 1979, 1985). Outcrops are confined to the Rauchkofel Imbricate Nappe Complex. The limestones of the Rauchkofel Facies are largely devoid of gravity flow and other coarse redeposited units and differ in this respect from the Findenig Facies.

Lower Devonian sections through the Rauchkofel Facies were measured at Seekopfsockel (Sks) and Rauchkofelboden (Rkb); sections through the Pragian/Emsian interval and the Emsian only, at Frauenhügel (H) and Wolayer Glacier (W.G.), respectively.

At Seekopfsockel 83 m of Devonian limestone are exposed of which 77.8 m are Lower Devonian. The Lochkovian interval encompasses 16.1 m of thin-bedded dark limestone, lighter grey "flaser" limestone and pink crinoidal limestones. Undifferentiated Pragian and Emsian "flaser" limestones (Findenig Limestone) with distinctive red colour comprise the remainder of the Lower Devonian succession.

Measuring of the section started at sample number 350 which marks the beginning of the Lochkovian (SCHÖNLAUB, 1980). The Lochkovian succession begins with 2.3 m of dark grey fine-grained bedded limestones with crinoidal debris. Particularly at the base white calcite veining is developed. Above, 1.1 m of thin-bedded dark limestones and shales follow overlain by 2.8 m of grey fine-grained stylo-bedded limestone. Thin sections show microskeletal wackestones with shell debris from trilobites, nautiloids and tentaculites in addition to relatively coarse crinoid debris. In one sample algae, small brachiopods and gastropods were found. Neither grading nor lamination was seen, and most units show signs of bioturbation in contrast to the laminated lower Lochkovian at Mount Cellon. The lithologies do not readily indicate deposition from turbidites but could also be deposits of a deep subtidal environment.

The thin-bedded limestones and shales are succeeded by 6,8 m of grey and pink, hackly weathering, crinoid limestone. All samples from this interval are composed of peloidal grainstone to packstone with varying amounts of coarse crinoid debris. Vague grading is seen in some samples. The different beds vary in the size of the skeletal debris which ranges from medium to coarse sand-size, whereas the peloids are of fine sand-size (rarely silt). The limestones in this interval of section show signs of resedimentation and the coarse crinoid debris was probably transported from a source further up-slope. Crinoidal calcarenites of similar age were reported from the Poludnig-Oisternig region in the eastern Carnic Alps by HERZOG (1988). He interpreted them as debris derived from a shallow water source and deposited down slope among grey lumpy and nodular limestones. The successions of Findenig Facies in this region contain numerous slump horizons, and an interpretation of the crinoidal units as slumps is also possible.

Fine-grained grey limestones with stylo-flaser fabric (3.1 m) form the top of the Lochkovian interval. They are characterized by yellow-brown stains, parting material and stylo-cumulate. Thin sections show skeletal wackestones with debris from tentaculites, ostracods, and trilo-bites. Crinoid debris is rare. The yellow-brown tinge stems from ferroan dolomite and brown flocculent matter in partings between lensoid limestone lumps.

The Silurian/Devonian boundary interval was investigated in detail in sections Sks. and Rkb. (SCHÖNLAUB, 1980, 1981). In both sections the lower Lochkovian is highly condensed (2 m at Rkb. compared to 9 m thickness at Oberbuchach).

Comparison of the Sks section with that at Rauchkofelboden shows similarities on a large scale but differences in details. The earliest Lochkovian is generally represented by dark, thin-ly bedded limestones interbedded with shales. This lower condensed unit is succeeded in all sections by the Boden Limestone, a grey, bedded "flaser" limestone with orthoconic nauti-loids at section RkB with a central unit of grey to pink echinoderm packstone occurring only at section Sks.

An abrupt colour change from grey to red (between sample # 35 and 36) marks the beginning of the Pragian (SCHÖNLAUB, 1980). The lower 23.5 m of the succession consist of inter-bedded red shale-rich and red and green mottled limestones, both with stylo-flaser fabric. Commonly units consist of 0.4 to 0.9 m of red recessively weathering shale-rich "flaser" lime-stone alternating with 1 m to 4 m thick massive red-pink "flaser" limestone. The Pragi-an/Emsian boundary is not clearly defined to date. SCHÖNLAUB (in BANDEL, 1972) placed the Siegen/Ems boundary about 18 m above the onset of red "flaser" limestone deposi-tion (just above sample # 48 [SCHÖNLAUB, 1980]).

The middle part of the red "flaser" limestone interval consists of 20 m of relatively massive "flaser" limestone with a peculiar pattern of patches of grey arenaceous wackestone that prob-ably represent burrow fills. The fractures run parallel and at low to moderate angles to bed-ding planes. Their number increases upsection. The cross cutting relationship with calcite filled fractures indicates that they are products of a later stage of deformation rather than synsedimentary fractures. The remaining 18.2 m of red "flaser" limestone are characterized by increasing limestone content and diminishing of the red colour. In the lower part of this inter-val are up to 15 cm thick grey limestone beds with no or little stylolites developed, spaced about 1 m apart. In the upper part occur 5-20 cm thick shale-rich beds alternating with 10-30 cm thick limestone-rich beds. Another abrupt colour change from red to grey indicates a posi-tion close to the top of the Lower Devonian. The exact location of the Emsian/Eifelian bound-ary is not known; it may coincide with the colour change from red to grey "flaser" limestone or may lie slightly lower as in the Wolayer Glacier section (GÖDDERTZ, 1982).

The Pragian/Emsian interval is characterized in all sections by the distinctive red "flaser" limestone. It appears quite uniform, but three vaguely confined units can be distinguished: (1) a lower unit with pink and red banding and locally, with pink and green mottling (at Sks on-ly), (2) a central shale-rich unit and (3) an upper red and grey banded unit.

Discussion

The deep water sections of the lower Lochkovian Rauchkofel Limestone Formation must be regarded as extremely condensed (SCHÖNLAUB, 1980), the remainder of the Lower Devonian is condensed compared to the distal slope sequences of the Findenig Facies. The additional amount of sediment derived from redeposition could probably explain the different thickness of the Findenig Facies.

BANDEL´s (1974) descriptions of "pelagic limestones with rare redeposited beds" from the region around Mount Rauchkofel include the limestones from sections measured at E. Pichl Hut, Seekopfsockel, Rauchkofelboden and Wolayer Glacier. He distinguished 5 different lithofacies and, based on his analyses, suggested deposition of the pelagic limestones in a basinal environment, ranging in depth between 300 m and 3000 m. SCHÖNLAUB (1980) suggested that the Lower Devonian (Lochkovian) cephalopod and tentaculite limestones of the Rauchkofel Facies were deposited on basinal swells and ridges, which formed as a result of increased bottom mobility at the end of the Lochkovian. KREUTZER et al. (1997) suggested that an extensional tectonic regime was responsible for the increasing bottom topography. A similar interpretation was invoked for the distribution of pelagic limestones and shales in the Frankenwald (H. TRAGELEHN, pers. com., 1999). The condensed pelagic limestones could also be deposits of the proximal basin floor or slope rise (the distal basin floor is preserved in the shales of the Bischofalm Facies) which was not reached by most turbidites. However, inspection of the Zollner Formation shows, that these rocks consist of interbedded cherts and siltstone units with the latter showing sedimentary structures indicative of turbidite deposition (flame structures, graded bedding, cross lamination, convolution). Consequently turbidites did reach the basin floor and their lack in the condensed pelagic limestone facies suggests that turbidites either bypassed this depositional environment or that it represented a separate depositional area.

The study of modern carbonate slopes shows that many different settings can occur along strike, depending on the varying oceanographic and geographic parameters. For example several different settings were documented from the Bahaman carbonate margin and slope, including a diagenetic ramp (MULLINS & NEUMANN, 1979). This model describes slopes which are quite gentle with little mass sediment transport. It is based on the situation on the northern side of the Great Bahama Bank where periplatform facies show downslope transition from hardgrounds to nodular ooze to unlithified ooze. Because of the windward position of this margin, redeposition involves mainly periplatform sediments with platform-derived material being sparse.

In contrast, the leeward margin at the western side of the Little Bahama Bank is characterized by a large percentage of redeposited platform-derived sediment.

The situation at the Tongue of the Ocean gave rise to the concentric facies belt model (SCHLAGER & CHERMAK, 1979). In this setting is sediment being supplied from windward, leeward and tide-dominated platform margins. Facies belts down slope are narrow and slopes are steep. A basinal pelagic facies is not developed because of the closed and narrow nature of the seaway. The Great Bahama Bank is a carbonate platform that was isolated from the American continent.

These models could account for the differences between the condensed pelagic limestone facies at Mount Rauchkofel and the expanded pelagic/redeposited limestone facies at Findenig and Oberbuchach. It could also explain the different pattern of sedimentation at Hoher Trieb where resedimentation is much reduced.

The change between reduced or zero sedimentation and full supply of oozes in pelagic limestones has been explained in terms of third-order sea-level fluctuations in Jurassic sequences of Spain (FELS & SEYFRIED, 1992). These authors found that lithification and erosion took place in the LST (low stand systems tract), ferromanganese crusts formed in the early TST (transgressive systems tract) and red limestones were characteristic for the late TST and HST (high stand systems tract).

VALENZUELA-RIOS & GARCIA-LOPEZ (1997) observed a diachronous event in pelagic sediments of northeastern Spain. In sections measured in the Catalonian Coastal Ranges and in the Spanish Central Pyrenees a change occurs from black shales with minor dark limestones to more massive light-coloured orange/reddish limestones with marl intercalations. This local event near the beginning of the Middle Lochkovian is marked by the disappearance of more endemic conodont faunas including *Icriodus* and the appearance of more cosmopolitan faunas with species of *Ancyrodelloides*. The conodont genus *Flajsella* is also common in this Middle Lochkovian interval (VALENZUELA-RIOS & MURPHY, 1997).

The Lochkovian Stage in the Barrandian sections is coincident with the Lochkov Formation and includes two principal lithostratigraphic units (members): the Radotin and the Kotys Limestones. The Radotin Limestone comprises dark bituminous platy limestones with variable amounts of dark shale intercalations and common cherts. Graded bedding and lamination are common sedimentary structures.

The Kotys Limestone is characterized by light-grey thick-bedded bioclastic limestones with debris from crinoids and brachiopods. A transitional facies is presented by the Kosor Limestone, a grey well-bedded bioclastic limestone with minor shale intercalations. SCHÖNLAUB (pers. com., 2001) noted the occurrence of *Ancyrodelloides transitans* in the upper part of the Lochkovian of the Barrandian.

CHLUPAC (1998) summarized facies trends in the Lower and Middle Devonian of central Bohemia. He recognized several stratigraphic events distinguishable in litho- and biofacies.

In the upper Lochkovian a trend of increasing energy and shallowing occurs followed by abrupt deepening at the Lochkovian/Pragian boundary. This is said to be an event of global significance (CHLUPAC & KUKAL, 1986) which can also be recognized in the Carnic Alps where in the basal Pragian of the Rauchkofel Nappes a significant change in lithology occurs (i.e. from grey to red "flaser" limestone).

The Pragian interval in central Bohemia is, according to CHLUPAC (1998), characterized by a trend of increasing water depth interrupted by a shallowing event at the base of the Zlichovian manifested in the increased transport of coarse biodetritus in the northeastern part. This interval approximates the base of the dehiscens Zone. In the sections at Oberbuchach this is the level where the first grey banded units begin to appear, some of these grey beds are bioclastic calcarenites whereas others are light grey micritic beds which may or may not be fine-grained turbidite deposits. It is also the level, where the limestone content in the red "flaser" limestones increases. This increase could either be due to increased lime production/offshore transport or decreased transport of terrigenous material. In view of the connection with increased turbidite flows, it seems more likely, that increased offshore transport and/or production of lime on the platform is the cause for this higher lime content. This would also imply, that the shale rich Pragian succession is a starved sequence where muds were slowly deposited and spent long periods of time exposed to oxygenated bottom waters which caused them to oxidize. The thicker grey beds which were the result of quasi-instantaneous events (i.e. turbidites) with thicknesses of several centimeters to decimeters were only superficially exposed to the bottom water and remained grey.

During the Pragian reefs and crinoidal sands accumulated on the shelf. During this time of presumably high sea level, transport of coarse material onto the slope was reduced (no high stand shedding!) and on the upper slope dominantly hemipelagic sediment was deposited. On the lower slope supply of carbonate was reduced and deposition rate slow. For the offshore deep basinal sequences (Zollner Formation) deposition of cherts is predicted. The pelagic carbonates of the Rauchkofel Facies display red and pink banding attaining a rhythmic character.

The Pragian/Emsian boundary coincides at Oberbuchach with the beginning of the grey banded interval with more calcareous red "flaser" limestones. At Mount Seewarte the boundary was drawn tentatively at the first appearance of *Polygnathus* sp. between sample numbers 16 and 18 (BANDEL, 1969; VAI, 1973), approximately 50 m below the onset of the lagoonal Seewarte Limestone Formation which is also Zlichovian in age (ERBEN et al., 1962; KREUTZER, 1990; SCHÖNLAUB, 1985). The succeeding Lambertenghi Limestone is composed of shallowing upward cycles of shallow intertidal to supratidal limestones and dolomites. Obviously, during the Emsian the platform margin prograded far seaward, a process that must have led to steepening of the slope. This steepening is reflected in the increasing occurrence and number of gravity flow deposits on the proximal slope. The grey limestone beds of the distal slope nappe represent the distal turbidites associated with this progradation.

The succeeding fossiliferous wackestones with favositids clearly indicate deepening on the shelf and backstepping of the shelf margin. There is little biostratigraphic control available for this interval. It may coincide with the early Eifelian Chotec event (transgressive event) observed at Oberbuchach (cf. WALLISER, 1990). Dark-greenish to grey shales were deposited in this time interval. At Mount Cellon and Mount Freikofel or other successions of the proximal slope facies this interval has to date not been identified. This is partly due to the lack of detailed biostratigraphic control and partly to the uniform style of sedimentation.

The overlying crinoidal calcarenites and bioclastic calcirudites probably belonging to the crinoid-cortoid facies of KREUTZER (1990), who interpreted them as back reef or subtidal shelf deposits, suggest progradation again. They are succeeded by peloidal calcarenites and finally birdseye limestones and *Amphipora* limestones suggesting restriction probably associated with the buildup of a rimmed platform margin. The abundance of reefal debris in the upper slope succession supports this interpretation. The sections reviewed reveal similarities in pattern that suggest widespread allocyclic controls. Moreover, event and sequence stratigraphy of CA sections, particularly those representing medial to distal slope facies (e.g. Oberbuchach road cut), show striking similaries of pattern to coeval Devonian sections of the northern Appalachian Basin (NAB) in eastern Laurentia (especially New York State and Pennsylvania) correlated with conodont biostratigraphy (C. BRETT, unpubl.).

All sections reveal evidence for a period of shallowing in the late Emsian to earliest Eifelian patulus-partitus Zones. In the distal-medial slope sections this event is marked by the appearance of grey crinoid-bearing carbonates that overlie red nodular deeper water carbonates of the earlier Emsian. In the medial to distal slope facies in the Carnic Alps these beds are followed by dark, argillaceous limestones and dark grey shales in the early Eifelian partitus-costatus Zones. The presence of dark organic rich bands near the base of the costatus Zone may be a local representation of the Chotec event, which has been recognized in the Pragian Basin and elsewhere.

The different sections show consistent changes that reflect the development of the Carnic carbonate platform in the Lower Devonian. Several sequence boundaries can be identified. Allocyclic patterns reflecting eustatic sea level changes and other global events are best documented in distal slope sections whereas margin architecture can be best deduced from the proximal slope and carbonate platform settings.

Carboniferous

According to SCHÖNLAUB et al. (1991) in the Carnic and Karawanken Alps the vertical range of the Variscan limestone successions varies considerably. Some end close to the Frasnian/Famennian boundary, others in the middle or upper Famennian, and others range within different levels of the Lower Carboniferous. Yet, at some localities the uppermost beds have yielded diagnostic conodonts and ammonoids of the *anchoralis latus* conodont Zone, thus indicating an age at the Tournaisian/Visean boundary. Recently, a slightly younger age has been inferred from additional sections from the Italian side of the Carnic Alps, west of Plöckenpass, which provided a "post-*Scaliognathus*" conodont fauna corresponding to the Pericyclus IIγ Stage of the uppermost Tournaisian or lowermost Visean Stage of the Lower Carboniferous (SCHÖNLAUB & KREUTZER, 1993; PERRI & SPALLETTA, 1998a,b; SPALLETTA & PERRI, 1998).

The nature of the transition from the above mentioned limestones to the overlying siliciclastics of the Hochwipfel Formation raised a long lasting controversy about the significance of tectonic events in the Lower Carboniferous.

Apparently, this has been settled after recognition of a wide variety of distinct paleokarst features in the Karawanken and the Carnic Alps (TESSENSOHN, 1974; SCHÖNLAUB et al., 1991). The paleokarst was caused by a drop in sea-level during the Tournaisian. Rise of sea-level and/or collapse of the basin promoted the transgression of the Hochwipfel Formation which presumably started in the Lower Visean.

Based on its characteristic lithology and sedimentology TESSENSOHN (1971, 1983), SPALLETTA et al. (1980), AMEROM et al. (1984), SPALLETTA & VENTURINI (1988) and others interpreted the 600 to more than 1000 m thick Hochwipfel Formation as a Variscan flysch sequence. In modern terminology the Kulm deposits indicate a Variscan active plate margin in a collisional regime following the extensional tectonics during the Devonian and Lower Carboniferous Periods. The main lithology comprises arenaceous to pelitic turbidites and other types of mass flow sediments. In addition to these lithologies, along the northern margin of the region up to 10 m thick plant-bearing sandstone beds (Middle Visean to Namurian age [AMEROM et al., 1984; AMEROM & SCHÖNLAUB, 1992]) consitute a prominent member of the Hochwipfel Formation. Except for trace fossils the paleontological evidence of the flysch sediment is very poor. Other stratigraphic data are derived from the fore-mentioned underlying limestone beds and locally occurring intercalations of limestone clasts with stratigraphically important fossils such as the coral *Hexaphyllia mirabilis*, the algae *Pseudodonezella tenuissima*, the foraminfera *Howchinia bradyana* and early fusulinids. These clasts were supplied from a shelf-like source area located originally to the north of the present Southern Alps but which was completely destroyed by later tectonic events.

According to LÄUFER et al. (1993) the volcaniclastites and basic volcanics of the Dimon Formation occur at the base of the Hochwipfel Formation and not as its lateral equivalents or as a succeeding event. They represent intraplate alkalibasalts indicating the climax of the rifting immediately before the onset of the deposition of the Hochwipfel Formation.

In the Southern Alps the Variscan orogeny reached the climax between the Late Namurian and the Late Westphalian Stages. This time corresponds to the interval from the Early Bashkirian to the Middle or Late Moscovian Stages. According to KAHLER (1983) the oldest post-Variscan transgressive sediments are Late Middle Carboniferous in age and, more precisely, correspond to the *Fusulinella bocki* Zone of the Upper Miatchkovo Substage of the Moscovian Stage of the Moscow Basin (for more details see KRAINER, 1992). In particular between Stranig Alm and Lake Zollner they rest with a spectacular angular unconformity upon strongly deformed basement rocks including the Hochwipfel Formation the Silurian-Devonian Bischofalm Formation and different Devonian limestones. This basal part named the Waidegg Formation consists mainly of basal conglomerates, disorganised pebbly siltstones and arenaceous and silty shales with thin limestone intercalations. Even meter-sized limestone boulders reworked from the basement were recognized at the base of the transgressive sequence (FENNINGER et al., 1976) and which was named Malinfier Horizon by Italian geologists (VENTURINI, 1990).

The lower part of the Bombaso Formation south of Naßfeld, i.e., the Pramollo Member, has also long been regarded as the base of the Auernig Group in this area (VENTURINI et al., 1982; VENTURINI, 1990). Based on new field evidence, however, for this member a clear relationship with the Variscan Hochwipfel Formation is suggested.

In the Naßfeld region the transgressive molasse-type cover comprises the 600 to 800 m thick fossiliferous Auernig Group. Although the oldest part may well correspond to the late Moscovian Stage (PASINI, 1963) the majority of sediments belong to the Kasimovian and Ghzelian Stages. Based on rich fusulinid evidence from the Schulterkofel section west of Rattendorf Alm the Carboniferous/Permian Boundary has recently been drawn by the first appearance of the genera *Pseudoschwagerina* and *Occidentoschwagerina* in the upper part of the Lower Pseudoschwagerina Limestone and not at its base as previously suggested (KAHLER & KRAINER, 1993).

Permian

In the Lower Permian the Auernig Group is succeeded by a series of more than 1000 m thick shelf and shelf edge limestones and clastics (KRAINER, 1992, 1993; FORKE, 1995). They characterize a differentially subsiding carbonate platform and outer shelf setting which were affected by transgressive-regressive cycles from the Westphalian to the Artinskian Stages. This cyclicity may be explained as the response to the continental glaciation in the Southern Hemisphere (KRAINER, 1991; SAMANKASSOU, 1997).

Upper Permian sediments rest disconformably upon the marine Lower Permian or its equivalents, and farther west, on the Ordovician Val Visdende Formation and quartzphyllites of the Variscan basement. They indicate a transgressive sequence starting with the Gröden Formation and followed by the Bellerophon Formation of Late Permian age (BOECKELMANN, 1991; HOLSER et al., 1991; KRAINER, 1993).

Field Trip Stops

Stop 1 – Cellon Section

The famous section is located between 1480 and 1560 m on the eastern side of the Cellon mountain, SSW of Kötschach-Mauthen and close to the Austrian/Italian border. It can be reached within a 15 minutes walk from Plöckenpass.

The Ordovician to Lower Devonian part of the Cellon section is best exposed in a narrow gorge cut by avalanches (Fig. 18). Thus, the German name for the section is "Cellonetta Lawinenrinne".

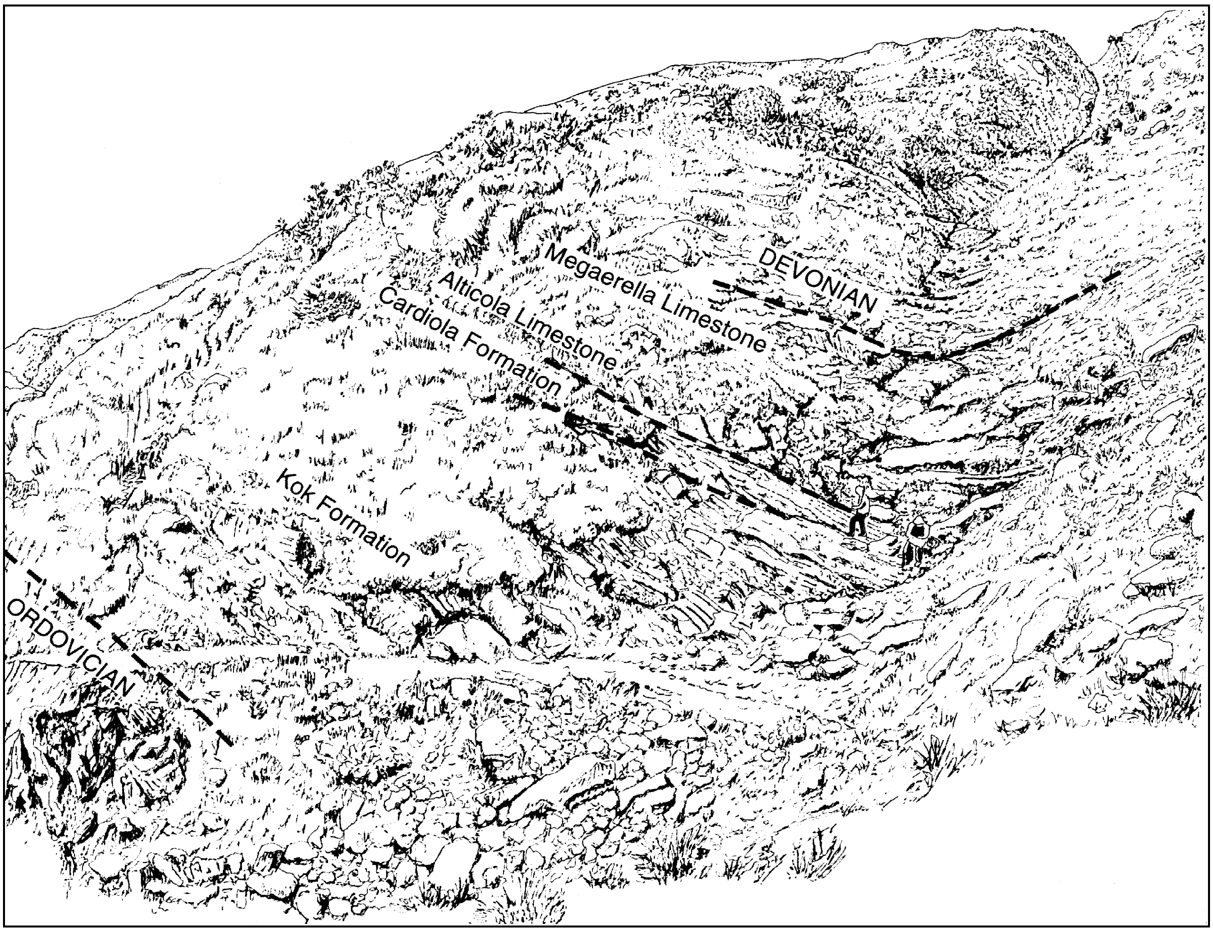


Fig. 18: View of the Cellon section (from HISTON et al., 1999).

Stratigraphy

The Cellon section represents the stratotype for the Silurian of the Eastern and Southern Alps. Nowhere else in the Alps has a comparably good section been found. It has been famous since 1894 when GEYER first described the rock sequence. In 1903 it was presented to the 9th IGC which was held in Vienna. According to v. GAERTNER (1931) who studied the fossils and rocks in great detail, the 60 m thick continuously exposed Upper Ordovician to Lower Devonian section could be subdivided into several formations. Since WALLISER's pioneering study on conodonts in 1964 it still serves as a standard for the worldwide applicable conodont zonation which, however, has been further detailed and partly revised in other areas during the last two decades. Although the conformable sequence, corresponding to the Plöcken Facies, suggests continuity from the Ordovician to the Devonian, in recent years several small gaps in sedimentation have been recognized which reflect eustatic sea-level changes in an overall shallow-water environment. From top to base the following formations can be recognized (Fig. 19):

Lochkovian	80.0 m	Rauchkofel Limestone (dark, platy limestone)
Silurian	8.0 m	Megaerella Limestone (greyish and in part fossiliferous limestone; equivalent to the Pridoli Series)
	20.0 m	Alticola Limestone (grey and pink nautiloid bearing limestone; Ludlow to Pridoli)
	3.5 m	Cardiola Formation (alternating black limestone, marl and shale; Ludlow)
	13.0 m	Kok Formation (brownish ferruginous nautiloid limestone, at the base alternating with shales; Late Llandovery to Wenlock)
Ordovician	5.4 m	Plöcken Formation (calcareous sandstone; Ashgill, Hirnantian Stage)
	6.5 m	Uggwa Limestone (argillaceous limestone grading into greenish siltstone above; Ashgill)
	>50 m	greenish and greyish shales and siltstones (Caradoc to Ashgill)

According to SCHÖNLAUB (1985) the Ordovician/Silurian boundary is drawn between the Plöcken and the Kok Formations, i.e. between sample nos. 8 and 9. In the Plöcken Fm. index fossils of Hirnantian age (brachiopods, trilobites, conodonts) clearly indicate a latest Ordovician age (JAEGER et al., 1975; FERRETTI & SCHÖNLAUB, 2001; SCHÖNLAUB & SHEEHAN, 2003). These strata represent the onset of the end-Ordovician - Lower Silurian transgressive cycle known from many places in the world (SCHÖNLAUB, 1988).

According to conodonts and graptolites from the basal part of the overlying Kok Fm. the equivalence of at least six graptolite and two conodont zones are missing in the Lower Silurian. Renewed sedimentation started in the late Llandovery within the range of the index conodont *P. celloni.*

At present the precise level of the Llandovery/Wenlock boundary can not be drawn. Graptolites and conodonts, however, indicate that this boundary should be placed between levels nos. 11 and 12. Consequently, the rock thickness corresponding to the Llandovery Series does not exceed some three meters.

According to SCHÖNLAUB in KRIZ et al. (1993) the boundary between the Wenlock and the Ludlow Series can be drawn in the shales between sample nos. 15 B1 and 15 B2. Apparently, this level most closely corresponds to the stratotype at quarry Pitch Coppice near Ludlow, England. We thus can assume an overall thickness of some 5 m for Wenlockian sedimentation. By comparison with the Bohemian sections the strata equivalent to the range of *Ozarkodina bohemica* are at Cellon extremely condensed suggesting that during the Homerian Stage sedimentation occurred mainly during the lower part. With regard to the foregoing Sheinwoodian Stage it may be concluded that at its base the corresponding strata are also missing or represented as the thin shaly interval between sample nos. 12 A and 12 C. At this horizon the *M. rigidus* Zone clearly indicates a late Sheinwoodian age.

By correlation with Bohemian sequences and the occurrence of index graptolites for the base of the Pridoli, the Ludlow/Pridoli boundary is drawn a few cm above sample No. 32

(SCHÖNLAUB in KRIZ et al., 1986). This horizon lies some 8 m above the base of the Alticola Lst. The corresponding sediments of the Ludlow have thus a thickness of 16.45 m.

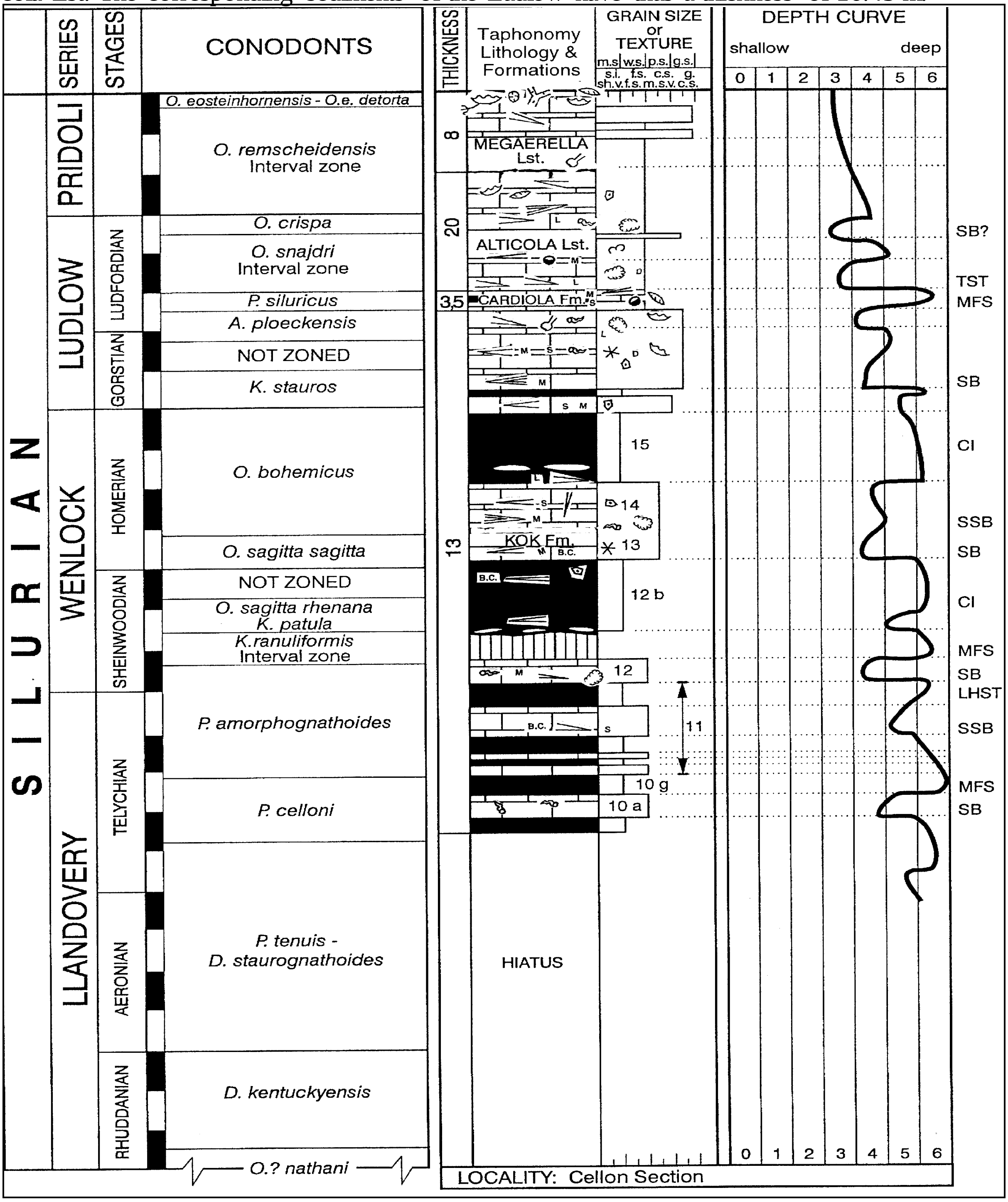


Fig. 19: Conodont stratigraphy, lithology, grain size, significant taphonomic features and depth curve of the Silurian of the Cellon section. Modified from SCHÖNLAUB, 1997.

At Cellon the Silurian/Devonian boundary is placed at the bedding plane between conodont sample nos. 47 A and 47 B at which the first representatives of the index conodont *Icriodus woschmidti* occur. It must be emphasized, however, that the first occurrences of diagnostic graptolites of the Lochkovian is approx. 1.5 m higher in the sequence. JAEGER (1975) recorded the lowermost occurrences of *M. uniformis, M.* cf. *microdon* and *Linograptus posthumus* in sample no. 50. The Pridoli may thus represent a total thickness of some 20 m.

Lithology and Microbiofacies

The first facial investigation at the Cellon section was carried out by FLÜGEL (1965). BANDEL (1972) studied the facies development of the Lower and Middle Devonian in the central part of the Carnic Alps. Middle and Upper Devonian and Lower Carboniferous strata (exposed as steep cliffs and on top of Cellon) were investigated by KREUTZER (1990). Photomicrographs from the Ordovician to Lower Carboniferous sequences comprising the whole Cellon section were published by KREUTZER (1992b) and a preliminary study of the Silurian was given by KREUTZER (KREUTZER & SCHÖNLAUB, 1994). Current work on the cephalopod limestone biofacies in the Carnic Alps with regard to the paleogeographical setting during the Silurian has highlighted many interesting microfacial aspects of the predominantly calcareous sequence.

Uggwa Limestone (Beds 1-4)

This up to 6 m thick limestone horizon comprises indistinctly bedded grey to coloured pelagic "flaser" limestones with ostracod, cystoid and bryozoan debris layers. Sceletal grains consist of brachiopods, ostracods, bryozoans, agglutinate forams, rare cephalopods, trilobites, conodonts and acritarchs.

Plöcken Formation (Beds 6-8)

The 5.40 m thick Plöcken Fm. comprises impure coarse-grained limestones in the lower part consisting of skeletal grains of echinoderms, brachiopods, ostracods, trilobites and conodonts. These grainstones grade into calcareous sandstones and siltstones and shales.

Kok Formation (Beds 9-20) (Fig. 20)

Bed 9: Base of the Silurian sequence: At the level of the Ordovician/Silurian boundary the transition from the greenish silts-shales of the Plöcken Fm. to the carbonate sequence of the Upper Llandovery is marked by the occurrence of flattened nodules approximately 3-5 cm in diameter which appear to be micritic, dark grey-black in colour, quite dense and showing iron weathering: The overlying shales and carbonate layers are badly deteriorated: Fossil content not apparent.

Bed 10: Again a series of shales and thin carbonate beds: level E is the best preserved and shows trace fossil features at the base and the first development of "crust" like shales otherwise fossil content not apparent although a trilobite fauna has been described from this level.

Bed 11: The base is marked by micritic lenses or nodules with "crusts". The overlying shales have a crinoid, trilobite and brachiopod fauna towards the top of the sequence: The first occurrence of nautiloids is at the base of the Wenlock with levels of alternating shales and of reddish-grey micritic carbonate levels which have upper and lower crusts. There is a nautiloid fauna both in the shales and limestones. The shales show flow features around the lenses and the nautiloids are enclosed within the shales. They are small to medium in dimension with an abundance of medium nautiloids towards the top of the sequence. They are parallel to bedding with both body chamber and apexes preserved and have an outer oxidised coating only in the carbonates. A change may be noted up the sequence in that the nautiloids become relatively more abundant in the carbonate levels whereas previously they were more abundant in the shales.

General remarks: Thin beds of ferruginous limestone, sometimes bioturbated, are intercalated at the base of the Kok Formation in dark shales locally rich in small brachiopods. At the top of bed 12, a thin and lenticular calcareous horizon (12b) in shales has provided an important cardiolid fauna (KRIZ, 1999). This is a cephalopod wackestone the matrix of which bears many ostracods, echinoderms, rare small bivalves and gastropods. Many muellerisphaerida are present in darker bituminous micritic areas.

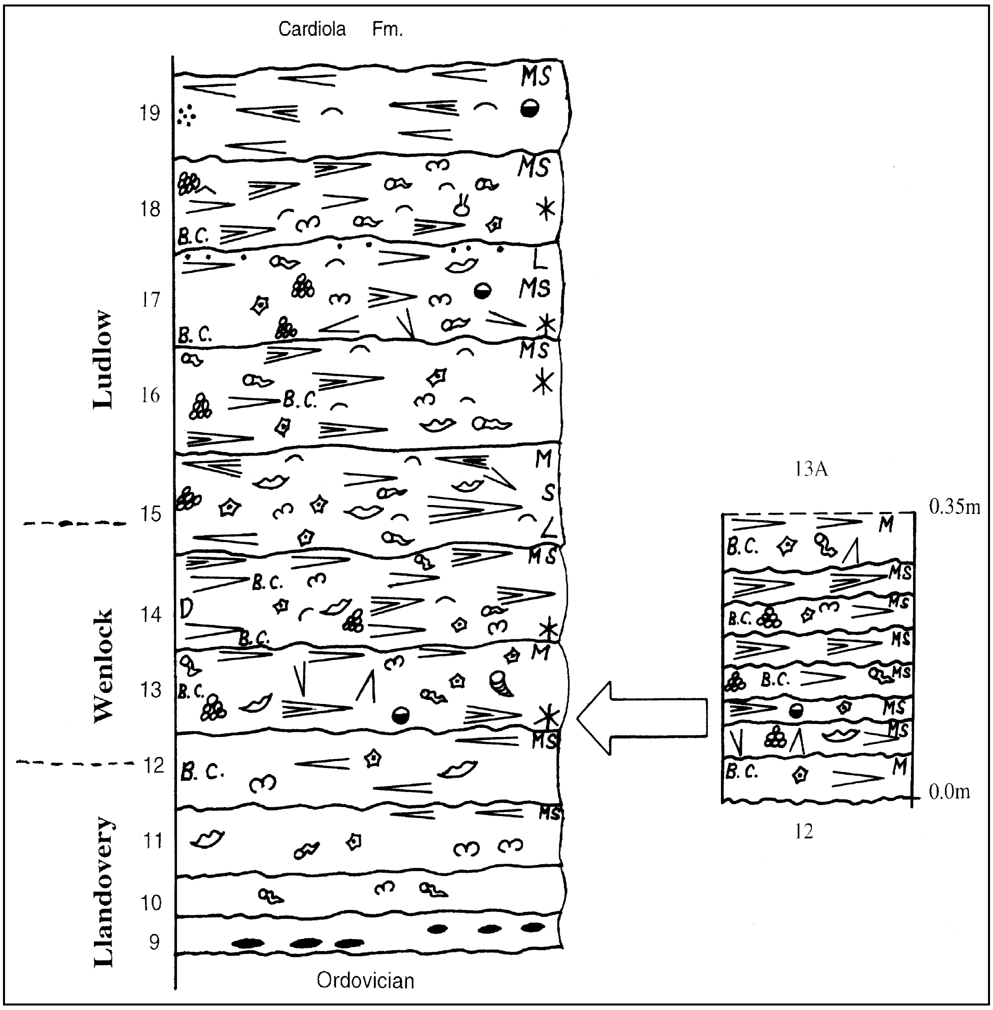


Fig. 20: Taphonomy of the Kok Formation. Note detail of small scale cyclic repetition of beds indicating changes in the hydrodynamic regime.

Starting from bed 13, the limestone becomes thicker and more massive. The reddish colour and the intensive bioturbation are the most typical features of the upper part of the Kok Formation up to level 17. This cephalopod wackestone is locally rich in brachiopods, echinoderm debris, trilobites, gastropods and ostracods. Some organisms, mostly cephalopods, reveal peculiar iron-banded coatings. Dolomitization is frequent. Around level 15 B1 a singular grainstone of well sorted equidimensional bioclasts occurs which strongly resembles the coeval horizon of the Rauchofel Boden section. Abundant small thin-shelled bivalves, preserving the two valves still connected, gastropods, trilobites and isolated echinoderm ossicles have iron-stained shells. Shell in shell structures are common there. Starting from around bed 18 the limestone becomes greyer. Pyrite aggregates in the matrix may be occasionally found.

Cardiola Formation (Beds 21-24)

It is represented by bioclastic shelly layers a few centimeters thick (wackestone-packstone) with a sharp base interbedded with dark shales. At the base of the Cardiola Formation (level 21) bioclastic wackestones rich in cephalopods, trilobites, crinoids and ostracods are intercalated in soft micritic sediments. Scouring traces at the top of the soft sediments, debris grainstone at the base of the overlying horizon with enrichment in iron and manganese oxides would exhibit, according to KREUTZER (1992b), the existence of a Fe-Mn hardground. Millimetric pavements of small brachiopods are present in bed 22. When seen in thin-section, they reveal a cephalopod-ostracod bioclastic packstone with abundant brachiopods, but also associated with graptolites, thin-shelled bivalves and micritized grains. Shelter porosity, common orientation of geopetal structures and telescoping of cephalopods have been observed. Sorting is moderate. These shelly laminae decrease in thickness towards the top of the formation and alternate with thin dark bands rich in organic matter and muellerisphaerida, possible ostracods and recrystallized cephalopods.

Alticola Limestone (Beds 25-39)

The Alticola Limestone (Ludlow-Pridoli in age) is distinctive in that it forms the base of the steep slope of the section. The erosive base of the grey dolomitised massive beds contrast sharply with the black shales of the underlying Cardiola Fm. and this reflects an easily recognizable greyish to reddish limestone formation. It has an overall thickness of 20 m and represents a transgressive carbonate series within more stable pelagic conditions (SCHÖNLAUB, 1997). Grey to dark pink limestones represented mainly by a bioclastic packstone with fine-grained micritic matrix with a variety of bed thickness and frequent stylolites are common in the Ludlow with a dominant nautiloid fauna. The beds decrease in thickness in the Pridoli and alternate with interbedded laminated micrites with a dominant nautiloid and brachiopod fauna. Several deepening events marked by the development of black shales have been documented within the uppermost levels of the Pridoli. Cephalopods are abundant, together with crinoids, trilobites, large gastropods and ostracods. Iron-coatings, mostly around trilobites, are again present. Bioturbation is common.

Megaerella Limestone (Beds 40-47A)

The Megaerella Limestone (Pridoli in age) comprises the upper Pridoli and Silurian/Devonian boundary transgressive sequences of carbonates rich in biodetritus, lenticular micrites and black shales. It has a thickness of 8 m and forms the steep step at the top of the section. Light grey limestones (wackestone to packstones) with cephalopods, ostracods, echinoderm debris and trilobites are dominant. A particular level of juvenile nautiloids (RISTEDT, 1968) occur in bed 40. Bryozoans (*Fenestella* s.l. sp. and a small indeterminate cryptostome [Wyse JACKSON, pers. comm.]) occur on a distinct bedding plane above the Silurian/Devonian boundary together with bivalves. Complete specimens of *Scyphocrinites* (HAUDE, pers. comm.), solitary corals and articulated cridoid stems are common in the lower beds of the Lochkov.

According to KREUTZER (1994) the bathymetric environment for the Upper Ordovician to Devonian sequence can be described as follows:

As early as in the Ordovician a facial differentiation can be recognized for the carbonates. The Cellon section with its Uggwa Limestone development (sample 1-5) represents the late Ordovician Uggwa Facies which is time-equivalent to the Wolayer Limestone of the Himmel-berg

Facies exposed, e.g., at the Rauchkofel-Boden section. Based on conodonts the Uggwa Limestone is well dated as being Ashgillian in age. According to DULLO (1992), the two formations represent the near-shore parautochthonous cystoid facies (Wolayer Limestone) and an off-shore basinal debris facies (Uggwa Limestone), respectively.

At the end of the Ordovician in the Carnic Alps a regression occurred. The Uggwa Limestone bed nos. 1-4 characterized by pelagic faunal elements, are followed by limestones composed of subtidal components of the Plöcken Formation (bed nos. 5-8). A significant unconformity separates the Plöcken Fm. from the overlying Kok Fm.

Transgression of the Kok Formation started in the Cellon section in the Upper Llandovery (bed no. 9). In contrast to the Cellon section the Rauchkofel section located some 8 km to the northwest exhibits a considerably reduced sequence. At Cellon the basal Silurian succession represents a moderately shallow environment which may have lasted until the Llandovery/Wenlock boundary or until the very beginning of the Wenlock. Sample 11 exhibits a very shallow to intertidal environment. During the remaining part of the Wenlock a transgressive trend can be recognized. However, at the Wenlock/Ludlow boundary (bed nos. 15A-F) some strata may be missing reflecting either submersion or reduced sedimentation.

During deposition of the Cardiola Formation (bed nos. 21-24) contemporary non-deposition may have occurred. Black limestone and shale beds with radiolarians alternate with pelagic limestone beds indicating an offshore environment. The following Alticola Limestone (bed nos. 25-39) reflects stable conditions in a pelagic environment which terminated in a regressive pulse (bed no. 40). With the beginning of the Megaerella Limestone (nos. 41-47A) a further transgressive trend can be inferred.

Starting in the Lochkovian Stage (bed 47B and >; Rauchkofel Limestone) and ranging to the Upper gigas Zone of Frasnian age (top region of the Cellon cliff) the Devonian transitional facies represents a fore-reef facies. While this slope facies accumulated at Cellon, only a few kilometers to the palinspastic SSW (today seen at the Kellerwand region) more than 1000 meters of Devonian shallow-water limestones were deposited. Moreover, coeval carbonates of pelagic origin, i.e. pelagic limestone facies of the Rauchkofel Nappe, with a markedly reduced thickness of not more than 100 meters were deposited within short distances to the NNE (SCHÖNLAUB, 1979, 1985; KREUTZER, 1990, 1992a, b).

During the crepida Zone of the Famennian a short-lasting regression occurred. In the Upper Famennian and Lower Carboniferous uniform cephalopod limestones were deposited (Pal and Kronhof Limestone, respectively). At the beginning of the Visean the flysch of the Hochwipfel Formation transgressed upon the Kronhof Limestone and limestone deposition ended.

In more detail the Devonian to Lower Carboniferous succession is subdivided into the following formations (KREUTZER, 1992). It represents the transitional facies between the southwestern shallow-water realm and the eastern to northeastern deep-water settting:

80 m	well-bedded pelagic Rauchkofel Lst.: dark grey and black plate limestones with occasional organodetritic interbeds (Lochkov);
120-150 m	Kellerwand Lst.: well-bedded yellowish tentaculite limestones alternating with skeletal debris layers (Pragian to Lower Emsian);
120 m	Vinz Lst.: well-bedded dark grey platy limestone interbedded with detritic layers (Emsian);
150-200 m	Cellon Lst.: grey massive limestone beds composed of pelagic biogenes, bioclasts and debris layers (Eifelian-Givetian);
50-100 m	Pal Lst.: greyish to reddish and also pinkish cephalopod limestone (Frasnian to Famennian);
1-3 m	Kronhof Lst.: greyish to reddish cephalopod limestone (Tournaisian).

A short distance to the west of the peak of Cellon at the famous Grüne Schneid section the Devonian/Carboniferous boundary beds are excellently exposed. The detailed distribution of conodonts, goniatites and trilobites as well as the lithology and major and trace element content was recently studied by an international working group (see SCHÖNLAUB et al., 1992).

The Ordovician-Silurian Boundary Event
(SCHÖNLAUB & SHEEHAN, 2003)

The mass extinction at the end of the Ordovician led to the disappearance of about 100 families, which represented about 22% of all marine families (SEPKOSKI, 1982, 1993). This demise affected mainly trilobites, brachiopods, echinoderms, stromatoporoids, corals, bryozoans, ostracods, bivalves, cephalopods, graptolites, conodonts, chitinozoa and acritarchs. In comparison with the great dying at the P/T boundary, this was the second largest catastrophe in the Phanerozoic.

During the last years a number of explanations have been suggested for this extinction, such as the species/area-effect as a negative consequence of the global ice age with an associated regression (BRENCHLEY, 1995; HARPER & JIA-YU, 1995; OWEN & ROBERTSON, 1995), increased sedimentation with related pollution due to a significant sea-level decrease (WYATT, 1995), or changes in the composition of sea water and precipitates (ORTH et al., 1986; WILDE et al., 1986; MELCHIN et al., 1991; GOODFELLOW et al., 1992; WANG et al., 1992, 1993; LONG, 1993). Furthermore, in a few areas, such as South China, the Canadian Arctic, on Anticosti Island, and in South Scotland (Dob's Linn stratotype area), elevated Ir contents were found in boundary layers. However, they have been interpreted to be of terrestrial origin (WANG et al., 1995).

The global ice age at the end of the Ordovician is unusual because it occurred at a time when the atmosphere had increased CO_2 contents and, thus, the Earth should have had a relatively stable greenhouse climate (BRENCHLEY et al., 1994). At that time the atmospheric CO_2 content was supposedly 14 to 16 times higher than today (BERNER, 1990, 1992, 1994; CROWLEY & BAUM, 1991; GRAHAM et al., 1995; MORA et al., 1996).

New studies seem to have clarified the long-standing question regarding the exact timing of the end-Ordovician mass extinction. According to SUTCLIFFE et al. (2001) and SHEEHAN (2001) this event occurred at the base of the Hirnantian Stage of the Upper Ordovician with the beginning of the graptolite Zone of *Normalograptus extraordinarius*. At that time the ratios of the stable isotopes of C, O and S changed, which was explained as a result of biomass reduction, temperature increase, and a short-term flooding of the continental shelf with anoxic water (GOODFELLOW et al., 1992). The latter supposedly was the ultimate cause of the mass extinction. However, an opposite trend was observed for the Hirnantian Stage in middle Sweden by MARSHALL & MIDDLETON (1990).

Based on recent stratigraphic and geochemical studies, the following scenario has been proposed for the Upper Ordovician: Beginning with the so-called gracilis-transgression of the older Caradoc Series, the global sea level increased until the end of the Ordovician (ROSS & ROSS, 1992). This second-order cycle was, however, overprinted by a regressive-transgressive trend in the late Ashgill Series lasting for about 0.5 to 1 million years, i.e. during the early to middle Hirnantian Stage. This trend was caused by glacio-eustatic changes and led to a sea level dropping of about 100 meters (BRENCHLEY & NEWELL, 1980; SHEEHAN, 1988, 2001; BRENCHLEY & MARSHALL, 1999; BRENCHLEY et al., 1991, 1994). The glaciation extended over an area of approx. 30 million square kilometers of the southern hemisphere. It resulted in a significant decrease in the average temperature, as well as in an increased productivity due to increased oceanic circulation. The latter is evident from anomalies in the oxygen and carbon isotope ratios of marine carbonates and in the organic carbon reservoir. This deterioration of the climate and the overall changes of the nutrient supply was held responsible for the first pulse of the twofold mass extinction. After the faunal demise the opportunistic Hirnantia Fauna started to invade middle and higher latitudes. This fauna reached its highest diversity within the *N. extraordinarius* Zone.

At the base of the graptolite Zone of *N. persculptus*, both isotope curves show an opposite trend (MARSHALL et al., 1994; BRENCHLEY et al., 1994; WANG et al., 1994). This signal is assumed to indicate the end of the glacial period, as well as a decreased production of biomass. This condition seems to have been the reason for a second mass extinction shortly before the end of the Ordovician.

Facies sequence data from Upper Ordovician deposits in the Carnic Alps also reflect a regressive-transgressive sedimentary pattern during the Hirnantian Stage (SCHÖNLAUB, 1988; SCHÖNLAUB & SHEEHAN, 2003) (Fig. 21). The regressive trend is well documented in the upper part of the Uggwa Limestone and culminates in the bioclastic Plöcken Formation of the late Hirnantian Stage. Newly recovered conodonts and graptolites from this formation seem to indicate a level immediately below the Ordovician/Silurian boundary (FERRETTI & SCHÖNLAUB, 2000; SCHÖNLAUB & SHEEHAN, 2003).

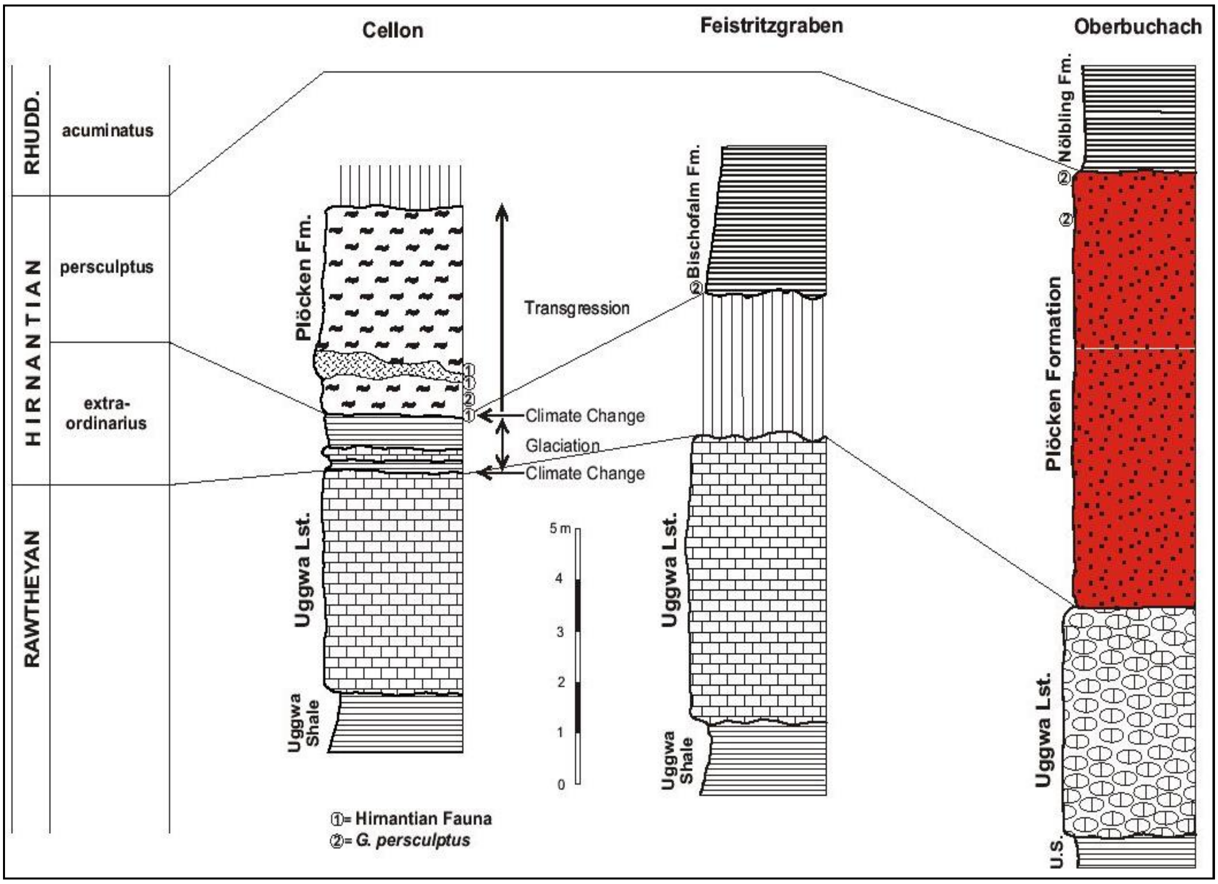


Fig. 21: The Upper Ordovician succession of the sections Cellon, Feistritz Gorge and Oberbuchach (Carnic Alps and Western Karawanken Alps) with inferred glacio-eustatic events.

In the Carnic Alps clastic sediments are the dominating lithologies during the Caradocian and early Ashgillian Series. They are succeeded by fossiliferous limestones known as the up to 20 m thick bryozoan and cystoid bearing Wolayer Lst. and the coeval 4-6 m thick Uggwa Lst., respectively. The latter represents a slightly deeper open marine setting being formed during the Rawtheyum Stage at the beginning of the upper Ashgillian.

The Uggwa Lst. is overlain by greyish and greenish siltsones with thin interbedded limestone layers. The transition from calcareous to pelitic sedimentation occurs approx. 0.40 m below the first appearance of the Hirnantia fauna characterizing the base of the succeeding Plöcken Formation. This fauna is associated with trilobites, e.g., *Mucronaspis m. mucronata* and graptolites such as *Normalograptus persculptus*.

The change from the Uggwa Lst. to the siltstones reflects significant environmental changes at the beginning of the Hirnantian Stage (Fig. 22). Hence, the greenish pelitic shales atop the Uggwa Lst. may represent glacio-marine sediments in distal regions of the icesheet covering large parts of southern Gondwana. They are separated from the overlying transgressive Plöcken Fm. by a distinct unconformity.

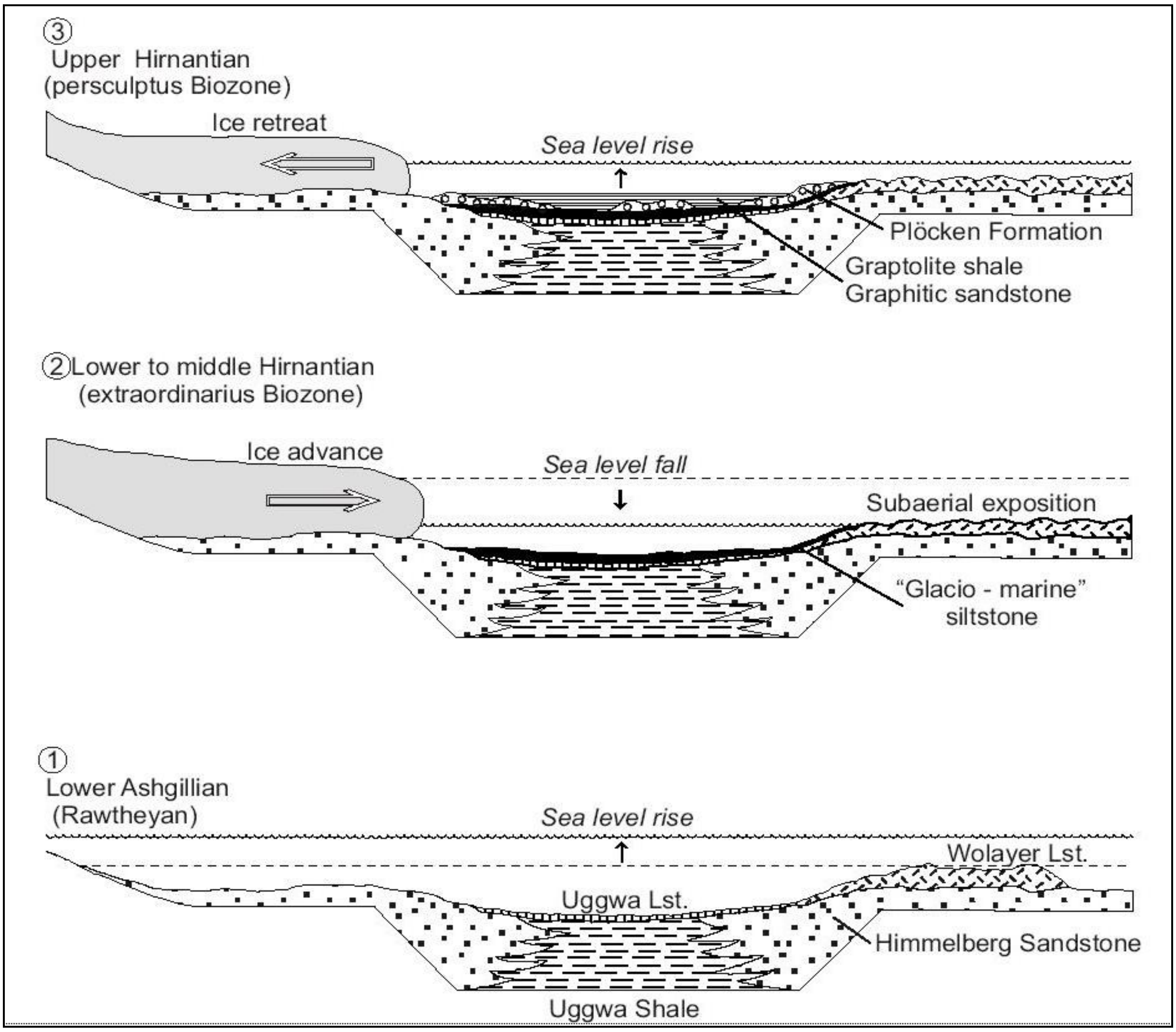


Fig. 22: Model showing the governing sedimentation pattern during the Ashgillian Series in the southern Alps.

At the Cellon section the Plöcken Fm. attains a thickness of 5.40 m. The lower 0.80 m thick portion is composed of arenaceous siltstones followed by impure limestones and calcareous sandstones with layers of bio- and lithoclasts. The fossil debris mainly represents disarticulated brachiopod shells but also bryozoans, trilobites, ostracods and conodonts are quite abundant. The whole package is strongly bioturbated, partly graded and convolute bedding and channeling occurs. This lithology suggests a storm-dominated shallow water environment which formed during the retreat of the ice in the *N. persculptus* Biozone.

Representatives of *N. persculptus* occur approx. 0.25 m above the base of the Plöcken Fm. Hence, this index graptolite testifies the upper Hirnantian Stage during which the transgression started on a global scale. Due to local tectonic uplifts, however, in the Carnic Alps a gap in sedimentation occurred at the base of the Silurian. Thus, at the Cellon section the equivalences of the lower and middle Llandovery are missing. Continued sedimentation across the passage from the Ordovician to the Silurian seems to have only occurred in the basinal black shale environment of the Bischofalm Facies.

Stop 2 – Devonian Succession at Mount Freikofel

Mt. Freikofel is located to the east of the Plöckenpass (Passo di Monte Croce Carnico) and can be reached by following Trail # 403 from the Plöcken Haus (1215 m) to the trail head of trail # 401 which climbs to the top of Mt. Freikofel (Cuelat, 1757 m). The trail on the Austrian side shows good exposures of the Frasnian/Famennian succession whereas the branch on the Italian side follows an old army track and shows best exposures of the Lochkovian to Middle Devonian succession.

Note: ***The military track is not difficult to walk (it was made for mules) but it is not secured and drops off steeply to the sides. It is not recommended for those afraid of heights and great care must be taken not to dislodge stones. Good foot wear (boots) is essential.***

Mount Freikofel exhibits a spectacular section which spans almost the entire Devonian, it is easily accessible, well preserved and well exposed.

Based on lithological criteria the succession can be subdivided into five units (Fig. 23):

Unit 1 Basal dark grey platy and lumpy limestones (~77 m thick).
Unit 2 Yellow-grey lumpy to nodular bedded limestones with intercalated calcarenite beds (~74 m thick).
Unit 3 Massive lithoclastic limestone with reefal debris and lithoclasts (~68 m thick).
Unit 4 Bedded lithoclastic limestone with intercalated clacarenite units, increasing bed thickness up section (~56 m thick).
Unit 5 Grey stylo-bedded fine-grained limestone and grey to pink burrow-mottled limestone with intercalated calcarenite and calcirudite beds (~36 m thick).

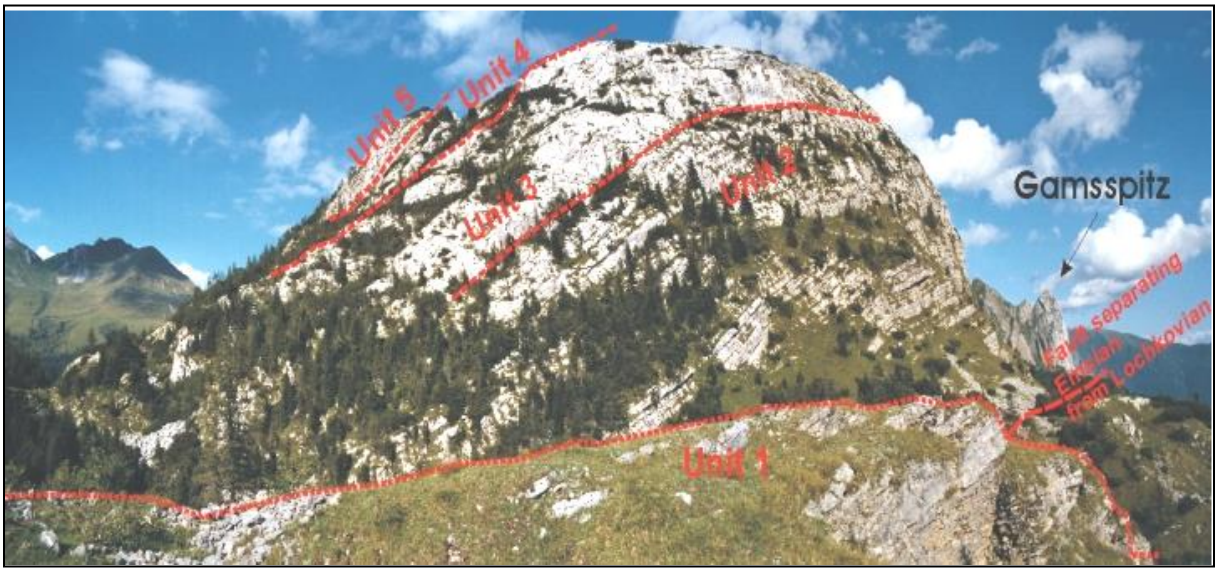


Fig. 23: The Devonian section at Mount Freikofel viewed from southwest.

The basal **unit 1** is exposed at the southern branch of Trail # 401 towards Rossboden Törl (Passo Cavallo).

The succession begins with dark grey fine grained wackestones and mudstones with chert nodules which are probably Lochkovian in age (Unit 1). Up section hackly weathering calcisiltites appear, intercalated with interbedded lumpy and nodular limestones. About 65 m up section the nodular limestones disappear and calcisiltites and thinly bedded wackestones and mudstones dominate the top part of the section up to 77 m. A Conodont sample from the top indicates upper Lochkovian age with *Oz. stygia*. The fauna is similar to that found at Rauchkofelboden (Bodenkalk) and section Oberbuchach (at the transition between black Rauchkofel Limestones to red Findenig Limestone).

About 50 m to the east and separated by a fault (Fig. 23) follows the base of the Mt. Freikofel section with unit 2.

Unit 2 begins at the lowest accessible limestones below the military track to the top of Mount Freikofel with yellow-grey lumpy limestones intercalated with stylo-bedded and nodular limestones. The yellow stain comes from high dolomite content and associated iron. About 21 m up section the first substantial lithoclastic limestone bed occurs (1.9 m thick) with up to 8 cm long lithoclasts, some Heliotithes and rugose corals. These lithoclastic beds are spaced in 1-10 m intervals with decreasing distance and increasing thickness up section. The intercalated fine grained limestone beds become more calcareous and massive up section. Unit 2 ends at 74 m.

Three Conodont samples taken from the base of the Freikofel succession indicate *P. dehiscens* Zone, Ems. Obviously the Pragian limestone (Vinz Limestone) is cut out at the fault between lower and upper sections (Fig. 23).

Unit 3 begins with 7 to 12 m thick massive lithoclastic limestone beds with a few calcarenite units separating them. The conglomeratic units are dominated by large rafts and flat pebbles of fine-grained limestone lithoclasts with subordinate numbers of bioclastic debris, namely crinoids, rugose and tabulate corals, stromatoporoids, and locally abundant *Stachyodes*. The amount of these reefal bioclasts increases up section, whereas crinoids are abundant throughout. Frequently the coarse lithoclastic units are capped with graded calcarenites suggesting deposition from waning flows. At 112 m large stromatoporoid fragments occur (up to 50 cm diameter) and very fossiliferous limestone clasts can be found in the adjacent loose debris. At 128 m there is a horizon with dark-stained (phosphoritic?) lithoclasts which could indicate the late Eifelian age (Kacak event) or the Eifelian/Givetian boundary (cf. BANDEL, 1972). At 137.8 m Unit 3 ends.

Unit 4 begins with bedded lithoclastic limestones with bed thicknesses ranging from 1 to 2 m. Flat pebble lithoclasts and reefal bioclasts are still common here but smaller in size. Conodont samples from this interval indicate basal Frasnian age with *Ancyrognathus triangularis.*

The dominantly clastic sedimentation ends at 166.9 m with finer-grained bedded calcarenites, calcisiltites, mudstones and wackestones which are, however, still intercalated with calcirudites. Unit 4 ends abruptly with a facies change to fine-grained stylo-bedded limestone at 193.6 m.

Unit 5 is characterized by 0.5-1.0 m thick beds of lithoclastic calcirudite with conspicuous absence of reefal debris. A conodont sample taken from the base of this interval indicates basal Famenne. The thickness of the calcirudite beds decreases up section and stylo-bedded mudstones and bioturbated grey and pink mottled wackestones become dominant. However, at 210.2 m coarser (up to 1.2 m thick) lithoclastic beds reappear. The succession ends with a 1.0 m thick lithoclastic limestone unit.

Summary

The section at Mount Freikofel is clearly dominated by gravity flow deposits. Their coarseness and abundance indicates proximity to the source. The varying clast sizes and massiveness of the lithoclastic beds reflects changes in the marginal slope or ramp region. Finer-grained units presumably are more distal and indicate back-stepping of the marginal source region and/or lack of transport and/or lack of marginal buildups. The composition of the clasts with reefal debris and rafts of fine-grained limestone lithoclasts reflects a source area with reef growth and (presumably) a fore slope region with fine-grained, early lithified lime mud. The largest clast sizes of reefal and lithoclastic debris are found in the most massive beds and are Middle Devonian in age. This time interval also yields the highest amounts of reefal debris whereas the Famennian interval (predictably) yields hardly any.

The slope succession as a whole reflects the buildup of a massive carbonate platform which reached its acme in the Middle Devonian and began to regress in the Frasnian to finally collapse in the late Devonian and early Carboniferous with onset of the Variscan orogeny.

Compared to the much thicker section at Mt. Cellon the Freikofel was probably located further away from the shelf platform and represents a more distal nappe in a series of imbricated thrust slices of slope sediments.

Stop 3 – Abandoned Quarry Near Base of Trail # 149 to Rifugio Marinelli

Trail # 149 branches off from the track # 148 to Rifugio Marinelli. At the base of this trail a large ridge of fossiliferous limestone is exposed and higher up the trail are large angular blocks of limestone cut from the rock walls. They provide an excellent and easily accessible exposure of Middle or upper Devonian reef limestone.

The blocks are composed of bioclastic limestone with large colonies of overturned or in situ stromatoporoids along with various accessory reef builders such as solitary rugose corals, ramose, laminar and massive tabulate corals and much crinoidal debris. The presence of *Heliolites* suggests Middle Devonian age. However, this needs to be confirmed through thin section study.

Most stromatoporoids are massive and reach up to 70 cm in diameter but laminar, encrusting, nodular and ragged shapes are also present along with *Stachyodes* and *Amphipora*. The matrix is fine-grained micrite with a large percentage of coarse bioclastic debris.
Centimetre to decimetre sized cavities are lined with fibrous calcite.

The lithology most likely represents a southern equivalent of the Kellergrat Limestone described by KREUTZER (1992) from the Kellergrat and also present at the southern side of Hohe Warte.

Plate 1: Devonian reef limestone slabs at the abandoned quarry at trail no. 145 to Rifugio Marinelli at alt. 1520 m.

Stop 4 – Ordovician to Lower Devonian of the Rauchkofel Boden Section

Annalisa FERRETTI, Kathleen HISTON & Hans Peter SCHÖNLAUB

The Rauchkofel Boden section, located on the southwestern slope of Mount Rauchkofel (Fig. 24), exposes a 28 m calcareous succession of the "Wolayer facies" (see SCHÖNLAUB & HISTON, this volume, for environmental setting) documenting the Late Ordovician (Ashgillian) - Early Devonian (Pragian), but with a significant Early Silurian gap (Fig. 25). Various studies of this section have been carried out during this century, both with general papers (e.g. GAERTNER, 1931; SCHÖNLAUB, 1970, 1980) and monographic works dealing, for example, with orthoconic nautiloids (RISTEDT, 1968), trilobites (HAAS, unpublished), bivalves (KRIZ, 1979, 1999) and conodonts (e.g. SCHÖNLAUB, 1980).

The Late Ordovician is represented by a 8.6 m thick white massive limestone, the **Wolayer Limestone** (n. 304-309 and n. 316-318), dated by conodonts of the *A. ordovicicus* Zone to the Ashgill, the final series of the Ordovician. Thin section observation reveals a packstone almost entirely represented by echinoderm debris, associated with rare bryozoans and trilobites. DULLO (1992) suggested for this formation a shallow water deposition in a low energy environment in a moderate climatic setting.

The Silurian starts with a 3.9 m thick grey/reddish micritic limestone, the **Kok Formation** (n. 310-315 and n. 319-325). The contact with the Ordovician is strongly irregular and undulated in outcrop, with local basal "pockets" infilled by a thin horizon of ooidal ironstone. This oolitic grainstone, dated to the *P. amorphognathoides* Zone, reveals the establishment of high-energy conditions. Echinoderm elements seem to be the most common coated nuclei.

The following beds (Wenlock in age) are represented by strongly recrystallized cephalopod wackestone to packstones, with cephalopod conchs embedded in a sorted micritic matrix rich in fragmentary trilobites, echinoderms, disarticulated bivalve shells, ostracodes, brachiopods and gastropods. In the Late Wenlock and Ludlow conodonts are fairly abundant. A rich fauna representing the *O. sagitta* Zone occurs from the Ordovician / Silurian boundary up to sample n. 313, i.e. 1.20 m above the base (Fig. 25). Although richly resampled, not a single specimen of *Ozarkodina bohemica* has yet been found in that interval. In sample n. 314 *Kockelella variabilis* first occurs suggesting the base of the Ludlow Series by comparison with Bohemia (SCHÖNLAUB in KRIZ et al., 1993).

A 1 m thick massive encrinitic limestone is present towards the middle part of the formation (n. 323/314). The first abundant nautiloid fauna (base 324/mid 314) occurs just above this horizon and is followed by thin layers of bioclastic accumulations and oolitic grainstones separated by thinly laminated iron-rich layers or crusts. A rich nautiloid fauna is preserved, the nautiloids sometimes being apparently trapped within the crusts revealing strong dissolu-tion of the conch wall (Fig. 26). Juvenile nautiloids, associated with equidimensional articulated brachiopods and gastropods, are visible as pinkish horizons towards the top of the formation (top 324-315) and are better visible in the middle part of the outcrop. Species of *Sphaerorthoceras*, *Merocycloceras* and *Parasphaerorthoceras* were described by RISTEDT (1968) from these levels.

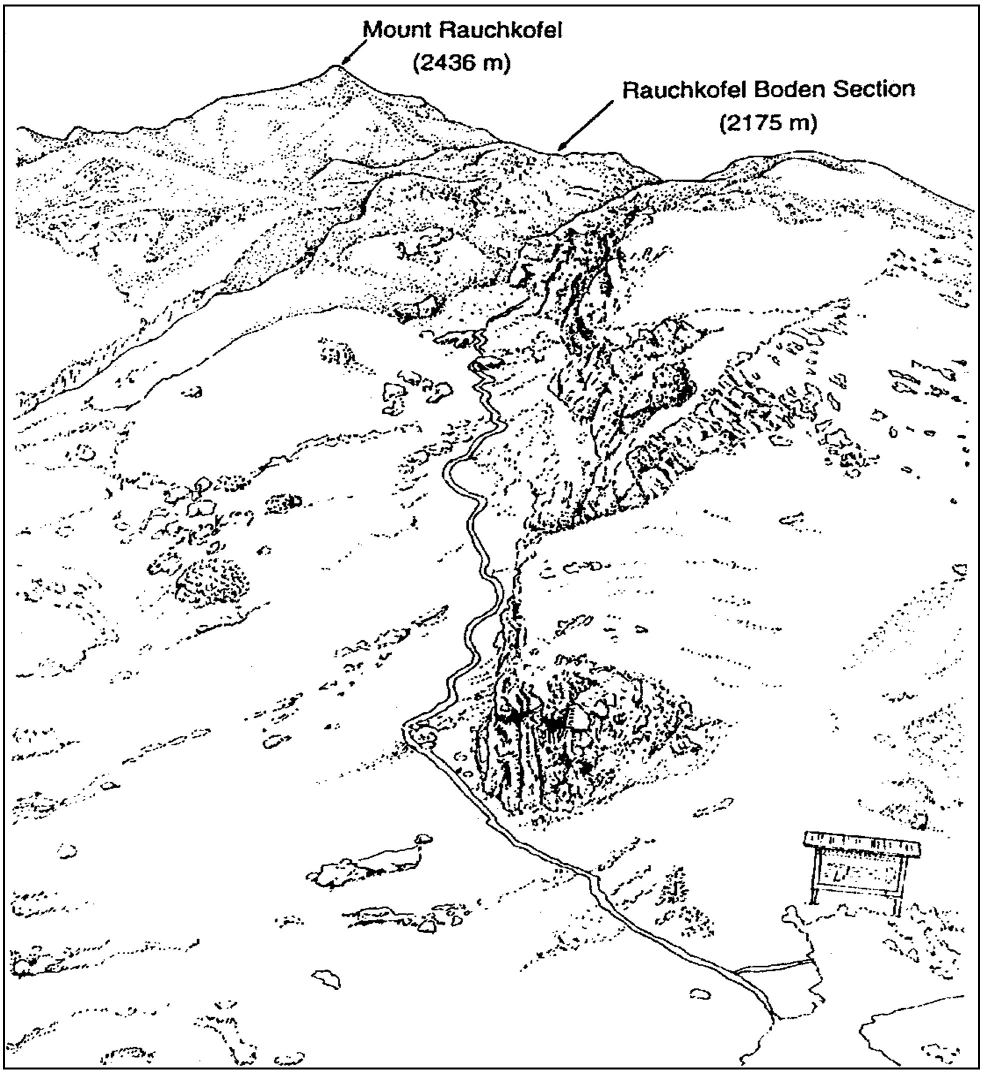


Fig. 24: General view of Mount Rauchkofel and of the Rauchkofel Boden section.

Spectacular cephalopod limestone beds *("Orthoceras"* limestones) are exposed at the internal border of the war trench (beds n. 325 and 315) just at the top of the Kok Formation. The lighter grey colour and the variety of the cephalopod fauna easily help in identification. The limestone is represented by a cephalopod-trilobite-brachiopod wackestone to packstone with gastropods, echinoderms, trilobites, bivalves and ostracodes. No sorting or gradation was observed.

An important feature in both the Kok Formation and the Alticola Limestone is that many organisms show regular iron-rich laminated coatings, involving the most prominent part of the shell (e.g. the trilobite represented in Fig. 27) or the entire individual (e.g. as a continuous structure all around the shell of cephalopods). Indeed these coatings are most commonly noted on trilobites and cephalopods, but they have also been observed on brachiopods. The high iron content of the limestone sequence is in general remarkable both in the form of (a) frequent iron staining of the shells (more frequent in the Kok Formation) with microborings for example in cephalopod and bivalve shells being infilled or echinoderm pores being impregnated by the iron-oxides or (b) of regular laminated iron-rich coatings (abundant at the top of the Kok Formation).

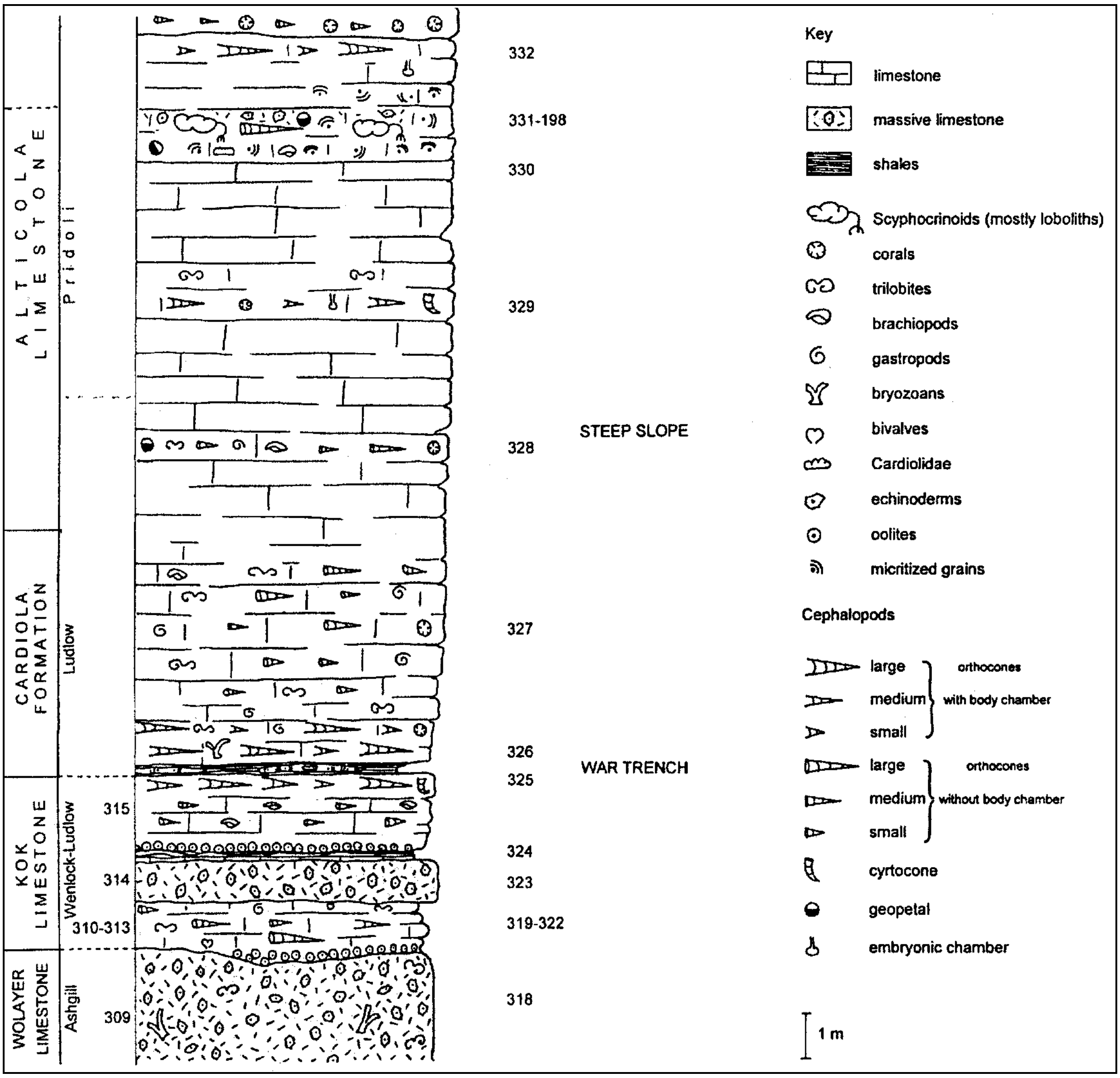


Fig. 25: Stratigraphic column of the Rauchkofel Boden section.

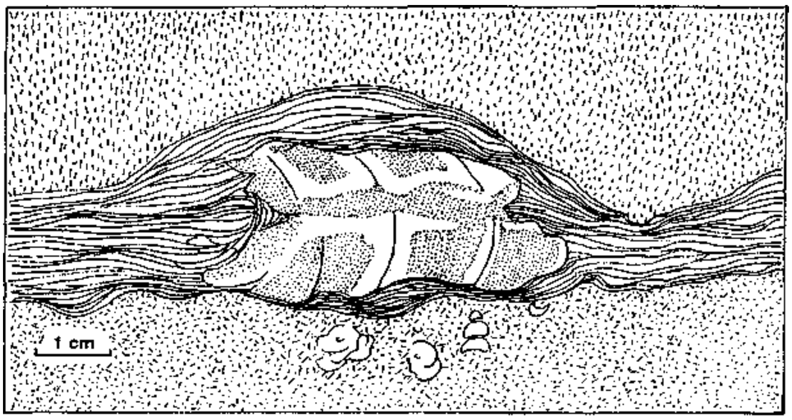


Fig. 26: Intensive dissolution of a cephalopod shell "trapped" within iron-rich crusts (Kok Formation).

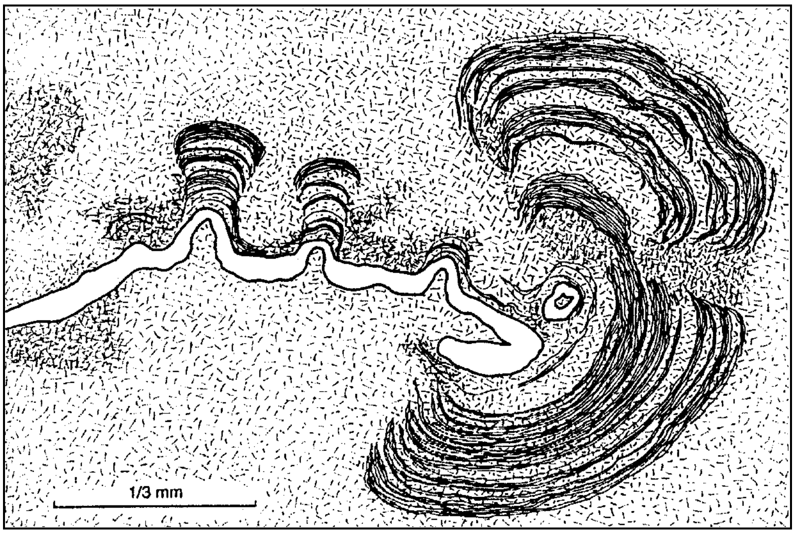


Fig. 27: Iron-banded coating of a trilobite shell. Note how these covers proceed from the most elevate parts of the shell (Kok Formation; redrawn from a thin-section).

Apart from the species described by RISTEDT (1968), citations by GARTNER (1931) and a faunal list by BOGOLEPOVA (1998) a detailed systematic study of the nautiloid fauna has not yet been published for this section. A revision of the material described by HERITSCH (1929) from the Carnic Alps has been carried out (HISTON, 1999a, in press) but only one specimen from this section was included in that monograph. The base of the formation is relatively barren in nautiloid fauna with respect to the upper beds. A specimen of *Phragmoceras* has been found in Bed 319 and specimens of *Plagiostomoceras*, *Michelinoceras* and *Arionoceras* are common in the Wenlock. The variety of fauna increases noticeably in the Ludlow with again a dominance of *Michelinoceras*, *Plagiostomoceras*, *Arionoceras*, *Geisono-ceras* and horizons of juvenile specimens of *Sphaerorthoceras*, *Merocycloceras* and *Parasphaerorthoceras* complete with embryonic chambers as well as elements of Oncocerida represented by *Oonoceras* sp. in beds 315, 325.

An account of the taphonomy of the nautiloid fauna from this section was given by HISTON (1999b). The orientation of the conchs to bedding and the presence of telescoping may be used as an indication of the energy of the environment in which they were deposited; telescoping being taken as an indication of high energy. Thus a high energy environment may be indicated for beds 319, 324 and some levels of 315. The preservation of the shells where they are relatively intact with body chambers and apexes present, may indicate little or no transport of the fauna as may be the case for beds 320, 322, some levels of 315 and 325. Vertical embedded cephalopods are present in beds 311, 312, 324 and 325. The associated fauna of articulated brachiopods, gastropods and solitary corals in these levels may also indicate a low energy setting. The orientation of the nautiloids on the bedding surface varies within individual beds but definite trends may be noted in some cases.

Preliminary measurements and conclusions on the orientation of cephalopod orthocones were proposed by BOGOLEPOVA (SCHÖNLAUB & BOGOLEPOVA, 1994). Three beds in this section were investigated, two respectively at the base, and at the top of the Kok Formation, the third in the Alticola Limestone. Two different trends (from SW to NE and from W to E) were recognized at the older level, while a SW to NE orientation (but having diverse angular values) was evidenced at the two upper horizons.

Data for the structural limits of the nautiloids based on a ratio of conch diameter to septal spacing indicates a mixed fauna in the lower beds of the formation becoming dominated by stronger fauna higher in the formation (HISTON, 1999b).

In general we can note the changing energy and oxygen levels of the formation from the data given and from the preservation and orientation of the nautiloid fauna and that there are many accumulated levels with intermittent changes in sea level particularly towards the top of the sequence.

The **Cardiola Formation** (Ludlow) is badly exposed in the war trench as loose blocks or lenses of dark micritic limestone (about 10 cm thick) which strongly resemble the well known cephalopod limestone of Bohemia and of the northern Gondwana margin. The Cardiola Fm. corresponds to the *P. siluricus* Zone of the stratotype at the Cellon section.

Isoriented cephalopods dominate, being embedded in a matrix of sorted aligned bioclasts, frequently coated by micritic envelopes (Fig. 28). Numerous bivalves of the *Cardiola* Community are reported from here and also from a thin layer immediately above bed 325. According to KRIZ (1979), representatives of *Cardiola* and other genera developed a peculiar living stratagem to adapt to a cephalopod-rich environment. The ventral part of the elongated anterior margin together with the large umbones represented three major points of stability (distributed at the vertices of a triangle) which enabled a stable byssal attachment to cephalopod shells in any position.

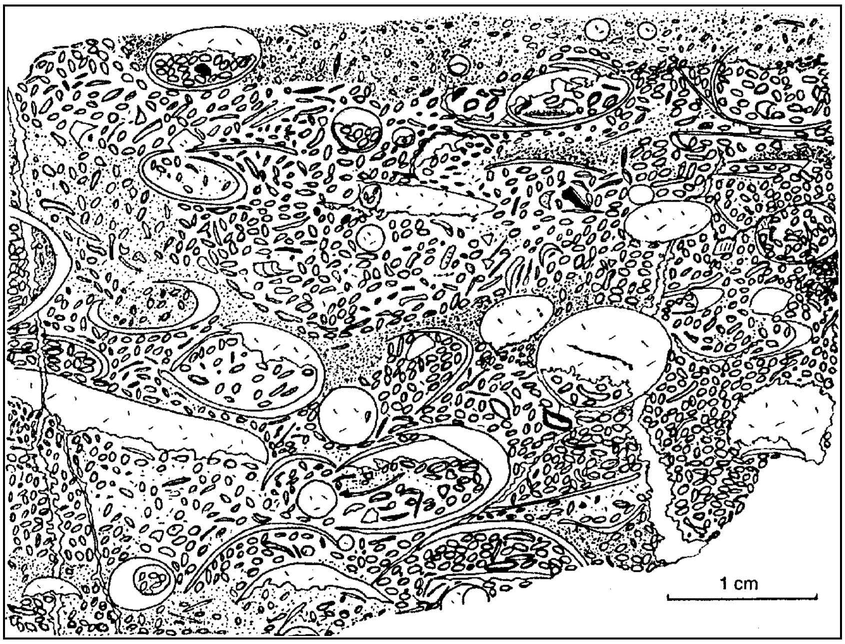


Fig. 28: Cardiola Formation; cephalopods embedded in a matrix mostly represented by micritized grains (redrawn from a thin-section).

The specimens in general are well preserved with body chambers and apexes being present. Geopetal structures have been noted in the body chambers of some specimens oriented parallel to bedding and an opposed orientation of conchs on the bedding plane is also indicated. Structural data indicates a mixed fauna (HISTON, 1999b) and species are similar to those of the upper Kok Formation, however, lacking the juvenile elements.

The **Alticola Limestone** (n. 326-331) documents the final part of the Silurian (Upper Ludlow - Pridoli) and the passage to the Devonian. Lower beds are represented by a cephalopod wackestone to packstone. Magnificent nautiloids, preserving body chambers, are exposed on the external border of the war trench. Solitary corals were recognized in many beds. Trilobites and cephalopods are still showing iron-banded coatings; furthermore, fragments of these coverings are present even in the matrix. Towards the top, the formation grades to darker thin-bedded beds, as a response to a major micrite content and to the presence of micritized grains. Echinoderm debris is quite abundant. A *Scyphocrinites* bed bearing complete specimens caps the formation.

Conodonts from the uppermost part of the black nodular limestones (sample n. 330, 331) belong to the apparatus of *Oz. r. eosteinhornensis*. In addition, *Oz. ortuformis and Oz. jaegeri* occur at this interval.

The preservation of the nautiloid fauna is similar to that of the Kok Formation but no *"Orthoceras"* bed may be determined within this sequence. The base and top of the formation are marked by the occurrence of large orthocones *(Columenoceras)* oriented both parallel and perpendicular to bedding but which also show definite trends on the bedding surface itself. Current direction has been given as SW-NE for both these points in the formation (SCHÖNLAUB & BOGOLEPOVA, 1994). The nautiloid fauna is quite well preserved throughout the formation even where a higher energy environmental setting is indicated by telescoping, with body chambers being intact and sometimes showing geopetal structures parallel to bedding which is a good indication of little transport of the fauna. The data for the structural limits of the fauna, even though quite general, show a mixed fauna throughout the formation dominated by weaker fauna in bed 327 and almost entirely weak fauna in bed 331 at the top of the sequence. This latter indicates the shallowest fauna in the formation with elements of Oncocerida and *Anaspyroceras* being dominant.

The Silurian/Devonian boundary is drawn at the base of grey and blackish platy crinoidal limestones containing *Scyphocrinites* (sample no. 331 = 198). Bed no. 198 as well as the overlying sample no. 199 yielded common occurrences of *Oz. r. eosteinhornensis* and, more frequently, *Oz. r. remscheidensis.*

The basal part of the overlying Lochkov sequence seems to be extremely condensed (Fig. 29). This interval is represented by well bedded, thin and blackish limestone beds with shaly intercalations (sample nos. 201b-201j). The index conodont for the base of the Devonian, *Icriodus woschmidti,* was collected in sample nos. 201 and 201a. However, as yet only juvenile specimens have been found. Neither at this horizon nor in any other parts of the section have graptolites yet been recorded.

With regard to the Lower Devonian part of this section we refer to Fig. 29 showing its lithology and faunal content. The 40 m thick undisturbed section is subdivided into the following formations:

- 1.80 m pelagic **Rauchkofel Lst.** comprising black limestones interbedded with marls (Lower Lochkovian)
- **c. 17 m Boden Lst.** comprising greyish coarsely bedded nautiloid bearing limestones rich in conodonts but rare in dacryoconarids and orthoconic and coiled nautiloids (Upper Lochkovian)
- 20 m nodular pink **Findenig Lst.** rich in dacryoconarids.

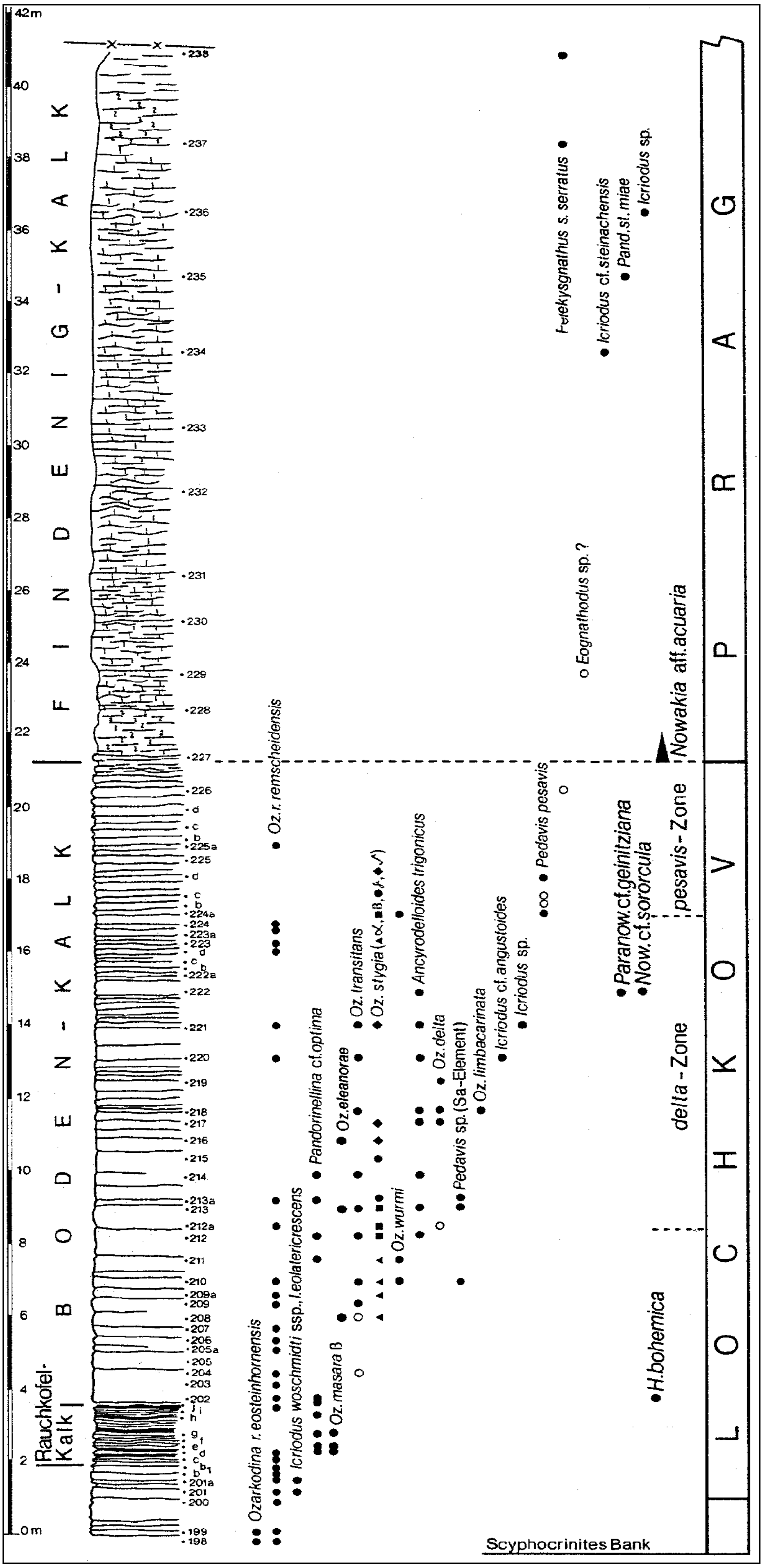


Fig. 27: Rauchkofel Boden section, Lower Devonian part with 1.80 m thick pelagic Rauchkofel Lst., Boden Lst. and Findenig Lst. (after SCHÖNLAUB et al., 1980, modified).

Stop 5 – Late Devonian Cephalopod Limestones in the Vicinity of Valentintörl

Hans Peter SCHÖNLAUB & Dieter KORN

West of the Valentintörl, the uppermost limestone beds at the southern slope of Mount Rauchkofel are exposed. The section is located close to the trail running from the Törl to Lake Wolayer. From this limestone succession representing the Pal Limestone of the Late Devonian, ammonoid faunas were recorded by FRECH (1902) and GAERTNER (1931). The old records could only in part be confirmed, and new collections show the following ammonoid assemblages:

Frasnian
Beloceras praecursor FRECH 1902, *Manticoceras* sp., *Ponticeras* sp.

Early and middle Famennian
Armatites sp., *Cheiloceras* sp., *Sporadoceras* sp., *Prolobites* sp., *Platyclymenia* sp., *Cyrtoclymenia* sp., *Rectoclymenia* sp.

Late Famennian
Alpinites kayseri (SCHINDEWOLF 1923)

Stop 6 – Valentintörl Section

Kathleen HISTON, Annalisa FERRETTI & Hans Peter SCHÖNLAUB

The section is exposed at the base of the steep western slope of Valentintörl (2138 m), a spectacular towering thrust sheet which forms the highest point of the Valentin pass (Fig. 30). Various lower Paleozoic sequences ranging from Late Ordovician to Early Carboniferous in age and representing different facies are fault bounded here as may be seen in a N-S section of the eastern side of the Mountain (Fig. 31). The sequence was initially studied by GEYER (1903) and later by GARTNER (1931) and SCHÖNLAUB (1970, 1971, 1980, 1985). The Upper Silurian sequence (Ludlow) corresponds broadly to the Plöcken facies (see SCHÖNLAUB & HISTON, this volume for environmental setting) with an irregular basal contact with the underlying Late Ordovician (Ashgill) **Wolayer Limestone.**

Only the conodont fauna has previously been studied from this section (SCHÖNLAUB, 1970, 1971) and the **Kok Formation** is first evidenced by the O. *crassa* Biozone (sensu WALLISER, 1964) documenting the Early Ludlow. A large hiatus exists therefore at the boundary as both the Llandovery and Wenlock conodont zones are missing. The 4.3 m calcareous sequence (Fig. 32) of reddish-grey predominantly micritic limestones is underlain by a Fe-Mn crust (Fig. 33) which is sometimes exposed as patches on the Wolayer Limestone.

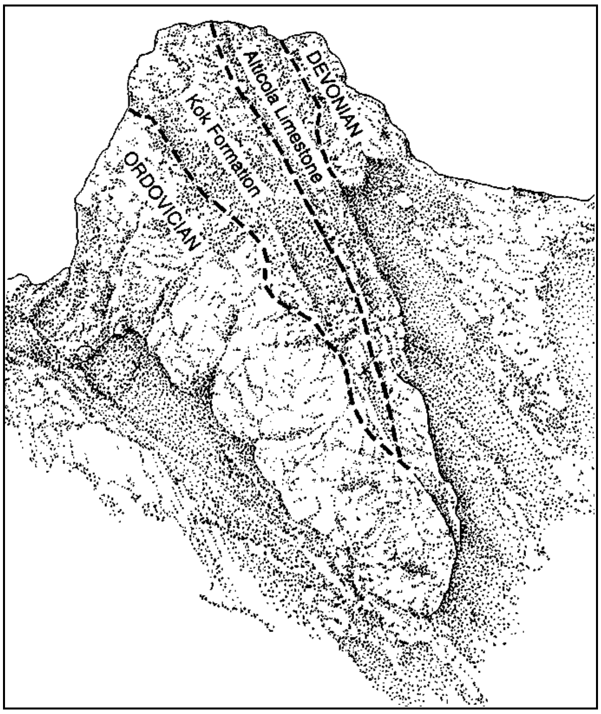


Fig. 30: View of the Valentintörl section from the west.

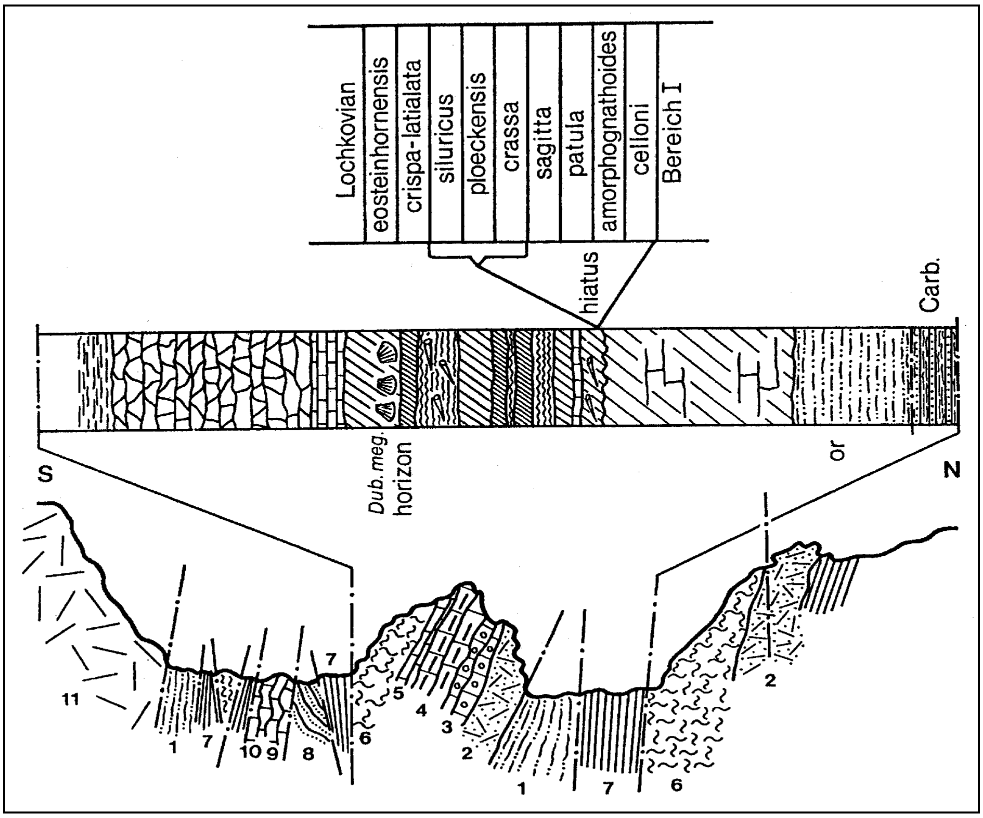


Fig. 31: N-S profile of Valentintörl from the east.
1: Uggwa shales (Ordovician); 2: Wolayer Lst. (Late Ordovician); 8: Himmelberg sandstone (Ordovician); 3, 9: Kok Fm. (Ludlow); 4: Alticola + Megaerella Lst. (Ludlow-Pridoli); 5: Rauchkofel Lst.; 6: Findenig Lst.; 7: Hochwipfel Fm.; 10: Devonian (unstudied); 11: Carboniferous (unstudied), (after SCHÖNLAUB, 1980).

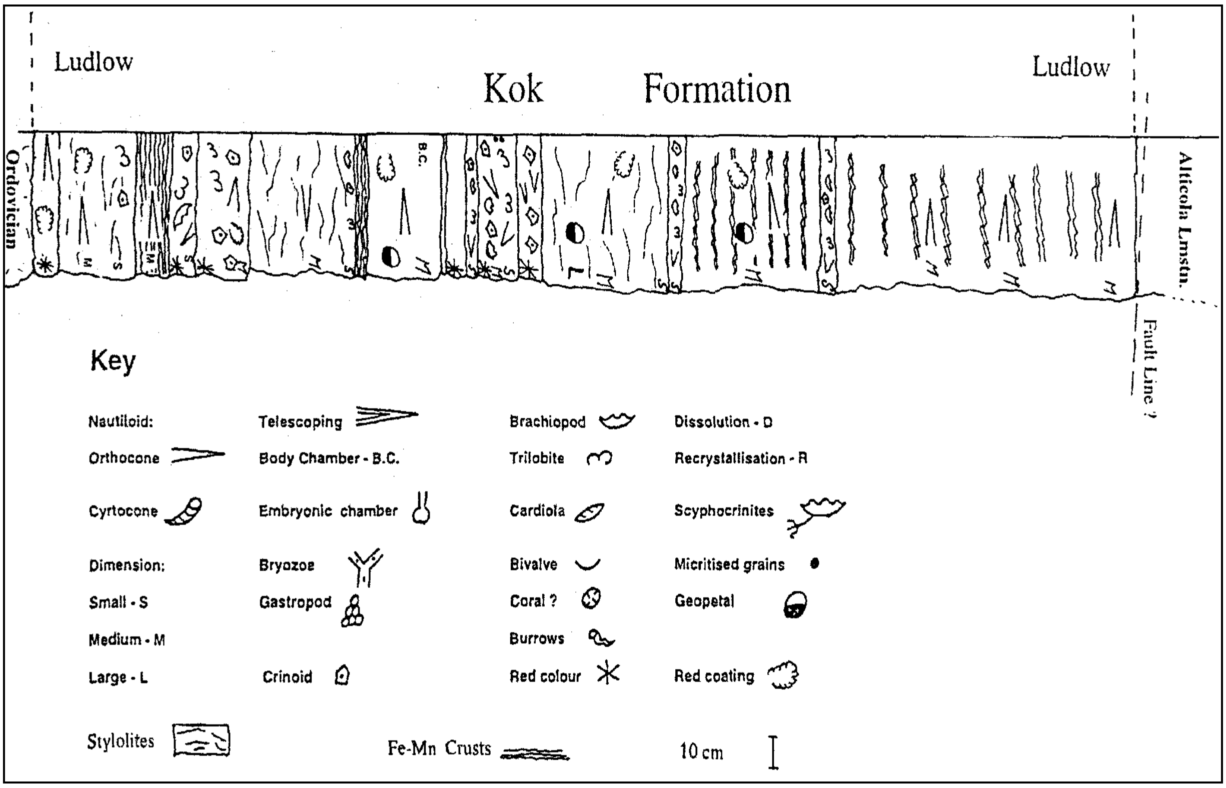


Fig. 32: Stratigraphic column of the Kok Formation, Valentintörl section.

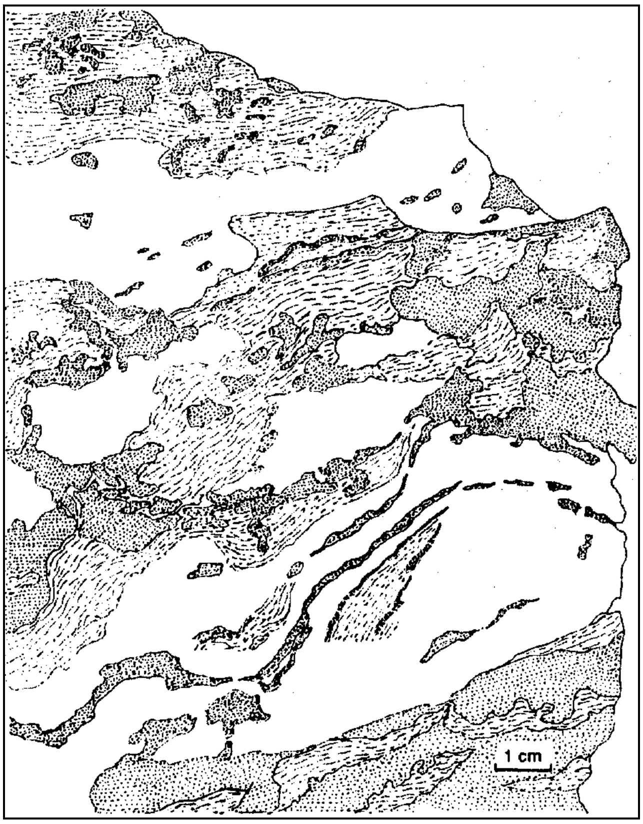


Fig. 33: Iron-rich mineralisation at the base of the Silurian.

Above the Ordovician / Silurian boundary a red micritic limestone with distinct red layering is developed with a sparse nautiloid fauna oriented parallel to bedding. The nautiloid fauna increases in abundance upwards in the section and a rich trilobite and crinoid fauna is seen. These two lower limestone horizons are capped by a 10-15 cm thick Fe-Mn crust which is distinctively blue-black in colour and contains nautiloid fragments within its laminations.

This is followed by a strata of biodetritus rich in echinoderm ossicles, trilobite and brachiopod fauna all with quite distinctive Fe coatings and seems to contain a juvenile nautiloid fauna. These horizons of juvenile fauna with biodetritus occur frequently thoughout the section. Reddening of the limestones is indicated in Fig. 32, as these "patches" or layered structures are quite prominent and frequent. The frequency of Fe-Mn crusts between the limestone strata increases from the middle to the top of the Kok Formation.

Two main limestone types have been preliminary observed in thin section. A trilobite wackestone-packstone showing echinoderm ossicles, rare small ostracodes, bryozoans, brachiopods, cephalopods and gastropods. The abundance of trilobites which appear to be complete or represented by large fragments is remarkable. Intensive and elaborated iron coatings and iron-staining are developed on the organisms, but iron is also quite widespread in the matrix (Fig. 33). No gradation, sorting or orientation is visible here. The dominance of benthic organisms and of iron-rich coverings of individuals characterize these sections.

A second type consists of faintly laminated wackestones with echinoderms representing fine biodebris associated with cephalopods. Rare gastropods, ostracodes, bivalves and small brachiopods have been observed in thin section. Iron is even there abundant, with echinoderm ossicles frequently showing iron-banded coatings and iron-staining.

The abundance of Fe-Mn crusts which sometimes are several centimetres thick and occur intermittently within the Kok Formation may be noted even in loose blocks in the debris along the path below the section.

The nautiloid fauna is quite abundant throughout the section and the preservation is similar to that of the Cellon and Rauchkofel Boden section with varying dimensions, orientation to bedding, presence of body chambers and levels of juvenile specimens which may be correlated at particular horizons. Body chambers and geopetals have been observed in certain beds and imply a more tranquil environment and little transport.

The faunal content has as yet not been systematically studied in detail.

The **Cardiola Formation** appears to be faulted out and the **Alticola Formation** has not been studied so far.

Stop 7 – Wolayer "Glacier" Section

Hans Peter SCHÖNLAUB, Michael M. JOACHIMSKI & Heiko HÜNEKE

The continuous Devonian sedimentary record of the Rauchkofel Nappe in the Carnic Alps consists of an up to 230 m thick succession of mostly pelagic and periplatform limestone deposits. Distal turbiditic limestone intercalations only occur at a few levels. They are derived from a peritidal carbonate platform and related slope-apron settings of the Kellerwand and Cellon Nappes, respectively (SCHÖNLAUB, 1971, 1985, 1992; BANDEL, 1969, 1972; KREUTZER, 1990, 1992).

The locality Wolayer Glacier is located halfway between Valentintörl and Lake Wolayer where the south-dipping Devonian strata are exposed forming a 20 m high cliff. The whole section reflects a strongly condensed sequence of pink nodular and greyish to reddish Flaser limestones commonly named cephalopod limestones. They have been deposited in a pelagic off-shore environment testified by radiolarians, foraminifera, dacryoconarids, styliolinids, ostracods, conodonts, trilobites and few goniatites.

The continuous section ranges from the Emsian to the Famennian. Of particular interest is the Frasnian/Famennian boundary, the sedimentology, conodont biostratigraphy and isotope geochemistry which has been studied by GÖDDERTZ & SCHÖNLAUB (1980, 1985), JOACHIMSKI et al. (1994) and HÜNEKE (2001, 2004 in press).

Biostratigraphy

According to the above cited authors continuous carbonate sedimentation started in the Lower Devonian and ranges to the *australis* Zone at the end of the Eifelian Stage. The succeeding equivalents of the Givetian are separated from the Eifelian by a gap in sedimentation which supposedly spans the interval from the *kockelianus* to *ansatus* conodont Biozones. The thin limestone beds of the Givetian represent the *latifossatus/semialternans* and *hermanni-cristatus* Zones.

In contrast to the approx. 6 m thick condensed deposits of the Eifelian, the equivalents of the Givetian are extremely reduced and comprise only 11 cm of limestone deposits. The latter are terminated by a distinct gap in sedimentation lasting from the *disparilis* to the *punctata* Zones. The overlying 10 cm thick limestone bed contains abundant phosphorite nodules, fish remains and mixed conodont faunas ranging from the *transitans* to the *hassi* Zones. Apparently, the youngest elements of this stratigraphic admixture, i.e. *Palamtolepis hassi* and *Ancyroides coeni*, represent the proper age of the formation. In fact, sedimentary structures and microfacies indicate a short accumulating event within the Early *hassi* Zone.

The conodont fauna of the following limestone bed contains *Ancyrognathus triangularis* which suggests the Late *hassi* Zone. This bed is overlain by condensed limestones of the *jamieae* to *crepida* Zones. Overall, the sediments of the late Frasnian do not exceed 1.8 m.

Description of facies

At the passage from the Emsian to the Eifelian the uniformly developed reddish and pink Findenig Lst. grades into the greyish Valentin Lst. The latter represent bioclastic wackestones and rarely packstones characterized by a typical pelagic fauna consisting of small trilobites, styliolinids, ostracods, cephalopods, bivalves, remains of crinoids and rugose corals. In particular in the limestones of the *australis* Zone iron-coated bioclasts and micritic oncoids occur abundantly. The sediment is strongly bioturbated and more or less homogenous. Indication of bedding is mostly obliterated or can be inferred by faint layers of fossil debris. Also, the amount of silty limestones in the matrix varies between individual beds.

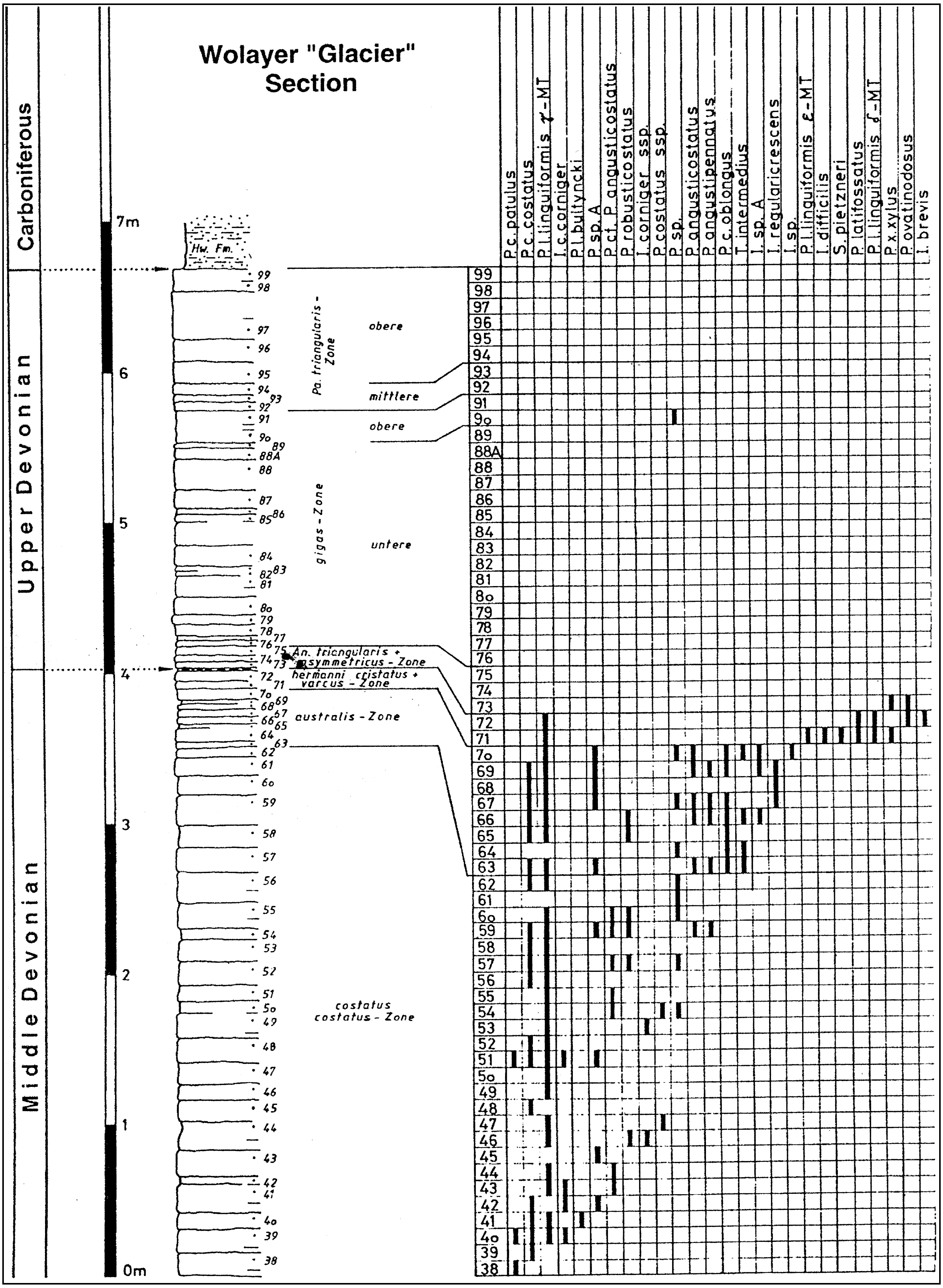
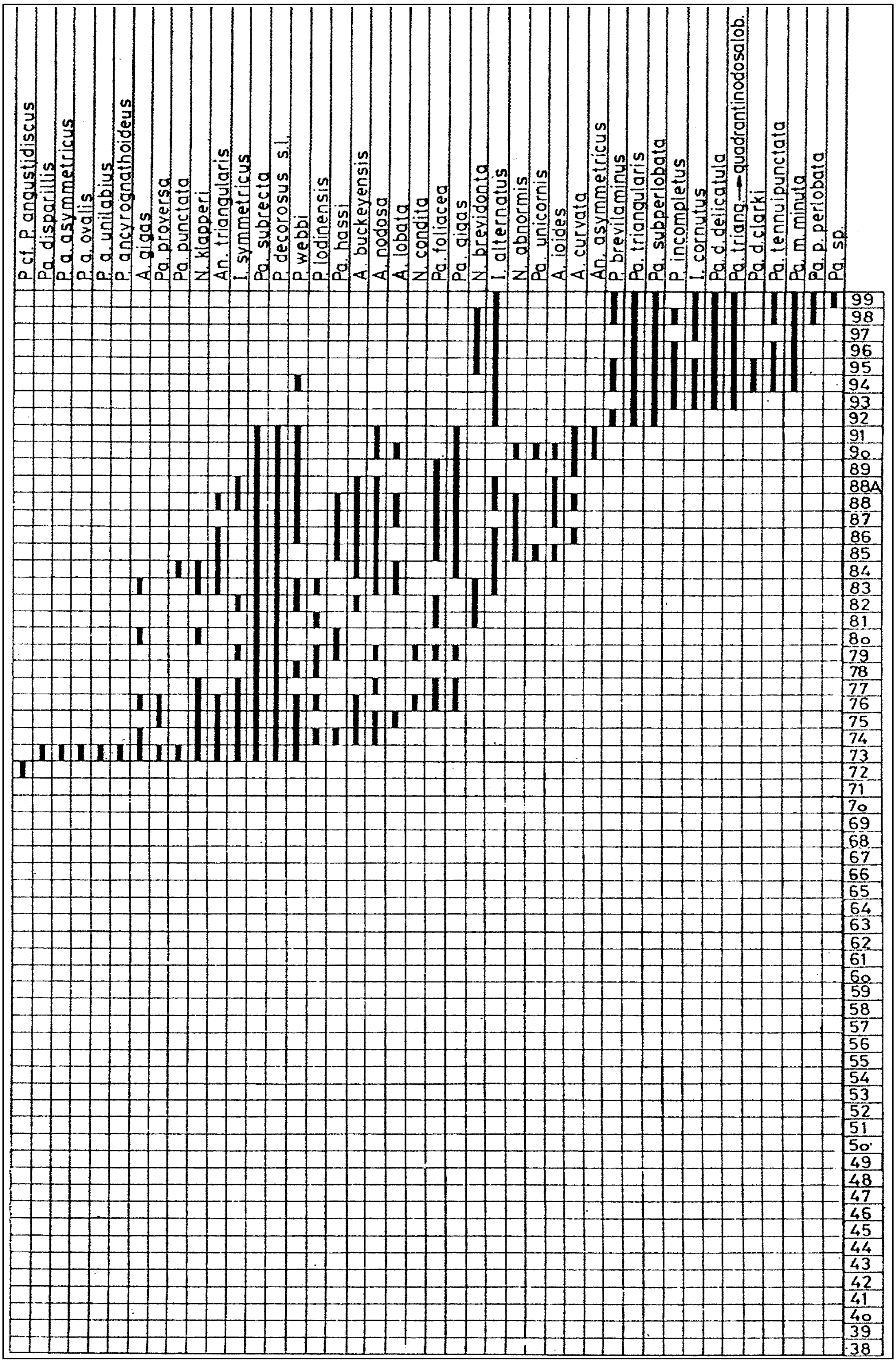


Fig. 34: Conodont ranges across Lower/Middle and Middle/Upper Devonian boundaries …



… at the Wolayer Glacier section.

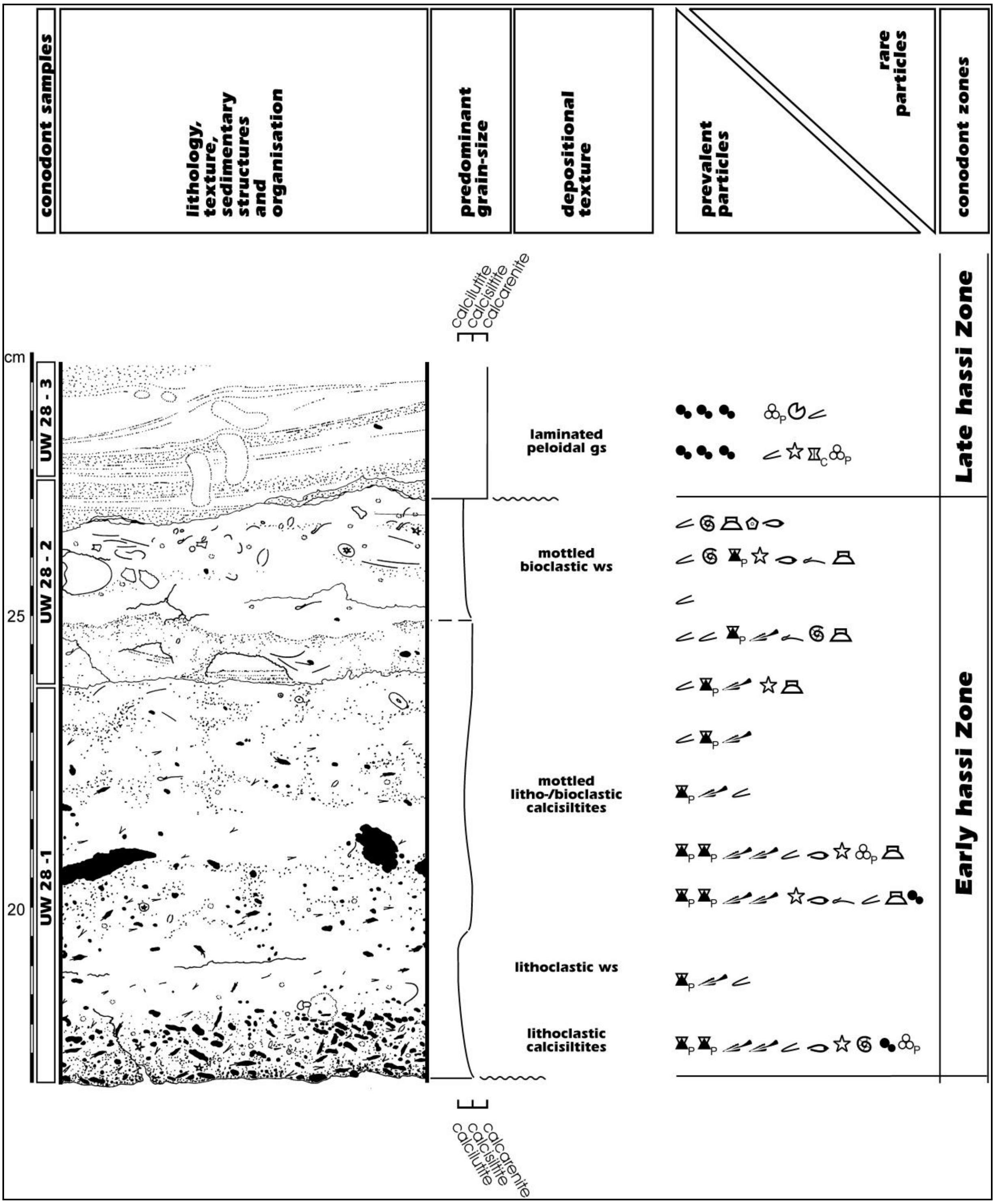
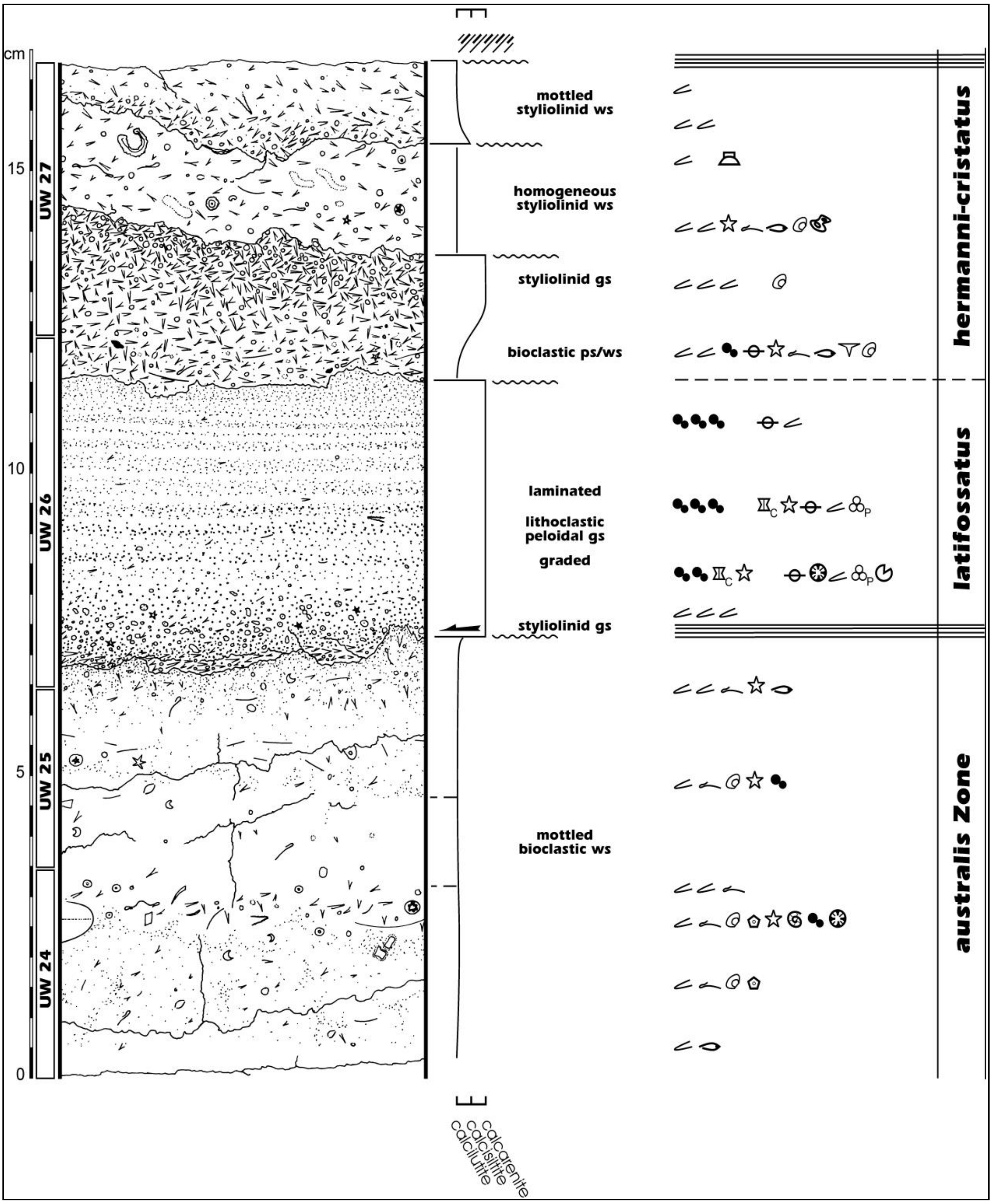


Fig. 35: Lithology, sedimentary texture and organic content of the late Givetian to early …



… Frasnian portion of the Wolayer Glacier section (from HÜNEKE, 2001).

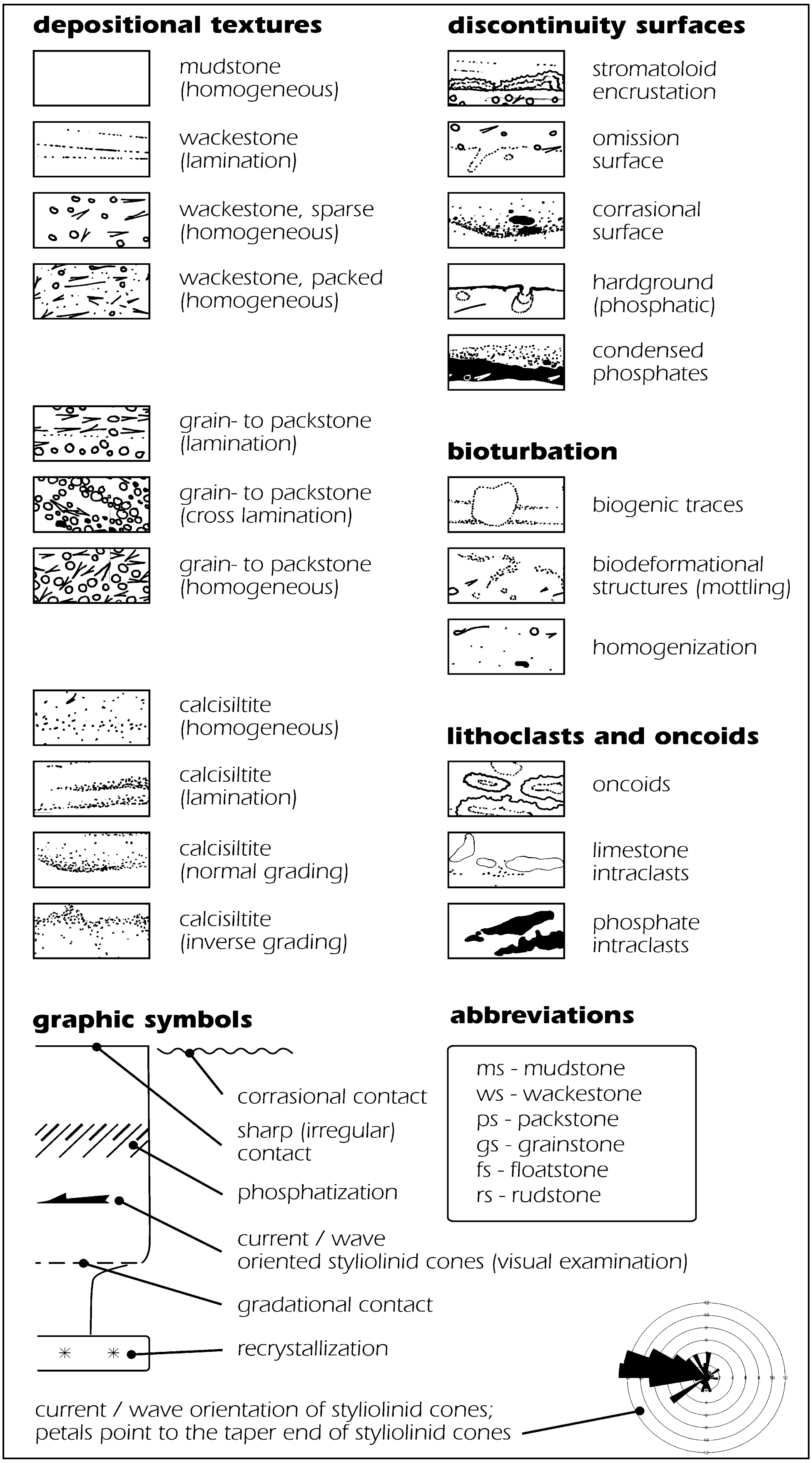


Fig. 36: Depositional textures, discontinuity surfaces, indication of bioturbation and symbols used in the graphics (from HÜNEKE, 2001, 2004 in press).

The small portion of limestones equivalent to the Givetian is well bedded. Immediately above the lower discontinuity surface which suggests erosion during the late Eifelian and early Givetian, thin laminae of styliolinid grainstones and packstones are preserved. This horizon is succeeded by graded layers consisting of peloidal grainstones with crinoids, cortoids, lithoclasts, styliolinids and solitary corals. Above this graded part bioclastic wackestones occur which grade into styliolinid grainstones. They are succeeded by two more beds comprising pelagic styliolinid wackestones with rarely occurring foraminifera, peloids and cortoids.

A difficulty of the studied successions in the Carnic Alps is the bedding-parallel orientation of stylolitic seams which usually follow discontinuity surfaces. However, distinct erosional contacts and hardgrounds are preserved in only few cases. Nevertheless, breaks in sedimentation can be recognized by the occurrences of index conodonts. In addition to this section, the succession of the Rauchkofel Nappe west of the Wolayer Lake exhibits interruptions in accumulation during the *kockelianus* to *ansatus* Zones and during the *disparilis* to *punctata* Zones. Thus, on a distance of some hundred metres, biostratigraphic gaps comprise slightly different ranges (GÖDDERTZ, 1982).

The equivalents of the Frasnian Series (Early *hassi* Zone) start at a phosphorite bearing horizon rich in conodonts and fish remains. Supposedly, its base is characterized by a gap in sedimentation spanning the *disparilis* and *punctata* conodont Zones. At the base of this distinct bed phosphorite lithoclasts are densely packed in the matrix consisting of calcisiltite while in the upper part up to 5 cm big clasts occur. Also the amount of calcisiltite varies showing locally internal erosional surfaces or shallow scours followed by well-graded laminated calcisiltites. Fragmented bioclasts are quite abundant representing styliolinids, thin shells of brachiopods, trilobites, cephalopods, ostracods and less abundantly crinoids, calcispheres, forams as well as peloids and cortoids. In addition the whole bed is strongly bioturbated.

The phosphorite horizon is overlain by mostly wavy laminated peloidal packstones and grainstones assigned to the Late *hassi* Zone. In this part of the section gradation and bioturbation rarely occur; bioclasts, however, resemble the underlying beds.

The uppermost portion is characterized by irregularly stratified mottled calcisiltites and bioclastic wackestones. Erosional contacts are rarely preserved. Immediately above such surfaces conodonts are enriched as well as abraded bioclastic shell remains. Interestingly peloids and mica may be found. With the transition to bioclastic wackestones the amount of the well preserved biogens increases consisting mainly of styliolinids, small trilobites, cephalopods, bivalves, ostracods, forams, calcisphaerids and some crinoids. Also, micritic oncoids and peloids occur as well as bioturbation obliterating primary from altered textures.

Interpretation

According to HÜNEKE (2001, 2004 in press) the Eifelian flaser limestones are the product of intensively bioturbated pelagic carbonate muds. Indistinct bedding, however, is still preserved. Occasionally, ferruginous coatings around biogens suggest longer periods of exposition at the sea floor. Abrasion and bottom-current-induced reworking started in the late Eifelian and continued at least until the middle Frasnian. For the Givetian corresponding deposits are only preserved in relics and thus it is difficult to decide whether or not bottom currents prevailed during this time. However, during the early Frasnian the velocity and erosive capacity of currents obviously decreased giving way to ongoing accumulation of a thin but continuous record of bottom-current deposits. Although these sediments include at some stratigraphic levels a high proportion of elements that point to a shallow water source area (peloids, cortoids, crinoids and fragments of rugose corals) they are all interpreted as deposits of bottom currents.

In conclusion, the redeposited calcareous material partly derived from bottom-current redeposited turbidites or periplatform carbonates which were delivered from a shallow water carbonate platform. According to KREUTZER (1990, 1992) such cortoid grainstones and ostracod and parathuramminid packstones occur in the upper part of the nearby Kellerwand and Cellon Nappes. Styliolinid grainstone laminae included at the base of peloidal grainstone layers, erosive down-cutting of bioclastic wackestones to packstones and following inversely graded transitions into styliolinid grainstones argue for deposition from a bottom current in most successions of the Rauchkofel Nappe. The late Frasnian and Famennian record of generally mud-supported limestones is interpreted as intensively bioturbated pelagic deposit without any clear indication of current-induced redeposition. They contain a typical pelagic fauna in which elements from shallow water sources are missing.

The net **accumulation rate** within the Rauchkofel Nappe of the Carnic Alps is deduced from detailed conodont stratigraphic data of SCHÖNLAUB (1980, 1985) and GÖDDERTZ (1982) at this section and additional studies by HÜNEKE (2001). The curve shows a steep incline for the Emsian part of the succession (5-10 m / 10^6 years). Condensation started during the early Eifelian and the net sediment accumulation rapidly decreased below 0.5 m / 10^6 years (*australis* Zone). During late Eifelian to early Frasnian (*kockelianus* to *punctata* Zones), condensation and sediment reworking prevented continuous accumulation. From the late Givetian (*latifossatus* and *hermanni-cristatus* Zones) only thin limestone layers of the bottom-current redeposited facies are preserved immediately below and above the hiatuses. A continuous record without biostratigraphically recognizable gaps persisted until the late Frasnian (Early *hassi* Zone) onwards starting with allochthonous phosphatic sediments and accumulation rates below 0.5 m / 10^6 years. The remaining part of the condensed Frasnian to Famennian succession is characterized by values between 2 and 0.1 m / 10^6 years.

With regard to the isotope signal the Wolayer Glacier profile represents a key section. Although anoxic sediments are missing at the F/F boundary the positive $\delta^{13}C$ excursion can clearly be recognized. Consequently, it may be concluded that these isotope excursions are valid on a global scale independent of anaerobic conditions. The positive excursions are explained by changes in the isotopic composition of the marine total dissolved carbon (TDC). The extension of the oxygen minimum zone during a short-term sea-level rise is thought to be responsible for the enhanced deposition of ^{12}C-enriched organic matter of the Kellwasser Horizons. This is recorded by the positive carbon isotope shift. The subsequent negative excursion is explained by erosion and oxidation of previously deposited organic carbon during sea-level fall. In addition, the withdrawal of large amounts of carbon from surface waters will also affect the atmospheric pCO_2 and thus result in climatic alterations with severe implications for the biosphere. According to these explanations, the main reason for the increased amount of organic carbon is not the result of increased productivity, but the beginning of anoxic reducing conditions in the late Frasnian. This view seems to be supported by the predominance of black layered sediments free of bioturbation, an increase in the concentrations of chalcophile elements such as S, Zn, As and Sb.

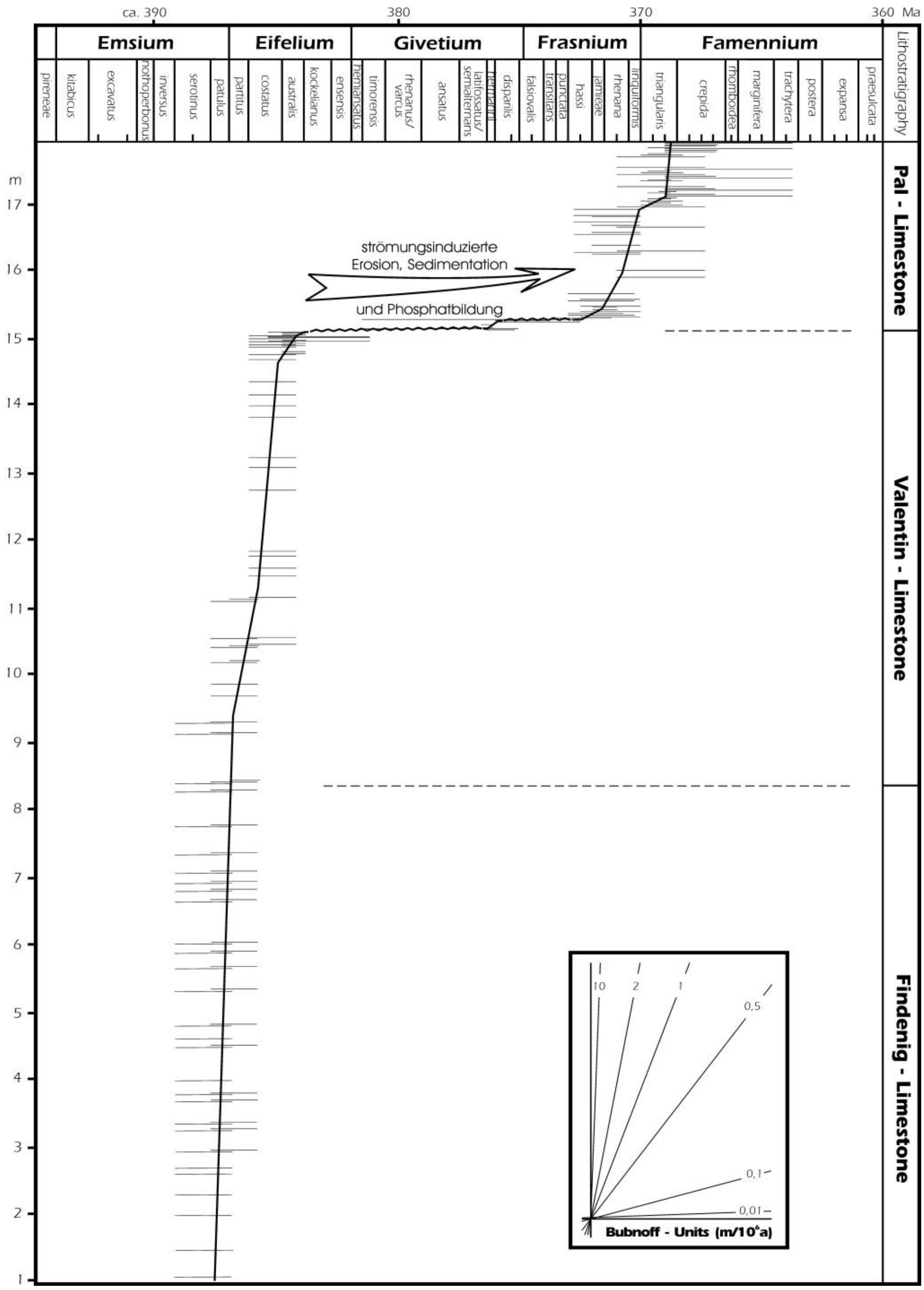


Fig. 37: Periods of condensation reflected in limestones of the Wolayer Glacier section based on accumulation rates versus absolute ages. Horizontal bars indicate conodont biostratigraphic data. Stratigraphic gaps are shown by wavy lines.
From HÜNEKE (2001).

At the F-F boundary, the positive signal of the stable carbon isotope ratio is overprinted by a short-term negative anomaly. According to JOACHIMSKI & BUGGISCH (1993, 1994) and JOACHIMSKI et al. (1994) this shift reflects a significant decrease of productivity and biomass formation in the upper water layers for which the above mentioned mass extinction is held responsible.

Whether or not the global Frasnian-Famennian biotic crisis may has been caused by oceanic ecosystem destabilization or by a single or by multiple impacts remains controversial and unsettled.

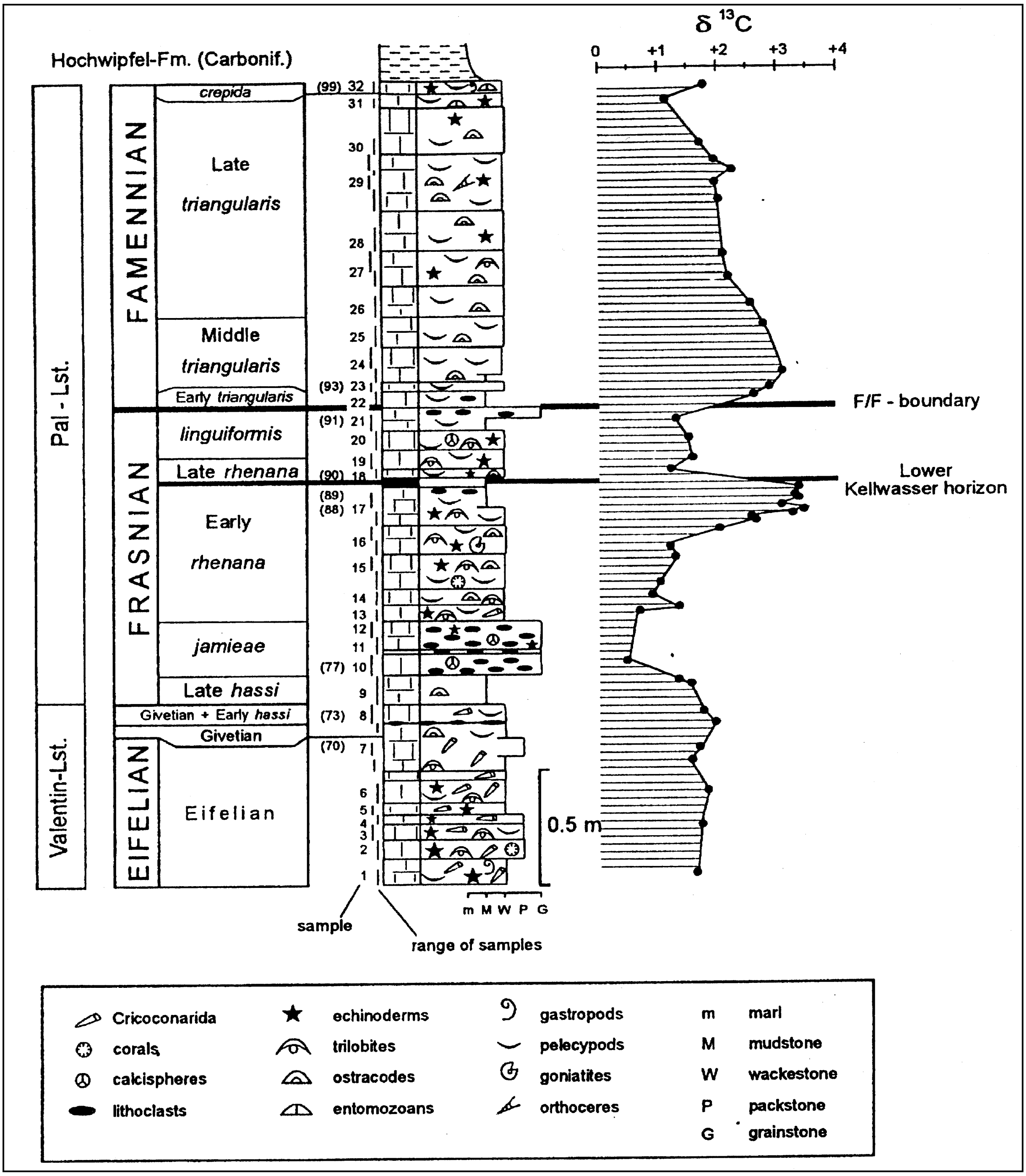


Fig. 38: Carbon isotope pattern across the Frasnian/Famennian boundary at the Wolayer Glacier section (modified from JOACHIMSKI, BUGGISCH & ANDERS, 1994)

Stop 8 – Paleozoic Ammonoids in the Carnic Alps

Paleozoic ammonoids from the Carnic Alps have been known for more than 100 years (FRECH, 1887), but a modern synthesis of the faunas is still lacking. Except for a few faunas, the current state of knowledge is strictly limited, and some of the old and destroyed finds could not be confirmed in more recent investigations.

Faunas from the Early and Middle Devonian were collected from the Valentintörl in the vicinity of Lake Wolayer (FRECH, 1887, 1894, 1902), but it is now unclear if the species do belong to the genera *Gyroceratites*, *Mimagoniatites*, and *Anarcestes* (as listed in FLÜGEL & KROPFITSCH-FLÜGEL, 1965). Not less problematic are the species newly erected by FRECH: *"Goniatites (Tornoceras) Stachei"*, and *"Goniatites (Tornoceras) inexpectatus"*, which all urgently require revision.

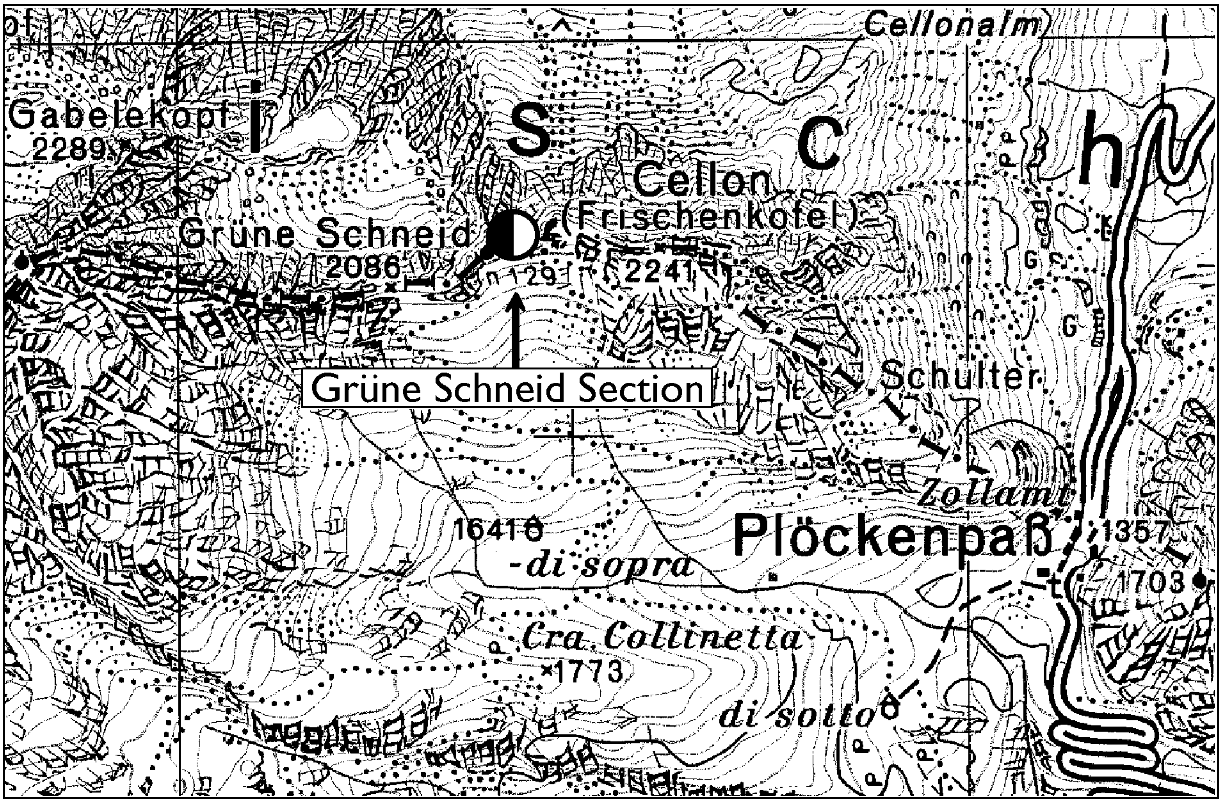


Fig. 39: Location of the Grüne Schneid section west of the Plöckenpass.

Frasnian and early Famennian ammonoids are better known. *"Beloceras praecursor"* was described by FRECH in 1902, and GAERTNER (1927, 1931) added numerous species of *Manticoceras* and *Ponticeras* from near Lake Wolayer. This material, however, was neither described nor figured. The same is true for early and middle Famennian Faunas, consisting of the genera *Prolobites, Platyclymenia, Tornoceras, Cheiloceras,* etc.

The latest Devonian *Clymenia* and *Wocklumeria* ammonoid Stages (late Famennian) are much better represented by diverse assemblages (Fig. 40, 41), suggesting a complete succession of faunas (DE ANGELIS D'OSSAT, 1899; GORTANI, 1907, 1912). Many of the old localities which are mostly located on the Italian side of the Carnic Alps have been revisited, and rich collections of ammonoids could be assembled by M.R. HOUSE, J.D. PRICE, and the author.

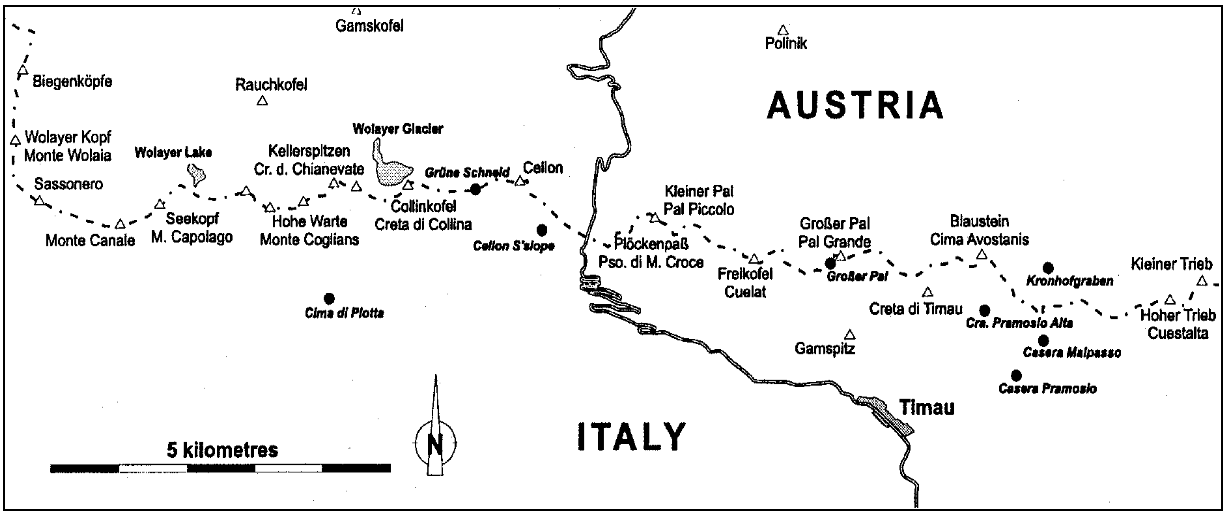


Fig. 40: Location of the Famennian and Tournaisian ammonoid localities in the Central Carnic Alps of Southern Austria.

Diverse ammonoid faunas of the *Clymenia* and *Wocklumeria* Stages are known especially from Großer Pal (Pal Grande; 3.6 km east of the Plöckenpass) and Casera Malpasso (7 km south-southeast of the Plöckenpass) located. These two latter localities yielded the clymeniid genera *Nodosoclymenia,* gen. nov. aff. *Clymenia, Piriclymenia, Cyrtoclymenia, Cymaclymenia, Falciclymenia, Kosmoclymenia, Gonioclymenia, Sellaclymenia,* and *Progonioclymenia* as well as the goniatites cf. *Prolobites, Discoclymenia, Alpinites, Gundolficeras, Erfoudites,* and *Mimi-mitoceras.* These genera indicate the presence of the *acuticostata* and *piriformis* Zones of the *Clymenia* Stage.

The Carnic faunas principally resemble the time-equivalent faunas of the Rhenish Massif and other regions, but are remarkable because of their high percentage of miniature forms. It is remarkable that a prolobitid ammonoid occurs in this fauna; only in sections of the South Urals these forms are found in the *Clymenia* Stage. Analyses of the biogeographical relations of the *Clymenia* Stage faunas led to the conclusion that the Carnic Alps are closely related to the South Urals, rather than to the Rhenish Massif or North Africa (Fig. 42).

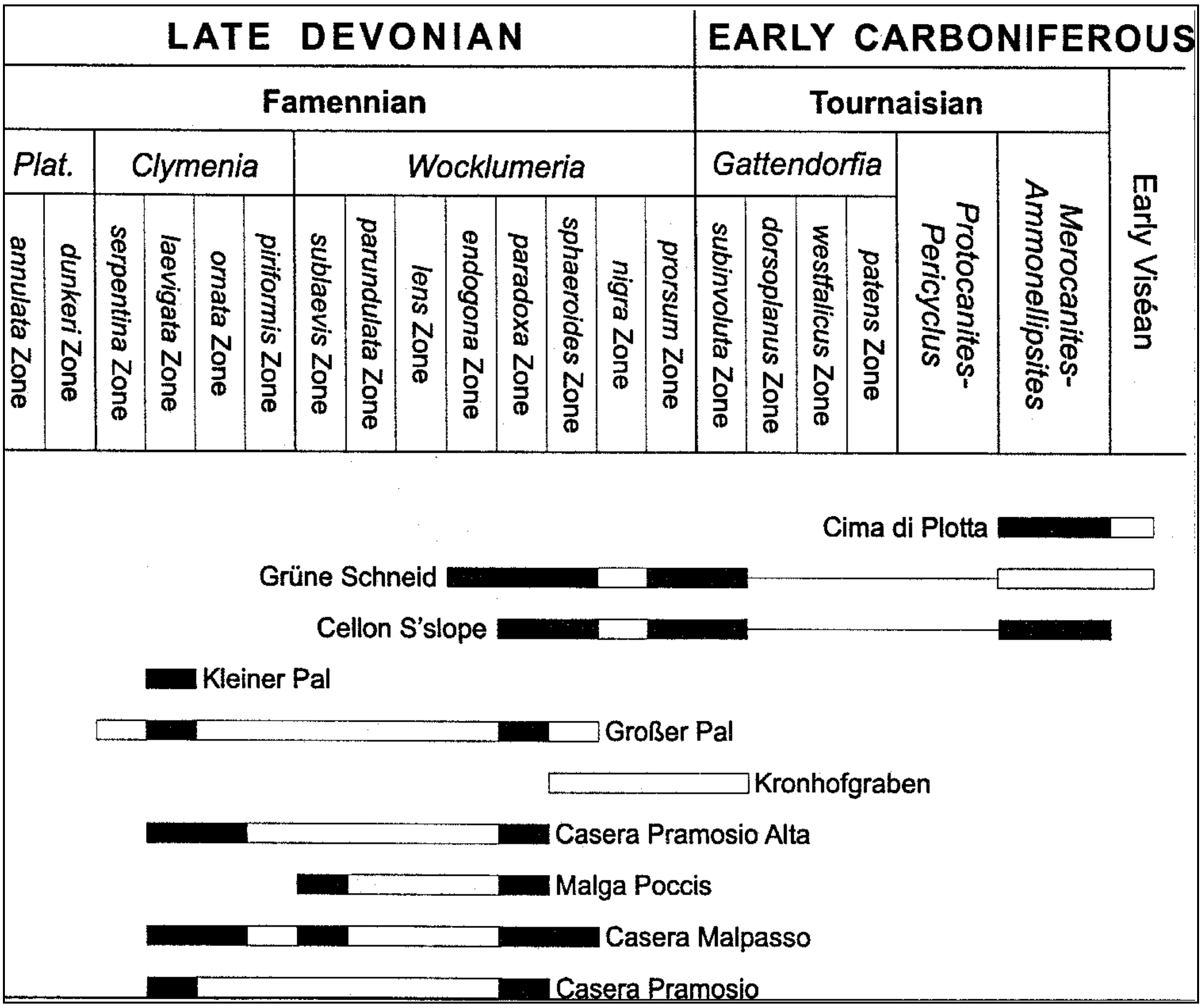
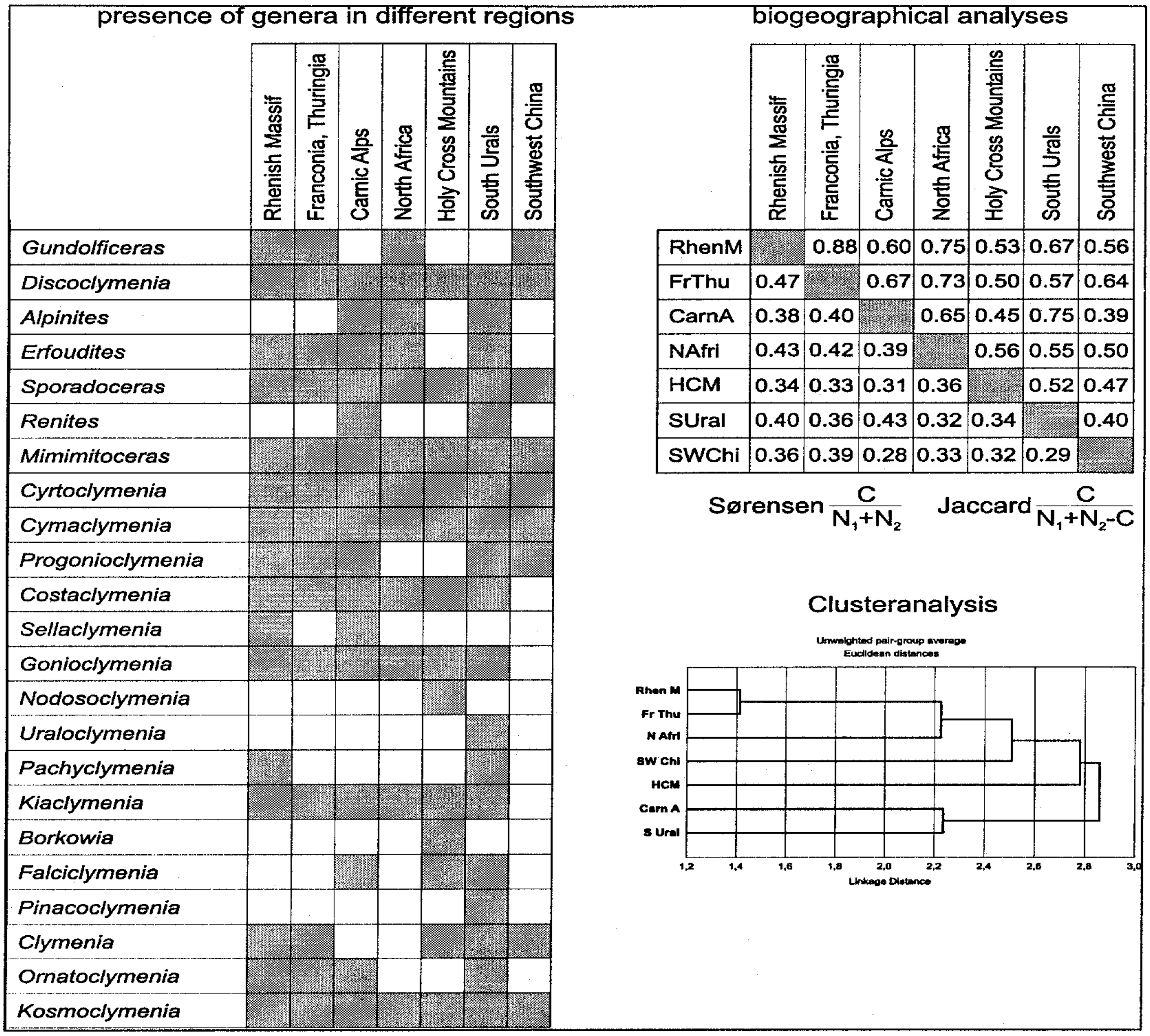


Fig. 41: Stratigraphical scheme of the late Famennian and Tournaisian ammonoid succession with indication of faunas represented in the Carnic Alps.

Limestones of the *Wocklumeria* Stage contain in sections at Casera Malpasso, Grime Schneid, and Großer Pal the clymeniid genera *Kalloclymenia, Finiclymenia, Sphenoclymenia, Wocklumeria, Parawocklumeria, Glatziella, Postglatziella, Kosmoclymenia, Linguaclymenia, Cymaclymenia* as well as the goniatites *Mimimitoceras* and *Balvia.* These demonstrate that horizons of the early and late part of this unit are represented. The faunal composition appears to be identical with the equivalents of the Rhenish and Thuringian Massifs and the Sudetes, and differs only in the lower species diversity.

The Devonian-Carboniferous Boundary is not well exposed in the Malpasso area, but can be studied at several other places, of which the Grime Schneid section yielded the most complete ammonoid record (KORN, 1992). The Hangenberg Event interval is characterised by a thin marly and unfossiliferous bed embedded in pure cephalopod limestones, and immediately above and below this bed characteristic ammonoid species were collected. The latest Devonian *prorsum* Zone as well as the basal Carboniferous *acutum* Zone are represented by their characteristic faunas, consisting of the goniatite genera *Acutimitoceras, Gattendorfia,* and *Eocanites.* The faunal composition closely resembles that of the Rhenish and Thuringian faunas.



	Rhenish Massif	Franconia, Thuringia	Carnic Alps	North Africa	Holy Cross Mountains	South Urals	Southwest China
RhenM		0.88	0.60	0.75	0.53	0.67	0.56
FrThu	0.47		0.67	0.73	0.50	0.57	0.64
CarnA	0.38	0.40		0.65	0.45	0.75	0.39
NAfri	0.43	0.42	0.39		0.56	0.55	0.50
HCM	0.34	0.33	0.31	0.36		0.52	0.47
SUral	0.40	0.36	0.43	0.32	0.34		0.40
SWChi	0.36	0.39	0.28	0.33	0.32	0.29	

Fig. 42: Biogeographical relations of ammonoid faunas from the *Clymenia* Stage (late Famennian).

At three places in the Plöckenpass area, late Tournaisian ammonoid faunas could be found. They consist of the genera *Merocanites, Irinoceras, Muensteroceras,* and *Ammonellipsites,* and can be referred to time-equivalent faunas known from North Africa, the Rhenish Massif, Ireland, and other areas.

Ammonoids of Late Carboniferous and Permian age are extremely rare in the Carnic Alps. SCHINDEWOLF (1939) mentioned *"Paragastrioceras* sp." and "Genus indet. aff. *Proshumardites* sp." from the "Stephanian" of Croce Pizzul, but the figured specimens do not allow closer determination. The description of *"Medlicottia artiensis* GRÜNEWALDT var. *carnica"* by HERITSCH (1933) from the white limestones of the Trogkofel refers to a specimen which is difficult to interpret. It belongs to the family Medlicottiidae and probably indicates an Early Permian age.

Grüne Schneid (Cresta Verde)

The locality is located 1500 metres west-northwest of the Plöckenpass (Monte Croce Carnico), and is in the depression between the Cellon (Creta di Collinetta) and the Kollinkofel (Creta di Collina) at an altitude of 2142 m (Fig. 39). It was first mentioned by GAERTNER (1931), who listed several ammonoid species without exact stratigraphical record from this place. His species identifications, however, cannot be confirmed. According to the material housed in the collection of the Institute and Museum for Geology and Palaeontology, Göttingen, it cannot be stated from which exact stratigraphical position these derive. MÜLLER (1959) mentioned a late Tournaisian goniatite from this locality. GEDIK (1974) published a columnar section of the locality, and by investigation of the conodont content first noticed the uninterrupted succession ranging from the latest Devonian into the Carboniferous.

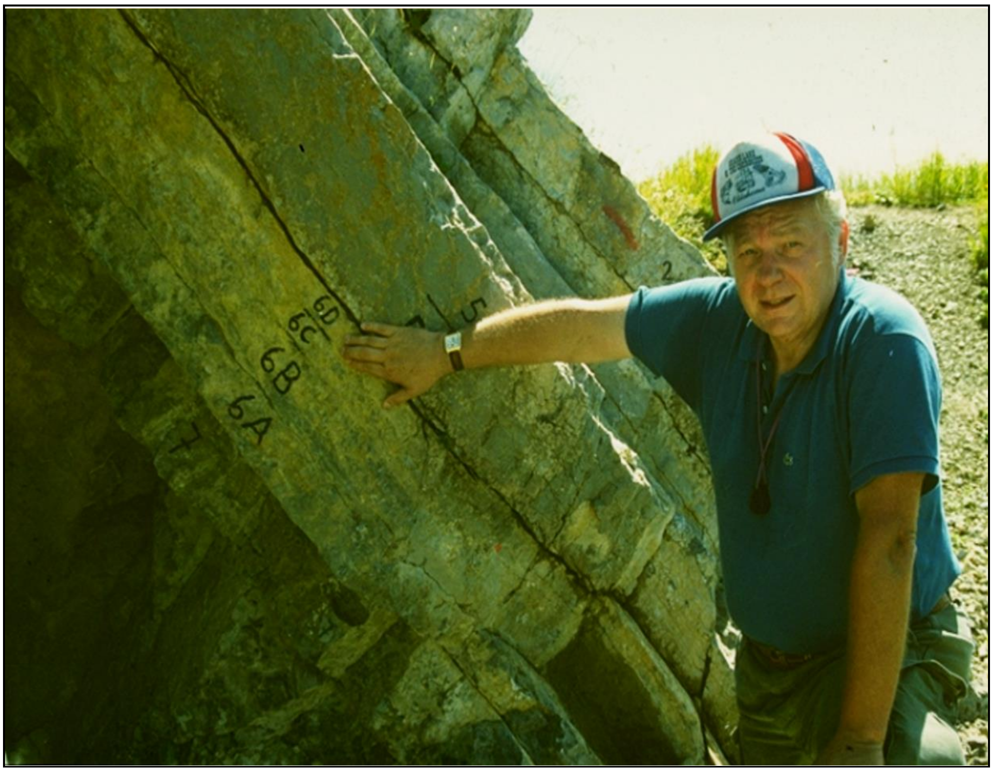


Fig. 43: Section around the Devonian-Carboniferous Boundary (between beds 6C and 6D) at Grüne Schneid.

During the activities for the search for an international stratotype for the Devonian-Carboniferous Boundary, H.P. SCHÖNLAUB (Vienna) revisited the section that is located immediately west of the western steep slope of the Cellon, about 5 m north of the Austrian-Italian frontier. The new results were preliminarily presented in 1988 (SCHÖNLAUB et al.; SCHÖNLAUB, FEIST & KORN), and further investigations lead to several detailed publications (KORN, 1992; FEIST, 1992; SCHÖNLAUB et al., 1992). In these papers, the far-reaching stratigraphical completeness of the pure limestone section was demonstrated.

The intensively studied portion that includes the D-C Boundary has a thickness of 3.60 m (Fig. 43). It is entirely composed of grey cephalopod limestone (mostly wackestone and mudstone), and almost every bed yielded ammonoids, trilobites, and conodonts. In total, 23 ammonoid species belonging to 10 genera were secured.

The ammonoid faunas from this locality have an age from the late *Wocklumeria* Stage (latest Famennian) up to the basal *Gattendorfia* Stage (Early Tournaisian), and include a fauna of the *prorsum* Zone, the latest Devonian ammonoid zone (Fig. 44). Among all the stratotype candidates under discussion, the Grime Schneid section displays the most complete ammonoid succession around the D-C Boundary. However, it was not chosen as the stratotype.

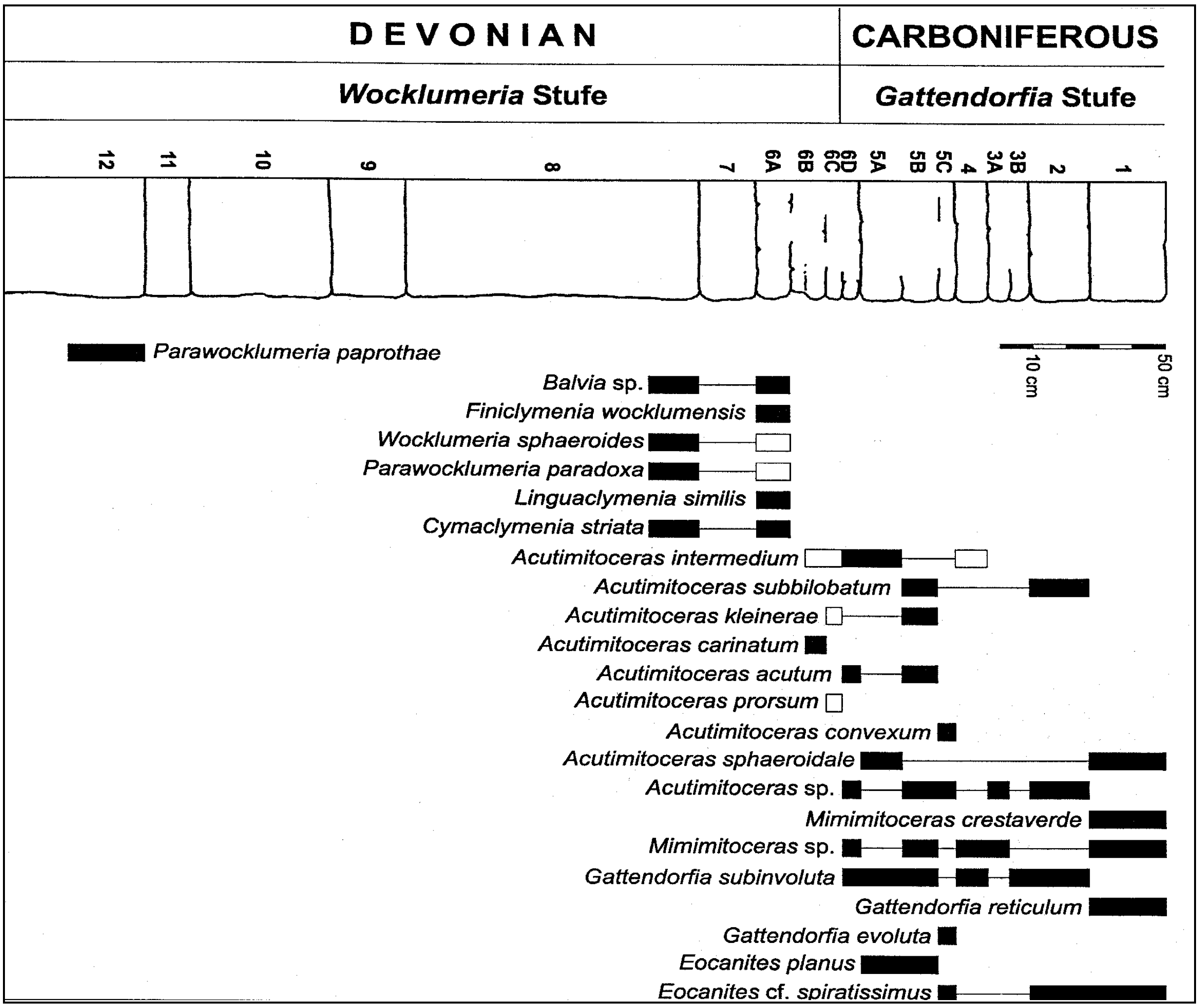


Fig. 44: Columnar section of the Grüne Schneid outcrop with ammonoid content.