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Cephalopods - Present and Past

Carnic Alps Excursion Guidebook

3 – 6th September 1999

Edited by
Kathleen Histon

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Vienna, July 1999

Cover: A sketch of the Wolayer Lake area from the fieldbook of Georg Geyer (1857 - 1936). The sketch was done on 12.VIII, 1893 while Geyer was mapping the Carnic Alps for the Geologische Reichanstalt. It is a view from the north towards the mountains of Seekopf and Coglians indicating the position of Lake Wolayer, "Weg zum See" – the path to the Lake. He produced the first maps of the region and later became Director of the Geologische Reichanstalt.
Courtesy of the Geologische Bundesanstalt archives A00074 – TB.

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Foreword

The Geological Survey of Austria cordially welcomes the participants of the V International Symposium "Cephalopods – Present and Past" to Vienna. We are very proud that our invitation to convene this meeting was accepted and we are looking forward to hosting this distinguished group of scientists in Vienna and during the excursion programme. This meeting will certainly be one of the highlights of the 150 years anniversary of the Geological Survey of Austria which we are celebrating during 1999.

At the Geological Survey of Austria reserach in biostratigraphy and historical geology of Palaeozoic sequences has a long tradition. With its foundation on November 15, 1849 the Survey's geologists were amongst the first to unravel the complex geological history of the Alps. They belonged to the first who discovered the equivalents of Palaeozoic systems defined in other countries only a few years ago: For this excursion it should be noted that as early as 1847 Franz von HAUER, the second director of the Survey recognized fossil-bearing Silurian rocks in the Greywacke Zone of the Northern Alps; Guido STACHE, the fourth director, discovered fusulinids of Permian age for the first time in 1872 and fossiliferous Ordovician sequences in 1884. Franz UNGER, a paleobotanist from Graz recognized strata of Devonian age already in 1843 soon after the original proposal to establish this system.

In the decades since this heroic phase of geological research mainly scientists from the Survey and from the Universities of Graz and Bologna have played a leading role in the study of the early history of the Alps. Nowadays this emphasis has spread to other universities in Austria and beyond the border aiming at the recognition of past relationships of faunas and floras between the classical fossiliferous sequences of Ordovician to end-Permian age in the Alps and adjacent regions in Europe, the reconstruction of wander ways of different groups of organisms, the palaeolatitudinal setting, i. e. the palaeoclimatic conditions, and finally, the geotectonic evolution of this piece of crust.

However, correlating and modelling of past environments needs a solid biostratigraphic framework which must be founded on sufficient palaeontological data. This is particularly true for cephalopods which represent a group of high priority for many (paleo)biological considerations including the taxonomy. This will be demonstrated in the field.

In this regard it should be noted that systematic study of Devonian ammonoids in the Carnic Alps already started in the last century. By accident, this was about the same time when such members of the Survey like Alexander BITTNER and Edmund von MOJSISOVICS carried out their famous ammonoid studies in the Triassic Hallstatt Lst. of the Northern Alps. In the Southern Alps the primary work was done by the German Fritz FRECH and was summarized by him in 1897. In 1921 Otto H. SCHINDEWOLF reviewed his data based on the collection in Wroclaw (which was destroyed during World War II) and a study of material in E. KAYSER's collection in Marburg. In addition he commented on the material described by Michele GORTANI (1907) and others. New records were later added by Hans Rudolf von GAERTNER (1931) and lately by Michael R. HOUSE & John D. PRICE (1980) and Dieter KORN (1992).

The *'Orthoceras'* Limestones from the Silurian of the Carnic Alps and the nautiloid fauna were well documented by STACHE and GEYER while mapping the area at the start of the century however, the only systematic study was done by HERITSCH in 1929. TARAMELLI, GORTANI and VINASSA DE REGNY produced the most important Italian works on the area in which these *'Orthoceras'* limestones were mentioned in detail. RISTEDT included material from the Cellon and Rauchkofelboden sections in his study of the Orthoceratidae and early ontogenetic features in orthoconic nautiloids. Interesting aspects of the taphonomy of the nautiloid fauna within the Silurian sequences from the Cellon and Rauchkofel sections have been highlighted by HISTON and FERRETTI within a recent multi-disciplinary study of the cephalopod limestone biofacies with regard to the paleogeographical setting of the Carnic Alps during the Silurian. New detailed collecting from various sections together with a revision of the older collections is also being carried out in order to test the biostratigraphic potential of the nautiloid fauna from the Carnic Alps.

It is the intention of this guide to present at least some of these accomplishments in only a few days in the field. The Survey greatly acknowledges the contributions for this guidebook from various authors and sources, and in particular the editorship by Kathleen Histon. Some data have been published previously but were updated and revised to document the latest available results.

Hans P. Schönlaub,
Director, Geological Survey of Austria

Contents

The Palaeozoic of the Southern Alps

Hans P. SCHÖNLAUB and Kathleen HISTON[1]

Summary

In this article the present knowledge about the classic Palaeozoic sequence of the Austrian part of the Southern Alps is summarized. The available faunal, floral and sedimentological data are derived from a continuous record of Middle to Upper Ordovician through end-Permian fossiliferous strata exposed in both the Carnic Alps and its eastward continuation in the Karawanken Alps. These data supplemented by palaeomagnetic measurements suggest a constant movement from more temperate regions of some 50° southern latitude in the late Ordovician to the equatorial belt during the Permian (Fig. 1)[2].

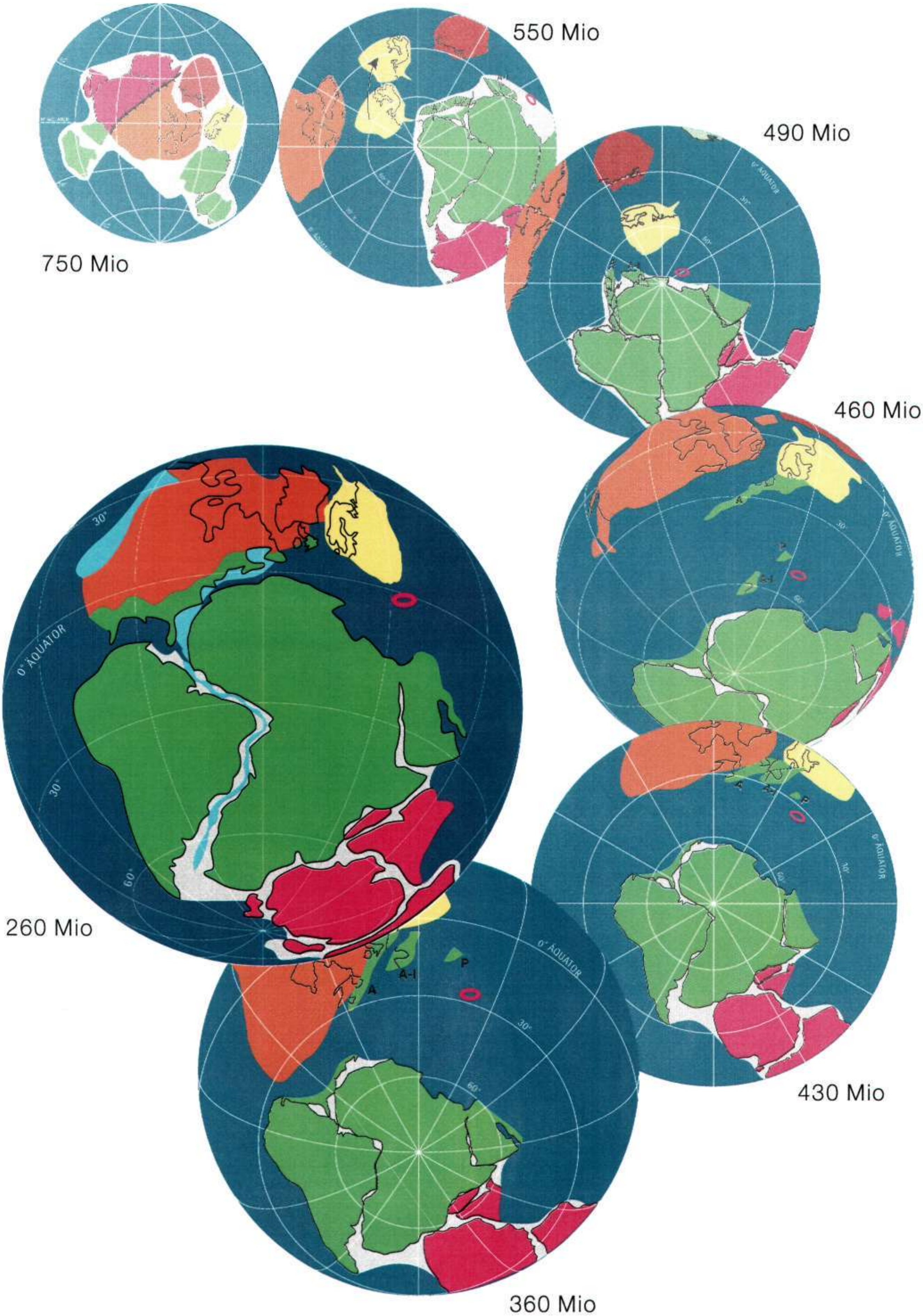
Although direct evidence is missing it may be concluded that the Southern Alps like other regions in Southern and Western Europe, belonged to the northern margin of the African part of Eastern Gondwana during the Cambrian. Initiation of rifting indicated by basic volcanism in parts of the Central Alps, may have occurred during the Lower Ordovician leading to fragmentation and northward drifting of small microcontinents. In fact, during the late Ordovician the supposed former close spatial relationship to northern Africa decreased.

Instead the faunistic and lithic pattern suggest a warm water influx from Baltica and even Sibiria. The following biota, in particular bivalves, nautiloids, trilobites and corals from the Silurian and Devonian shows close affinities to coeval faunas and floras from southern, central and southwestern Europe. However, the relationships to the Atlantic bordering continents and microplates in low latitudinal position such as Baltica, Avalonia and also Sibiria were also remarkably close suggesting a setting of about 35°S for the Silurian and within the tropical belt of some 30° or less for the Devonian. Whether or not Sardinia, the Montagne Noire, Iberia and the Armorican Massif occupied a similar palaeolatitudinal position or were attached to Northern Africa remains open. In any case, exchange of faunas between these regions and the Southern Alps seems well documented and may have been aided through currents.

During the Visean Stage of the Lower Carboniferous the Lower Palaeozoic sequence of the Southern Alps collided with the Central Alps and migration paths developed across the accreted Alpine terranes. Both Lower and Upper Carboniferous faunas and floras appear of limited biogeographic significance as they exhibit either cosmopolites or represent a general humid equatorial setting. Nevertheless they provide key elements for correlating continental deposits and shallow marine sequences. Progressive northward drifting during the Late Carboniferous and the Permian resulted in semi-arid and arid conditions which started in the Central Alps in the Lower and in the Southern Alps during the Middle Permian indicating that

[1] Authors' addresses: Geological Survey of Austria. Rasumofskygasse 23, A-1031 Vienna.

[2] Fig. 1. (Facing page – colour insert) Wander path of continents between 750 and 260 Ma. Circle indicates approxoimate position of the Proto-Alps. Main plate configration after I. W. D. DALZIEL 1995, T. H. TORSVIK et al. (1996) and L. R. M. COCKS & C. R. SCOTESE 1991.



750 Mio
550 Mio
490 Mio
460 Mio
430 Mio
360 Mio
260 Mio
0° ÄQUATOR
30°
60°
A
A-I
P

the forerunner of the Alps may have crossed the equator at different times during the Upper Palaeozoic.

In the Southern Alps the spatial distribution of the different Upper Ordovician to Lower Carboniferous litho- and biofacies indicates a SW-NE directed polarity from shallow water environments to an open marine and deep-sea setting. The latter must be assumed further north of the present Carnic and Karawanken Alps which, however, are fault-bounded. At least during the Lower Carboniferous this northern counterpart comprised an extensive shallow water carbonate platform of which, however, only small remnants and exotic limestone clasts have been preserved embedded mainly in the flysch-type Hochwipfel Formation. Therefore, any conclusion about the width of this intervening area and the nature of the rocks separating different Alpine terranes, remains a matter of speculation.

On a larger scale these Alpine blocks represent peri-Gondwanide terranes and arcs similar to Avalonia, Armorica-Iberia, Perunica, Mixteca, Zapoteca, Famatina and others which originally formed the northern and western margin of Gondwana. Some of these may have been permanently or loosely attached to Africa while others including the Southern Alps split off in the early Ordovician to drift northward more or less rapidly until they successively collided and accreted with Laurentia and Baltica, respectively, during the Devonian and Carboniferous.

Introduction

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 Palaeozoic age has been preserved. 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 Palaeozoic 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 Palaeozoic strata are distributed on either side of the Periadriatic Line (Gailtal Fault) which separates the Southern and the Central or Northern Alps (Fig. 2). These rocks have been subdivided into a northern and a southern domain, respectively. The latter extends beyond the state border to northern Slovenia.

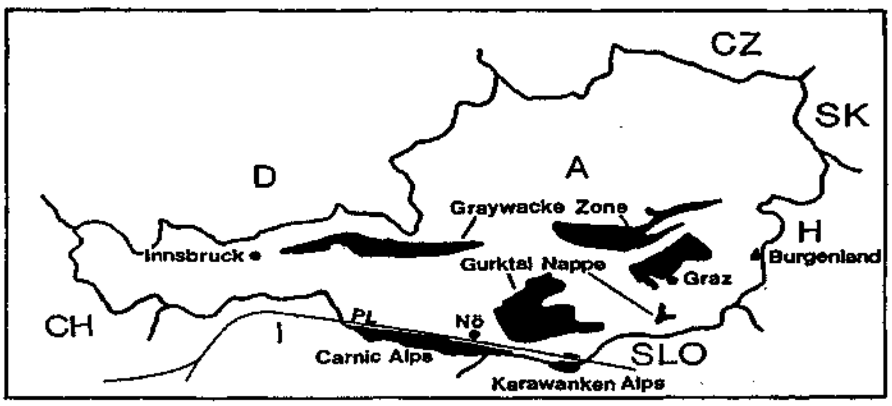


Fig. 2. Main occurrences of fossiliferous Palaeozoic rocks in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Carboniferous of Nötsch).

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. Interestingly, the equivalents of the Lower Palaeozoic were first found in the Karawanken Alps and not in the more fossiliferous Carnic Alps (E. SUESS 1868, F. TIETZE 1870). In this latter area the 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 mostly by G. GEYER from the Geological Survey of Austria and detailed studies by F. FRECH. During the first half of this century F. HERITSCH and his research group from Graz University revised the stratigraphy on the Austrian side while M. 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 Palaeozoic was provided by H. R. von GAERTNER (1931). The detailed knowledge of Upper Carboniferous and Permian rocks resulted mainly from studies by F. 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., H. P. SCHÖNLAUB 1971, 1980, 1985, 1997, H.P. SCHÖNLAUB & L. H. KREUTZER 1994).

Review of Stratigraphy

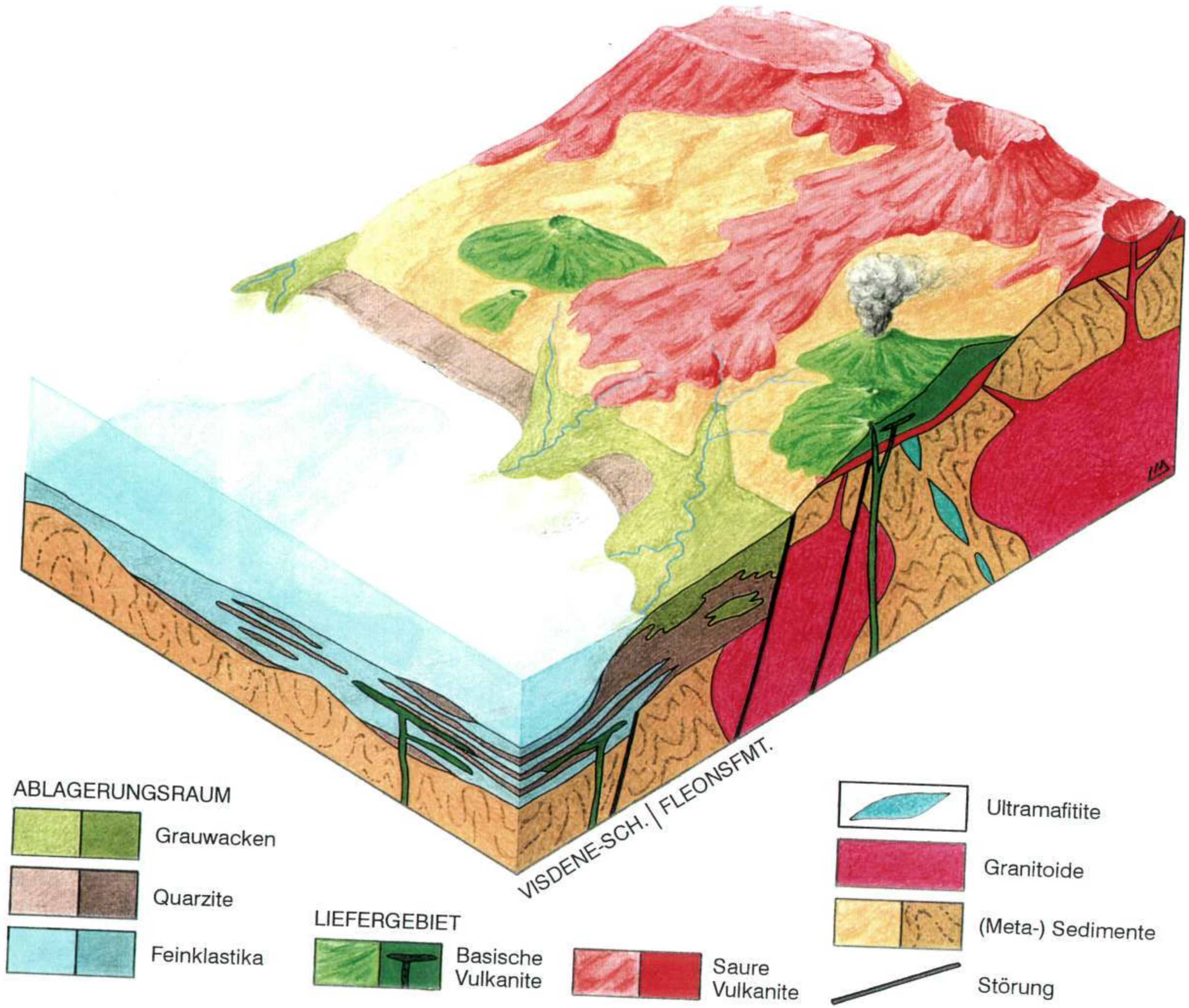
Fig. 4 summarizes the stratigraphy and facies distribution of the sedimentary sequences of the Carnic Alps. With minor modifications this framework can also be applied to the Karawanken Alps (H. P. SCHÖNLAUB 1980, B. MOSHAMMER 1989).

Ordovician

The oldest megafossil-bearing strata of the Southern Alps indicate an early Upper Ordovician age. In the western Carnic Alps and in the Brixen Phyllite Complex even older rocks occur the age of which, however, is not precisely known. Presumably, the oldest part of this sequence may be attributed to the Cambrian or Lower 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 (Fig. 3) [3], 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 (V. HAVLICEK et al. 1987). According to R. D. DALLMEYER & F. NEUBAUER (1994) detrital muscovites from the sandstones are

[3] Fig. 3. (Facing page – colour insert) Sketch of Upper Ordovician volcanism in the western Carnic Alps (modified from M. HINDERER 1992).



VISDENE-SCH. | FLEONSFMT.
ABLAGERUNGSRAUM
Grauwacken
Quarzite
Feinklastika
LIEFERGEBIET
Basische Vulkanite
Saure Vulkanite
Ultramafitite
Granitoide
(Meta-) Sedimente
Störung

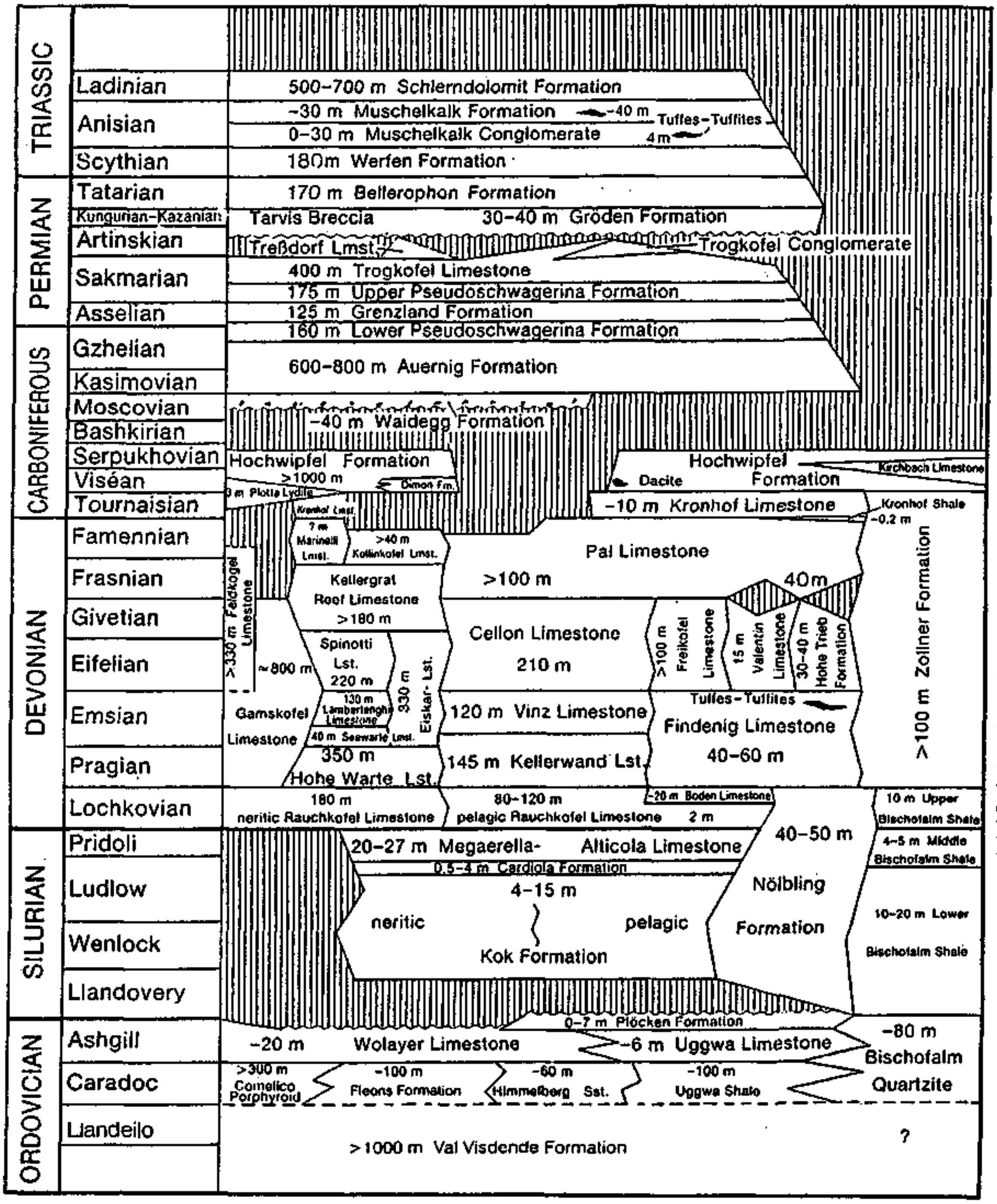


Fig. 4. Biostratigraphic scheme of the Palaeozoic sequence of the Carnic Alps. With only minor modifications this subdivision can also be applied in the Karawanken Alps (after H. P. SCHÖNLAUB 1985, modified).

characterized by appparent ages (40Ar/39Ar) of c. 600 to 620 Ma and may thus be derived from a source area affected by late Precambrian (Cadomian) metamorphism.

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 parautochthounous bioclasts from 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* (H. P. 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 H. P. 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 (H. P. SCHÖNLAUB 1992, A. FERRETTI & C. R. BARNES 1998, A. FERRETTI 1997, G. BAGNOLI et al. 1998, O. BOGOLEPOVA & H. P. 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, e.g. the genus *Clarkeia* appearing in uppermost Ordovician strata of the central Carnic Alps (H. JAEGER et al. 1975). Based on the available evidence from the Ordovician of the Southern Alps H. P. SCHÖNLAUB (1992) inferred a palaeolatitudinal position at roughly 50°S. Originally this conclusion was based solely on lithic and faunal data but subsequently was confirmed by palaeomagnetic measurements (M. SCHÄTZ, J. TAIT, V. BACHTADSE & H. SOFFEL 1997).

Silurian

The Silurian strata of Austria are irregularly distributed within the Alpine nappe system with occurrences in the Gurktal Nappe of Middle Carinthia and southern Styria, the surroundings of Graz and the Graywacke Zone of Styria, Salzburg and Tyrol while to the south of the Periadriatic Line they occur in the the Carnic and Karawanken Alps. The main differences on either side of the Periadriatic Line being the distribution of fossils, the facies pattern, rates of subsidence, supply area, amount of volcanism and the spatial and temporal relationship of climate sensitive rocks (H.P. SCHÖNLAUB 1992)

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. 5). Uniform limestone sedimentation during the Pridoli suggests that more stable conditions were developed at this time (H.P. 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 60m. The available data for the Carnic and Karawanken Alps suggest a complete but considerably condensed succession in the carbonate-dominated facies and a continous record in the graptolite-bearing sequences something which is not possible to demonstrate in other areas of the Eastern Alps due to bad preservation, lack of fossils and metamorphic overprints.

In the Carnic Alps the Silurian transgression started at the very base of the Llandovery, i.e. in the graptolite zone of *Akidograptus acuminatus*. Its forerunner from the latest Ordovician, *Gl. persculptus* was reported from the western Karawanken Alps (H. JAEGER et al. 1975). 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 in both the Carnic and Karawanken Alps. At some places even uppermost Pridolian strata may disconformably rest upon Upper Ordovician limestones.

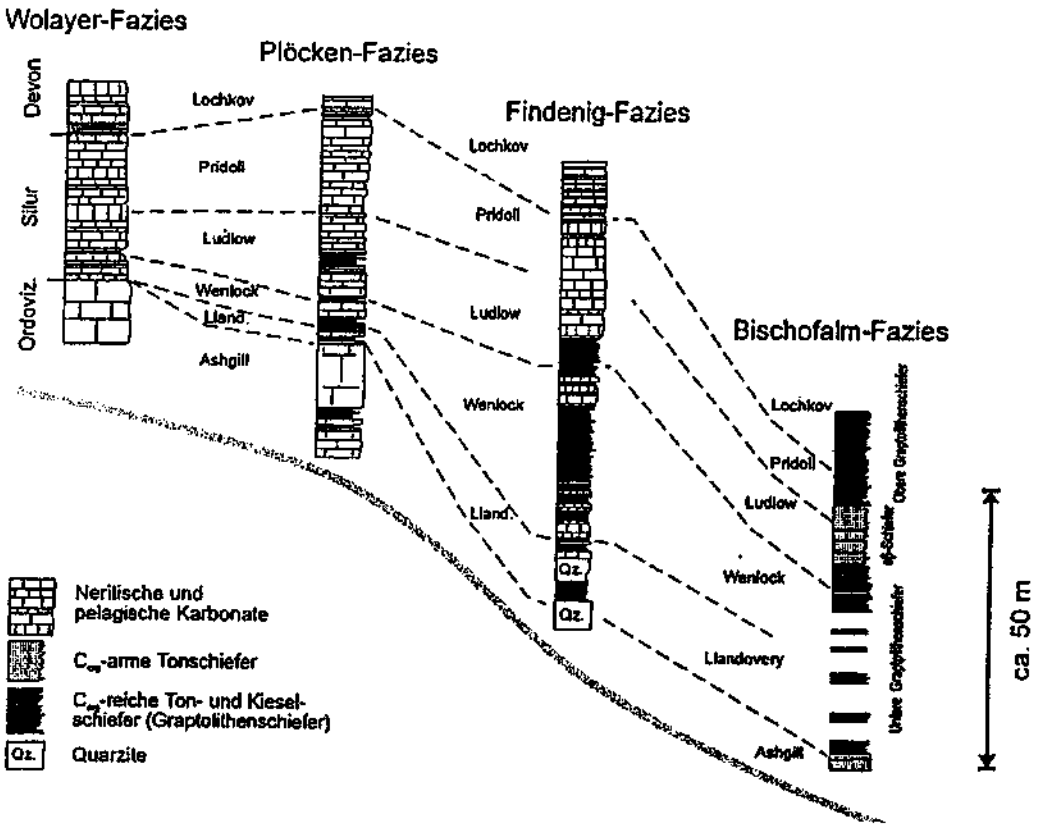


Fig. 5. Lithology of Silurian sediments of the four different lithofacies of the Carnic Alps. Brickstone reflects carbonates, black corresponds to C_{org} rich graptolite-bearing shales and cherts and C_{org} rich carbonates of the Wolayer facies. Light gray represents C_{org} poor shales. Columns from left to right show the sections Rauchkofel Boden, Cellon, Oberbuchach 1-2 and Nölblinggrabe-Graptolithengraben. In the latter composite section Lower Silurian sediments are not continuously exposed. From B. WENZEL 1997.

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* Formation, 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 Lst., 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 ruguse corals. A *Scyphocrinites* bed bearing complete specimens caps the formation and marks the Silurian /Devonian boundary and the shallowest level of the sequence.

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 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 clastic Plöcken Fm. the carbonate sequence of the Plöcken Facies were deposited in a relatively shallow environment, periodically effected by storm currents, with intervals of reduced deposition 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 occuring 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). WENZEL (1997, fig. 7) also illustrates several variations of the oxygen Isotope ratio throughout the Kok Formation in particular at the transition of the Llandovery/Wenlock and Wenlock/Ludlow. Frequent levels showing bioturbation and condensed brachiopod accumulations also demonstrate changes in hydrodynamic regime (K. AZMY et al. 1998).

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 Formation (Ludlow) indicate a slightly deeper offshore environment with probable contemporary non-deposition taking place. Current activity of varying hydrodynamic regime is evidenced by

these accumulations and periodic increases in oxygen content throughout the sequence may be implied from the concentrations of brachiopods /bivalves and pockets of *chondrites*.
A more stable pelagic environment is developed in the Alticola and Megaerella Limestones from the upper Ludlow continuing into the Prídolí (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* (JAEGER, 1975).
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 (Lochovian) with the occurrence of a bryozoan fauna.
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. PRIEWALDER (1997) indicates a rich chitinozoan fauna from the Pridoli - Lochkovian interval therefore the depositional environment was of a low hydrodynamic regime favorable for their preservation.

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 of the Nölbling Formation which is locally underlain by a quartzose sandstone.
The stagnant water graptolitic "Bischofalm Facies" is represented by black siliceous shales, lydites and clayish alum shales. The transgressional regime in both of these more basinal facies continued from the Llandovery to the Ludlow when a slight decrease in the subsidence of the basin is documented by the green-gray shales of the Middle Bischofalm Shale Formation. A return to the deeper water graptolitic sequence is seen in the late Pridoli to Lochkov.

The evidence from the Silurian indicates faunal affinities, e.g. conodonts, trilobites, brachiopods, molluscs, chitinozoa and architarchs 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.

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 C.E. BRETT and H.P. SCHÖNLAUB based on a sequence stratigraphy study of the sections (Fig. 6). The variations in sea-level compare quite well with those inferred by M.E. JOHNSON

(1996) and D. K. LOYDELL (1998) for the global sea-level changes during the Lower Silurian. A correlation of the sequence boundaries and sea-level changes determined for the Carnic Alps with those of N.E. America and Britain (C.E. BRETT et al. 1990, W.M. GOODMAN and C.E. BRETT 1994) suggests proximity also with Laurentia and Avalonia during this time interval as the global eustatic changes effecting the Gondwana-derived terranes to the east and Laurentia to the west are quite similiar.

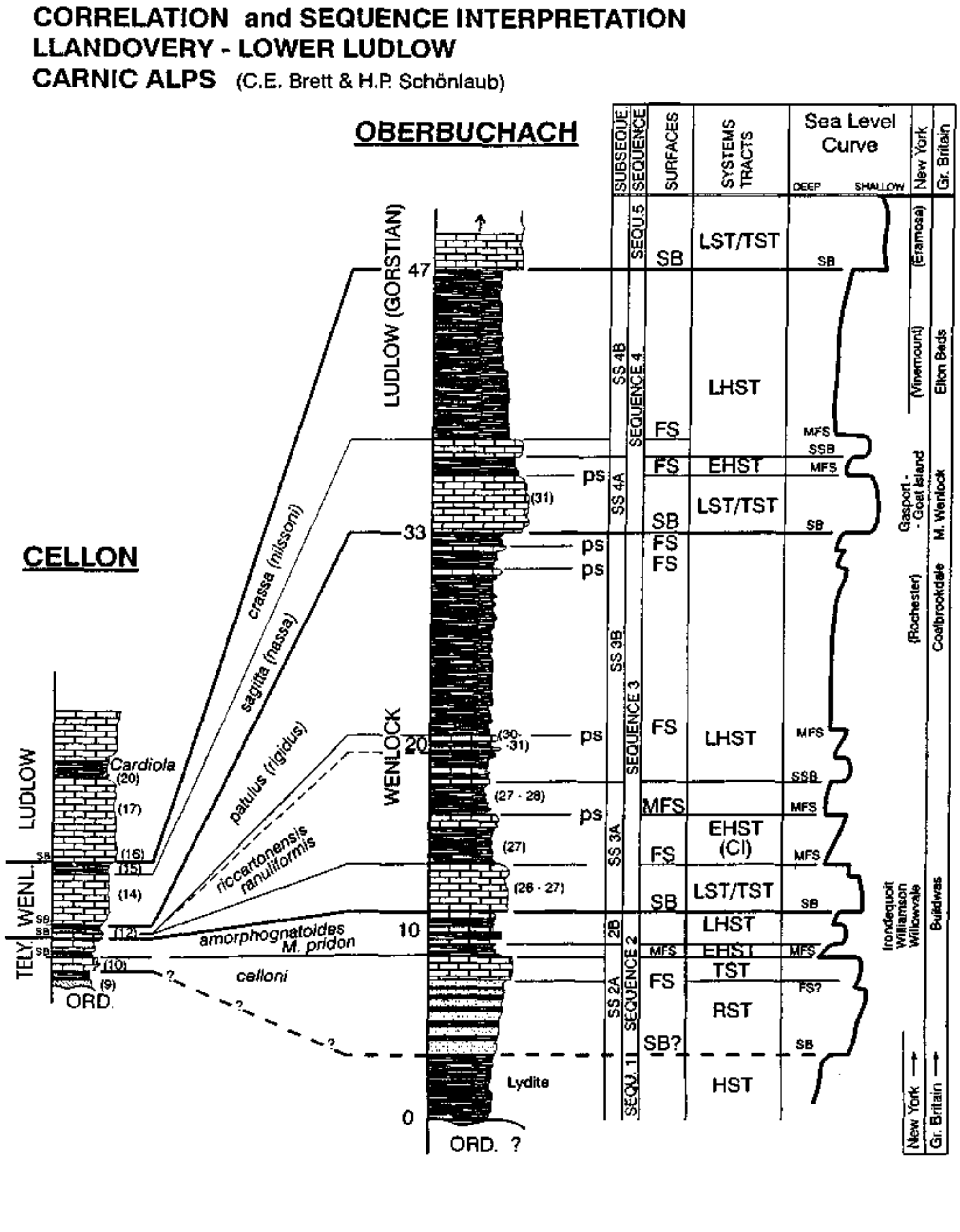


Fig. 6. Correlation and sequence interpretation Llandovery - Lower Ludlow, Carnic Alps. (C.E. BRETT & H. P. SCHÖNLAUB)

Devonian

In the Southern Alps the Devonian Period is characterized by abundant shelly fossils, varying carbonate thicknesses, reef development and interfingering facies ranging from near-shore sediments to carbonate buildups, lagoonal and slope deposits, condensed pelagic cephalopod limestones to deep oceanic off-shore shales. The ratio of thicknesses between shallow-water limestones and contemporary cephalopod limestones approximates 1200 : 100 m and thus indicates differentially subsiding mobile basins affected by extensional tectonics. This regime lasted until the early Lower Carboniferous. Rifting-related volcanism, however, is only known in the Central Alps, e.g., in the Graywacke Zone and the surroundings of Graz.

The Lower Devonian is characterized by a transgressional sequence including the neritic Rauchkofel Lst. (up to 180 m thick) which corresponds to some 20 m of pelagic limestones (Boden Lst.). During the Pragian and Emsian Stages the differences even increased. Within short distances of less than 10 km a strongly varying facies pattern developed indicating a progressive but not uniform deepening of the basin. It was filled with thick reef and near-reef organodetritic limestones including different intertidal lagoonal deposits of more than 1000 m thickness in the Carnic Alps and some 300 m in the Karawanken Alps. They are time-equivalent to some 100 m of pelagic cephalopod limestones and the pelitic Zollner Formation:

During the Upper Ordovician and the Silurian, reef evolution never exceeded a pioneer faunal stage with pelmatozoans suggesting flat biostromes and a weak tendency to form low topographic carbonate buildups. In the Lochkovian and Pragian Stages, the appearance of corals and stromatoporoids indicate more favourable life conditions and first patch reefs accumulated. Main reef builders were stromatoporoids, tabulate corals and calacareous algae such as *Renalcis*.

According to L. H. KREUTZER 1992a,b in the Carnic Alps five north-northeast to south-southwest directed facies belts developed in the Devonian Period. During later orogenic events these belts were strongly deformed, being distributed in different nappes and tectonic slices which from top to base can be subdivided into the following units (Fig. 7):

1. Southern shallow-water facies of the Cellon-Kellerwand nappe
   - a: Intertidal subfacies at Biegengebirge and Gamskofel
   - b: Back reef subfacies at Upper Kellerwand, Hohe Warte, Biegengebirge
   - c: Reef subfacies at Hohe Warte and Upper Kellerwand
   - d: Reef debris subfacies at Hohe Warte and Upper Kellerwand
2. Transitional facies of Cellon nappe
3. Pelagic limestone facies of Rauchkofel nappe
4. Pelagic off-shore basinal facies of Bischofalm nappe
5. Northern shallow water facies.

In the Carnic Alps the approximately 1300 m high cliffs of the Kellerwand and of Hohe Warte (2784 m above sea level) represent the depocenters of the Devonian reef building which reached the climax during the Givetian and Frasnian Stages. The strongly varying thicknesses of all facies belts during the Devonian contrasts markedly with the foregoing Silurian Period. In the interval from the Lockovian to the Frasnian in facies belt 1 more than 1100 m of limestones accumulated corresponding to some 100 m of cephalopod limestones in facies belt

3. Between both facies belts an intermediate environment developed in facies belt 2. According to L. H. KREUTZER 1990, 1992b at least 13 different carbonate microfacies types can be recognized for the Devonian.

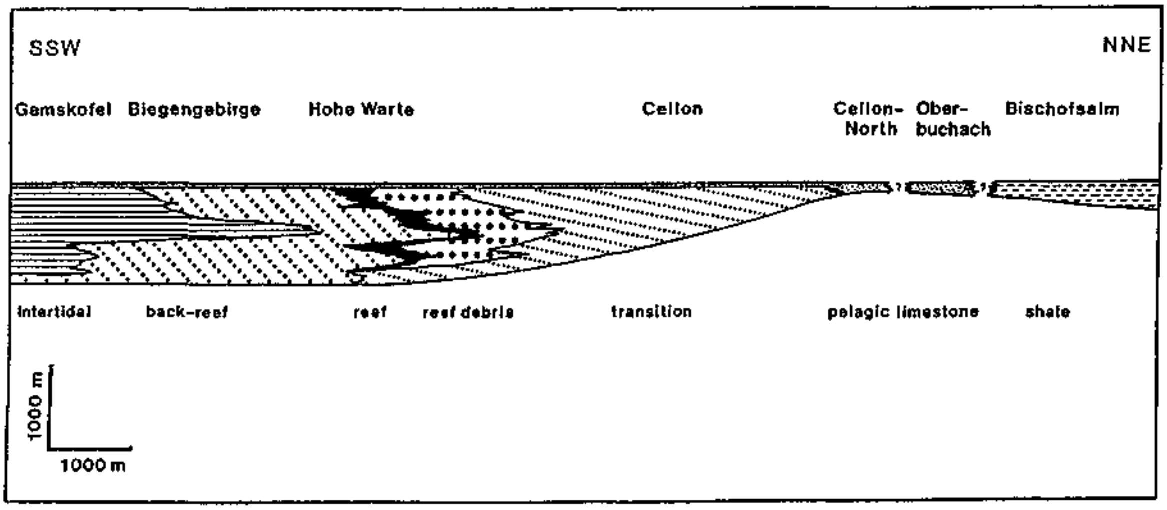


Fig. 7. Palinspastic profile of the Carnic Alps at the Devonian/Carboniferous boundary. Gamskofel, Biegengebirge, Hohe Warte: Southern shallow water facies (Kellerwand nappe. Cellon: Transitional facies (Cellon nappe). Cellon-North, Oberbuchach: Pelagic limestone facies (Rauchkofel nappe). Bischofalm: Offshore pelagic basinal facies (Bischofalm nappe). Further to the north the northern shallow water facies of the Feldkogel nappe occurs. After L. H. KREUTZER 1992a.

The reef development ended in the Late *P. rhenana* conodont Zone of the upper Frasnian. At the Frasnian/Famennian boundary the reefs drowned and a uniform pelagic environment developed which lasted across the Devonian/Carboniferous boundary. During the Famennian the reddish, pinkish and greyish Pal Limestone was deposited followed by the Kronhof Lst. in the Tournaisian which both represent cephalopod-trilobite-ostracod-bearing wackestones.

Northeast of facies belt 3 the almost carbonate-free facies 4 occurred attaining a thickness comparable to the cephalopod limestone facies. This siliciclastic facies comprises mainly black and greenish shales, siltstones and siliceous shales and massive and well bedded variegated cherts together named the Zollner Formation. It succeeded the Silurian to Lochkovian graptolite-bearing black Bischofalm Formation at the base of the Pragian and continued into the Lower Carboniferous. So far, in these rocks only a few conodont data from bedding planes and interbedded limestone lenses provide age assignements and hence pose some problems to infer the actual thickness of the Zollner Formation.

For the Karawanken Alps G. RANTITSCH (1990) concluded an arrangement of reefs resembling present-days atolls as opposed to the Carnic Alps with its barrier-type reefs (L. H. KREUTZER 1990, 1992a). Depending on adequate subsidence the location of the reef core shifted spatially and temporarily during the Devonian. Differing from the Carnic Alps with its 150 m thick reefs of Givetian age, in the Karawanken Alps there are no good records from the Middle Devonian. In both areas, however, the reef development ended in the Frasnian when the former shallow sea subsided being followed by a drowning and erosion of the reefs.

Similar to the Carnic Alps in the Karawanken Alps these shallow water deposits were also replaced by uniform pelagic goniatite and clymeniid limestones.

During the Devonian Period faunal exchange between the peri-Gondwanide microcontinents, including those possibly attached to northern Africa, and affinities to the equatorial warm-water realm in the vicinity of Baltica increased suggesting the continued approach of the Southern Alps towards lower latitudes. In particular, Lower Devonian brachiopods, corals, gastropods, trilobites and algae reflect close relationships with southern, central and western Europe but also to the Ural-Tienshan region as opposed to northern Africa (H. P. SCHÖNLAUB 1992, B. HUBMANN & A. FENNINGER 1993). In addition, equatorial gyres may have aided the distribution of several planctonic groups of organisms.

As mentioned above the Devonian of the Southern Alps is particularly characterized by thick carbonate deposits which locally have formed buildups containing a highly diversified fauna and flora. Within short distances of only a few kilometers these shallow water deposits grade into coeval sequences with reduced thicknesses. This facies pattern implies spatially and temporary enhanced rates of subsidence in an extensional regime and thus characterizes a passive plate margin prior to the collison with a land area to the north. In the whole Southern Alps evidence for rifting-related volcanism is generally very weak and may only occur in the Karawanken Alps.

In conclusion, the combined lithic and fossil data from the Devonian Period suggest that the Southern Alps were placed within the tropical belt of some 30° S or less (SCHÖNLAUB 1992). This estimation seems well constrained by palaeomagnetic data (SCHÄTZ et al. 1997).

Carboniferous

According to H. P. 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 (Fig. 8). 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. Recenty, 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 (H.P. SCHÖNLAUB & L. H. KREUTZER 1993, M. C. PERRI & C. SPALLETTA 1998a,b, C. SPALLETTA & M. C. 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 (Fig. 9).

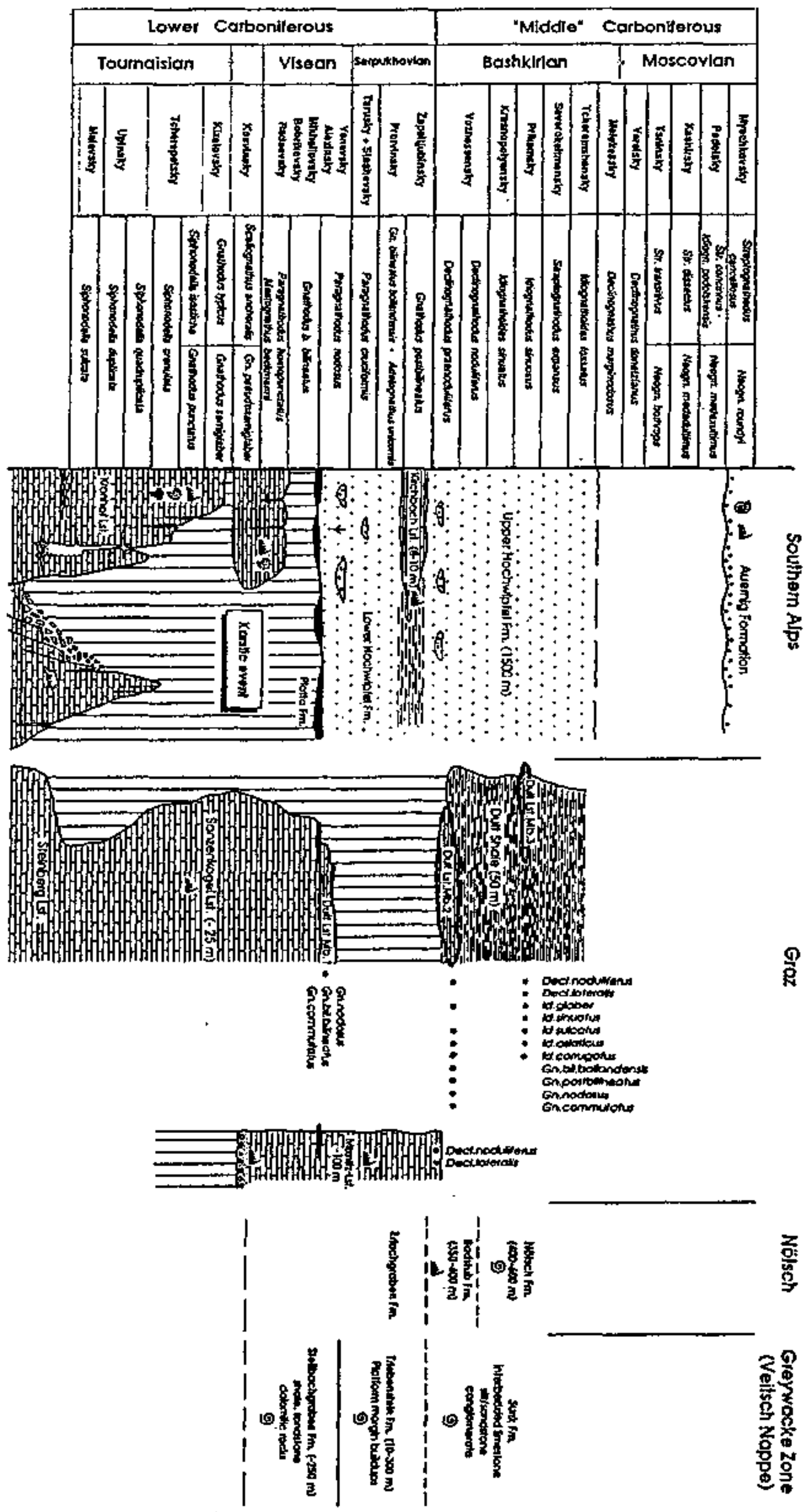
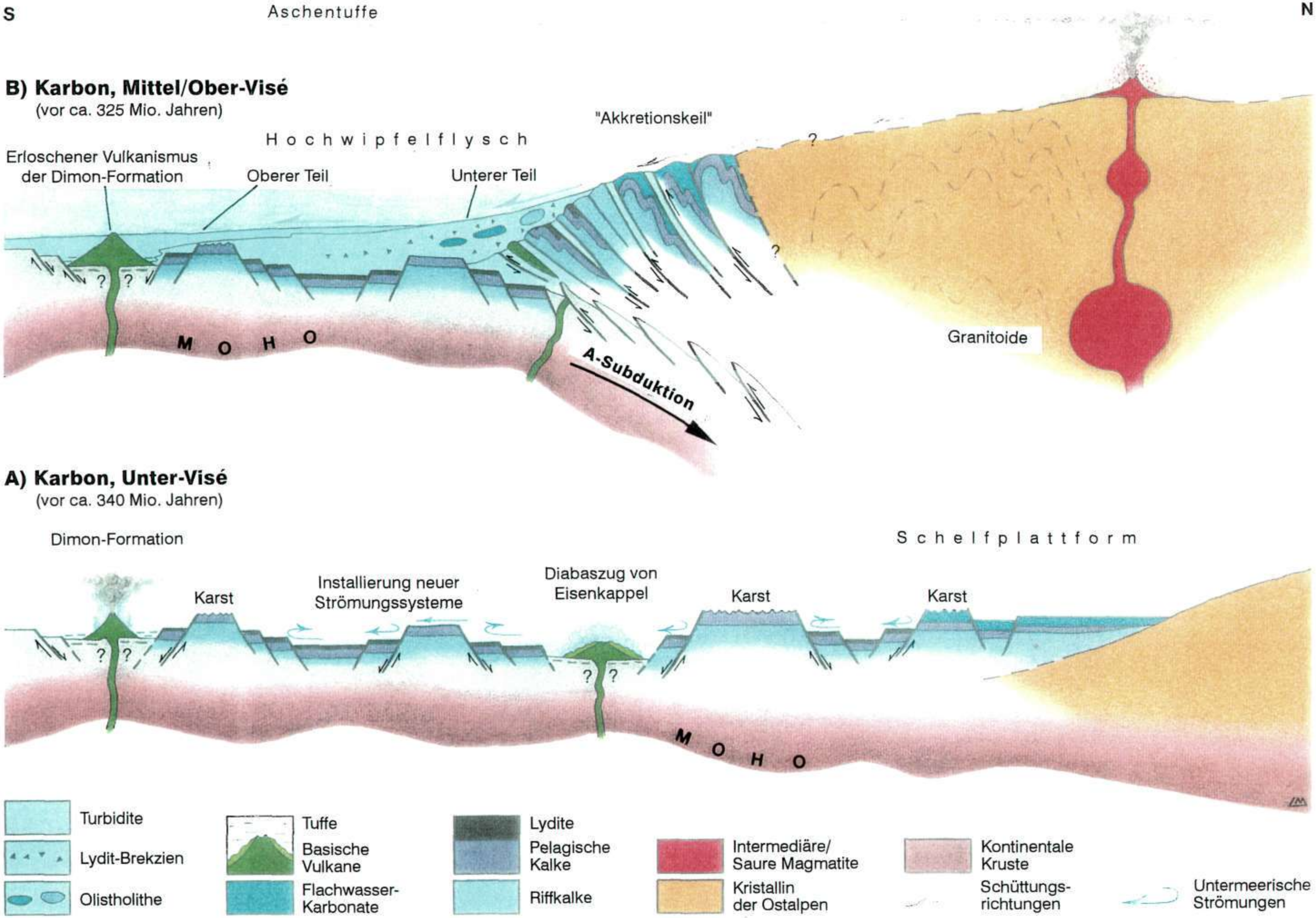


Fig. 8. Correlation of Lower Carboniferous squences of the Southern and Eastern Alps. Note the palaeokarst event.[4]

[4] Fig. 9. (Facing page-colour insert) Geodynamic model of the tectonic and sedimentary history of the Southern and Central Alps during the Lower Carboniferous transition from a passive to an active plate margin regime (after A. LÄUFER et al. 1993, modified).



S
Aschentuffe
N
B) Karbon, Mittel/Ober-Visé
(vor ca. 325 Mio. Jahren)
"Akkretionskeil"
Hochwipfelflysch
Erloschener Vulkanismus der Dimon-Formation
Oberer Teil
Unterer Teil
?
?
? ?
M O H O
A-Subduktion
Granitoide
A) Karbon, Unter-Visé
(vor ca. 340 Mio. Jahren)
Dimon-Formation
Schelfplattform
Karst
Installierung neuer Strömungssysteme
Diabaszug von Eisenkappel
Karst
Karst
? ?
? ?
M O H O
Turbidite
Lydit-Brekzien
Olisthlithe
Tuffe
Basische Vulkane
Flachwasser-Karbonate
Lydite
Pelagische Kalke
Riffkalke
Intermediäre/ Saure Magmatite
Kristallin der Ostalpen
Kontinentale Kruste
Schüttungs-richtungen
Untermeerische Strömungen

Apparently, this has been settled after recognition of a wide variety of distinct palaeokarst features in the Karawanke and the Carnic Alps (F.TESSENSOHN 1974, H.P. SCHÖNLAUB et al. 1991) including an extensive palaeorelief with surface-related collapse breccias, fissures, strata-bound ore carbonate deposits, a silcrete regolith ("Plotta Lydite"), and formation of caves with cave sediments, speleothems and palaeokarst-related cements in the subsurface . The palaeokarst 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 F. TESSENSOHN 1971, 1983, C. SPALLETTA et al. 1980, H. W. J. van AMEROM et al. 1984, C. SPALLETTA & C. 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 with intercalations of several tens of meters of thick pebbly mudstones, chaotic debris flows and chert and limestone breccias in its lower part which may represent submarine canyon fillings or inner fans. In addition to these lithologies, along the northern margin of the region up to 10 m thick plant-bearing sandstone beds consitute a prominent member of the Hochwipfel Formation. Except for trace fossils the palaeontological evidence of the flysch sediment is very poor. However, plant remains are locally very common suggesting a Middle Visean to Namurian age for its formation (H. W. J. van AMEROM et al. 1984, H. W. J. van AMEROM & H. P. SCHÖNLAUB 1992). Other stratigraphic data are derived from the fore-mentioned underlying limestone beds and locally occurring intercalations of the Kirchbach Limestone which provided index conodonts of the Visean/Namurian boundary (E. FLÜGEL & H. P. SCHÖNLAUB 1990). Also of great interest are limestone clasts within the debrites which comprise a broad spectrum of shallow water carbonate shelf types 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 localted originally to the north of the present Southern Alps but which was completely destroyed by later tectonic events.

According to A. 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 F. 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 K. 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 (A. FENNINGER et al. 1976) and which was named Malinfier Horizon by Italian geologists (C. VENTURINI 1989, 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 (C. VENTURINI et al 1982, C. 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 (M. 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 *Pseudoschwagrina* and *Occidentoschwagerina* in the upper part of the Lower Pseudoschwagerina Lst. and not at its base as previously was suggested (F. KAHLER & K. 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 (K. KRAINER 1992, 1993, H. C. 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 (K. KRAINER 1991, E. 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 (K. BOECKELMANN 1991, W. T. HOLSER et al. 1991, K. KRAINER 1993).

Upper Carboniferous and Permian molasse-type sediments also occur in the Seeberg area of the Eastern Karawanken Alps (F. TESSENSOHN 1983, F. BAUER 1983). Although strongly affected by faults the general lithology and the fossil content resemble that of the Auernig Group of the Carnic Alps being dominated by interbedded fusulinid and algal bearing limestones, areanceous shales, sandstones and massive beds of quartz-rich deltaic conglomerates. Equivalents of the Permian are represented by the Trogkofel Lst., its coeval detritic Trogkofel Formation and the Gröden Formation. The Bellerophon Formation is only locally preserved.

In the Eastern Karawanken Alps, north of the Periadriatic Line, rocks of Palaeozoic age have long been known. They belong to the so-called "Diabaszug von Eisenkappel" (Fig. 10). This narrow belt extends in a W-E direction from Zell Pfarre via Schaidasattel to east of

Eisenkappel and continues further east to Slovenia. In Austria this zone has a length of more than 25 km and a maximum width of 3,5 km. The 650 m thick Palaeozoic sequence comprises up to 350 m of volcanic and volcaniclastic rocks and sediments. According to K. LOESCKE 1970-1977, 1983, J. LOESCHKE et al. 1996) the first group is dominated by basic tuffs and tuffitic rocks, massive pillow lavas and basic sills of hawaiitic composition with ultrabasic layers. Sills and pillow lavas represent spilites which differentiated from alkali olivine basalts, the original geotectonic setting of which is yet not known. Subsequent low-temperature metamorphism associated with devitrification and metasomatic replacement processes caused the spilitic mineral composition in these rocks. The sedimentary rocks are monotonous gray shales and slates with intercalations of conglomeratic graywackes, quartzitic and graphitic sandstones and thin limestone beds. The definite age of this succession is yet not exactly known although some poorly preserved single cone conodonts recovered from the limestone intercalations are rather in favour of an Ordovician than any younger age (F. NEUBAUER, pers. comm.).

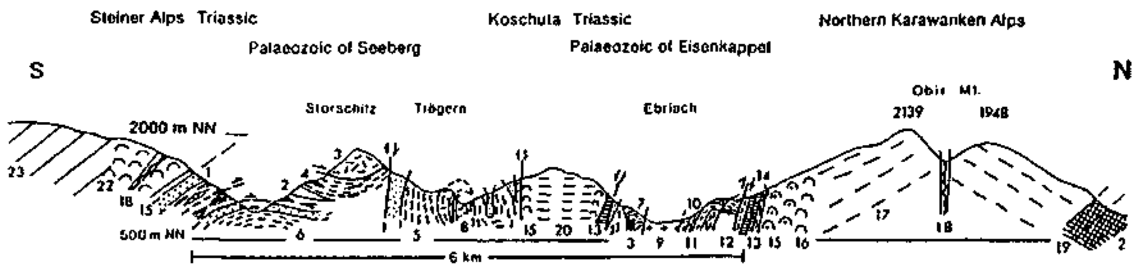


Fig. 10. N-S directed section through the Eastern Karawanken Alps. Numbers indicate (1) post Variscan Permian and Late Carboniferous, (2) banded limestone thurst sheets in imbricate structure, (3) Devonian limestones, (4) undated volcanics, (5) Hochwipfel Fm., (6) Seeberg Shale, (7) Upper Ordovician and Silurian rocks, (8) volcanics of the Upper Ordovician, (9) Granite of Eisenkappel, (10) pillow lava of the "Diabaszug of Eisenkappel", (11) sills, (12) Werfen Fm., (13) Muschelkalk Fm., (14) Partnach Fm., (15, 16, 17) Wetterstein Lst., (18) Raibl Fm., (19) Rhätian to Jurassic deposits, (20) Schlern Dolomite, (21) Tertiary, (22, 23) Dachstein Lst. (from H. P. SCHÖNLAUB 1979).

Tectonic Remarks

The Palaeozoic sequence of the Carnic and Karawanken Alps represents a strongly compressed WNW-ESE running thrust sheet complex composed of isoclinally folded anchi-to epimetamorphic Palaeozoic rocks. The Palaeozoic and Triassic succession was affected by both the Variscan and Alpine orogenic cycles. Based on illite crystallinities from the Carboniferous Hochwipfel Formation and K-Ar ages A. L. LÄUFER 1996 concluded that Variscan epizonal metamorphism was equal or slightly higher than the Alpine overprint. Thus, Variscan deformations were not completely destroyed. In contrast the less intensely folded late Carboniferous to Triassic cover in the central and eastern Carnic Alps reached mainly anchizonal conditions with temperatures roughly between 235 and 270°C. The northernmost tectonic units adjacent to the Periadriatic Line reveal two deformation events. The younger epizonal metamorphism and ductile deformation is of late Alpine age and is related to Tertiary activities along the Periadriatic Line and exhumation by transpression (A. L. LÄUFER 1996).

The south-verging fold-and-thrust belt developed during the Variscan orogeny in the Late Namurian or Early Westphalian. It is sealed by the post-Variscan cover overlying the deformed basement with a distinct angular unconformity. Paraconformities occur at different levels within the Palaeozoic sequence, for example, at the end of the Ordovician, in the late Middle and early Upper Devonian and in the Lower Carboniferous. Presumably, they were caused by sea-level changes related to the glaciation of parts of Gondwana at the end of the Ordovician, to seismic shock events, and to a palaeokarstic event, respectively. Lowering of sea-level and/or block faulting may also have acted at the end of the Trogkofel Stage being responsible for extensive erosion and accumulation of reworked limestones, stratigraphic gaps, formation of fissures and local karstification.

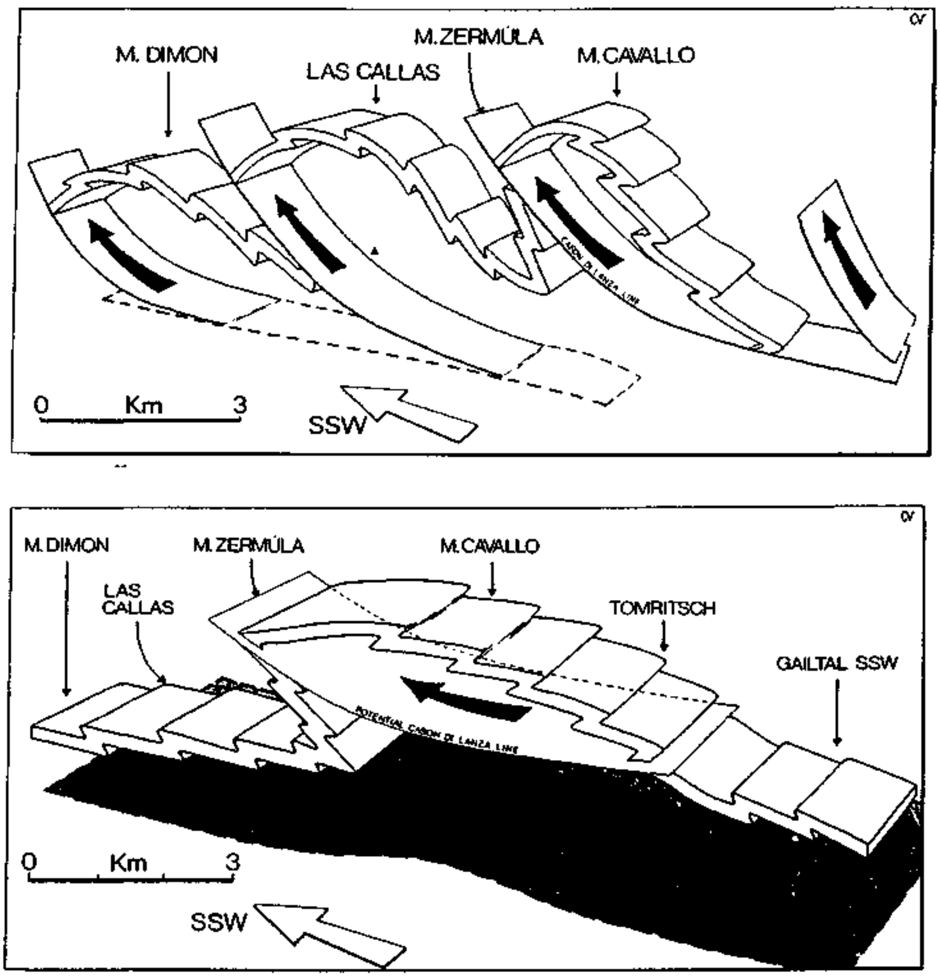


Fig. 11. Hercynian deformation of the Carnic Alps. The 1st and 3rd (Figure above) deformative phases are shown. The huge asymmetric fold affected the whole Palaeozoic belt. The 3rd phase formed thrusts with open folds which re-folded the older structures of the 1st and 2nd deformative stages (from C.VENTURINI 1990).

For many years the complicated tectonics of the Carnic Alps was explained in terms of 9 nappes produced during the Variscan orogeny. Each north verging nappe consisted of a more or less continuous Ordovician to Devonian sequence and was separated from the next by the clastics of the Hochwipfel Formation. The extent of Alpine overprints on this pile of nappes was difficult to decipher. With respect to the less deformed post-Variscan cover, however, it was concluded that the intensity of the Variscan tectonics was much stronger than the Alpine deformation. Nevertheless, the latter resulted in interferences between both and was responsible for a complex deformative pattern in the Southern Alps (A. CASTELLARIN & G. B. VAI 1981)

According to G. B. VAI 1979 the horizontal shortening of the Carnic Alps during the Variscan deformation is estimated to 75-80% of its original width. This value does not consider the assumed detachment from pre-Ordovician basement rocks.

Based on new field data, mainly from the Naßfeld area, the old concept was challenged by C. VENTURINI (1990, 1991) who proposed a new structural model. He speculated on three distinct and interacting phases that resulted in different systems of asymmetric folds and faults distributed along a N 120° - 140° E direction (Fig. 11):

1. Middle or early Upper Carboniferous compressional tectonics caused a huge SSW-verging fold that affected the whole belt. Synkinematically a back fold system with clear northern vergence developed behind it. Such smaller-scale syn-and anticlines can be recognized, for example, on Roßkofel, at Hoher Trieb, at Plöckenpaß-Kleiner Pal-Piz Timau. Perhaps even the fold structure separating the Cellon subnappe from the Kellerwand-subnappe (L. H. KREUTZER 1990) can be attributed to this deformation.

2. In response to uplifting brittle deformation occurred with development of flat fault planes along shale horizons. As a result the huge asymmetrical fold was cut into smaller tectonic slices.

3. The third phase occurred during further uplift. It produced huge open antiforms following new thrust planes and older folded structures. These were later reactivated during the Alpine compression.

The formation of sedimentary basins in the Upper Carboniferous was governed by extensional tectonics (C. VENTURINI 1990). They were related to 120° to 130° directed fault zones, forming thus an elongated trough with an original width of not more than 15 km, shortened today to a narrow zone of some 10 km.

With regard to the Alpine deformation of the Carnic Alps the reader is referred to P. EICHÜBL (1988) and C. VENTURINI (1990, 1991).

The tectonic framework of the Eastern Karawanken Alps is characterized by the north verging anticlinal structure of the central and southern part (Fig. 12). Its axis dips gently towards southwest. The whole area may be subdivided into two superimposed allochthonous units. In addition, north of the Seeberg anticline the folded Trögern area further complicates the deformation style.

1. In the area around the Seeberg Pass the uppermost part is represented by the Reef Unit. Rocks of the core are well exposed near the Pass. They comprise reef and near-reef limestones, e.g., north of Plasnik (P.1257), at Rapold, Pasterk, Storschitz and at the Grintoutz localities. Laterally this facies grades into forereef and pelagic deposits. Generally, the

sequence within this unit consists of different limestones of Devonian age, followed locally by the Carboniferous Hochwipfel Formation and transgressive sediments of Late Carboniferous and Permian age. At the southern limb geologically well known outcrops are located such as Paulitschwand, Leßnik and Sadnikar, while on the northern side Sadonighöhe, Stanwiese, Grintoutz and Hirschfelsen have long been famous. The lateral movement of the Reef Unit is estimated to be some 4,5 km.

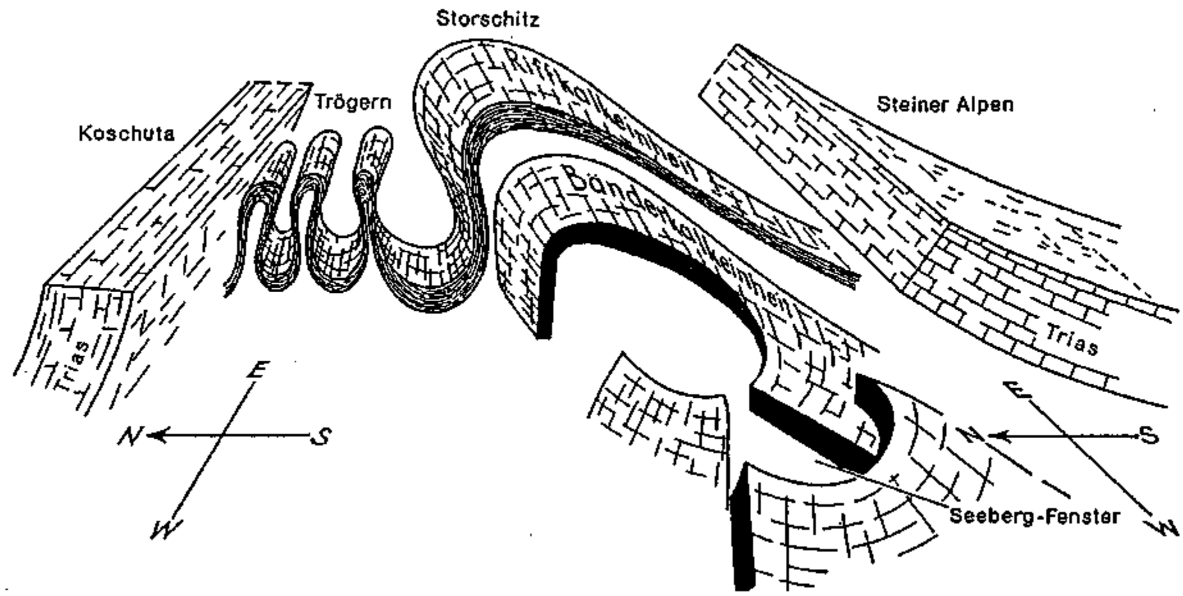


Fig. 12. Diagram showing the main tectonic units of the Seeberg area of the Eastern Karawanken Alps (from J.ROLSER & F.TESSENSOHN 1974).

2. The above mentioned uppermost unit is underlain by the Bänderkalk Unit ("Striated banded limestone Unit"). It is dominated by banded limestones as well as over and underlying clastics. Locally, at its base nautiloid bearing Silurian limestones and Lower Devonian tentaculite bearing limestones occur. The amount of thrusting in this unit does not exceed 1,5 km.

3. The Basal Unit is well distributed between the village of Bad Vellach und the locality "Steiner". Structurally, this unit can be regarded as a tectonic window (Fig. 13). Its sequence consists of the so-called "Seeberg Shale" the age of which has not yet been ascertained and its transgressive cover formed by the equivalents of the Auernig Group, i.e., fusulinid bearing limestones, shales, sandstones and quartz-rich conglomerates.

To unravel the complicated tectonic deformation of the Eastern Karawanken Alps the above mentioned Late Carboniferous sediments are of critical importance as they provide clear evidence of the age of nappe-forming processes. Due to the fact that the post-Variscan molasse-type sediments are also involved in the nappe pile the main deformation in this area must be of Alpine age.

North of the anticline formed by the above mentioned nappes the folded zone of Trögern occurs. It is characterized by a steep to vertical dipping sequence dominated by clastic rocks of the Hochwipfel Formation. Locally also the Devonian substratum and the post-Variscan cover are exposed showing a mushroom and drop-like appearance due to squeezing of competent rocks between clastic layers. This zone may locally attain a width of more than 3 km.

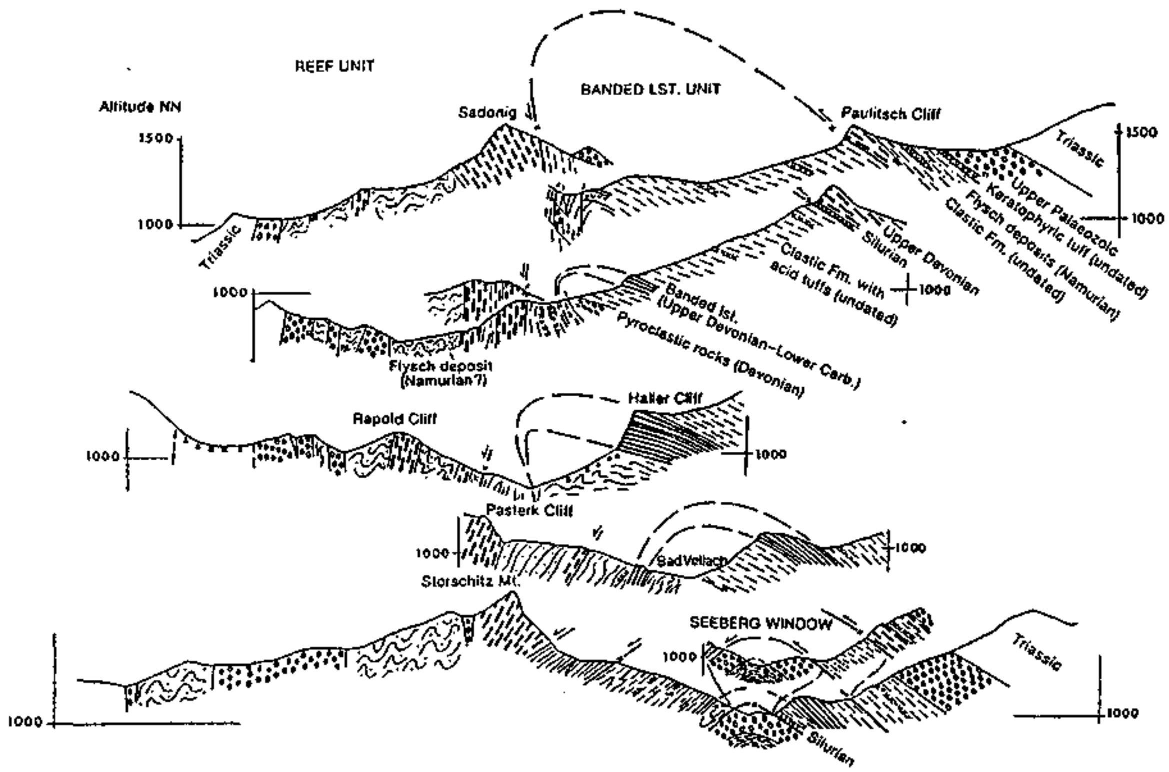


Fig. 13. N-S running sections through the Palaeozoic of the Seeberg area of the Eastern Karawanken Alps (after J.ROLSER & F.TESSENSOHN 1974, modified)

In addition to the huge fold structures with amplitudes of several hundreds of meters small-scale folding is very common in the Seeberg area. It mainly affects those regions which are occupied by shales, i.e. the Seeberg Shale and the Hochwipfel Formation. Finally, steep faults have further subdivided the whole area into numerous small blocks. During the uplift of the area the Triassic cover of the Koschuta belt and the Steiner Alps detached from the underlying Late Carboniferous and Permian rocks.

The narrow belt of the "Diabaszug of Eisenkappel" north of the Periadriatic Line is fault bound to the north and the south (Fig. 10). It represents a highly compressed folded and faulted north verging zone showing several repetitions. To the north this belt of Palaeozoic rocks is thrust upon Late Permian and Triassic rocks. Most probably they formed the original cover of the Lower Palaeozoic volcaniclastic sequence suggesting thus a Variscan deformation for this Palaeozoic series. The southern boundary is formed by the northward thrusted Karawanken Granite. According to radiometric dating it was formed during Late Variscan times (R. A. CLIFF et al. 1975). During intrusion the Diabase of Eisenkappel and its accompanying metamorphic rocks were marginally affected by contact metamorphism (C. EXNER 1972).

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The Chitinozoans in the upper Ordovician to lowermost Devonian succession of the Cellon-Section. – A preliminary report.

Helga PRIEWALDER [1]

Introduction.

The investigations of the chitinozoans from the Cellon section [Caradoc- Lochkovian] were part of a project with the goal of examining the geographic and stratigraphic distribution of the main palynomorph groups (acritarchs, chitinozoans, spores) within the different environments of the upper Ordovician to lower Devonian series in the Carnic Alps.

In the Silurian, the period mainly concerned by this research, these environments are: the "Plöcken Fazies", a shallow water environment with predominantly calcareous deposits; the "Bischofalm Fazies", a siliciclastic basinal environment, and the transitional "Findenig Fazies", mediating between the former two [the nearshore environment ("Wolayer Fazies") with strongly condensed sediments of very shallow water has not yet been studied].

In none of these facies *spores* could be observed. The *acritarchs* turned out to be highly influenced by the local environments. Their only remarkable occurrence is in the Lower Silurian of the Cellon section which belongs to the calcareous shallow water facies [PRIEWALDER, 1987].

The *chitinozoans* however, proved to be the geographically and stratigraphically widest distributed group of the palynomorphs.

From the siliciclastic and the transitional facies altogether 79 samples have been examined so far by spot checks to estimate the appearance of the chitinozoans: 60% of them were found to be fossiliferous.

From the Upper Ordovician to Lower Devonian sequence in the Cellon section 95 samples have been prepared. 48 of them [= 51%] yielded chitinozoans.

As the chitinozoans were opaque to transmitting light the investigations had to be carried out mainly under SEM. About 4.300 micropalaeontological objects [chitinozoans as well as chitinozoan-like and/or problematic particles] have been examined in this way.

It has to be pointed out that the names of the chitinozoans in this report are provisional because they are based on gross determinations only. Detailed morphological studies have yet to be done and will result in more diverse chitinozoan associations at many horizons of the Cellon section.

In the studied section, the chitinozoans appear in the following sequences [Fig.1]:

- ⇨ in the Plöcken Formation [upper Ashgill];
- ⇨ in the lower part of the Kok Formation [upper Llandovery];
- ⇨ in the sequence from the uppermost Kok Formation to the top of the Cardiola Formation [upper Ludlow];
- ⇨ in the sequence from the upper part of the Alticola Limestone

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to the lower-most Rauchkofel Limestone [Ludlow/Pridoli boundary - lowermost Lochkovian].

The Chitinozoans of the upper Ordovician.

In the Uggwa Shale and Uggwa Limestone, respectively, chitinozoans are lacking. Instead, black and glossy particles with chitinozoan-like contours, probably consisting of graphite, are frequently present. In the light-microscope they may easily be confused with badly preserved chitinozoans.

Stratigraphically the chitinozoans make their debut in sample ***126*** at the base of the Plöcken Formation with a few insignificant specimens of the genera *Conochitina EISENACK 1931* and *?Tanuchitina JANSONIUS 1964*. Further, numerous melanosklerits with a strong resemblance to chitinozoans can be observed, as well as chitinozoan-like graphitic particles.

At the top of this formation 3 assemblages [samples ***128***, ***129***, ***45***] contain representatives of the genera *Conochitina*, *Desmochitina EISENACK 1931 [e.g., Desmochitina minor EISENACK 1931]*, *?Rhabdochitina EISENACK 1931*, *Spinachitina SCHALLREUTER 1963* and of the Ancyrochitininae, but most of all two taxa which are diagnostic for the Ashgill: *Armoricochitina nigerica (BOUCHÉ 1965)* and *Tanuchitina elongata (BOUCHÉ 1965)* thus indicating the Hirnantian ***Tanuchitina elongata*** **- Biozone** (PARIS 1990).

The Ashgillian samples yielded very few chitinozoans in a rather bad state of preservation: most specimens are three-dimensionally preserved, but broken.

The Chitinozoans of the upper Llandovery.

Between the Ordovician Plöcken Formation and the overlying Silurian Kok Formation there is a large stratigraphical gap comprising the entire Rhuddanian and also the Aeronian.

The lowermost part of the Kok Formation [samples ***46A***, ***47***, ***130***, ***131***] yielded chitinozoan faunas with a great number of undeterminable specimens of the Lagenochitinidae and the Ancyrochitininae and taxa such as *Ancyrochitina* gr. *ancyrea (EISENACK 1931)*, *Cyathochitina caputoi DA COSTA 1971*, many specimens of *Bursachitina TAUGOURDEAU 1966* and *Conochitina* [e.g., *C.sp. cf. emmastensis NESTOR 1982]*, as well as *Eisenackitina dolioliformis UMNOVA 1976* which is a very characteristic Cellon-species and the index species of the upper Aeronian-lower Telychian ***Eisenackitina dolioliformis*** **- Biozone** [VERNIERS et al.1995].

Also the upper Telychian part of the Kok Formation [samples ***49***, ***50***, ***132***, ***133***] is rich in chitinozoans. Less important taxa are representatives of *Cyathochitina EISENACK 1955*, *Eisenackitina JANSONIUS 1964*, *Lagenochitina EISENACK 1931 and Sphaerochitina EISENACK 1955*. However, here also occurs one *Conochitina*-species [besides several others] which is similar to the important upper Telychian to lower Sheinwoodian *C.proboscifera EISENACK 1937*, and an *Angochitina*-species which closely resembles *A.longicollis EISENACK 1931*, *suggesting* the ***Angochitina longicollis*** **- Biozone** [VERNIERS et al.1995] of upper Telychian age.

The chitinozoans from this part of the section are entirely or partly flattened and frequently folded. In cases of intense folding or variable flattening of the vesicles [e.g. thinner-walled necks are more, thicker-walled body chambers less strongly deformed] their contours may be altered to an extent that the original taxon is difficult to recognize.

The Chitinozoans of the Wenlock - lower Ludlow.

Throughout the Wenlockian sequence of the Cellon section, the strata of which attain a thickness of only 5 meters thus indicating an extreme condensation [SCHÖNLAUB 1997], and also in the lower Ludlow , that means, in the middle and upper part of the Kok Formation, associations of determinable chitinozoans are missing. Only sporadic and badly preserved fossils are present [samples ***135, 54, 136, 56***].

The Chitinozoans of the upper Ludlow.

From the uppermost bed of the Kok Formation [sample ***63***] to the top of the Cardiola Formation [sample ***145***] a great variety of chitinozoans occurs.

The assemblages are dominated by *Angochitina-* [e.g., *A. echinata EISENACK 1931*], *Sphaerochitina-* [e.g., *S.sp.* cf. *impia LAUFELD 1974*], *Belonechitina-* and *Conochitina* - species [*e.g., B.sp.* cf. *latifrons (EISENACK 1964), B.sp. cf. lauensis (LAUFELD 1974)* and *C.sp.* cf. *tuba EISENACK 1932*].

Furthermore, some representatives of the genera *Ancyrochitina EISENACK 1955, Bursachitina TAUGOURDEAU 1966, Cingulochitina PARIS 1981, Eisenackitina JANSONIUS 1964* and *Linochitina EISENACK 1968* appear.

At the base of this sequence however, an *Angochitina*-fragment resembling *A.elongata EISENACK 1931* was found, consequently referring the Cardiola Formation to the upper Gorstian-lower Ludfordian ***Angochitina elongata*** **- Biozone** [VERNIERS et al.1995].

Here an other - unusual - state of preservation of the chitinozoans can be observed: the vesicles of thin-walled taxa from limestones had collapsed three-dimensionally similar to a deflated rubber ball. This feature probably developed at an early stage of diagenesis when the internal cavities of the chitinozoans became dehydrated before mineral fillings precipitated. These fillings are common in chitinozoans from limestones and they are responsible for the three-dimensional preservation of the fossils.

From the base of the Alticola Limestone up to the end of the Ludlow, the examined samples did not yield chitinozoans.

The Chitinozoans of the uppermost Ludlow to the lower Lochkovian

From the Ludlow/Pridoli boundary beds within the Alticola Limestone up to the end of the examined section in the lower part of the Rauchkofel Limestone of lower Lochkovian age, numerous diverse chitinozoan assemblages occur.

At the base of this succession [sample ***73*** = uppermost Ludfordian; samples ***74, 75*** =

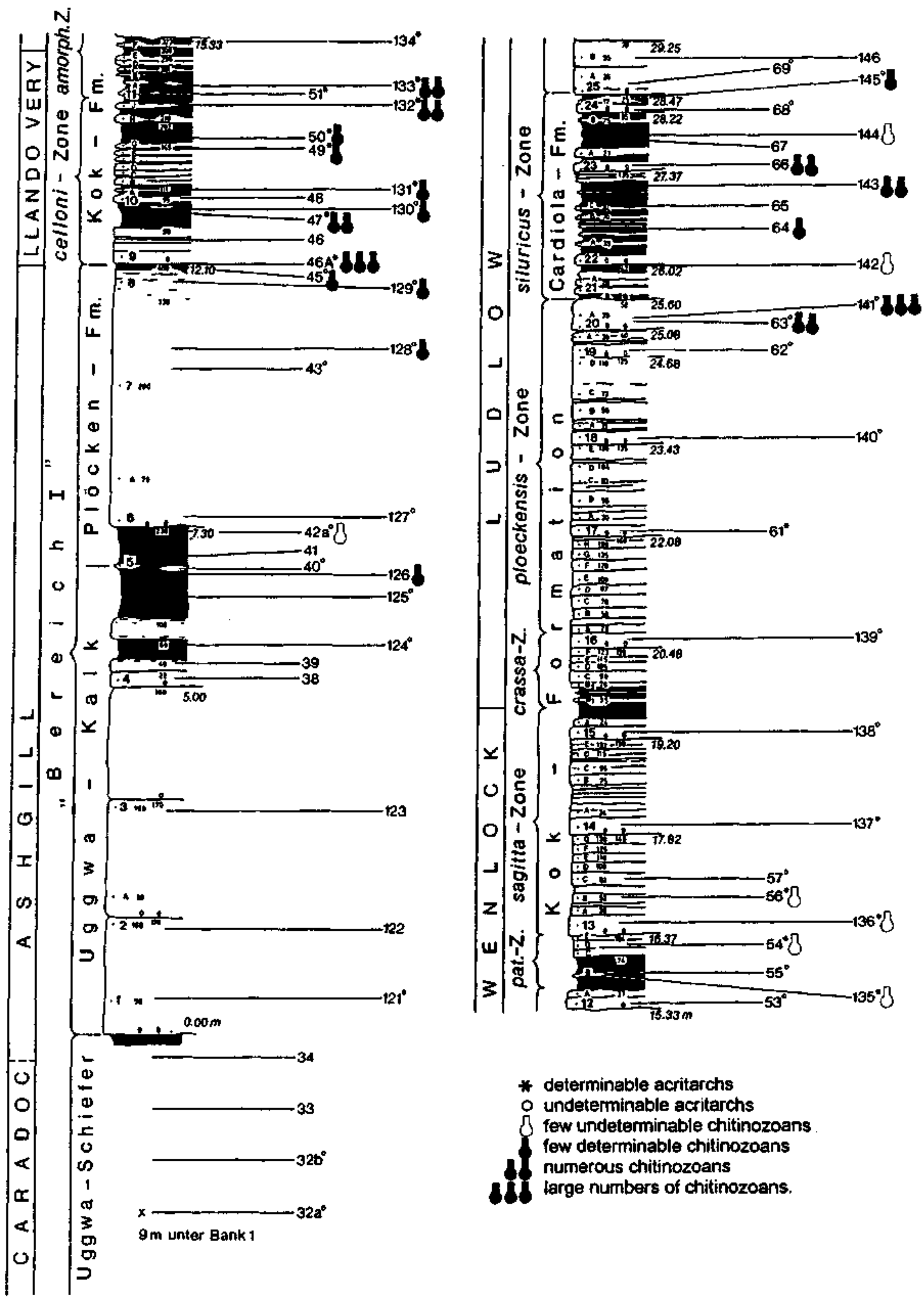
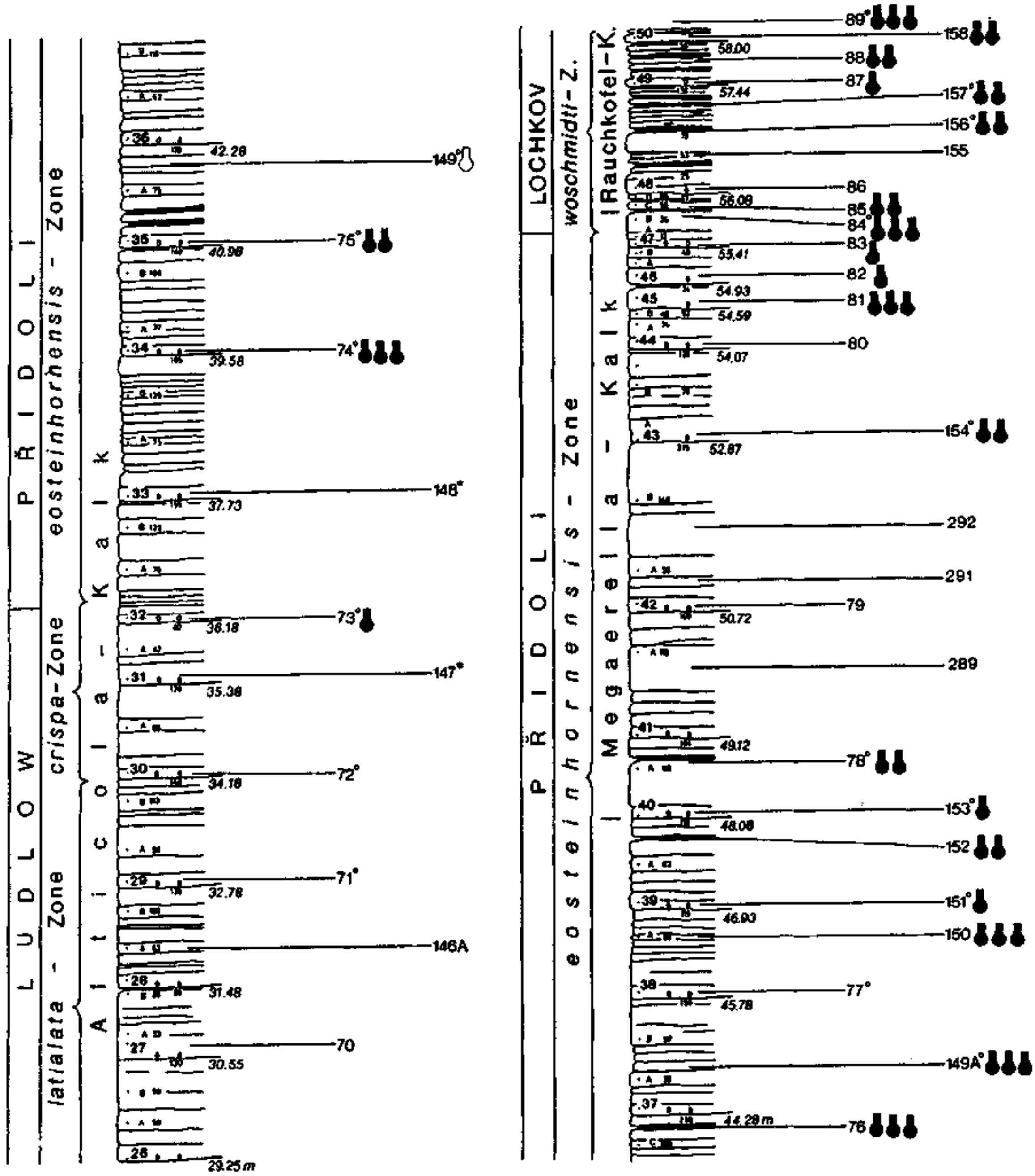


Fig.1: The location of the samples in the Cellon-section (drawing of the section after SCHÖNLAUB 1985).


LUDLOW
PŘIDOLI
latialata - Zone
crispa-Zone
eosteinhorhensis - Zone
Alticola - Kalk
LOCHKOV
woschmidti - Z.
Rauchkofel-K.
Megaerella - Kalk
29.25 m
44.28 m

lower Pridoli] *Ancyrochitina* gr. *ancyrea (EISENACK 1931), Eisenackitina granulata (CRAMER 1964), E. intermedia (EISENACK 1955), Sphaerochitina* cf. *sphaerocephala (EISENACK 1932), some Angochitina EISENACK 1931, Bursachitina TAUGOURDEAU 1966 , Gotlandochitina LAUFELD 1974* and the stratigraphically most important taxa *E. barrandei PARIS & KRIZ 1984* and *Urnochitina urna (EISENACK 1934),* the latter in an atypical version, are present.

E.barrandei is the index species of the uppermost Ludfordian ***Eisenackitina barrandei* - (total range) - Biozone** of VERNIERS et al. 1995, while the total range of *U.urna* defines the entire Pridoli.

At the global stratotype section of the Ludlow/Pridoli-boundary at Pozáry Quarry (Prague Basin, Bohemia), the two species occur together within a very short intervall in the Ludfordian/Pridoli – boundary-beds. Compared to the ranges of *E. barrandei* and the atypical *Urnochitina urna* in the Cellon section, some discrepances are obvious which have to be settled by further studies.

The assemblages of the upper part of the Alticola Limestone and the lowermost Megaerella Limestone [samples ***149, 76, 149A, 150, 151, 152, 153, 78, 154***] are generally dominated by typical *U.urna*. Further important species are *E. granulata* and *Bursachitina krizi (PARIS & LAUFELD 1980),* the latter makes its debut in sample ***149A*** with large quantities of individuals and then after a sudden and drastic reduction in the number of specimens disappears in the upper Megaerella Limestone. Some insignificant specimens of *Ancyrochitina, Angochitina, Linochitina* and *Sphaerochitina* are co-occurring.

The strata between the samples ***78*** and ***154*** in the lower part of the Megaerella Limestone proved to be barren of chitinozoans.

Above this level the chitinozoan fauna starts to rearrange: *U.urna* loses its numerical dominance, while representatives of other genera like *Angochitina EISENACK 1931, Cingulochitina PARIS 1981, Gotlandochitina LAUFELD 1974, Linochitina EISENACK 1968, Sphaerochitina EISENACK 1955* and especially *Ancyrochitina EISENACK 1955* become more and more frequent.

The uppermost Pridolian samples [***81, 82, 83***] of which the lower one yielded an enormous amount of chitinozoans are represented -among others - by *Linochitina klonkensis PARIS & LAUFELD 1980, Calpichitina corinnae JAGLIN 1986, Sphaerochitina* cf. *sphaerocephala (EISENACK 1932),* very few specimens of *U. urna (EISENACK 1934)* and a distinctiv *Ancyrochitina*-species provided with simple processes with very broad bases.

The Pridoli is defined by the total range of *Urnochitina urna,* which at the global stratotype section for the Silurian/Devonian-boundary at Klonk, Prague Basin, disappears exactly at the boundary, while in the Karlstejn section it ranges a few decimeters above the base of the Lochkovian [PARIS, LAUFELD & CHLUPÁC 1981].

Due to the lack of the index-fossils, the chitinozoan biozones of the Pridoli which are the ***Fungochitina kosovensis* -**, the ***Margachitina elegans* –** and the ***Anthochitina superba* – Biozones** of VERNIERS et al.1995, could not be identified at Cellon.

Sample ***84*** from the lowermost Lochkovian bed yielded comparatively numerous *U. urna,* which is the last documented occurrence in the section, as well as many well preserved and diverse representatives of *Angochitina, Gotlandochitina, Sphaerochitina* [e.g. *S. sphaerocephala*] and a few *Ancyrochitina* with unusual processes.

The chitinozoan assemblage of sample ***85*** contains a few *Angochitina* and *Cingulochitina* and also several well preserved *Eisenackitina bohemica (EISENACK 1934)*, a species typical of the Lochkovian, which in the Prague Basin appears a few decimeters above the base of the Devonian, i.e. in bed 21 at the Klonk section [PARIS 1981].

The remaining samples in the Cellon section [***156***, ***157*** , ***87*** , ***88*** , ***158*** and ***89***, the latter with a large number of chitinozoans] are dominated by numerous *Ancyrochitina* [at least 5 different species]. Moreover, there occure different taxa of *Angochitina, Sphaerochitina, Gotlandochitina, Linochitina* and *Cingulochitina* [e.g. *C. ervensis (PARIS 1979)*] .

The chitinozoans of the Pridoli/Lochkovian sequence are generally three-dimensionally preserved, especially thicker-walled specimens; thinner-walled individuals are often more or less strongly collapsed.

Conclusions.

1.) In the Cellon section, the chitinozoans are present in almost all series of the upper Ordovician to lower Devonian succession. This is in contrast to the acritarchs which are mainly restricted to the upper Llandovery to lower Wenlock sequence.

In several samples [***46A***, ***141***, ***74***, ***76***, ***149A***, ***150***, ***81***, ***84***, ***89***] the chitinozoans occur with large numbers of individuals and generally great diversity.

2.) The chitinozoan assemblages of the Ashgillian and the upper Llandoverian strata of the Cellon section, which rest conformably one upon the other but are seperated by a large stratigraphical gap are unequivocally different and in each case typical for their ages.

The Llandovery/Wenlock-boundary and the Wenlock/Ludlow-boundary, respectively, cannot be established by the aid of chitinozoans because these fossils are missing throughout the Wenlock and also in the lower Ludlow.

As for the chitinozoans, the position of the Ludlow/Pridoli- boundary in the Cellon section is not yet clear and needs further inverstigations.

Finally, the base of the Lochkovian is well documented by diagnostic chitinozoan assemblages.

Almost all of the chitinozoan bearing sequences of the Cellon section can be assigned to the existing global chitinozoan biozones. These are:

the Hirnantian *Tanuchitina elongata* - Biozone;
the upper Aeronian - lower Telychian *Eisenackitina dolioliformis* – Biozone;
the upper Telychian *Angochitina longicollis* - Biozone;
the upper Gorstian - lower Ludfordian *Angochitina elongata* – Biozone;
the uppermost Ludfordian *Eisenackitina barrandei* - Biozone;
the Pridolian *Urnochitina urna* - Biozone;
the lower Lochkovian *Eisenackitina bohemica* - Biozone.

3.) Obviously, environmental conditions were more favourable for the chitinozoans in the upper than in the lower part of the section: Starting with the topmost layer of the Kok Formation [upper Ludlow] up to the lower Lochkovian Rauchkofel Limestone, the assemblages show greater diversities, larger numbers of individuals and also better preservation than in the upper Llandoverian to lower Ludlowian Kok Formation. This is in good accordance with the results of recent studies concerning the environmental development of the Cellon section, suggesting more stable pelagic conditions from the Alticola Limestone onward [HISTON & SCHÖNLAUB, 1999 (in press)].

However, presently the reasons for the occurence of at least some chitinozoans in the unfavourable high energy environment of the Plöcken Formation, and their absence in the off-shore low-energy facies of the Uggwa Limestone and the Uggwa Shale are difficult to explain.

4.) The Hirnantian-age chitinozoans of the Cellon section show a pronounced relationship with assemblages of the Northern Gondwana cold-water realm, while in the Silurian and lower Devonian their affinities to representatives of the warm-water environments of Baltica/ Avalonia are obvious.

Most probably because of the palaeogeographic vicinity of the two depositional areas, the Silurian and lower Devonian chitinozoans of the studied section are very similar to those from Bohemia (so far, only very few and insignificant chitinozoan associations have been observed in the Ashgillian of the Barrandean region) [DUFKA, 1992; DUFKA & FATKA, 1993; KRIZ, 1992; KRIZ et al. 1986; PARIS & KRIZ, 1984; PARIS et al., 1981].

On the other hand, in the Cellon section samples from the base of the Wenlock to the lower Ludlow succession did not yield determinable chitinozoans whereas in Bohemia diverse faunas can be obtained from coeval strata [KRIZ, 1992; KRIZ et al., 1993]. This phenomenon might be caused by unfavorable conditions for the chitinozoans' preservation in the sedimentary environment of the Cellon section, like a high hydrodynamic regime in a very shallow sea - at least temporary, non-deposition of protecting sediment, oxidation.

Acknowledgment.

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I would like to thank *Dr.Florentin Paris*, University of Rennes, France, for his engaged and valuable discussion of my large collection of chitinozoans from the Cellon section.

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Field Trip Programme

V International Symposium

Cephalopods - Present and Past

Excursion Programme

3 – 6th September 1999

Excursion A: Cephalopod Limestone sequences in the Palaeozoic of the Carnic Alps.

Leaders: Hans Peter Schönlaub, Kathleen Histon, Dieter Korn

Short Program

September 3rd 1999

08.00 Meeting point - Geological Survey of Austria, Rasumofskygasse 23, A-1031 Vienna
(U-Bahn line U3 – Station Rochusgasse – Exit Rochusmarkt)

08.30 Departure for the Carnic Alps (5 hour drive)

Route (Fig. 1): via Autobahn A2 to Graz, Klagenfurt, Villach. and on through the Gail Valley to Kotschach-Mauthen (approx. 450 km).

Early Afternoon: **Stop 1** Cellon Section.	Silurian Cephalopod Limestones
Overnight stay – Pensions in Kotschach-Mauthen	

September 4th 1999

Travel to Wolayer Lake area (National Park).
1.5 hour walk – luggage will be brought in the field vehicle

Stop 2	Rauchkofel Boden Section	Silurian Cephalopod Limestones
Stop 3	Valentintörl West Section	Devonian Ammonoid Limestone
Stop 4	Valentintorl Section	Silurian Cephalopod Limestones
Stop 5	Wolayer "Glacier"	Devonian Limestone Sequence

Overnight stay - E. Pichl Mountain Hutte at Wolayer Lake

September 5th 1999

Return travel from Wolayer Lake

Stop 6	Grüene Schneid Section	Devonian / Carboniferous Boundary Ammonoid Limestone Sequence

Overnight stay – Pensions in Kotschach-Mauthen

September 6th 1999

Early morning return to Vienna

Fig. 1 Excursion area with location of stops (Modified from Kreutzer, 1992).

Key to abbreviations :

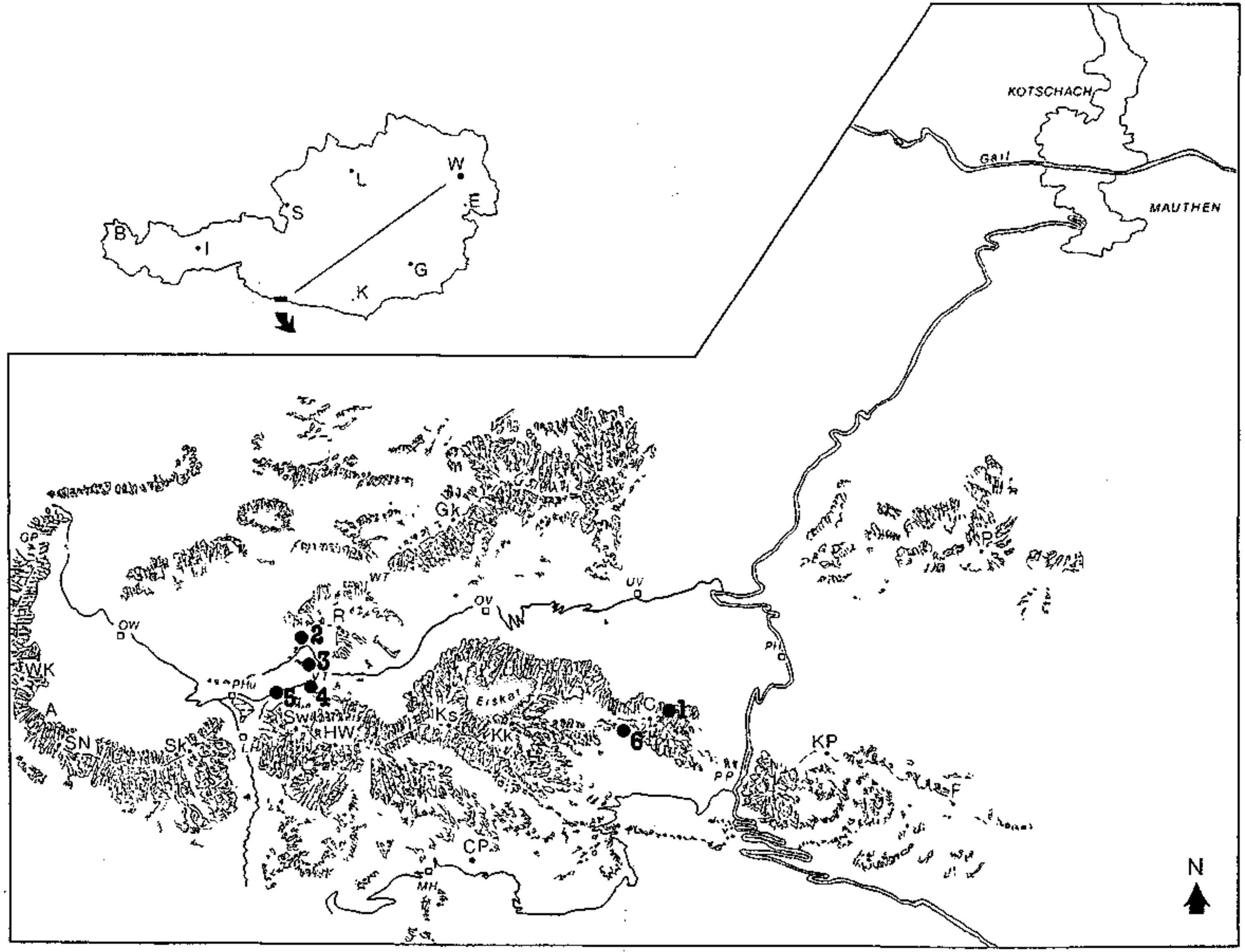
General Map of Austria: B = Bregenz; E = Eisenstadt; G = Graz; I = Innsbruck; K = Klagenfurt; S = Salzburg; W = Wien.

Detailed Map of Carnic Alps excursion area:

Mountains – A = Austriascharte; C = Cellon; CP = Cima Plotta; F = Freikofel; Gk = Gamskofel; HW = Hohe Warte; Kk = Kollinkofel; KP = Kleiner Pal; Ks = Kellerspitzen; P = Polinik; SN = Sasso Nero; Sk = Seekopf; Sw = Seewarte.

Passes – PP = Plöcken Pass; VT = Valentintörl; WT = Wodnertörl.

Alpenvereins_Hütten & Alms (Refuges) – LH = Rifugio Lambertenghi e Romain; MH = Rifugio Giovanni & Olinto Marinelli; OV = Obere Valentinalm; OW = Obere Wolayer Alm; PH = Plöckenhaus; PHü = Eduard Pichl-Hütte; UV = Untere Valentinalm.


KOTSCHACH
Gail
MAUTHEN
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Sk
Sw
HW
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1
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3
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PP
KP
P
F
CP
MH
N

Stop 1

Silurian Cephalopod Limestone sequence of the Cellon Section, Carnic Alps, Austria

Kathleen HISTON[1], Annalisa FERRETTI[2] & Hans Peter SCHÖNLAUB[1]

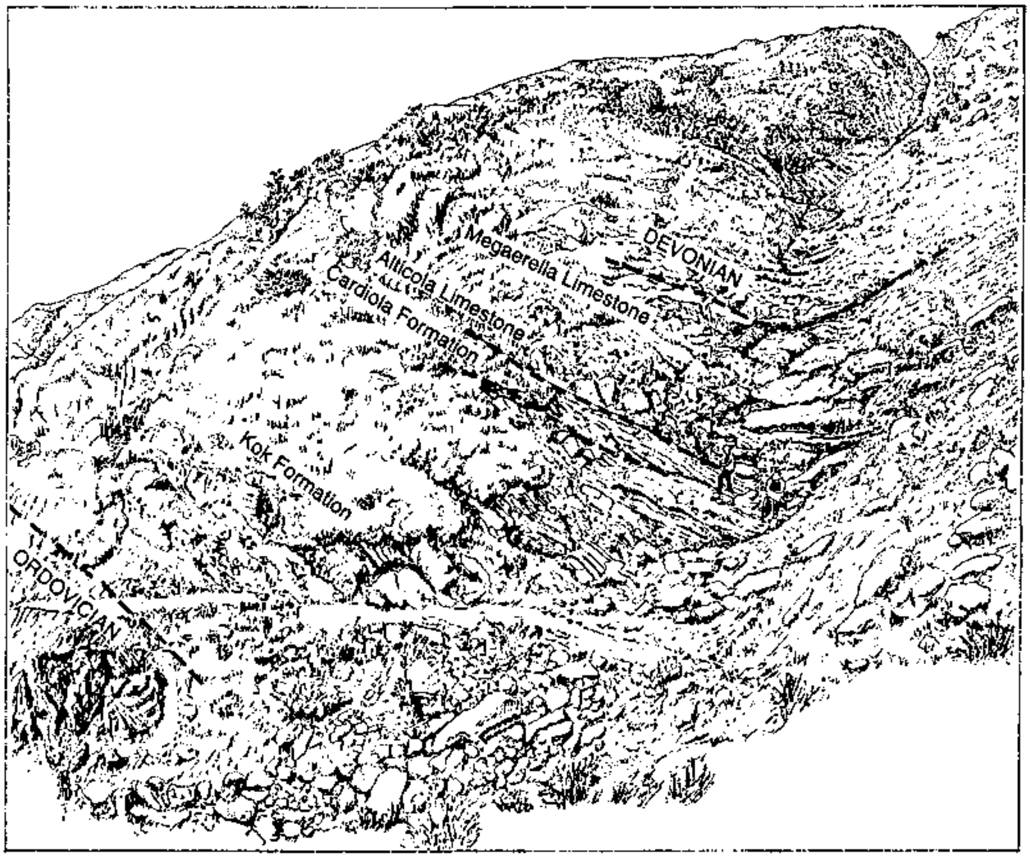

Fig. 2 - View of the Cellon section

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The 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-minute walk from Plöcken Pass.

The Silurian part of the Cellon section is best exposed in a narrow gorge cut by avalanches (Fig. 2). Thus, the German name for the section is "Cellonetta Lawinenrinne".

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 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 (see SCHÖNLAUB & HISTON this volume for environmental setting), 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. 3. and see PRIEWALDER, Fig. 1 this volume)):

Devonian	80.0m	Rauchkofel Limestone (dark, platy limestone; Lochkovian)
Silurian	8.0m	Megaerella Limestone (greyish and in part fossiliferous limestone; Pridoli)
	20.0m	Alticola Limestone (grey and pink nautiloid bearing limestone; Ludlow to Pridoli)
	3.5m	Cardiola Formation (alternating black limestone, marl and shale; Ludlow)
	13.0m	Kok Formation (brownish ferruginous nautiloid limestone, at the base alternating with shales; Late Llandovery to Wenlock)
Ordovician	4.8m	Plöcken Formation (calcareous sandstone; Ashgill, Hirnantian Stage)
	7.3m	Uggwa Limestone (argillaceous limestone grading into greenish siltstone above; 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 clearly indicate a latest Ordovician age. These strata represent the culmination of the end-Ordovician regressive 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 Early Silurian. Renewed sedimentation started in the Late Llandovery within the range of the index conodont *P. celloni.*

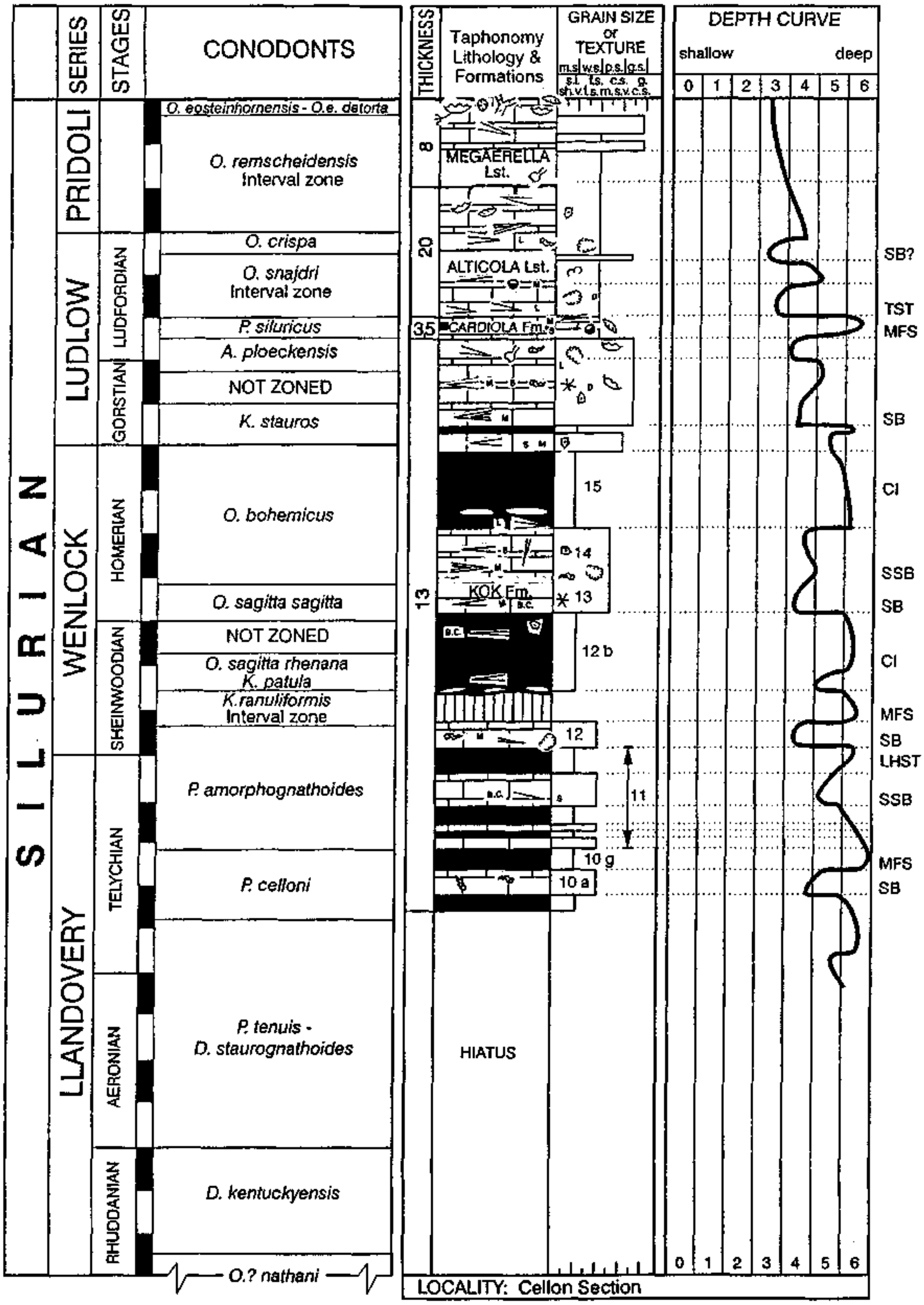

Fig. 3 - Conodont stratigraphy, lithology, grain size, significant taphonomic features and depth curve of the Silurian of the Cellon section (Modified from SCHÖNLAUB 1997)

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 5m 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.

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. H. 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.

Data about acritarchs and chitinozoans can be found in the paper by H. PRIEWALDER in this volume.

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 Early 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 palaeogeographical setting during the Silurian has highlighted many interesting microfacial aspects of the predominantly calcareous sequence.

Kok Formation (Beds 9 – 20):

Thin beds of ferruginous limestone, sometimes bioturbated, are intercalated at the base of the 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 ostracodes, echinoderms, rare small bivalves and gastropods. Many muellerisphaerida are present in darker bituminous micritic areas.
Starting from bed 13, the limestone becomes thicker and more massive. The reddish colour and the intensive bioturbation (Fig. 4) 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 ostracodes. Some organisms, mostly cephalopods, reveal peculiar iron-banded coatings (see Stop 2, Fig. 9). 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 there common. Starting from around bed 18 the limestone becomes greyer. Pyrite aggregates in the matrix may be occasionally found.

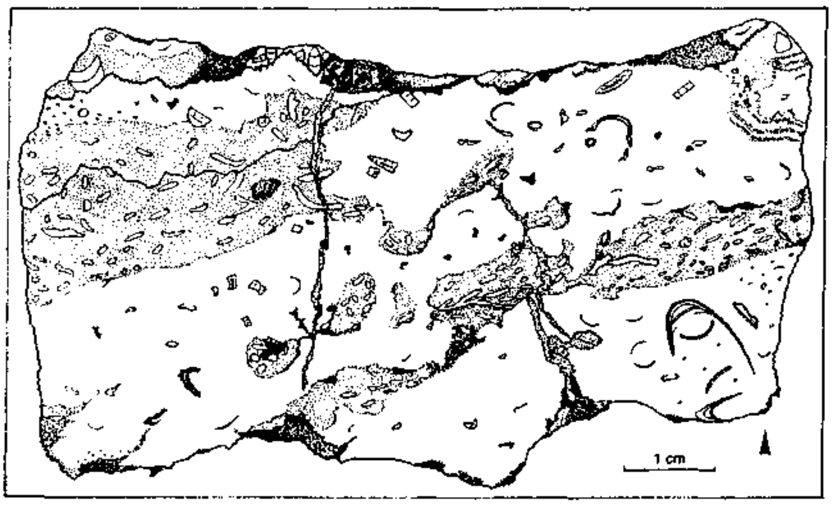

Fig. 4 - Intensive bioturbation in the Kok Formation (bed 16) redrawn from a thin section.

Cardiola Formation (Beds 21 – 24):

It is represented by a few centimeter thick bioclastic shelly layers (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 ostracodes 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 hard-ground.

Millimetric pavements of small brachiopods are present in bed 22. When seen in thin-section, they reveal a cephalopod-ostracode 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 ostracodes 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 ostracodes. Iron-coatings, mostly around trilobites, are again present. Bioturbation is common.

Megaerella Limestone (Beds 40-47 A):

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. 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, ostracodes, 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.

Nautiloid Fauna

The *'Orthoceras'* Limestones from the Silurian of the Carnic Alps and the nautiloid fauna have been well documented by various workers at the start of the century when the geology of the area began to be studied in detail: TIETZE (1870), STACHE (1879), FRECH (1887, 1894), GEYER (1894, 1903) GAERTNER (1931) but these works consist principally of faunal lists.The only systematic study was done by HERITSCH (1929) who described some of the earlier material collected together with his own from Dienten, Kokberg (Mt. Cocco) and Cellon giving clear stratigraphic data for the species. A total of 52 species were described by these early workers and these were revised by HERITSCH (1943) who also gave the stratigraphic occurrence of the species (HISTON, 1998). A more recent generic assignment of the species has been given by HISTON (1999a). Seventeen genera and twenty species are represented in the collection from the *Michelinoceratinae, Kionoceratinae, Leurocycloceratinae, Sphaerorthoceratinae, Anaspyroceratidae, Geisonoceratidae, Spyroceratinae, Oncoceratidae, Barrandeoceratidae, Uranoceratidae and Lechritrochceratidae.* TARAMELLI (1870, 1881, 1895), GORTANI & VINASSA DE REGNY (1909), VINASSA DE REGNY & GORTANI (1910), VINASSA DE REGNY (1908, 1913) are the most important Italian works on the area in which these *'Orthoceras'* limestones are mentioned in detail. A total of 18 nautiloid species were described by GNOLI & HISTON (1998) from the *Michelinoceratinae, Kionoceratinae, Leurocycloceratinae, Geisonoceratidae, Oncoceratidae and Rutoceratidae.* The Italian colections from the Carnic Alps are currently being revised (GNOLI, HISTON & SERVENTI, in press).

RISTEDT (1968, 1969, 1971) included material from the Cellon and Rauchkofelboden sections (Carnic Alps, Austria) in his study of the Orthoceratidae and early ontogenetic features in orthoconic nautiloids and described 12 new species from the area: *Merocycloceras declivis, Sphaerorthoceras carnicum, Sphaerorthoceras* sp. A (sensu RISTEDT), *Sphaerorthoceras* sp. F (sensu RISTEDT), *Parasphaerorthoceras accuratum, Parasphaerorthoceras* sp. A (sensu RISTEDT), *Parasphaerorthoceras* sp. C (sensu RISTEDT), *Parasphaerorthoceras* sp. D (sensu RISTEDT), *Parasphaerorthoceras* sp. E (sensu RISTEDT), *Parasphaerorthoceras* sp. L (sensu RISTEDT), *Hemicosmothoceras laterculum, Hemicosmothoceras celloni.* He sampled horizons 20 (Ludlow) and 40 (Pridoli) of the Cellon 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 the Cellon section.

The biostratigraphic potential of the nautiloid fauna was proposed as early as 1894 by FRECH who suggested *Orthoceras potens* BARRANDE as an index fossil for the lower red "Orthoceras" limestones and *Orthoceras alticola* BARRANDE for the upper red "Orthoceras" limestones.

In 1943 HERITSCH proposed the following zonation:

Orthoceras apollo BARRANDE	-	Kok Kalk
Orthoceras electum BARRANDE	-	Kok Kalk and Alticola Kalk
Orthoceras neptunium BARRANDE	-	Alticola Kalk

However, he states that it is difficult to define zones based on the nautiloid fauna as most species are found in both the Kok and Alticola Kalk.

RISTEDT (1969) suggests that the following species may be useful as marker fossils as they are found as mass occurrences at these horizons in the Carnic Alps:

Merocycloceras declivis RISTEDT	-	Upper Wenlock / Lower Ludlow
Hemicosmothoceras celloni RISTEDT	-	Base of the Cardiola Fm.
Hemicosmothoceras laterculum RISTEDT	-	Base Megaerella Kalk

New detailed collecting from both the Cellon and Rauchkofel Boden sections together with a revision of the older collections will test the biostratigraphic potential of the nautiloid fauna from the Carnic Alps which may allow a more precise comparison to be made with the nautiloid assemblages proposed by GNOLI & SERPAGLI (1991) from Sardinia and current work on Bohemian fauna. There are close affinities particularly between the Carnic Alps nautiloid fauna and the Bohemian fauna but also with the Sardinian fauna though with the latter some differences have been noted.

A detailed study of the taphonomy of the nautiloid fauna from this section (Fig. 3) has been done by HISTON & SCHONLAUB (1999).

The abundance, dimension, orientation, preservation, morphology and structural strengths of the fauna have been observed for each level of the Silurian as defined by WALLISER (1964) in his study of the conodonts from this section (see PRIEWALDER, Fig. 1. this volume). In some cases these divisions have been subdivided on the basis of the taphonomy of the fauna observed, an example is illustrated for the Kok Formation (Fig. 5). There are various cycles within these beds which show minor changes in the energy levels of the depositional environment (a detail of the base of Bed 13 is given in the illustration). This study of the Silurian nautiloid fauna from the Cellon section has shown that various events may be identified from the preservation of the fauna with regard to the changing oxygen content and hydrodynamic regime of the relatively shallow water carbonate sequence of the Plöcken facies (shallow to moderately deep marine environment). The palaeoecological and bathymetric implications of the morphological structure of the nautiloids have been used together with the taphonomy to deduce environmental setting.

At present the data for the nautiloid fauna indicate a possible placement for the lower beds of the Kok Formation in taphofacies 4 (shallow to moderately deep environment) and the upper beds in taphofacies 2, a shallow environment (of SPEYER & BRETT, 1991). Taphofacies 6 (relatively deep) may be indicated for parts of the Cardiola Formation while a return to taphofacies 4 is suggested for the lower part of the Alticola Limestone. Taphofacies 3 (shallow to moderately deep environment) may be indicated for some bioturbated levels in the Ludlow and taphofacies 2 for thoses levels of that have been winnowed by gentle currents.
The frequency of stylolites and the overall complexity of the cycles developed makes determination of taphofacies for the overall sequence quite difficult. A more complete environmental interpretation will be possible when the present results are combined with Bivalvia paleoecological data (KRIZ, in prep.), the microbiofacies data (FERRETTI, in prep.) and an overall study of the cephalopod taphonomy and biosedimentology of the sections (FERRETTI & HISTON, in prep.).

Acknowledgements

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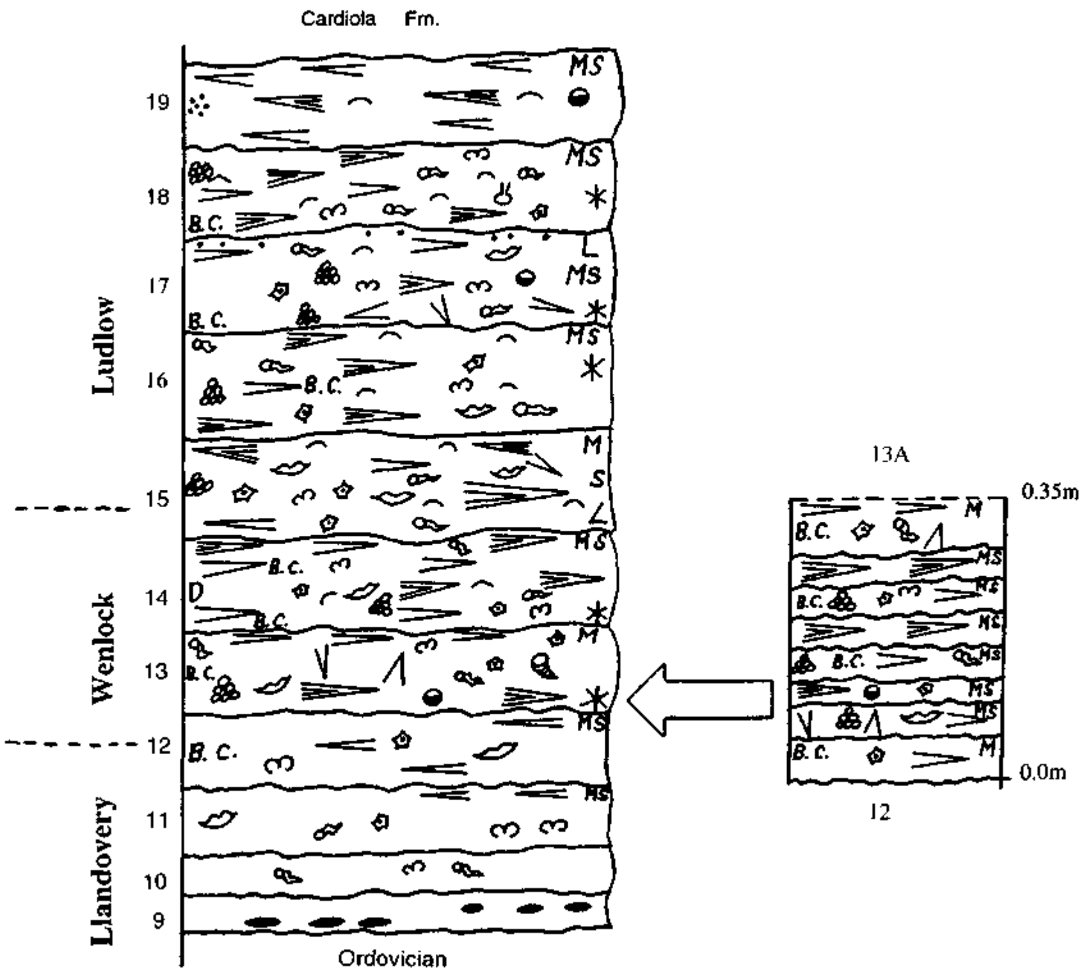

Fig. 5 - Taphonomy of the Kok Formation. Note detail of small scale cyclic repetition of beds indicating changes in the hydrodynamic regime.

Stop 2

The Silurian and Early Devonian of the Rauchkofel Boden Section, Southern Carnic Alps, Austria.

Annalisa FERRETTI[1], Kathleen HISTON[2] & Hans Peter SCHÖNLAUB[2]

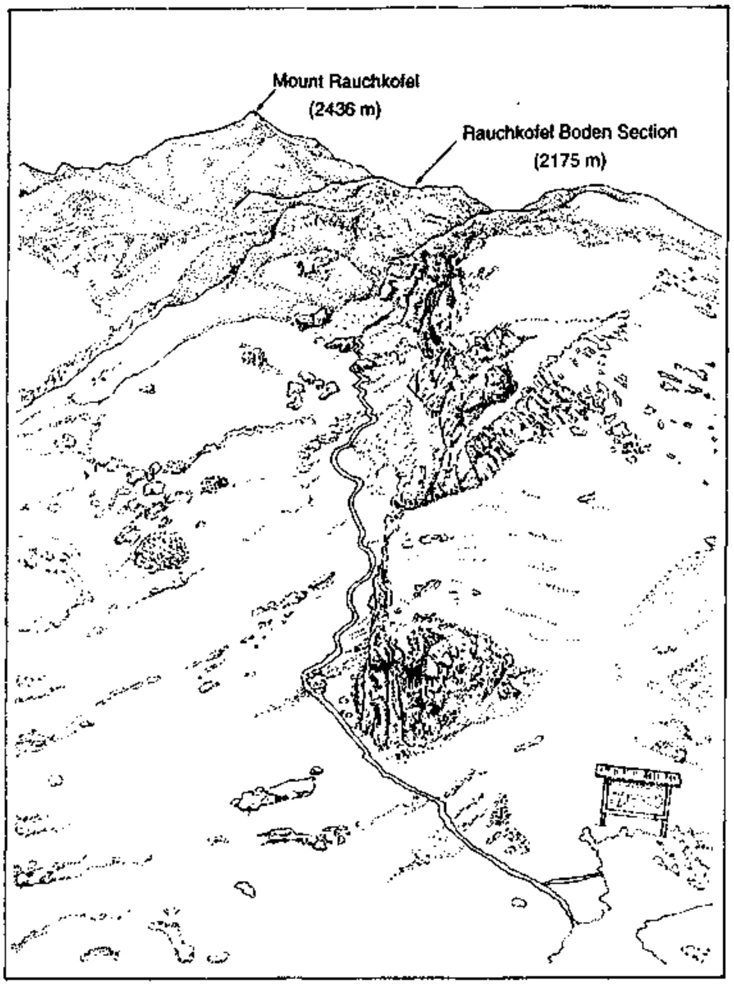

Fig. 6 - General view of Mount Rauchkofel and of the Rauchkofel Boden Section.

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The Rauchkofel Boden section, located on the southwestern slope of Mount Rauchkofel (Fig. 6), 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. 7). Various studies of this section has 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 (eg. SCHÖNLAUB, 1980).

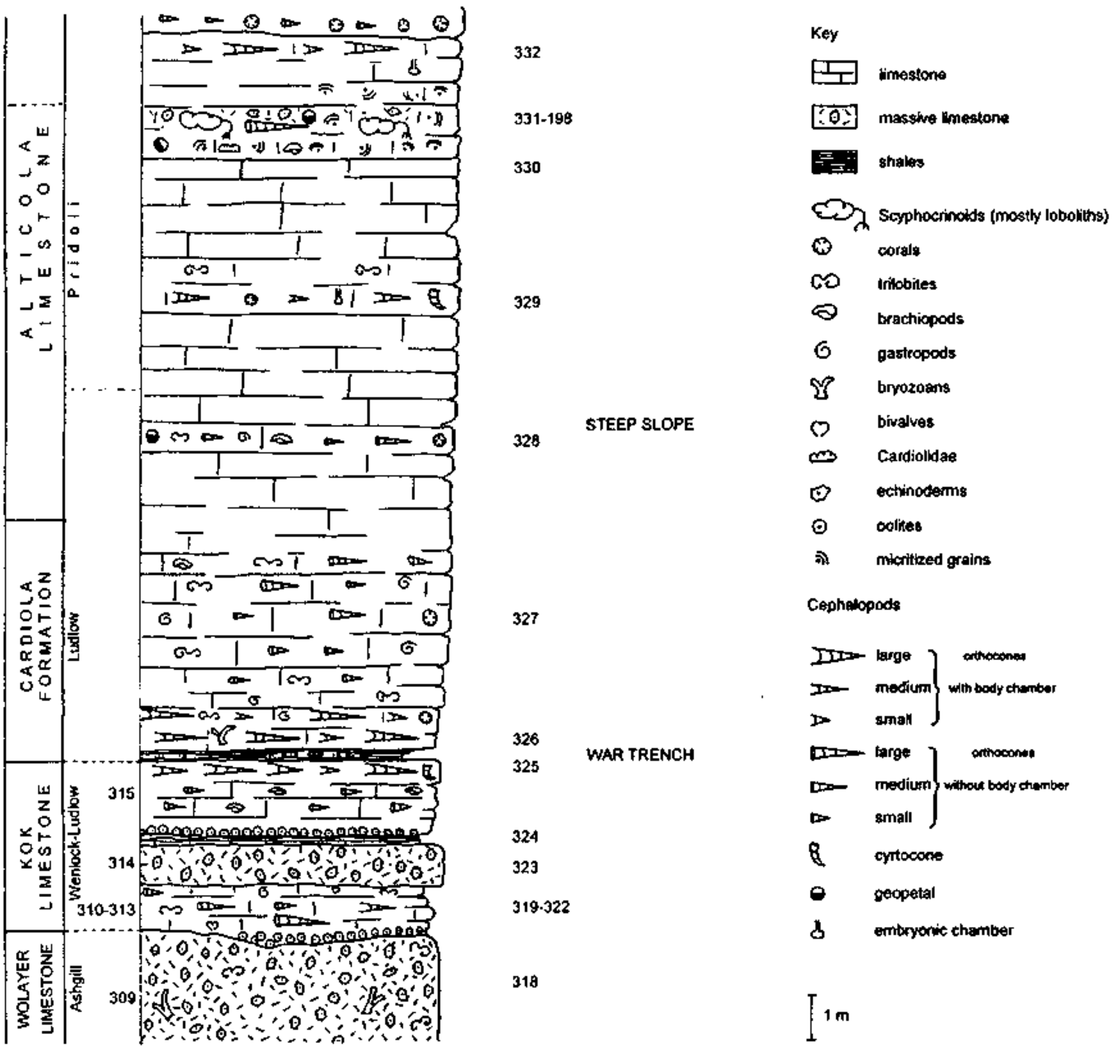

Fig. 7- Stratigraphic column of the Rauchkofel Boden Section.

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 no. 313, i.e. 1.20 m above the base (Fig. 7). Although richly resampled not a single specimen of *Ozarkodina bohemica* has yet been found in that interval. In sample no. 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 dissolution of the conch wall (Fig. 8). 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.

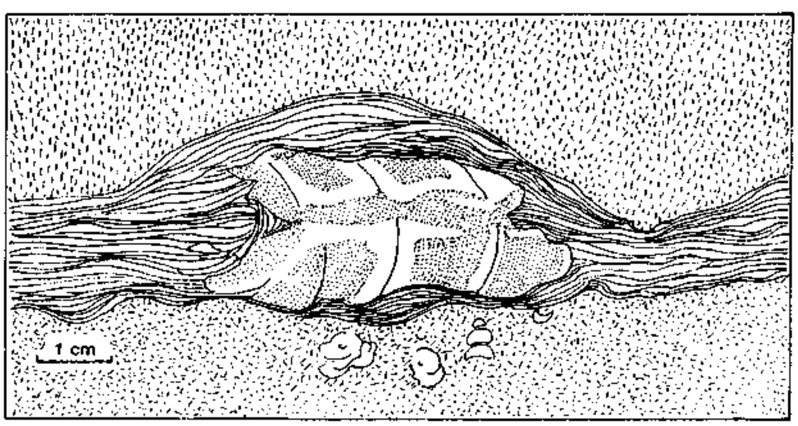

Fig. 8 - Intensive dissolution of a cephalopod shell "trapped" within iron-rich crusts (Kok Formation).

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. 9) 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).

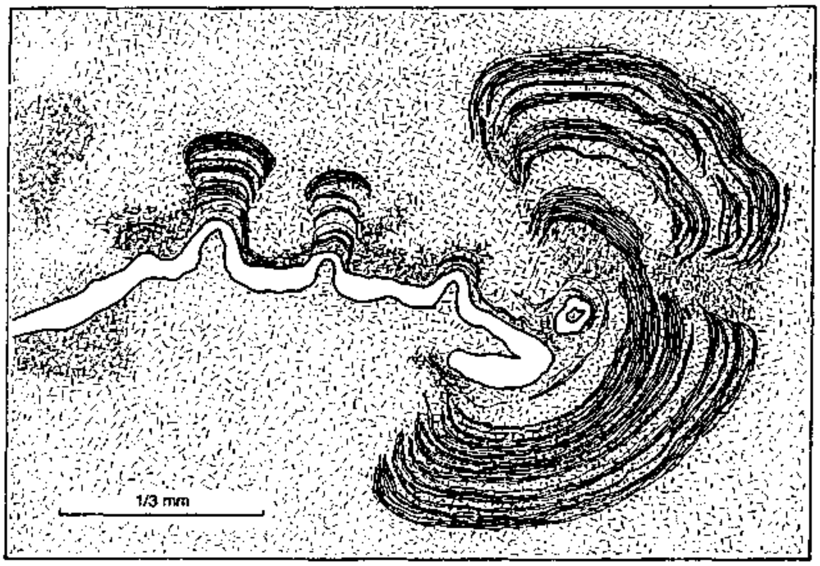

Fig. 9 - Iron-banded coating of a trilobite shell. Note how these covers proceed from the most elevate parts of the shell (Kok Formation; redrawn from a thin-section).

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*, *Geisonoceras* 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 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. 10). 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.

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.

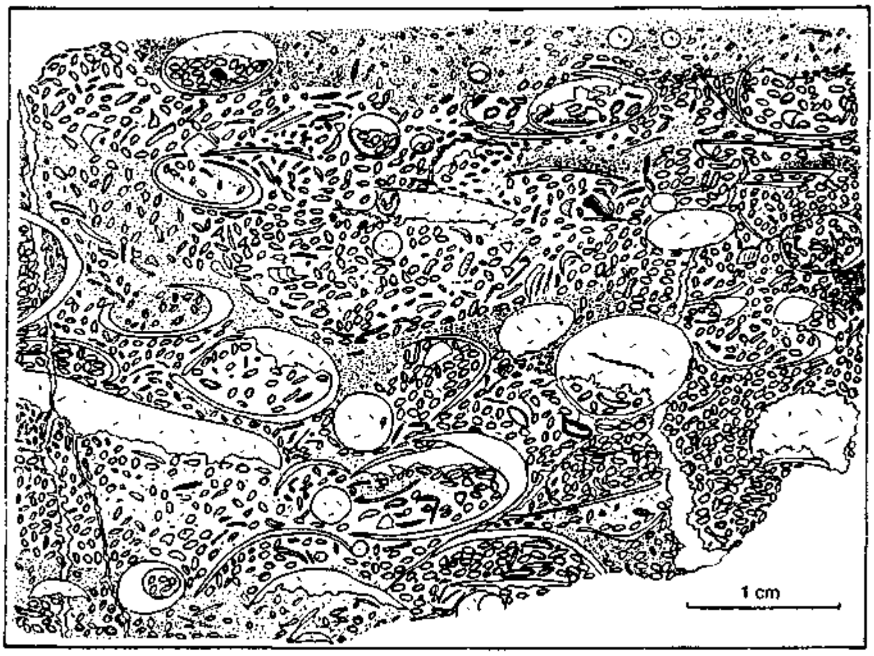

Fig. 10 - Cardiola Formation; cephalopods embedded in a matrix mostly represented by micritized grains (redrawn from a thin-section).

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 nos. 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 comprised almost entirely of 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. 11). This interval is represented by well bedded, thin and blackish limestone beds with shaly intercalations (sample nos. 201 b-201 j). The index conodont for the base of the Devonian, *Icriodus woschmidti,* was collected in sample nos. 201 and 201 a. 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. 11 showing its lithology and faunal content. The 40 m thick undisturbed section is subdivided into the following formations:

1.80 m pelagic **Rauchkofel Lmstn.** comprising black limestones interbedded with marls (Lower Lochkovian)

c. 17 m **Boden Lmstn.** comprising greyish coarsely bedded nautiloid bearing limestones rich in conodonts but rare in dacryoconarids and orthoconic and coilded nautiloids (Upper Lochkovian)

20 m nodular pink **Findenig Lmstn.** rich in dacryoconarids

Acknowledgements

Our sincere thanks to Enrico Serpagli for helpful suggestions and constructive review.
This work has been greatly improved by illustrations, derived by expert photo-computer composition by Piero Vezzani (Wildlife Image Bank) and magnificent redrawing by Giancarlo Leonardi (University of Modena), to all of which our thanks are due.
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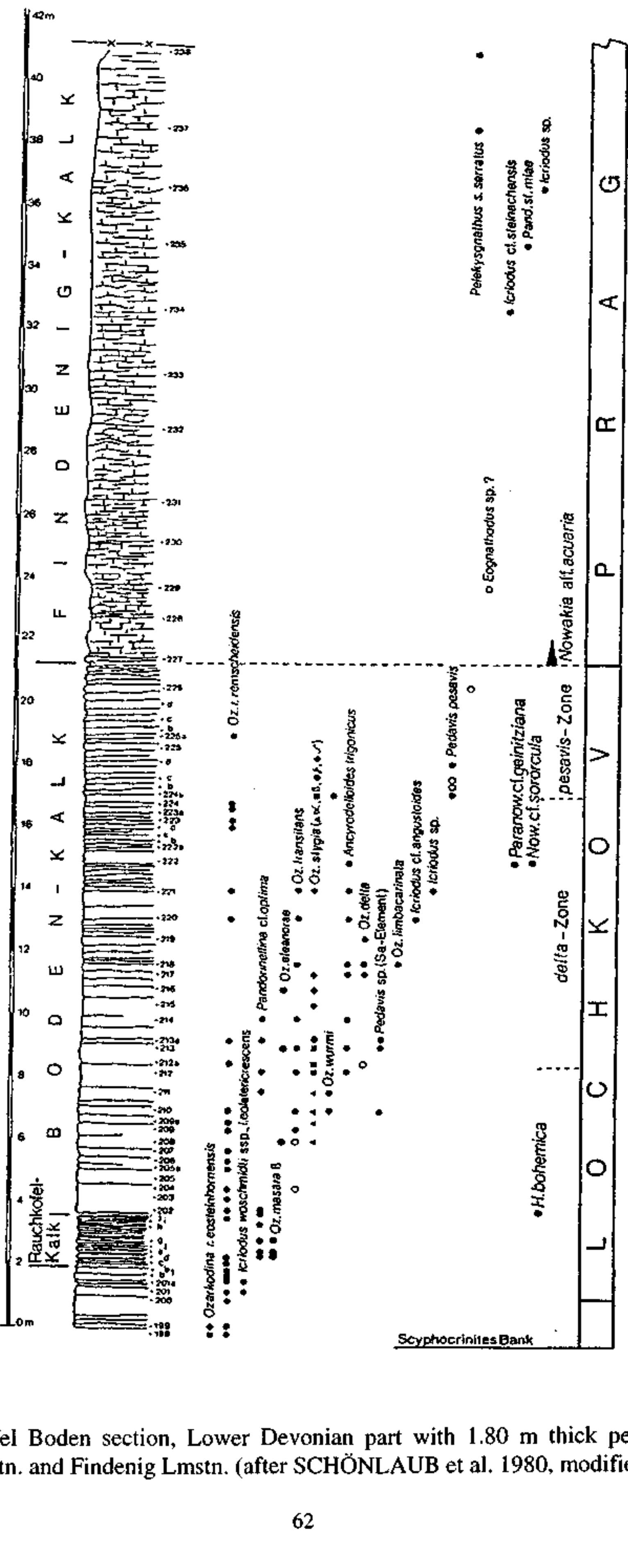

Fig.11 - Rauchkofel Boden section, Lower Devonian part with 1.80 m thick pelagic Rauchkofel Lmstn., Boden Lmstn. and Findenig Lmstn. (after SCHÖNLAUB et al. 1980, modified).

Stop 3

Late Devonian cephalopod limestones in the vicinity of Valentintörl

Hans Peter SCHÖNLAUB[1] & 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 corfirmed, 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)

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Stop 4

The Upper Silurian sequence at the Valentintörl section

Kathleen HISTON[1], Annalisa FERRETTI[2] & Hans Peter SCHÖNLAUB[1]

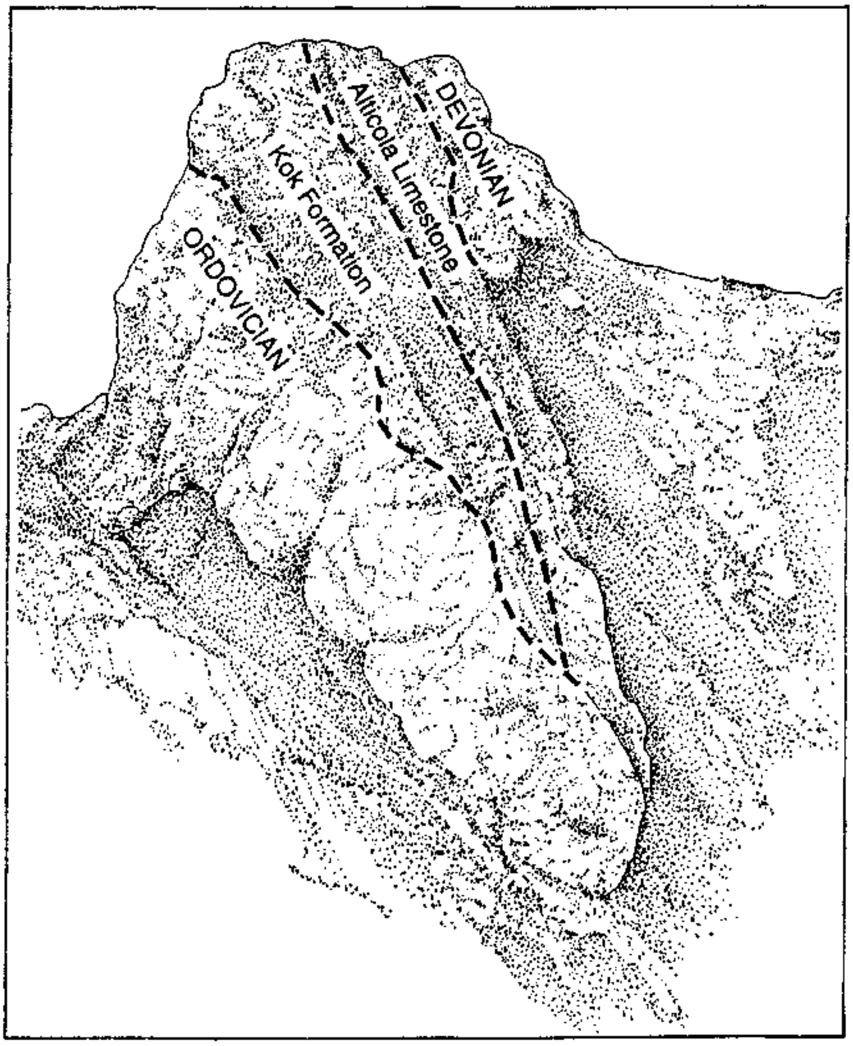

Fig. 12 - View of the Valentintörl section from the west.

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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. 12). Various lower Palaeozoic 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. 13). 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**.

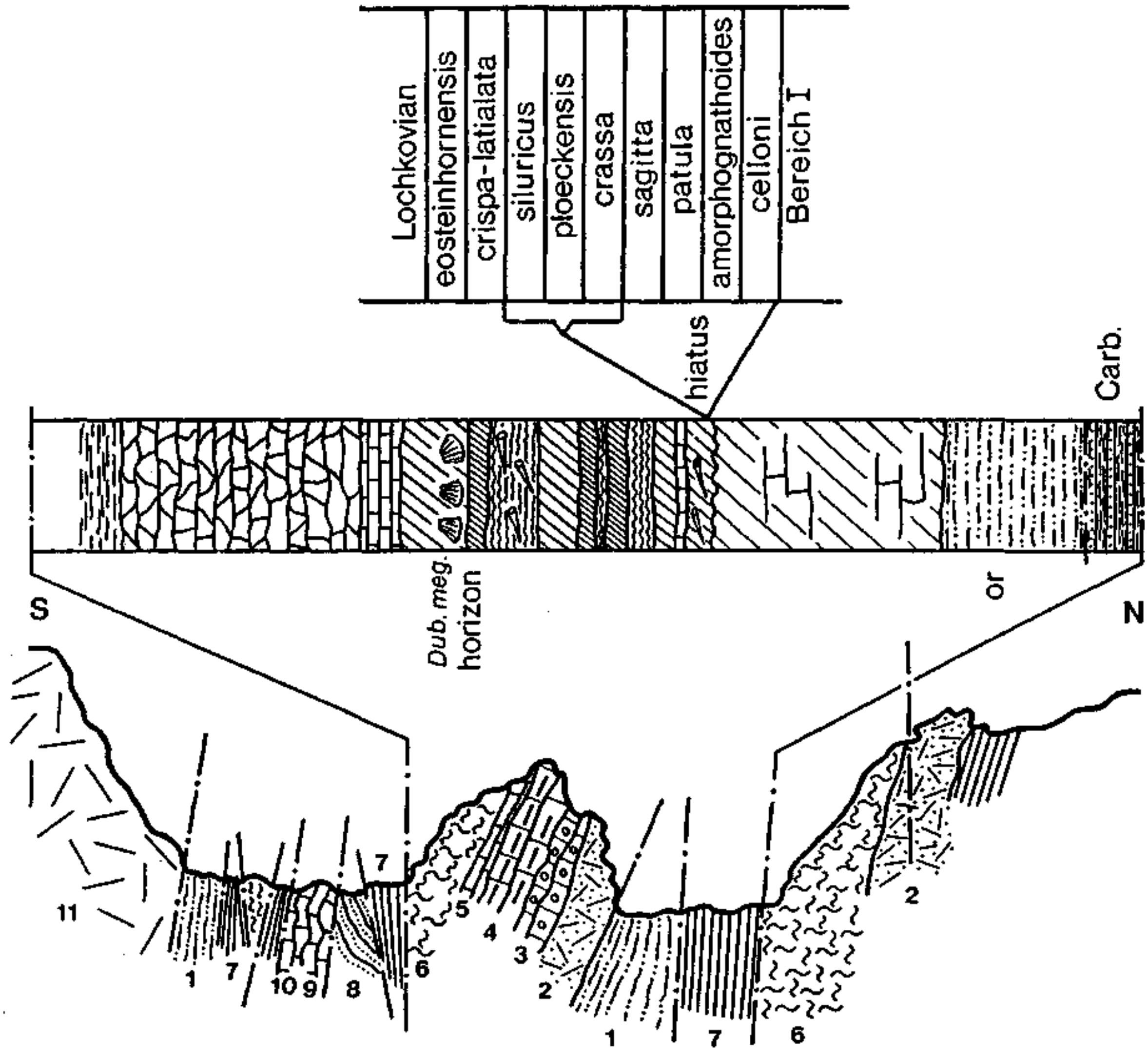


Fig. 13 N-S profile of Valentintorl from the east.
1-Uggwa shales (Ordovician); 2-Wolayer Lmstn. (Late Ordovician); 8-Himmelberg sandstone (Ordovician); 3, 9- Kok Fm (Ludlow); 4-Alticola + Megaerella Lmstn. (Ludlow-Pridoli); 5-Rauchkofel Lmstn.; 6-Findenig Lmstn.; 7-Hochwipfel Fm.; 10 - Devonian (unstudied); 11-Carboniferous (unstudied). (after SCHÖNLAUB 1980)

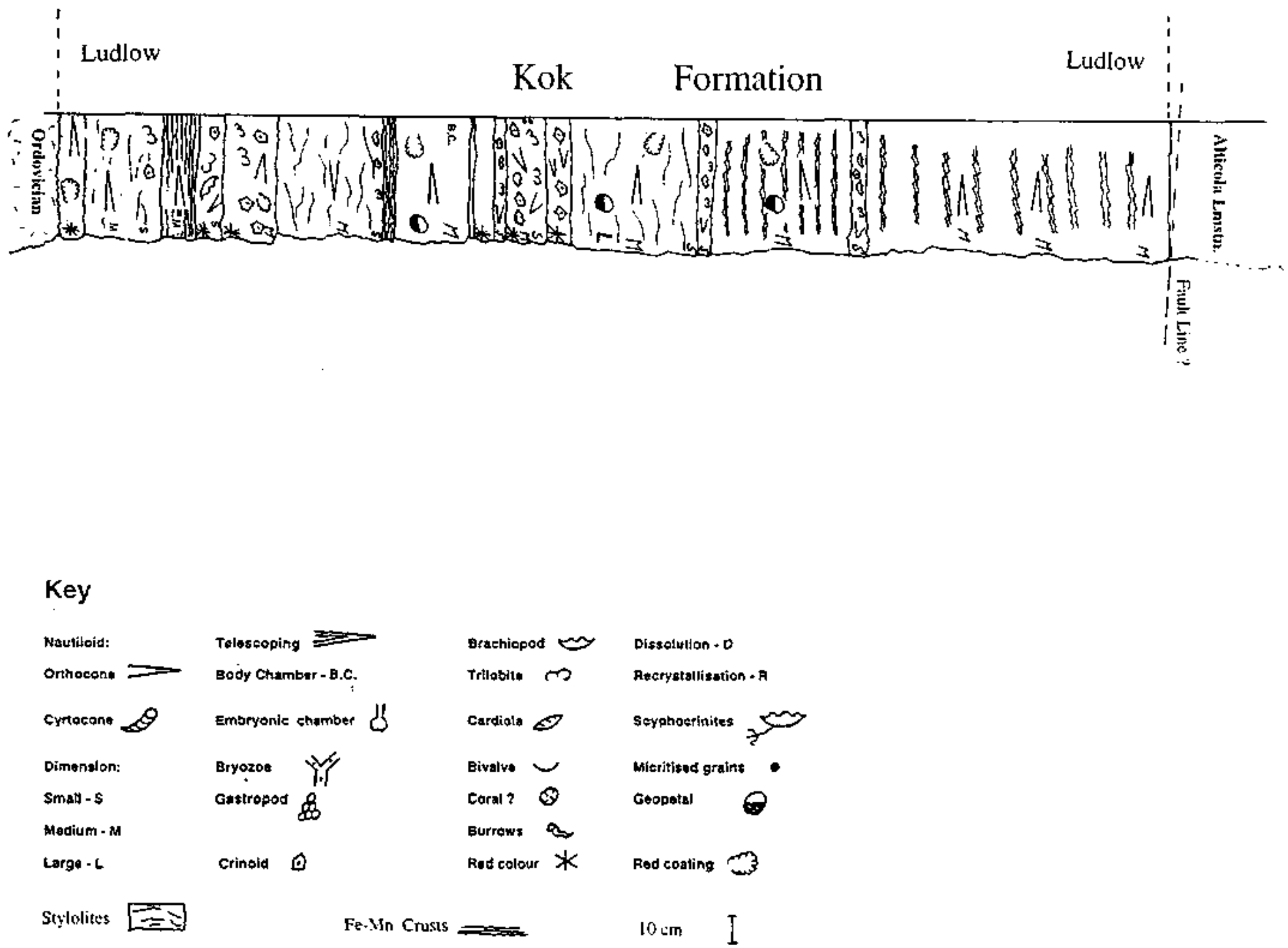


Fig. 14 - Stratigraphic column of the Kok Formation, Valentintörl section.

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. 14) of reddish-grey predominantly micritic limestones is underlain by a Fe-Mn crust (Fig. 15) which is sometimes exposed as patches on the Wolayer Limestone.

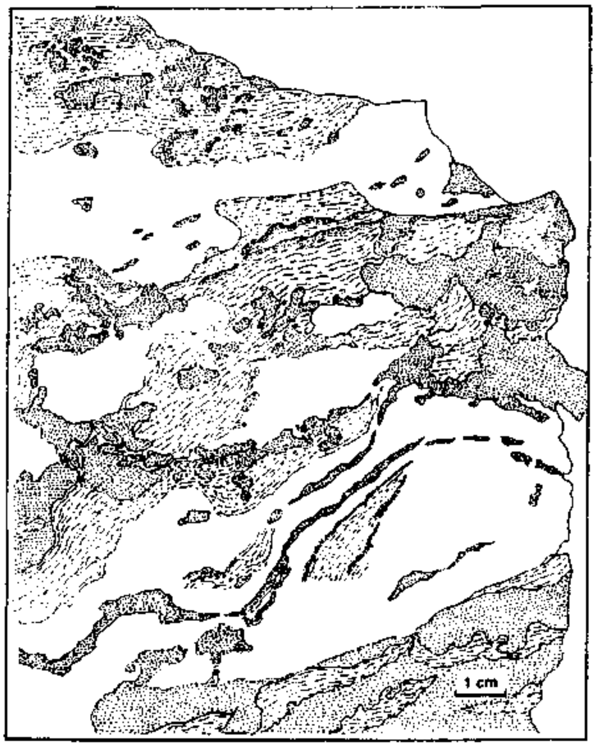


Fig. 15 - Iron - rich mineralisation at the base of the Silurian.

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 biodetris 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 biodetris occur frequently thoughout the section. Reddening of the limestones is indicated in Fig. 14 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. 15). No gradation, sorting or orientation is here visible. 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.

Acknowledgements.

Many thanks to Sherpa for dedicated and careful assistance in the snowy conditions. This work has been greatly improved by illustrations, derived by expert photo-computer composition by Piero Vezzani (Wildlife Image Bank) and magnificent redrawing by Giancarlo Leonardi (University of Modena), to all of which our thanks are due.

This paper was carried out under the auspices of the I.G.C.P. project 421 (North Gondwanan Mid-Palaeozoic bioevent/biogeography patterns in relation to crustal dynamics). K. Histon acknowledges a fellowship from the Austrian Science Foundation (Fonds zur Förderung der wissenschaftlichen Forschung) with which this research is being funded.

Stop 5

Wolayer "Glacier" Section

Hans Peter SCHÖNLAUB

This locality 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-reddish Flaser limestones commonly named cephalopod limestones. They have been deposited in a pelagic off-shore environment testified by radiolarians, forams, dacryoconarids, styliolinids, ostracods, conodonts, trilobites and few goniatites.

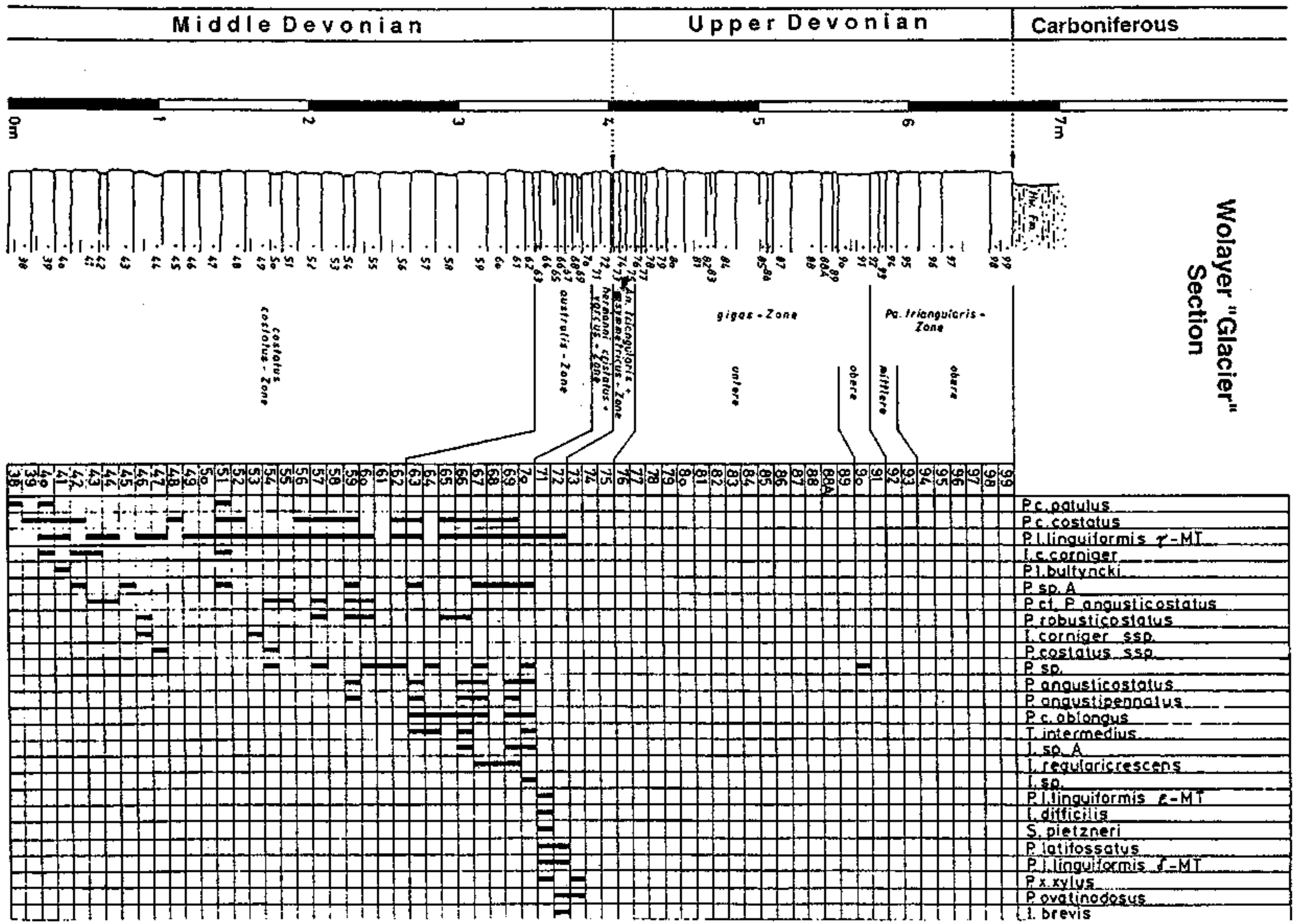
The continuous section ranges from the Emsian to the Famennian (Fig.16)[1]. Of particular interest is the Frasnian/Famennian boundary the sedimentology, conodont stratigraphy and isotope geochemistry of which has been studied by GÖDDERTZ & SCHÖNLAUB (1980, 1985) and JOACHIMSKI et al. (1994).

According to these authors the lower part of the so-called Valentin Lst. comprises styliolinid-rich wackestones with fragments of echinoderms, brachiopods, gastropods and trilobites. Larger clasts are coated by Fe-Mn crusts indicating reduced sedimentation. In particular, the Givetian/Frasnian boundary interval is characterized by a distinct horizon of nodular phosphorite. In contrast, the boundary between the Emsian and Eifelian, i.e., the Lower/Middle Devonian boundary, is within a uniform cephalopod limestone development. Based on conodonts it is placed at the bedding plane between sample nos. 28 and 29.

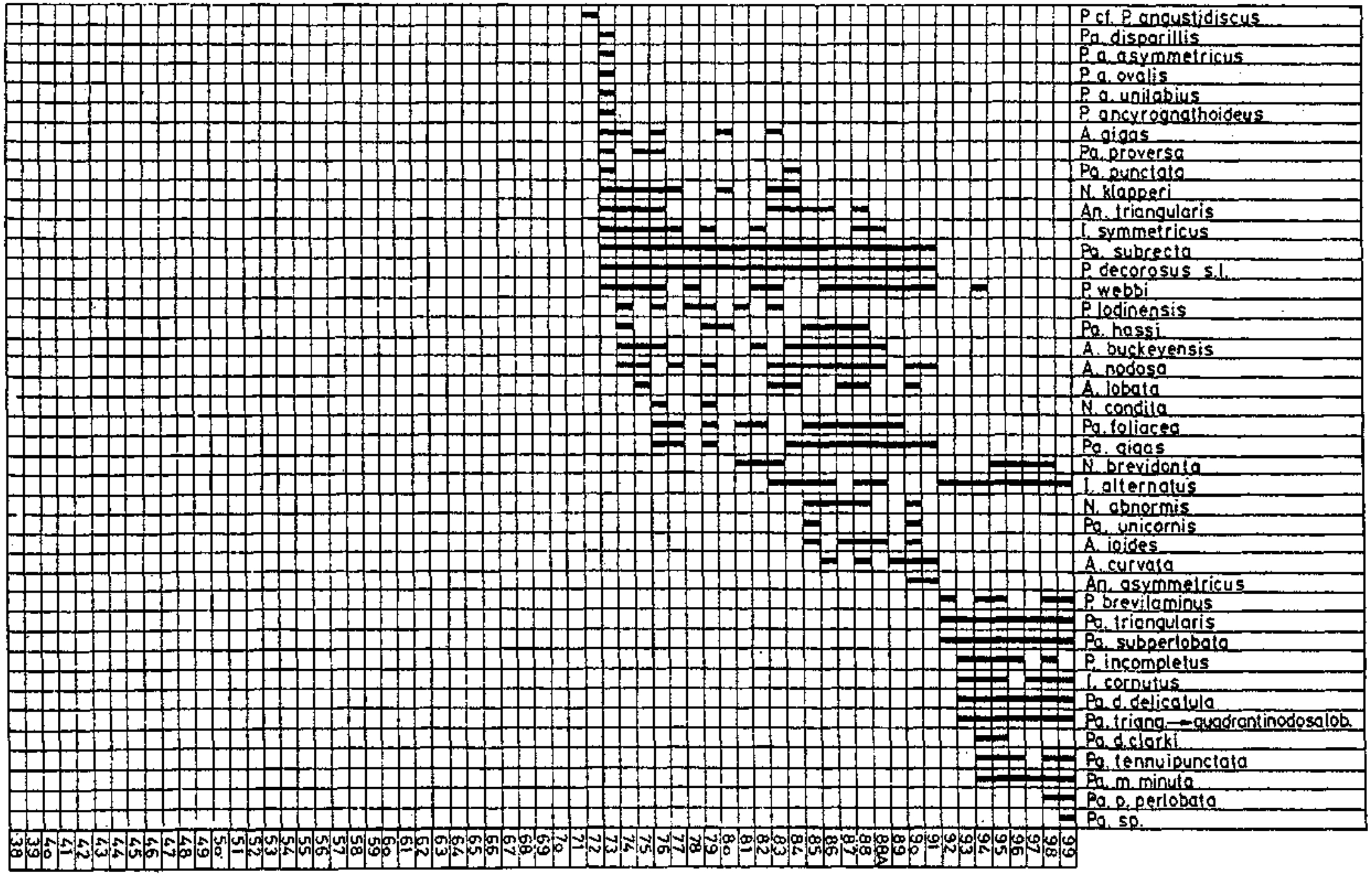
The Pal Lst. of Frasnian age is characterized by mudstones to wackestones with fragments of bivalves, ostracods, echinoderms, trilobites and rare occurrences of corals and styliolinids. Thin biosparitic and quartz-rich layers suggest distal turbidites. Of special interest is an up to 6 cm thick black shale horizon interpreted as an equivalent of the Lower Kellwasser Horizon (JOACHIMSKI et al. 1994). However, at this section bituminous limestones are missing. Instead, well oxygenated conditions with bioturbation are documented across the Frasnian/Famennian boundary rendering this section as an example for uniform limestone deposition at this critical interval of global importance.

The carbon isotope signatures are shown in the lithologic column (Fig. 17). At the base of the studied section the $\delta^{13}C$ values range from +1.5‰ to + 1.9‰. Carbon isotope values in the Lower Frasnian are around +1‰ with a sharp drop in the Late hassi conodont Zone. A distinct positive excursion occurs in the late Early rhenana Zone. Most enriched values of +3.3‰ are found below the black shale horizon corresponding to the Lower Kellwasser Horizon. In the overlying beds the signal shifts back to Frasnian background levels. A second positive excursion starts below the Frasnian/Famennian boundary with most enriched $\delta^{13}C$ values around +3.1‰ some cm above the boundary. During the Lower Famennian these values gradually shift back to lighter values. According to JOACHIMSKI & BUGGISCH (1993) this characteristic twofold pattern can be recognized in many boundary sections around the globe.

[1] Fig. 16 - Wolayer Glacier section. Distribution of conodonts in the Valentin and Pal. Lmstn. (from GÖDDERTZ, 1982)



Wolayer "Glacier" Section
Middle Devonian
Upper Devonian
Carboniferous
0m
1
2
3
4
5
6
7m
costatus costatus - Zone
australis - Zone
gigas - Zone
Pa. triangularis - Zone
untere
obere
mittlere
obere
P. c. patulus
P. c. costatus
P. l. linguiformis γ-MT
I. c. corniger
P. l. bultyncki
P. sp. A
P. cf. P. angusticostatus
P. robusticostatus
I. corniger ssp.
P. costatus ssp.
P. sp.
P. angusticostatus
P. angustipennatus
P. c. oblongus
T. intermedius
I. sp. A
I. regularicrescens
I. sp.
P. l. linguiformis ε-MT
I. difficilis
S. pietzneri
P. latifossatus
P. l. linguiformis δ-MT
P. x. xylus
P. ovatinodosus
I. brevis


P. cf. P. angustidiscus
Pa. disparillis
P. a. asymmetricus
P. a. ovalis
P. a. unilabius
P. ancyrognathoideus
A. gigas
Pa. proversa
Pa. punctata
N. klapperi
An. triangularis
I. symmetricus
Pa. subrecta
P. decorosus s.l.
P. webbi
P. lodinensis
Pa. hassi
A. buckeyensis
A. nodosa
A. lobata
N. condita
Pa. foliacea
Pa. gigas
N. brevidonta
I. alternatus
N. abnormis
Pa. unicornis
A. ioides
A. curvata
An. asymmetricus
P. brevilaminus
Pa. triangularis
Pa. subperlobata
P. incompletus
I. cornutus
Pa. d. delicatula
Pa. triang.→quadrantinodosalob.
Pa. d. clarki
Pa. tennuipunctata
Pa. m. minuta
Pa. p. perlobata
Pa. sp.
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 88A 89 90 91 92 93 94 95 96 97 98 99

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. More precisely, the well-known Frasnian/Famennian faunal crisis may have been caused by such perturbations.

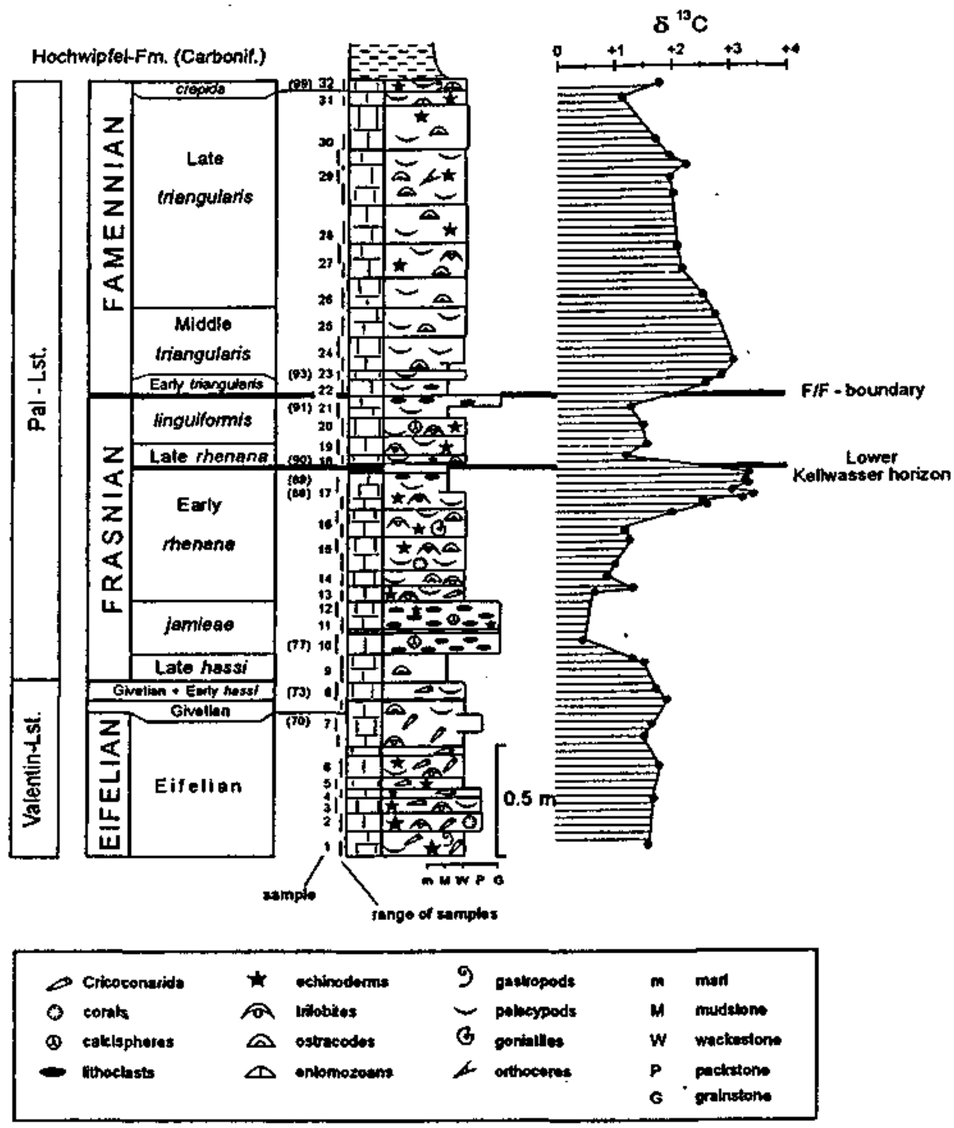


Fig. 17 - Carbon isotope pattern across the Frasnian/Famennian boundary at the Wolayer Glacier section (modified from JOACHIMSKI, BUGGISCH & ANDERS, 1994)

Stop 6

Palaeozoic ammonoids in the Carnic Alps

Dieter KORN[1]

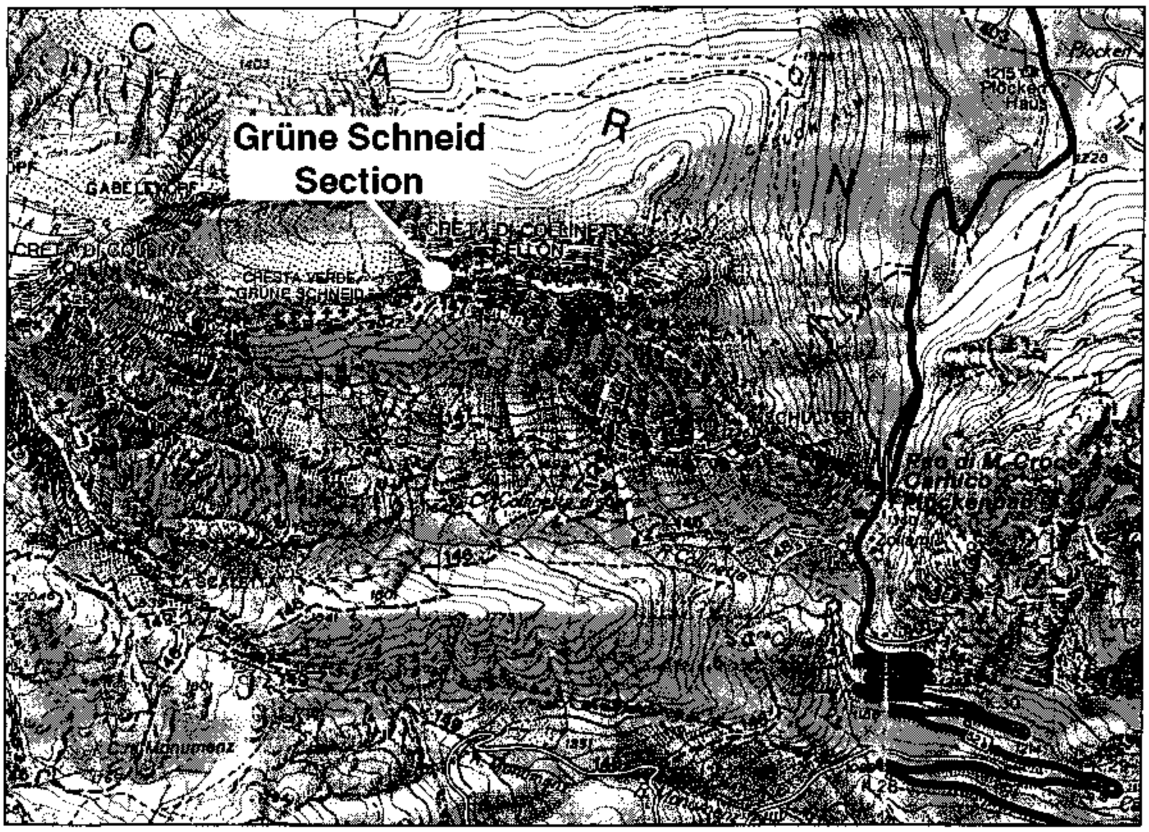


Fig. 18 - Location of the Grüne Schneid section west of the Plöckenpaß.

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Introduction.

Palaeozoic ammonoids from the Carnic Alps are 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.

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.

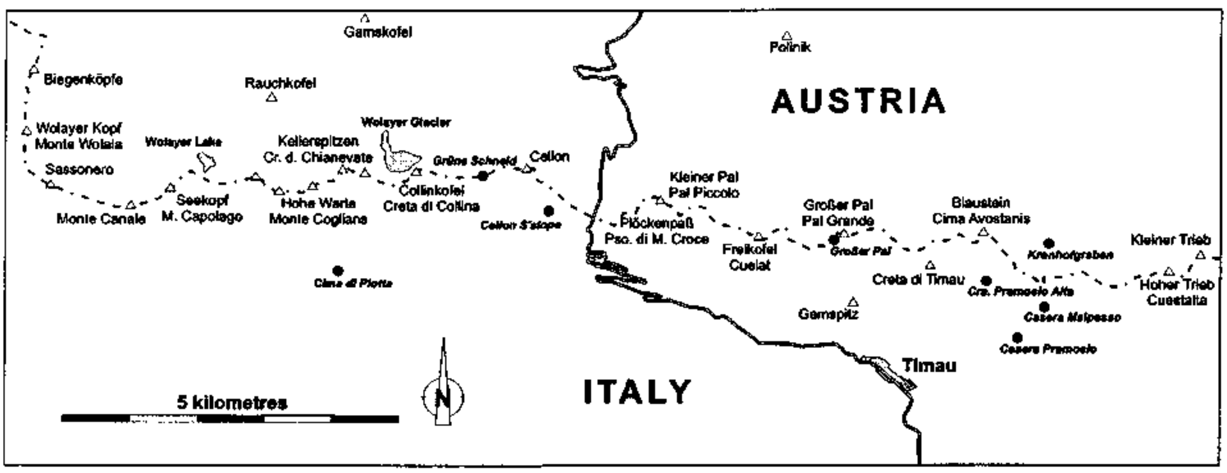


Fig. 19 - Location of the Famennian and Tournaisian ammonoid localities in the Central Carnic Alps of Southern Austria.

The latest Devonian *Clymenia* and *Wocklumeria* ammonoid Stufen (late Famennian) are much better represented by diverse assemblages (Fig. 19, 20), 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.

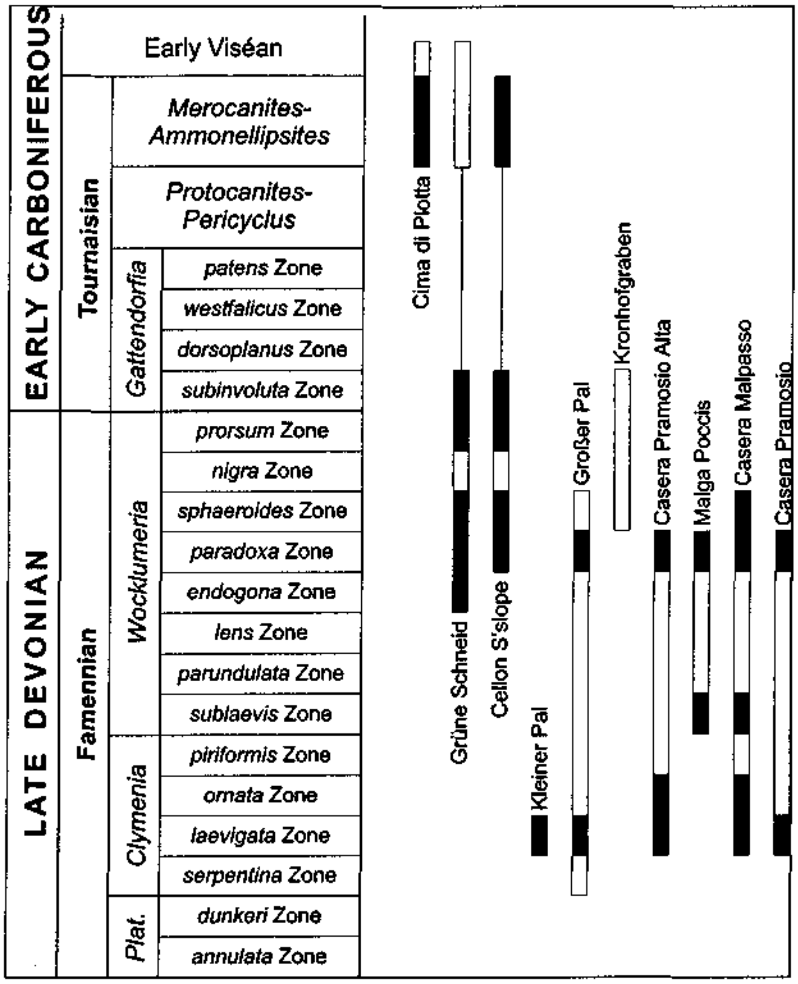
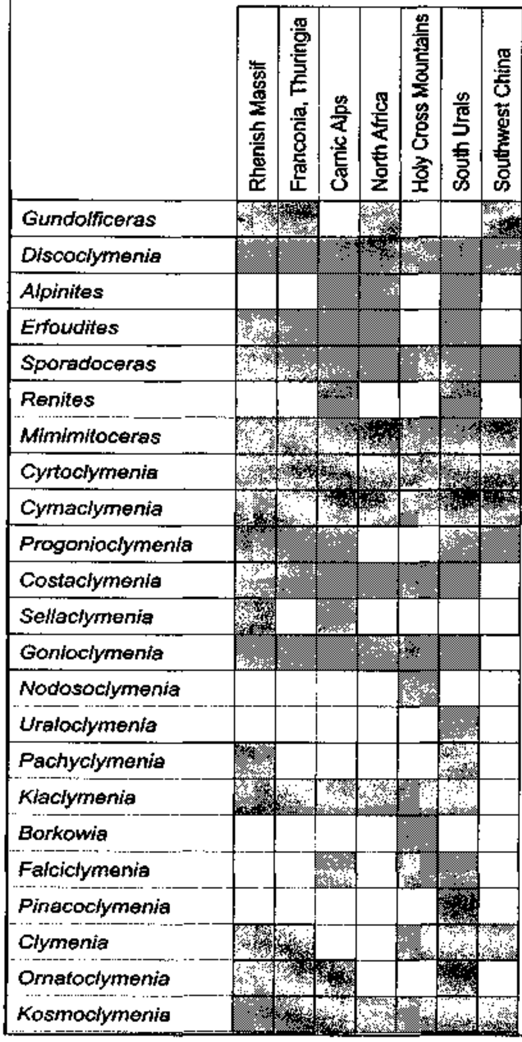


Fig. 20 - Stratigraphical scheme of the late Famennian and Tournaisian ammonoid succession with indication of faunas represented in the Carnic Alps.

Diverse ammonoid faunas of the *Clymenia* and *Wocklumeria* Stufen 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 *Mimimitoceras*. These genera indicate the presence of the *acuticostata* and *piriformis* Zones of the *Clymenia* Stufe.

The Carnic faunas principally resemble the time-equivalent faunas of the Rhenish Massif and other regions, but are remarkable for 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 maintain into the *Clymenia* Stufe. Analyses of the biogeographical relations of the *Clymenia* Stufe faunas led to the conclusion that the Carnic Alps are close related to the South Urals, rather than to the Rhenish Massif or North Africa (Fig. 21).

presence of genera in different regions



biogeographical analyses

	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	

Sørensen $\frac{C}{N_1+N_2}$ Jaccard $\frac{C}{N_1+N_2-C}$

Clusteranalysis

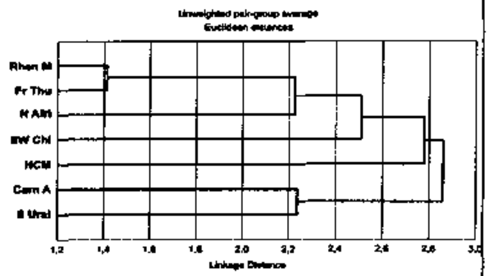


Fig. 21 - Biogeographical relations of ammonoid faunas from the *Clymenia* Stufe (late Famennian).

Limestones of the *Wocklumeria* Stufe contain in sections at Casera Malpasso, Grüne 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 Grüne 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.

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 Crocce 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 an 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. 18). 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.

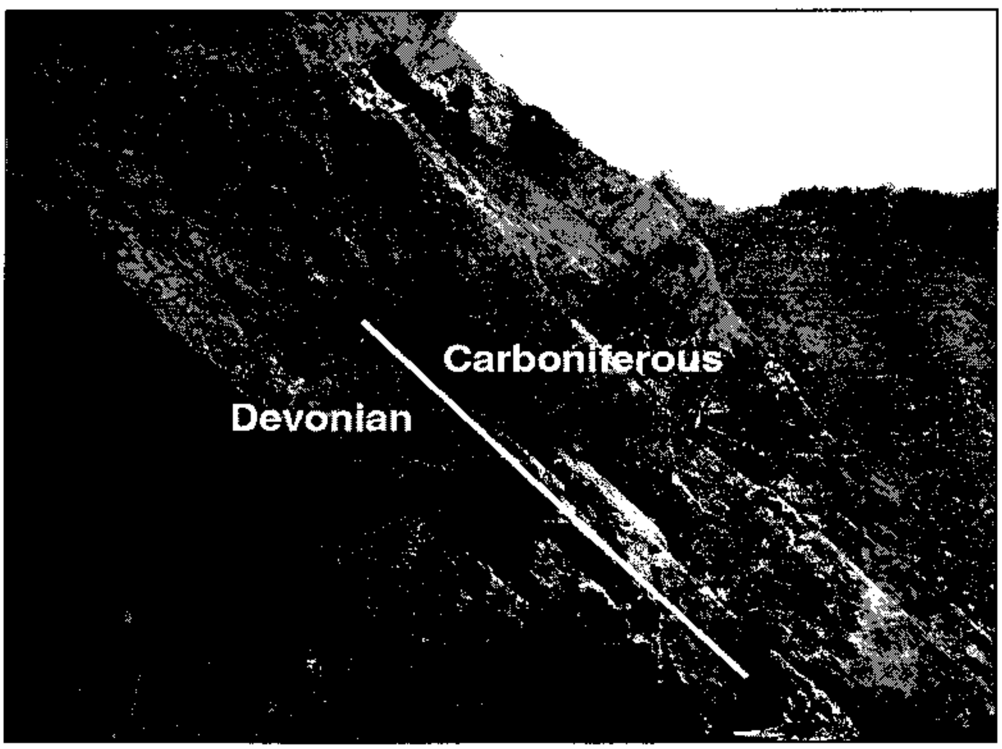


Fig. 22 - Photograph of the section around the Devonian-Carboniferous Boundary (between beds 6C and 6D) at Grüne Schneid.

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 preliminary 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 metres (Fig. 22). It is entirely composed of grey cephalopod limestone (mostly wackestone and mudstone), and yielded from almost every bed 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* Stufe (latest Famennian) up to the basal *Gattendorfia* Stufe (Early Tournaisian), and include a fauna of the *prorsum* Zone, the latest Devonian ammonoid zone (Fig. 23). Among all the stratotype candidates under discussion, the Grüne Schneid section displays the most complete ammonoid succession around the D-C Boundary. However, it was not chosen as the stratotype.

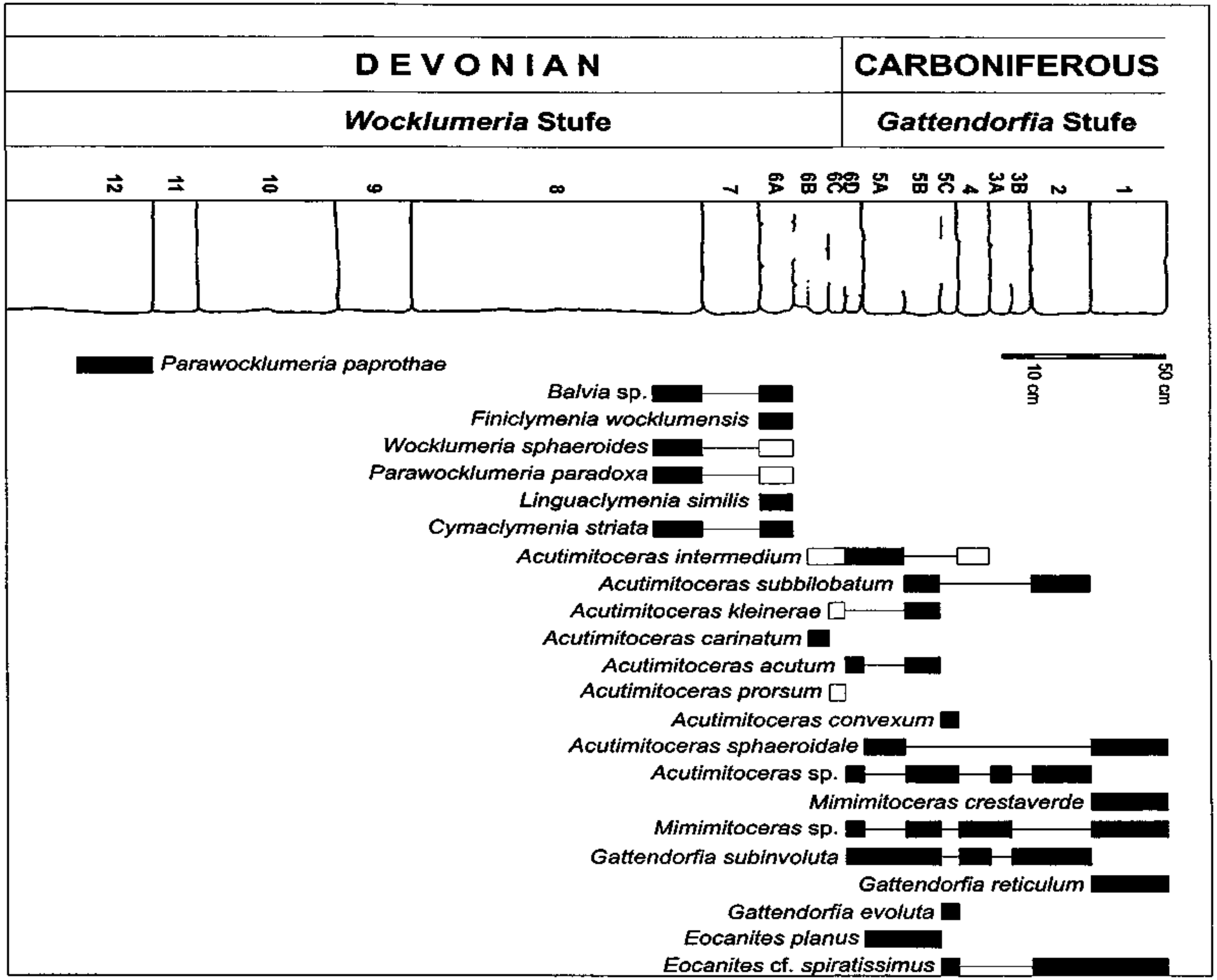


Fig. 23 - Columnar section of the Grüne Schneid outcrop with ammonoid content.

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