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Guidebook

edited by

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Editorial

The Austrian National Committee for the IGCP and the Geological Survey of Austria cordially welcome the participants of the Inaugural Meeting of IGCP 421 at Vienna! We look forward to hosting this distinguished group of geological 'pathfinders on Earth' and hope your stay in Vienna and the following excursion will be a pleasant and successful one.

At the Geological Survey of Austria research in biostratigraphy and historical geology of Paleozoic sequences has a long tradition. With its foundation in the year 1849 the survey's geologists started to unravel the geological history of the Alps from its very beginning. They were among the first who discovered the equivalents of Paleozoic systems defined in other countries only a few years ago: As early as 1847 Franz v. HAUER, the second director of the survey recognized fossil-bearing Silurian rocks in the Graywacke Zone of the central Alps; Guido STACHE, the fourth director, discovered fusulinids of Permian age for the first time in 1872 and fossiliferous Ordovician in the year 1884. To this list of discoveries Franz Unger must be added, a palaeobotanist from Graz who recognized strata of Devonian age already in the year 1843, soon after the original proposal to distinguish this system in England.

In the decades since then scientists mainly from the survey and the Department of Geology at Graz University have taken the leading role in the study of the early history of the Alps. Nowadays this focus has spread to other universities in Austria and beyond the border line aiming at the recognition of past relationships of faunas and floras between the 'classic' fossiliferous sequences of Ordovician to end-Permian age in the Alps with adjacent regions of Europe, the reconstruction of pathways of different groups of organisms, the palaeolatitudinal setting, i. e. the palaeoclimate, and finally, the geotectonic evolution of this piece of crust.

The 'Proto-Alps' seem to be best suited to start this project and to present some guidelines for further studies: In fact, in recent years old collections have been restudied and rich new material has been added; all major groups of faunas and floras are fairly well known; and taxonomy has been revised. In addition, due to integrated research into the petrography of limestones, siliciclastic rocks and volcanics supplemented by modern methodologies in geochemistry any conclusions about the depositional environment have been based on a well-founded comprehensive database.

It is our intention to present at least some of these accomplishments during the lecture and excursion programme in Austria. Any suggestion, critical comment or stimulating discussion is, however, highly appreciated as it may help to make further progress in this particular region of the former northern margin of Gondwana.

Also, the editor greatly acknowledges the contributions for this guidebook and the financial support for the meeting by the authors responsible for various articles or chapters and by the Austrian National Committee for IGCP, respectively. Some data which are marked have been published previously but were re-evaluated and upgraded to document the latest scientific results.

Hans P. Schönlaub, Director, Geological Survey of Austria

Foreword

In this initial meeting of IGCP 421 "North Gondwanan Mid-Paleozoic Bioevent/Biogeography Patterns in Relation to Crustal Dynamics" we take our first steps towards gathering and organising data that will enable the project to move towards its goals, particularly testing the extent to which biogeographic/bioevent data may illuminate the dispositions and motions of the various North Gondwana crustal blocks/terranes "calved" from the former supercontinental margin of Gondwana and now accreted to the "underbelly" of Europe and Asia. The region considered includes the generally northern regions of the residual continental blocks: Australia, India, Africa and South America, as well as New Zealand. The project requires generation of lithofacies/biofacies databases for all regions involved, increased precision in stratigraphic alignments, and improved paleogeographic and paleoclimatologic syntheses, as well as accurate taxonomic databases for computer analysis.

The Geologische Bundesanstalt has had a long and exemplary history of achievement in the Earth sciences, and has been consistently in the forefront of applying the latest ideas to clarification of geological problems, not only nationally but, highly commendably, on the global scale. Austria has many important mid-Paleozoic sequences of international significance. Austrian geologists working on these sequences have contributed influentially to elucidation of Variscan and pre-Variscan crustal dynamics. It is therefore appropriate that the initial meeting of IGCP 421, with its pre-Variscan focus, should be held in Austria. We are especially grateful to the Geologische Bundesanstalt for hosting this meeting.

Raimund Feist *John A. Talent*

Joint-leaders of IGCP 421.

Contents

The Biogeographic Relationships of Ordovician Strata and Fossils of Austria[1]

by

Hans P. Schönlaub
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with 6 figures

Fossiliferous rocks of Cambrian age have yet not been recognized in the Alps. All previous reports on such occurrences were misleading since they have not been based on true fossils (see H. P. SCHÖNLAUB 1979, p.11, p. 39).

Remarkably well preserved acritarchs do, however, occur in phyllitic slates near the base of the Graywacke Zone in the vicinity of Kitzbühel, Tyrol (E.REITZ & R. HÖLL 1989) and in the Innsbruck Quarzphyllite (E.REITZ & R.HÖLL 1990). They suggest an Early Ordovician age equivalent to the Tremadocian Series of the British succession. In contrast to this report the supposed occurrence of Tremadocian graptolites (E. HABERFELNER 1931) has not been confirmed; it probably represents an artifact (H. JAEGER 1969).

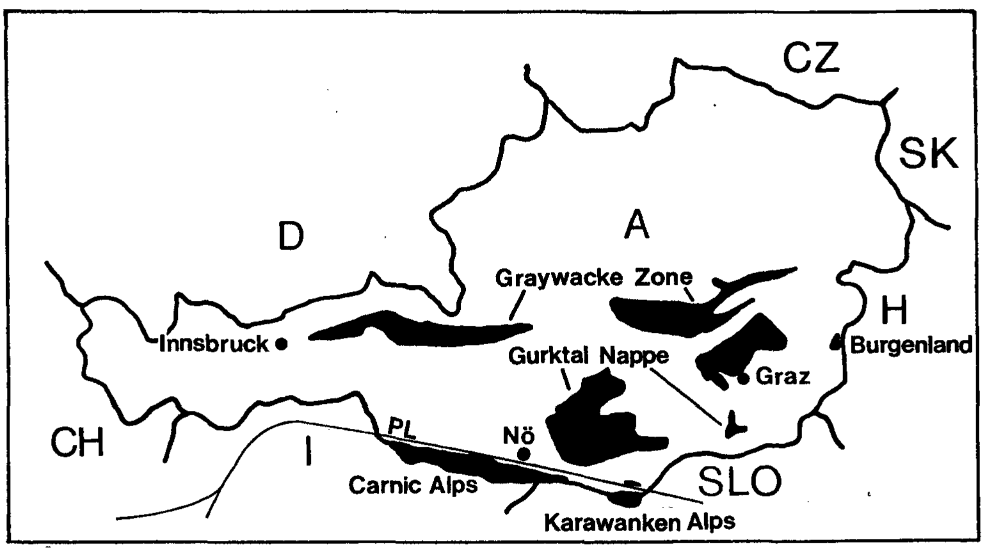

Fig. 1: Main regions with fossiliferous Paleozoic strata in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Nötsch).

The oldest megafossil assemblage of the Alps is of Upper Llandeilian age corresponding to the lower Berounian Series of Bohemia (V. HAVLICEK et al. 1987). It is derived from the locality Bruchnig on the mountain Magdalensberg north of Klagenfurt, Carinthia. The fossils comprise mostly brachiopods which occur in tuffaceous strata on top of basic metavolcanic and pyroclastic rocks. They represent mildly alkaline within-plate basalts which have been altered to spilites (J. LOESCHKE 1989a,b).

[1] Updated version of a chapter from the author's original paper of 1992 (Jb. Geol. B. - A., 135, 381 - 418).

The second important fossil assemblage was recorded from arenaceous shales in the Carnic Alps and appears to be slightly younger, i.e. Caradocian in age. The highly diversified fauna comprises brachiopods, bryozoans, trilobites, cystoids and very rare hyolithes (H.P.SCHÖNLAUB 1971, 1988, G.B.VAI 1971, L. MAREK 1976, G.B.VAI & C. SPALLETTA 1980, V. HAVLICEK et al. 1987).

Interestingly, these two fossil sites, located to the north and the south of the Periadriatic Line, differ significantly from coeval cold-water Mediterranean associations, i.e., those from Bohemia ("Perunica" according to V. HAVLICEK et al. 1994) and Morocco, although these regions and the Alps have some elements in common, for example, *Svobodaina ellipsoides, Gelidorthis meloui, Saukrodictya porosa, Aegiromena aquila aquila* and *Paterorthis paterina.* Instead, in their presence of warm water elements such as representatives of *Dolerorthis, Iberomena, Longvillia, Porambonites, Eoanastrphia* a.o. they exhibit a closer affinity to Sardinia, the British Isles and North Europe which indicates an invasion of North European warm water brachiopods as far south as the Alps, Sardinia, Montagne Noire and Spain (V.HAVLICEK 1976, V. HAVLICEK et al. 1987).

During the Hirnantian Stage the supposed relationship with Baltoscandia can still be seen in the ostracod and echinoid fauna described by R.SCHALLREUTER 1990 from the Carnic Alps. This time, corresponding roughly to the glacial maximum, is, however, also characterized by a cold water influx from Gondwana (H.JAEGER et al. 1975). On a global scale it is associated with a worldwide retreat of the sea coupled with a distinct interval of faunal extinction and the appearance of the widespread Hirnantia Fauna (A. D. WRIGHT 1968, W.B.N.BERRY & A.J. BOUCOT 1973, P.M.SHEEHAN 1973, 1975, 1979, 1988, H. JAEGER et al. 1975, P.J. BRENCHLEY & G. NEWALL 1980, N. SPJELDNAES 1981, P.J.BRENCHLEY 1984, 1994, P.J.BRENCHLEY & B. CULLEN 1984, J. RONG 1984, H.P. SCHÖNLAUB 1988, 1996, P.M. SHEEHAN & P.J. COOROUGH 1990, P. J. BRENCHLEY et al. 1994, J. D. MARSHALL et al. 1994, a.o). Its distribution is concentrated in the higher latitudes of the southern hemisphere but exceptions do occur in a tropical belt and in northern low latitudes suggesting that this unique fauna was adapted to a glacially induced cold climate and consequently cooler waters at the close of the Ordovician.

The Upper Ordovician conodont fauna of the Alps has been well known from detailed studies by O.H. WALLISER 1964, E. SERPAGLI 1967 and G. FLAJS & H.P.SCHÖNLAUB 1976 from the Uggwa Limestone of the Carnic Alps and different limestone units of the Graywacke Zone of Styria. They have been less well described from a few weakly metamorphosed occurrences in between (F. NEUBAUER 1979, M. F. BUCHROITHNER 1979, F. NEUBAUER & J. PISTOTNIK 1984). Apparently, this conodont association represents the *Hamarodus europaeus-Dapsilodus mutatus-Scabbardella altipes* (HDS)-Biofacies of W.C.SWEET & S.M.BERGSTRÖM 1984. Although their precise age within the uppermost Caradocian or early Ashgillian Series remains open the conodont bearing limestones clearly can be assigned to the *Amorphognathus ordovicicus* Zone. According to W.C.SWEET & S.M. BERGSTRÖM 1984 who tentatively revised the published conodont elements from the Carnic Alps in terms of the modern multielement taxonomy, the Late Ordovician Uggwa Limestone is dominated by *Scabbardella altipes* (43%), *Hamarodus europaeus* (17%), *Amorphognathus* cf. *ordovicicus* (8%) and *Dapsilodus mutatus* (2.4%). Less abundant are *Plectodina alpina, Belodella pseudorobusta, "Prionoidus" ethingtoni* and *Strachanognathus parvus.* The occurrence of these species and the abundance of the others, in particular *Hamarodus europaeus*, varies from coeval faunas of Thuringia, Spain and France. Yet, it seems unclear which factors are involved in these differences (J.DZIK 1989).

A comparison between this fauna from the Carnic Alps and the two others from the Graywacke Zone is difficult to assess due to probably minor differences in age and state of preservation (G.FLAJS & H.P.SCHÖNLAUB 1976). In particular, this regards the large collection derived from the limestone lenses underlying the thick acid volcanics of the so-called Blasseneck-Porphyroid in the surroundings of Eisenerz, Styria. Apparently, the revised conodont association represents the same general type as the one from the Carnic Alps in being equally dominated by *Amorphognathus* cf. *ordovicicus, Scabbardella altipes, Hamarodus europaeus, Dapsilodus mutatus* and perhaps *Plectodina alpina*; less abundant are *Belodella pseudorobusta, Panderodus* ssp. and certain elements which tentatively have been assigned to *Birkfeldia circumplicata*. Other differences between these two faunas were thoroughly reviewed by G. FLAJS & H.P.SCHÖNLAUB 1976.

According to S. M. BERGSTRÖM 1990 the "Coefficient of Similarity" (CS) between conodonts from Baltoscandia and the Mediterranean area has a value of 0.30 indicating moderate similarity between the two regions. For example, they share the occurrences of specimens of *Amorphognathus, Scabbardella* and *Dapsilodus* while others appear to be restricted to continental Europe or North Africa. Obviously, the distribution of late Ordovician conodonts follows a similar pattern as inferred from megafossil assemblages and facies data. This led W.C.SWEET & S.M. BERGSTRÖM 1984 to conclude that the Mediterranean Province was a cold water realm in a polar or subpolar latitudinal setting.

In a recent conodont study of the Kalkbank Limestone of Thuringia A. FERRETTI & C. R. BARNES (1997) concluded that this fauna closely resembles coeval conodonts from Libya, Spain and France which belongs to the cold-water realm of the Mediterranean Province. Apparently less close relations exist with the Carnic Alps and Sardinia. Conodonts from these two regions seem to be closer related to temperate faunas such as those in Britain.

In the Alps, occurrences of carbonate sediments provide broad latitudinal constraints for the Upper Ordovician. Potentially useful though only of limited climatic significance is the distribution of limestones in the Carnic Alps, the Graywacke Zone and the Gurktal Nappe in between. According to W.C. DULLO 1992 the up to 20 m thick carbonate units, in the local stratigraphical schemes named Wolayer and Uggwa Lst., respectively (H.P.SCHÖNLAUB 1985a), represent grayish and whitish grainstones to rudstones and occasionally also bafflestones with abundant debris of cystoids and bryozoans and less frequently trilobites and nautiloids. Cathodoluminescence studies have revealed the rare occurrence of coated grains. Moreover, of special significance are dogtooth-cements suggesting a vadose diagenetic environment for the Wolayer Limestone in contrast to the coeval and slightly deeper Uggwa Lst. which is enriched in clay and shell fragments but decreased in the content of bryozoans and echinoderms. At about the Caradocian/Ashgillian boundary they succeed various clastic sequences which dominated the Early and Middle Ordovician interrupted by basic volcanics of presumably Llandeilian age as well as of acid volcanics in the Caradocian (M. HINDERER 1992, Fig. 2).

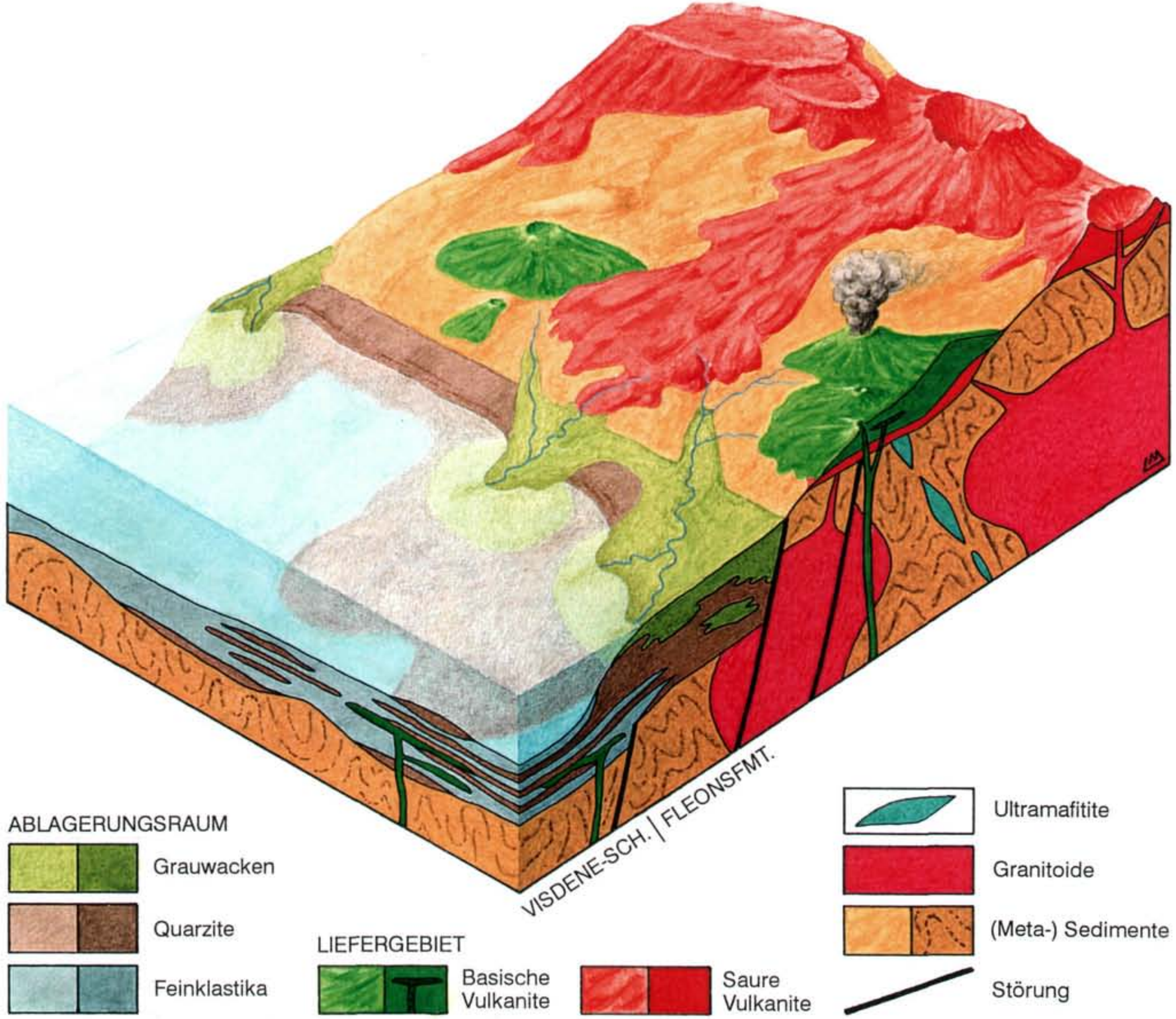

Fig. 2.
Sketch of Upper Ordovician volcanism in the Western Carnic Alps (Modified from M. HINDERER 1992).

In a general climatically based latitudinal framework these carbonate units suggest a position within the confines of the larger "carbonate belt", i.e., between latitudes of about 45° North and South where it was moderately warm and where there was adequate light penetration rather than high water temperature (A.M. ZIEGLER et al. 1984). Whether or not the late Ordovician limestones from the Alps may represent cool water carbonates analogous to modern and Cenozoic carbonates off Southern Australia (N.P. JAMES & Y.BONE 1991) is presently difficult to decide. More plausible, the nature of the corresponding sediments may have developed as the direct response to climatic changes during the Ordovician. For the Ashgillian P.D. WEBBY 1984 suggested a global climatic amelioration as the main cause for the increasing carbonate production. Alternatively, a progressive northward shift of the sedimentary basins into lower latitudes may also explain their temporal and spatial distribution (T.P.YOUNG 1990). In the Ordovician of the Mediterranean Province contemporary carbonates are widely distributed and have been reported from Sardinia (G.B.VAI & T.COCOZZA 1986, A. FERRETTI & E. SERPAGLI 1991), Montagne Noire, the Massifs of Mouthoumet and Agly of Southern France (W.ENGEL et al.1981), the Armorican Massif (F. PARIS et al. 1981, F.PARIS & M.ROBARDET 1990, M.ROBARDET et al.1990, M.MELOU 1990), the Pyrenees (J.J.A.HARTEFELT 1970, H. DURAN et al. 1984), Catalonia and other areas in Spain (W. HAMMAN 1976, M. HAFENRICHTER 1980, H.DURAN et al. 1984, R.W. OWENS & W. HAMANN 1990, A. FERRETTI 1992), Portugal (T.P.YOUNG 1985, 1988, 1990), Libya (S. M. BERGSTRÖM & D. MASSA 1979, 1987, 1992) and the Anti-Atlas of Morocco (J.DESTOMBES et al. 1985). Consequently, the Alpine occurrences of Upper Ordovician rocks suggest a position at considerably lower and more temperate latitudes than has been shown in the revised World maps of C. R. SCOTESE & W. S. McKERROW 1990. More precisely, available faunal and lithic data from the Upper Ordovician of the Alps rather indicate a position between approximately 40 and 50° southern latitude instead of being placed around 60 degrees South. This setting, still beyond the present day Darwin Point of some 35° (R.W. GRIGG 1982), is consistent with the paleogeography of the West European Platform as proposed by T.P. YOUNG 1990.

Conclusions

Although the database to establish a paleobiogeographic approach during the Cambrian and Ordovician Periods of Central and Southern Europe is sparse and far from being sufficient some related trends in the interchange of past communities and in the geodynamic evolution of this area can clearly be recognized (Figs. 3 - 6):

1. During the Cambrian and Lower Ordovician thick clastic sequences are the dominating sediments in northern Africa and in the adjacent southern and central European depocenters. Though these rocks are of no or only limited climatic significance their inherited zircon population indicates Africa as source area (D. GEBAUER et al. 1993).

2. Carbonates first occur in the Lower Cambrian of Southern and Central Europe suggesting a low latitudinal position and close faunal relationships between the individual occurrences within the Mediterranean faunal realm (K.SDZUY 1962, G. FREYER 1987, P. COURJAULT-RADÉ et al. 1992, W. S. McKERROW et al. 1992). Yet, in the Alps the corresponding rocks have not been found. The oldest limestones are of Upper Ordovician age and occur in various parts of the Eastern Alps. Their

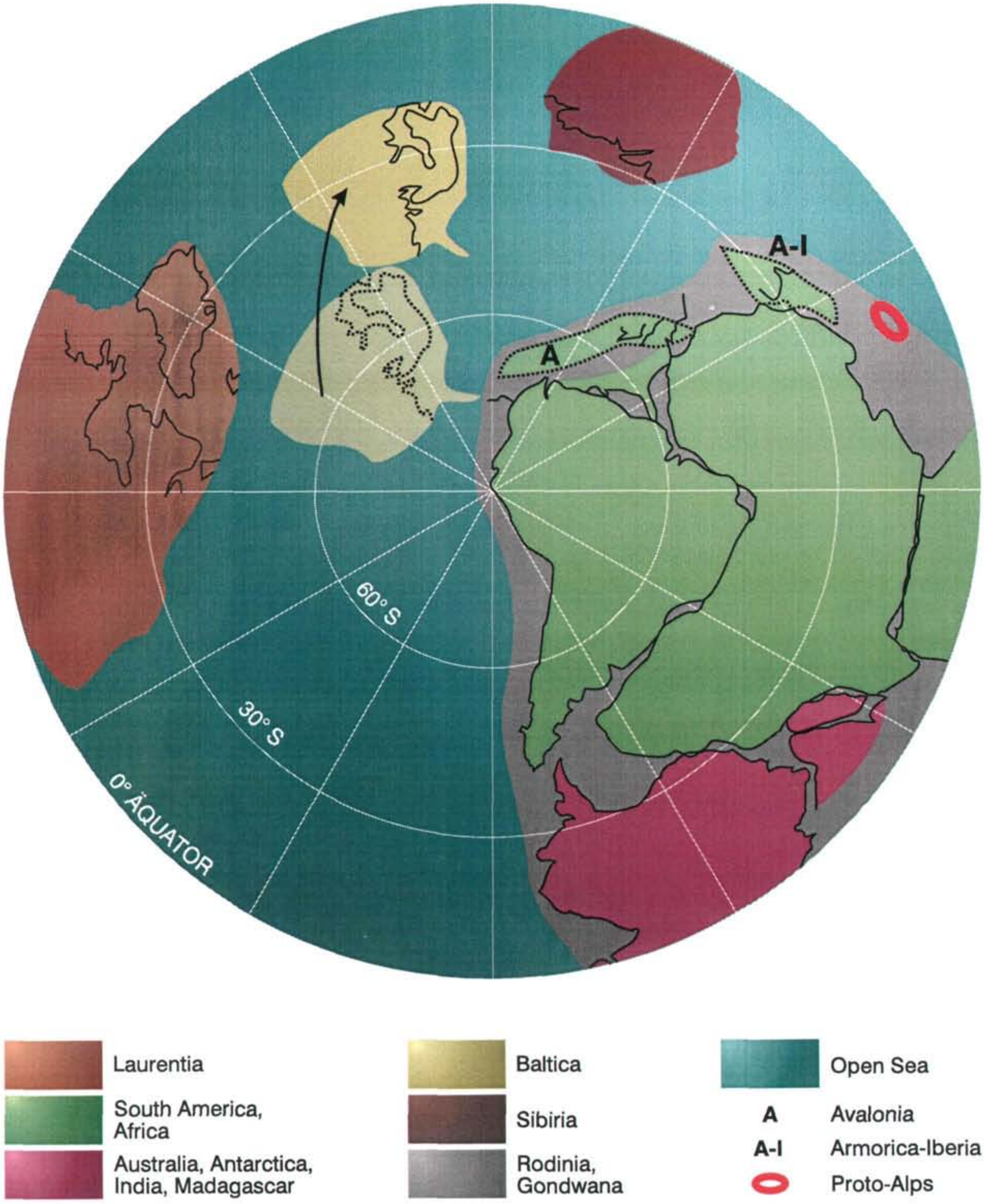

Fig. 3.
Paleogeographic reconstructions for the latest Vendian at c. 550 Ma with indication of Avalonia and and the Armorican-Iberian Massifs forming the Cadomian Arc at the northern margin of Gondwana. Also indicated is the low-latitude position of the forerunner of the Alps. Main plate configuration after T. H. TORSVIK et al. (1995).

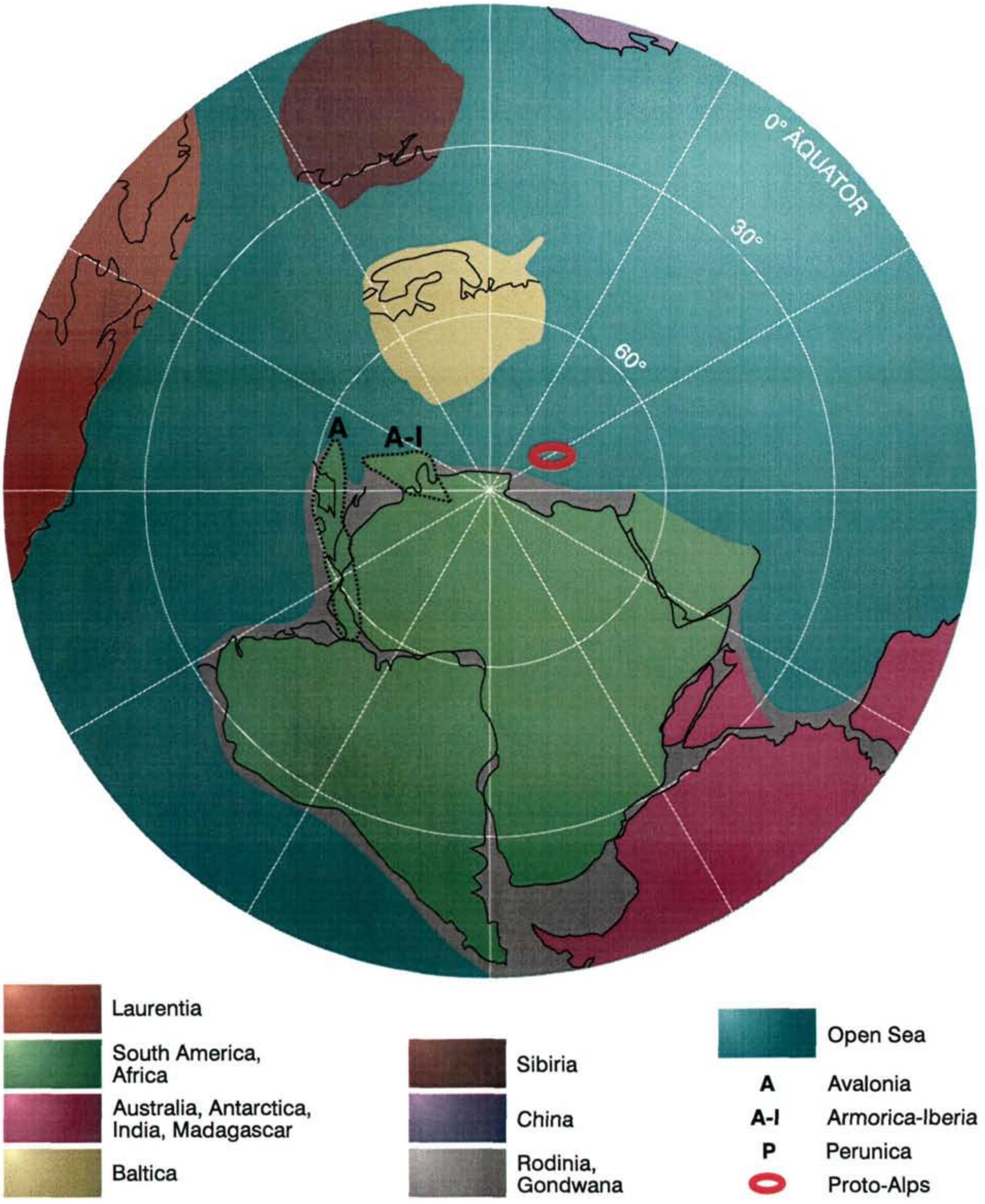

Fig. 4.
Paleogeographic reconstructions for the lowermost Ordovician at c. 490 Ma (after T. H. TORSVIK et al. 1995, modified). Note early to mid-Ordovician break-up of Gondwana including rifting of Avalonia, the Armorican-Iberian Massifs, Perunica and the ancestral Alps. The latter are located in high latitudes.

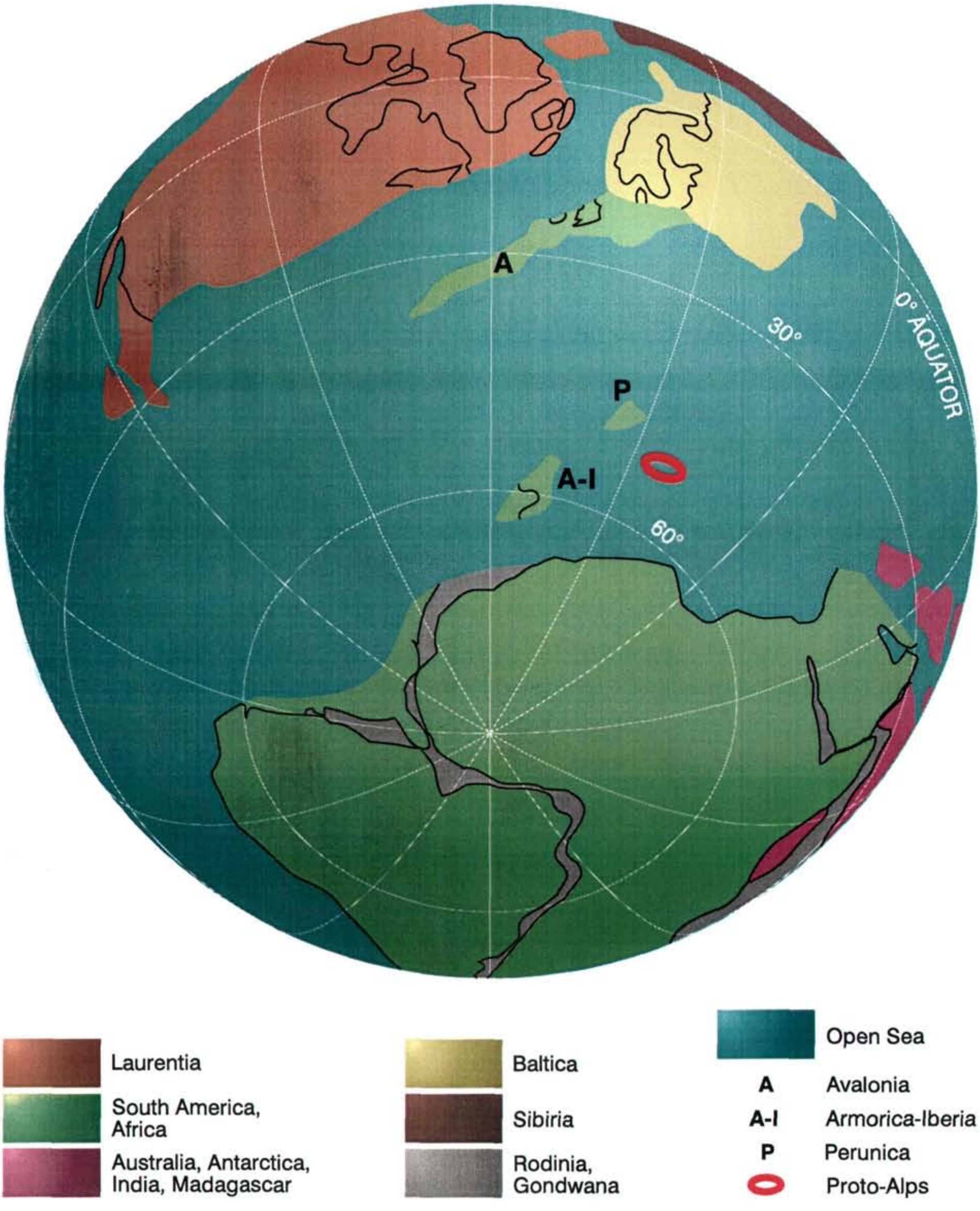

Fig. 5.
Paleogeographic reconstructions of the Atlantic bordering continents in the Upper Ordovician at c. 460 Ma (after L. R. M. COCKS & C. R. SCOTESE 1991, modified).

fossil content and microfacies indicate a moderate climate in a temperate latitudinal setting.

3. Upper Ordovician fossils, in particular most brachiopods, cystoids, ostracods and conodonts, are more closely related to coeval warm water faunas of northern Europe, Great Britain and Sardinia than to northern Africa. Exceptions are, however, the occurrences of the African brachiopod species *Paterorthis paterina* in the Caradocian, the Ashgillian Hirnantia fauna and the brachiopod *Clarkeia* sp. which indicate a temporary minor cold water influence from southern high latitudes.

4. Probably during the Llandeilian a rifting related basic volcanism occurred first recognized in Middle Carinthia but supposedly also occurring at other places of the Alps. Interestingly, this event seems to coincide with calc-alkaline igneous activity in the Ardennes, Wales and SE Ireland (B.P. KOKELAAR et al. 1984) when Avalonia started to rift off from Gondwana (L.R.M.COCKS & R.A. FORTEY 1982, W.S.McKERROW & L.R.M.COCKS 1986, K.T.PICKERING 1989, C.R. SCOTESE & W.S.MCKERROW 1990, F.PARIS & M.ROBARDET 1990 with opposing statements). An analogous plate disruption and subsequent separation might well be assumed for certain parts of the Variscan Alps (J. LOESCHKE & H. HEINISCH 1993, H. P. SCHÖNLAUB 1993).

5. A second major magmatic event occurred in the Early Ashgillian and has been regarded as a collision-subduction related process (J.LOESCHKE 1989a). In accordance with paleomagnetic data from Gondwana it seems reasonable to suggest that this event reflects the rapid northward movement of Africa (T. H. TORSVIK et al. 1996) and its final collision with an unknown microcontinent or terrane located to the north.

6. Our best estimate for the paleolatitudinal position of the late Ordovician of the Alps and its relationship with adjacent areas is illustrated on the amended map of L. R. M. COCKS & C. R. SCOTESE (1991) for this time (Fig. 1). This plate configuration is based on the data from the Alps presented in the foregoing chapters and seems well constrained by sedimentary and faunal evidence from the West and Central European Platform (M.ROBARDET et al. 1990, M.MELOU 1990, T.P.YOUNG 1990, F. PARIS & M.ROBARDET 1990).

References

BERGSTRÖM, S. M. & MASSA, D. (1979): Upper Ordovician conodonts from Libya (abstr.). - IX Intern. Congr. Carboniferous Stratigr. and Geology, Abstract of Papers, 245 - 246.

BERGSTRÖM, S. M. & MASSA, D. (1992): Stratigraphic and biogeographic significance of Upper Ordovician conodonts from Northwestern Libya. In: The Geology of Libya, IV, 1323 - 1342 (eds. SALEM, M. J., HAMMUDA, O. S. & ELIAGOUBI, B. A.). - Elsevier Sc. Publ., 1 - 551.

BERGSTRÖM, S.M. (1990): Relations between conodont provincialism and the changing palaeogeography during the Early Palaeozoic. - In: McKERROW, W.S. & SCOTESE, C.R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 105-121.

BERGSTRÖM, S. M. & MASSA, D. (1987): Stratigraphic and biogeographic significance of Upper Ordovician conodonts from Northwestern Libya (abstr.). - Third Symposium on the Geology of Libya, 35.

ERRY, W. B. N. & BOUCOT, A. J. (1973): Glacio-eustatic control of Late Ordovician-Early Silurian platform sedimentation and faunal changes. - Geol. Soc. Amer. Bull., 84, 275-284.

BLODGETT, R. B., ROHR, D. M. & BOUCOT, A. J. (1990): Early and Middle Devonian gastropod biogeography. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 277-284.

BRENCHLEY, P. J. (1984): Late Ordovician extinctions and their relationship to the Gondwana glaciation. - In: BRENCHLEY, P. J. (Ed.): Fossils and Climate. - 291-327, Chichester (John Wiley & Sons).

BRENCHLEY, P. J. (1995): Preface. The late Ordovician mass extinction. - Modern Geology, 20, i.

BRENCHLEY, P. J. & NEWALL, G. (1980): A facies analysis of Upper Ordovician regressive sequences in the Oslo region, Norway - A record of glacio-eustatic changes. - Palaeogeography, Palaeoclimatology, Palaeoecology, 31, 1-38.

BRENCHLEY, P. J. & CULLEN, B. (1984): The environmental distribution of associations belonging to the Hirnantia fauna - evidence from North Wales and Norway. - In: BRUTON, D. L. (Ed.): Aspects of the Ordovician System. - Palaeont. Contr. from Univ. Oslo, 295, 113-126.

BRENCHLEY, P. J., MARSHAL, J. D., CARDEN, G. A. F., ROBERTSON, D. B. R., LONG, D. G. F., MEIDLA, T., HINTS, L. & ANDERSON, T. F. (1994): Bathymetric and isotopic evidence for a short-lived Late Ordovician glaciation in a greenhouse period. - Geology, 22, 295 - 298.

BUCHROITHNER, M. F. (1979): Biostratigraphie und fazielle Untersuchungen im Paläozoikum von Mittelkärnten. - Carinthia II, 169, 71-95.

COCKS, L. R. M. & SCOTESE, C. R. (1991): The Global Biogeography of the Silurian Period. - In: The Murchison Symposium, Proc. of an Intern. Conf. on the Silurian System (M. G. BASSETT, P. D. LANE & D. EDWARDS, eds.). - Special Pap. in Palaeontology, 44, 109 - 122.

COURJOULT-RADÉ, P., DEBRENNE, F. & GANDIN A. (1992): Paleogeographic and geodynamic evolution of the Gondwana continental margins during the Cambrian. - Terra Nova, 4, 657 - 667.

DALZIEL, W. D. (1995): Earth before Pangea. - Scientific American, 1995, 38 - 43.

DESTOMBES, J., HOLLARD, H. & WILLEFERT, S. (1985): Lower Palaeozoic rocks of Morocco. - In: HOLLAND, C.H. (Ed.): Lower Palaeozoic rocks of the world, 4, 91-336.

DULLO, W. C. (1992): Mikrofazies und Diagenese der oberordovizischen Cystoideen-Kalke (Wolayerkalk) und ihrer Schuttfazies (Uggwakalk) in den Karnischen Alpen.- Jb. Geol. B.-A., 135, 317 - 333.

DURAN, H., GIL IBARGUCHI, J. I., JULIVERT, M. & UBACH, J. (1984): Early Paleozoic acid volcanism in the Catalonian coastal ranges (Northwestern Mediterranean). - In SASSI, F. P. & JULIVERT, M. (eds.): Newsletter IGCP Project 5, No 6, 33 - 43.

DZIK, J. (1989): Conodont Evolution in High Latitudes of the Ordovician. - Cour. Forsch-Inst. Senckenberg, 117, 1 - 28.
ENGEL, W., FEIST, R. & FRANKE, W. (1981): Le Carbonifère anteStéphanien de la Montagne Noire: Rapports entre mise en place des nappes et sédimentation. - Bull. BRGM, Ser. 2, Sec 1/4, 1980-1981, 341 - 389.
FERRETTI, A. (1992): Biostratigrafia a conodonti del margine settentrionale del Gondwana (Ordoviciano sup. - Ashgill). - Unpubl. Ph.D. Thesis, Univ. Modena, 1 - 281.
FERRETTI, A. & SERPAGLI, E. (1991): First record of Ordovician conodonts from southwestern Sardinia. - Riv. Ital. di Paleontol. e Stratigr., 97, 27 - 34.
FERRETTI, A. & BARNES, C. R. (1997): Upper Ordovician Conodonts from the Kalkbank Limestone of Thuringia, Germany. - Palaeontology, 40, 15 - 42.
FLAJS, G. & SCHÖNLAUB, H. P. (1976): Die biostratigraphische Gliederung des Altpaläozoikums am Polster bei Eisenerz. (Nördliche Grauwackenzone, Österreich). - Verh. Geol. B. - A., 1976, 257 - 303.
FREYER, G. (1987): Über Archaeocyathinen-Funde und den lithologischen Aufbau des Unterkambriums im Gebiet von Torgau. - Z. Geol. Wiss. Berlin, 15, 665 - 680.
GEBAUER, D. (1993): The Pre-Alpine Evolution of the Continental Crust of the Central Alps - An Overview. - In: Pre-Mesozoic Geology of the Alps (eds. J. F. von RAUMER & F. NEUBAUER), Springer Verl., 93 - 117.
GRIGG, R.W. (1982): Darwin Point: A threshold for atoll formation. - Coral Reefs, 1, 29 - 54.
HABERFELNER, E. (1931): Graptolithen aus dem unteren Ordovicium von Gaishorn im Paltental. - Verh. Geol. B.- A., 1931, 235 - 238.
HARTEFELT, J. J. A. (1970): Geology of the Upper Segre and Valira valleys, Central Pyrenees, Andorra/Spain. - Leidse Geol. Med., 45, 167 - 236.
HAVLICEK, V. (1976): Evolution of Ordovician brachiopod communities in the Mediterranean Province. - In: BASSETT, M.G. (ed.) The Ordovician System: Proceedings of a Palaeontological Association Symposium, Birmingham 1974. 349 - 358, Univ. Wales Press and Nat. Mus. Wales.
HAVLICEK, V., VANEK, J. & FATKA, O. (1994): Perunica microcontinent in the Ordovician (its position within the Mediterrandean Province, series subdivision, benthic and pelagic associations). - Sbornik geol. ved, 46, 23 - 56.
HAVLICEK, V., KRIZ, J. & SERPAGLI, E. (1987): Upper Ordovician brachiopod assemblages of the Carnic Alps, Middle Carinthia and Sardinia. - Boll. Soc. Paleont. It., 25, 277 - 311.
HINDERER, M. (1992): Die vulkanoklastische Fleonsformation in den westlichen Karnischen Alpen - Sedimentologie, Petrographie und Geochemie. - Jb. Geol. B. - A., 135, 335 - 379.
JAEGER, H. (1969): Kritische Bemerkungen zu einigen Angaben über Graptolithenfunde in den Ostalpen. - Anz. Österr. Akad. Wiss. Wien, math.-naturw. Kl., 1969, 173 - 177.
JAEGER, H., HAVLICEK, V. & SCHÖNLAUB, H. P. (1975): Biostratigraphie der Ordovizium/Silur-Grenze in den Südalpen - Ein Beitrag zur Diskussion um die Hirnantia-Fauna. - Verh. Geol. B.-A., 1975, 271 - 289.
JAMES, N. P. & BONE, Y. (1991): Modern and Cenozoic, cool water open platform carbonates, Southern Australia. - In: A. BOSELLINI, R. BRANDNER, E. FLÜGEL, B. PURSER, W. SCHLAGER, M. TUCKER & D. ZENGER (eds.). - Abstracts, Dolomieu Conference on Carbonate Platforms and Dolomitization, 125 - 126.
KOKELAAR, B. P., HOWELLS, M. F., BEVINS, R. E., ROACH, R. A. & DUNKEY, P. N. (1984): The Ordovician marginal basin of Wales. - In: KOKELAAR, B. P. & HOWELLS, M. F. (eds.): Marginal Basin Geology. - Geol. Soc. Spec. Publ., 16, 245 - 269.
LOESCHKE, J. (1989a): Lower Palaeozoic volcanism of the Eastern Alps and its geodynamic implications. - Geol. Rdsch., 78, 599 - 616.
LOESCHKE, J. (1989b): Die paläotektonische Stellung der Vulkanite der Magdalensberg-Serie (Ober-Ordovizium, Gurktaler Decke, Kärnten, Österreich). - Carinthia II, 179, 491 - 507.

LOESCHKE, H. & HEINISCH, H. (1993): Palaeozoic Volcanism of the Eastern Alps and its Palaeotectonic Significance. In: Pre-Mesozoic Geology in the Alps (eds. J. F. von RAUMER & F. NEUBAUER), Springer Verl., 441 - 455.
MAREK, L. (1976): The distribution of the Mediterranean Ordovician. - In: BASSETT,M. G. (Ed.): The Ordovician System. - Proceedings of a Paleont. Ass. Symp. Birmingham 1974, 491 - 499, Cardiff (Nat. Mus. Univ. Wales Press).
MARSHALL, J. D., BRENCHLEY, P. J., CARDEN, G. A. MASON, P., HINTS, L. & MEIDLA, T. (1994): Isotopic changes associated with End-Ordovician glaciation and mass-extinction - Erlanger geol. Abh., 122, 42.
McKERROW, W. S. & COCKS, L. R. M. (1986): Oceans, island arcs and olistostromes: the use of fossils in distinguishing sutures, terranes and environments around the Iapetus ocean. - J. Geol. Soc. London, 143, 185 - 191.
McKERROW, W. S., SCOTESE, C. R. & BRASIER, M. D. (1992): Early Cambrian continental reconstructions. - J. Geol. Soc. London, 149, 599 - 606.
MELOU, M. (1990): Brachiopodes articulés de la coupe de l'Ile de Rosan (Crozon, Finistère). Formation des Tufs et Calcaires de Rosan (Caradoc-Ashgill). - Geobios, 23, 539 - 579.
NEUBAUER, F. (1979): Die Gliederung des Altpaläozoikums südlich und westlich von Murau (Steiermark/Kärnten). - Jb. Geol. B.- A., 122, 455 - 511.
NEUBAUER, F. & PISTOTNIK, J. (1984): Das Altpaläozoikum und Unterkarbon des Gurktaler Deckensystems (Ostalpen) und ihre paläogeographischen Beziehungen. - Geol. Rdsch., 73, 149 - 174.
PARIS, F. & ROBARDET, M. (1990): Early Palaeozoic palaeobiogeography of the Variscan regions. - Tectonophysics, 177, 193 - 213.
PARIS, F., PELHATE, A. & WEYANT, M. (1981): Conodontes ashgilliens dans la Formation de Rosan, coupe de Lostmarc'h (Finistère, Massif armoricain). Conséquences paléogéographiques. - Bull. Soc. géol. minéral. Bretagne, 13, 15 - 35.
PICKERING, K. T. (1989): The destruction of Iapetus and Tornquist's Oceans. - Geology Today, Sept./Oct. 1989, 160 - 166.
RAUMER von, J. F. & NEUBAUER, F. (1993): Late Precambrian and Palaeozoic Evolution of the Alpine Basement - An Overview. In: Pre-Mesozoic Geology in the Alps (eds. J. F. von RAUMER & F. NEUBAUER), Springer Verl., 625 - 639.
REITZ, E. & HÖLL, R. (1988): Jungproterozoische Mikrofossilien aus der Habachformation in den mittleren Hohen Tauern und dem nordostbayerischen Grundgebirge. - Jb. Geol. B.- A., 131, 329 - 340.
REITZ, E. & HÖLL, R. (1989): Unterordovizische Acritarchen aus der Nördlichen Grauwakkenzone (Ostalpen). - Jb. Geol. B.- A., 132, 761 - 774.
REITZ, E. & HÖLL, R. (1990): Biostratigraphischer Nachweis von Unterordovizium in der Innsbrucker Quarzphyllitserie (Ostalpen). - Jb. Geol. B.- A., 133, 603 - 610.
ROBARDET, M., PARIS, F. & RACHEBOEUF, P. R. (1990): Palaeogeographic evolution of southwestern Europe during Early Palaeozoic times. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 411 - 419.
RONG, J. Y. (1984): Distribution of the Hirnantia fauna and its meaning. - In: BRUTON, D.L. (Ed.): Aspects of the Ordovician System. - Palaeont. Contr. Univ. Oslo, 295, 101 - 112.
SCHALLREUTER, R. (1990): Ordovizische Ostrakoden und Seeigel der Karnischen Alpen und ihre Beziehungen zu Böhmen und Baltoskandien. - N. Jb. Geol. Paläont., Mh. 1990, 120 - 128.
SCHÖNLAUB, H. P. (1971): Palaeo-environmental studies at the Ordovician/Silurian boundary in the Carnic Alps. - In: Colloque Ordovicien-Silurien Brest 1971. - Mem. Bur. Rech. géol. minières, 73, 367 - 377.
SCHÖNLAUB, H. P. (1979): Das Paläozoikum von Österreich. - Abh. Geol. B.- A., 33, 1 - 24.
SCHÖNLAUB, H. P. (1985): Das Paläozoikum der Karnischen Alpen. In: Arbeitstagung der Geologischen Bundesanstalt 1985, 34 - 52. - Wien (Geol. B.- A.).

SCHÖNLAUB, H. P. (1988): The Ordovician-Silurian boundary in the Carnic Alps of Austria. - In: COCKS, L. R. M. & RICKARDS, R. B. (eds.): A Global Analysis of the Ordovician-Silurian Boundary. - Bull. Brit. Mus. Nat. Hist. (Geol), 43, 107 - 115.
SCHÖNLAUB, H. P. (1993): Stratigraphy, Biogeography and Climatic Relationships of the Alpine Palaeozoic. In: Pre-Mesozoic Geology in the Alps (eds. J. F. von RAUMER & F. NEUBAUER), Springer Verl., 65 - 91.
SCHÖNLAUB, H. P. (1996): Scenarios of Proterozoic and Paleozoic Catastrophes: A Review. - Abh. Geol. B. - A., 53, 59 - 75.
SCOTESE, C. R. & McKERROW W. S. (1990): Revised World maps and introduction. - In: McKERROW, W.S. & SCOTESE, C.R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 1 - 21.
SDZUY, K. (1962): Neue kambrische Fossilien aus Bohrungen im Gebiet von Doberlug. - Geologie, 11, 1087 - 1101.
SERPAGLI, E. (1967): I conodonti dell'Ordoviciano superiore (Ashgilliano) delle Alpi Carniche. - Boll. Soc. Paleont. It., 6, 30 - 111.
SHEEHAN, P. M. (1973): The relation of Late Ordovician glaciation to the Ordovician-Silurian changeover in North America brachiopod faunas. - Lethaia, 6, 147 - 154.
SHEEHAN, P. M. (1975): Brachiopod synecology in a time of crisis (Late Ordovician - Early Silurian). - Palaeobiology, 1, 205 - 212.
SHEEHAN, P.M. (1979): Swedish Late Ordovician marine benthic assemblages and their bearing on brachiopod zoogeography. - In: GRAY, J. & BOUCOT, A. J. (eds.): Historical Biogeography, Plate Tectonics and the Changing Environment. - 61 - 73, Corvallis (Oregon State Univ. Press).
SHEEHAN, P. M. (1988): Late Ordovician events and the terminal Ordovician extinction. - In: WOBERG, D. L. (Ed.): Rousseau Flower Volume. - New Mexico Bur. Mines. Miner. Res. Mem., 44, 31 - 49.
SHEEHAN, P. M. & COOROUGH, P. J. (1990): Brachiopod zoogeography across the Ordovician-Silurian extinction event. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 181 -187.
SPJELDNAES, N. (1961): Ordovician climatic zones. - Norsk Geol. Tidsskr., 41, 45 - 77.
SWEET, W. C. & BERGSTRÖM, S. M. (1984): Conodont provinces and biofacies of the Late Ordovician. - In: CLARK, D.L. (ed.): Conodont Biofacies and Provincialism. - Geol. Soc. Amer. Spec. Pap., 196, 69 - 87.
TORSVIK, T. H., SMETHURST, M. A., MEERT, J. G., VAN DER VOO, R., McKERROW, W. S., BRASIER, M. D., STURT, B. A. & WALDERHAUG, H. J. (1996): Continental break-up and collision in the Neoproterozoic and Palaeozoic - A tale of Baltica and Laurentia. - Earth Planet. Rev., 40, 220 - 258.
VAI, G. B. (1971): Ordovicien des Alpes Carniques. - In: Coll. Ordovicien-Silurien Brest 1971. - Mém. BRGM, 73, 437 - 450.
VAI, G. B. & COCOZZA, T. (1986): Tentative schematic zonation of the Hercynian chain in Italy. - Bull. Soc. Géol. France, 2, 95 - 114.
VAI, G. B. & SPALLETTA, C. (1980): In: SCHÖNLAUB, H.P.: Field Trip A. - In: SCHÖNLAUB, H.P. (Ed.): Second European Conodont Symposium ECOS II, Guidebook Abstracts. - Abh. Geol. B.-A., 35, 48 - 50.
WALLISER, O. H. (1964): Conodonten des Silurs. - Abh. hess. L.- Amt. Bodenf., 41, 1 - 106.
WEBBY, P. D. (1984): Ordovician reefs and climate: a review. In: BRUTON, D.L. (Ed.): Aspects of the Ordovician System. - Palaeont. Contrib. Univ. Oslo, 295, 89-100.
WRIGHT, A. D. (1968): A westward extension of the upper Ashgillian Hirnantia fauna. - Lethaia, 1, 352 - 367.
YOUNG, T.P. (1990): Ordovician sedimentary facies and faunas of Southwest Europe: palaeogeographic and tectonic implications. - In: McKERROW, W. S. & SCOTESE, C. R. (Eds.): Palaeozoic Palaeogeography and Biogeography. Geol. Soc. Mem., 12, 421 - 430.
YOUNG, T. P. (1985): The stratigraphy of the Upper Ordovician of central Portugal. - PhD Thesis Univ. Sheffield.

YOUNG, T. P. (1988): The lithostratigraphy of the Upper Ordovician of central Portugal. - J. Geol. Soc. London, 145, 377 - 392.

ZIEGLER, P. A. (1984): Caledonian and Hercynian crustal consolidation of Western and Central Europe - A working hypothesis. - Geol. en Mijnb., 63, 93-108.

ZIEGLER, A. M., HULVER, M. L., LOTTES, A. L. & SCHMACHTENBERG, W. F. (1984): Uniformitarianism and palaeoclimates: Inferences from the distribution of carbonate rocks. - In: BRENCHLEY, P. J. (Ed.): Fossils and Climate. - 3 - 25, Chichester (John Wiley & Sons).

The Silurian of Austria[2]

by
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with 8 figures

Geography

In the Austrian Alps fossiliferous Silurian strata are irregularly distributed (Fig. 1). They form a mosaic-like pattern of dismembered units incorporated into the Alpine nappe system. Such areas include the Gurktal Nappe of Middle Carinthia and southern Styria, the surroundings of Graz and the Graywacke Zone of Styria, Salzburg and Tyrol. Corresponding rocks are also exposed along the northern margin of the Southern Alps to the south of the Periadriatic Line, i. e. in the Carnic and Karawanken Alps. In addition, a certain portion of the sedimentary precursor sequences of quartzphyllites and even amphibolite-grade metamorphic rocks may also have been deposited during the Silurian Period but due to lack of fossils it is as yet not possible to correlate these series with the so-called "classical Paleozoic areas" (Fig. 1).

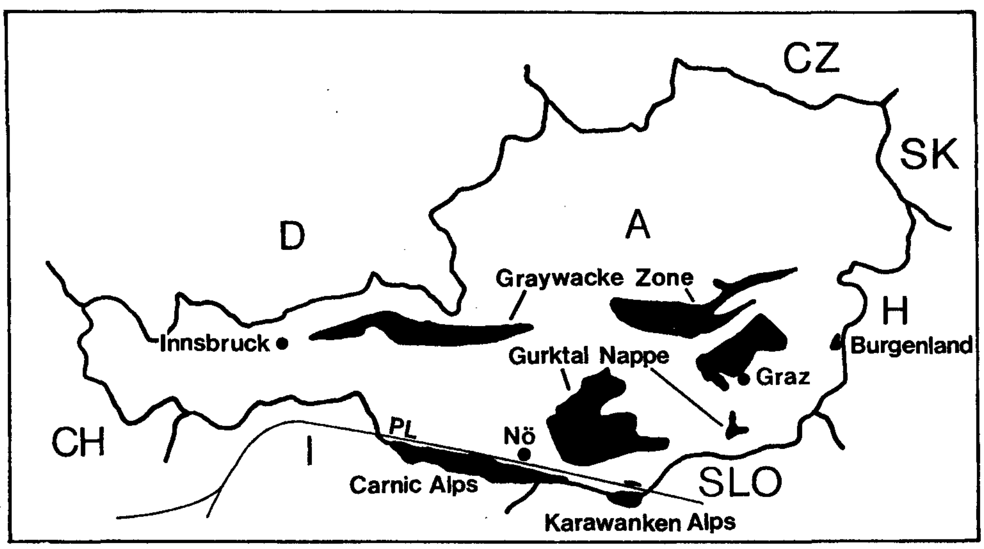

Fig. 1. Main regions with fossiliferous Paleozoic strata in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Nötsch).

Geology - Main Features

Since the discovery of Silurian fossils in the Alps by F. v. HAUER in 1847 the knowledge of rocks and organic remains has considerably increased. Largely responsible for this progress was the introduction of research method to investigate the micro and nannofossil content of strata but also on many collection campaigns of different

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working groups to elaborate a more detailed biostratigraphic framework as well as to assess the lithological characteriscs of different Silurian strata.

Silurian deposits range from shallow water carbonates to graptolitic shales. Thicknesses are overall similar and generally do not exceed some 60 m. Main differences on either side of the Periadriatic Line concern 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 1993).

Biostratigraphical important fossil groups include primarily graptolites and conodonts; of almost equal importance with a supposedly great potential for correlation are trilobites, bivalves, chitinozoans and acritarchs, the latter, however, only in the Lower Silurian (upper Llandovery to lower Wenlock). Brachiopods and nautiloids provide further data and are useful for paleoecological and paleogeographical considerations.

The stratigraphic record of the Southern Alps comprises Ordovician to Middle Triassic strata. The Ordovician Series are characterized by mainly clastic rocks with minor participation of acid and basic volcanics. This facies resembles other areas in the Mediterranean region. Also, in the Carnic Alps the widespread end-Ordovician (Hirnantian) glacial event has been recognized being responsible for sedimentary gaps in the basal part of the succeeding Silurian. During this period a considerable variety of different lithologies developed which, however, exhibit some common features outlined in more detail in the following chapters. Due to extensional tectonics and highly different rates of subsidence the facies pattern changed significantly during the following Devonian. This is documented by more than 1200 m of shallow water limestones which are time equivalent to some 100 m of condensed nodular limestones. After drowning of the reefs limestone sedimentation was more uniform and continued during the Famennian and early Lower Carboniferous when a phase of emersion and karstification occurred near the end of the Tournaisian Stage. The final collapse of the Variscan basin started in the Visean and resulted in more than 100 m flysch deposits indicating an active margin at the northern part of the Southern Alps culminating in the main deformation stage in the Upper Carboniferous Westphalian Stage. The transgressive Late Carboniferous to Middle Triassic cover comprises thick shelf deposits ranging from near-shore siliciclastics to fossiliferous algal and fusulinid limestones.

The area north of the Periadriatic Line has only few rocks in common with the Southern Alps. This concerns thick piles of siliciclastic rocks in the interval from the Ordovician to the Devonian, a contemporaneous local reef development during the Silurian and the Devonian Periods, basic magmatism in the Ordovician, Lower Silurian and in the Middle Devonian. The inccreased input of clastic material suggests a proximity to a land area. On the other hand intense volcanism may be related to crustal extension. However, this activity may also be responsible for the different facies development which occurred in most areas north of the Periadriatic Line during the Silurian and parts of the Devonian.

The Carnic and Karawanken Alps

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 part of the Karawanken Alps near Villach. Due to the unconformity relationship which separates the Ordovician from the Silurian in both the Carnic and Karawanken Alps a varying thick sedimentary pile is locally missing which corresponds to several conodont zones in the Llandovery and Wenlock. At a few places even basal Lochkovian strata may disconformably rest upon Upper Ordovician limestones.

The Silurian lithofacies is subdivided into four major facies reflecting different depths of deposition and hydraulic conditions (Fig. 2). A moderately deep marine environment represents the Plöcken Facies characterized in succeeding order by the pelagic Kok Formation, the Cardioala Fm. and the Alticola-Megaerella Limestones. The classical section is the 60 m thick Cellonetta profile well known for its merits for the Silurian conodont zonation established by O. H. WALLISER in 1964.

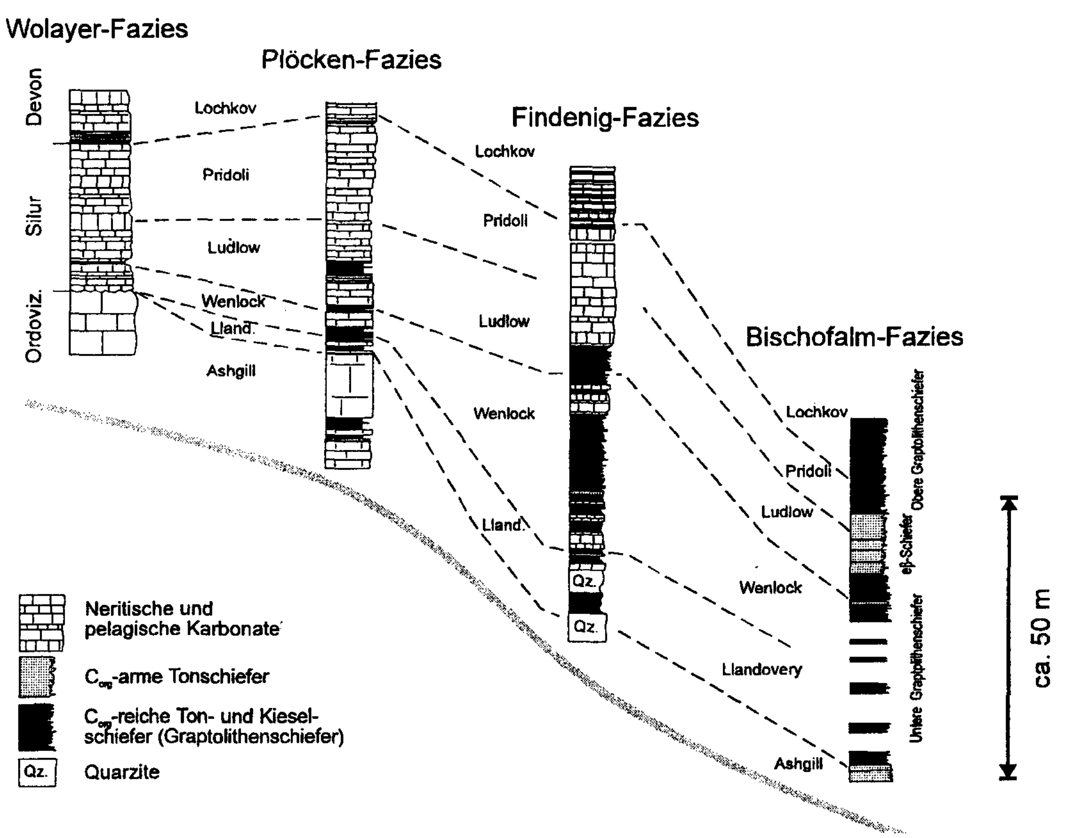

Fig 2. Lithology of Silurian sediments of the four different lithofacies of the Carnic Alps. Brickstone drawing reflects carbonates; black colour corresponds to C_{org} rich graptolite-bearing shales and cherts and C_{org} rich carbonates of the Wolayer Facies. Light gray areas represent C_{org} poor shales. Columns represent from left to right the sections "Rauchkofel Boden", "Cellon", "Oberbuchach 1-2" and "Nölblinggraben-Graptolithengraben". In the latter composite section Lower Silurian sediments are not continuously exposed. From B. WENZEL 1997 (in press).

The Wolayer Facies represents an apparently shallower environment. It is characterized by fossiliferous limestones with abundant orthoconic nautiloids, trilobites, bivalves, small brachiopods, gastropods, crinoids and few corals. Due to a hiatus at the base this facies is represented by only 10 to 15 m thick variegated limestones. The classical sections are located in the Lake Wolayer region of the central Carnic Alps.

The stagnant water graptolite facies is named Bischofalm Facies. It is represented by 60 to 80 m thick black siliceous shales, black cherty beds ("Lydite") and clayish alum shales which contain abundant graptolites. Their distribution has been clearly outlined by the comprehensive work of Herman Jaeger in the past (H. JAEGER 1975, H. W. FLÜGEL et al. 1977, H. JAEGER & H. P. SCHÖNLAUB 1980, 1994, H. P. SCHÖNLAUB 1985). According to H. JAEGER the Bischofalm Facies can be subdivided into three members, i. e. the Lower, Middle and Upper Bischofalm Shales.

The Findenig Facies represents an intermediate facies between the shallow water and the starving basinal environment. It comprises interbedded black graptolite shales, marls and blackish limestone beds. At its base a quartzose sandstone may locally occur.

The four Silurian lithofacies reflect different rates of subsidence. From the Llandovery to the beginning of the Ludlow sedimentation suggests a steadily subsiding basin and a transgressional regime. This tendency decreased and perhaps stopped during the Pridoli to form balanced conditions with uniform limestone sedimentation. Simultaneously, in the Bischofalm Facies black graptolitic shales were replaced by greenish shales and grayish shales named Middle Bischofalm Shale. At the base of the Devonian in the Bischofalm Facies the deep-water graptolitic environment was restored until the end of the Lochkovian Stage.

Lithostratigraphy, Biostratigraphy, Depositional Environment

In the Carnic Alps the Cellon section has served since the study of O. H. WALLISER (1964) as a standard for the worldwide applicable conodont zonation which, however, has been further detailed and partly revised in other areas. In fact, this section represents the stratotype for the Silurian of the Eastern and Southern Alps. The conformable sequence suggests continuity from the Ordovician to the Devonian. However, in recent years several small hiatuses have been recognized which reflect sea-level changes within an overall shallow to moderately deep environment. From top to base the Silurian part is subdivided into the following formations (Fig. 3):

- 8 m Megaerella Lst. (greyish and partly fossiliferous limestone; Pridoli)
- 20 m Alticola Lst. (grey and pink nautilod bearing limestone; Ludlow to Pridoli)
- 3.5 m Cardiola Fm. (alternating black limestone, marl and shale; Ludlow)
- 13 m Kok Fm. (ferruginous nautiloid limestone, with shaly interbeds at the base; upper Llandovery to Wenlock)
- 4.8 m Plöcken Fm. (calcareous sandstone; Ashgill, Hirnantian Stage).

According to H. P. SCHÖNLAUB (1985, 1988) the Ordovician/Silurian boundary is drwan between the Plöcken and Kok Formations. Conodonts and graptolites from the basal part of the Kok Fm. indicate that at least the equivalences of six graptolite

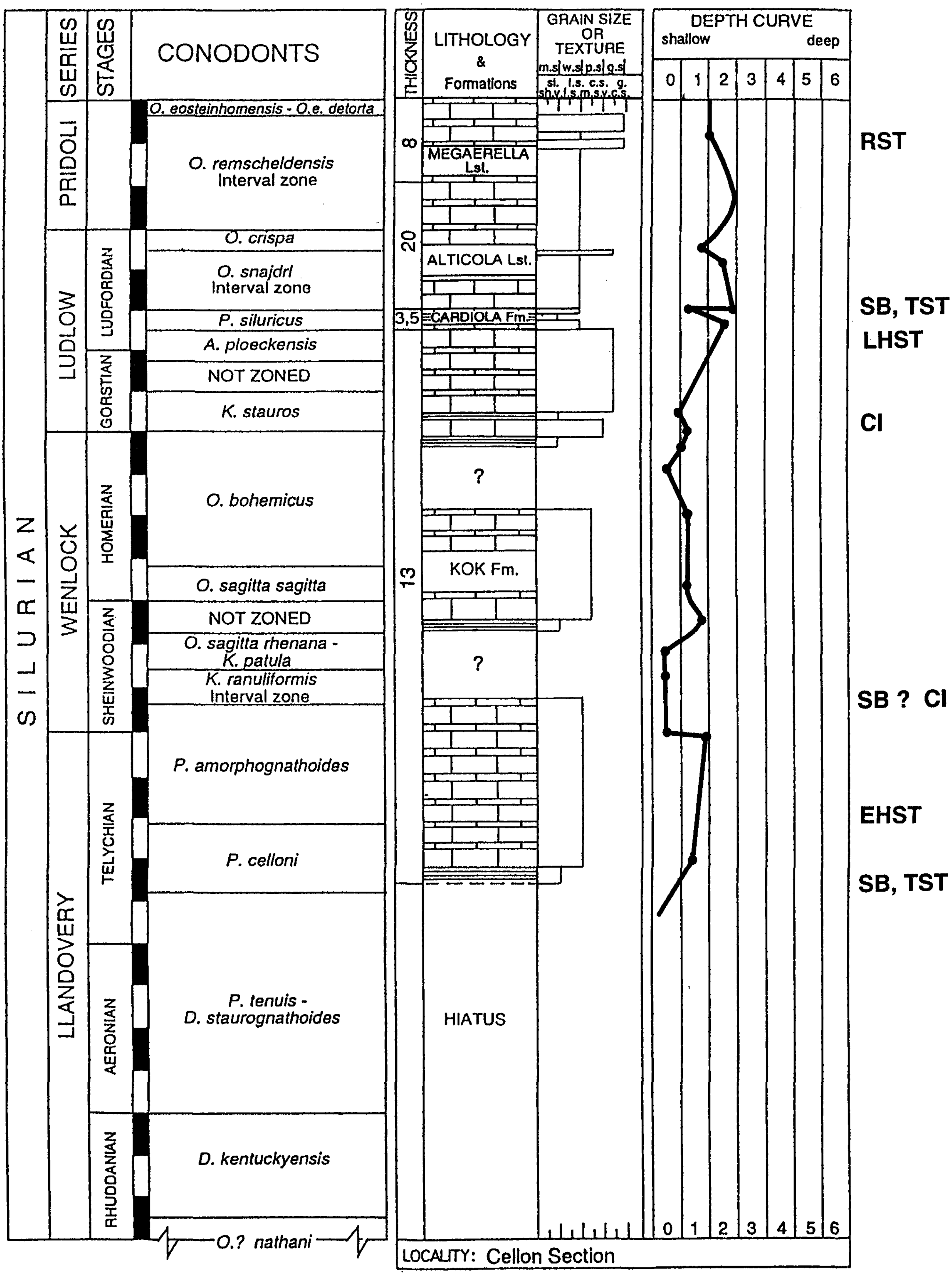

Fig. 3. Conodont stratigraphy, lithology, grain size and depth curve of the Silurian portion of the Cellon section (CI - condensed interval, EHST - early highstand system tract, LHST - late highstand (regressive) system tract, RST - regressive system tract, TST - transgressive system tract, SB - sequence boundary).

and two conodont zones are missing in the Lower Silurian. Sedimentation started in the upper Llandovery within the range of the index conodont *Pterospathodus celloni.*

At present in the Cellon section the precise level of theLlandovery/Wenlock boundary can not be drawn. Based on graptolites and conodonts this boundary should be placed between sample nos. 11 and 12 of O. H. WALLISER´s conodont-based subdivision. As a consequence, the thickness of the exposed Llandovery strata does not exceed some three meters.

The boundary between the Wenlock and Ludlow Series is precisely drawn between the conodont sample numbers 15B1 and 15B2. This level most closely corresponds to the stratotype at quarry Pitch Coppice near Ludlow. For the entire Wenlock an overall thickness of some 5 m is thus concluded. By comparison with the Bohemian sections strata equivalent to the range of the index conodont *Ozarkodina bohemica* are extremely condensed at Cellon suggesting that sedimentation occurred mainly during the lower part of the Homerian Stage. As stated by H. P. SCHÖNLAUB 1994 with regard to the foregoing Sheinwoodian Stage it may be inferred that at its base the corresponding strata are also missing or they are represented as the thin shaly interbed between sample nos. 12A and 12C. At this horizon the *M. rigidus* Zone clearly indicates an upper Sheinwoodian age.

Correlation with the Bohemian sequences and the occurrence of the index graptolite *M. parultimus* for the base of the Pridoli indicates the position of the Ludlow/Pridoli boundary a few cm above the conodont sample no. 32 (see H. P. SCHÖNLAUB in J. KRIZ et al. 1986). This level lies 8m above the base of the Alticla Lst. suggesting that the thickness of Ludlow strata is about 16.45 m.

At Cellon the Silurian/Devonian boundary is placed at the bedding plane between sample nos. 47A and 47B. At this latter horizon the first representatives of the index conodont *Icriodus woschmidti* occur. The first occurrence of diagnostic index graptolites for the base of the Lochkov Stage is however some 1.5 m higher. H. JAEGER (1975) recorded in sample no. 50 the lowermost occurrence of *M. uniformis*, *M.* cf. *microdon* and *Linograptus posthumus.* In total, the Pridoli part of the Cellon section may this reach a thickness of some 20 m.

Data about the distribution of acritarchs, chitinozoans, brachiopods, bivalves and unrevised occurrences of nautiloids and trilobites are included in the SSS-Field Meeting and summary report edited by H. P. SCHÖNLAUB & L. H. KREUTZER (1994).

Depositional environment: In the Carnic Alps as early as in the Upper Ordovician a twofold facies development can be deduced. According to W. DULLO (1992) the Wolayer Lst. represents the near-shore parautochthonous cystoid facies and the Uggwas Lst. its off-shore basinal debris counterpart. Follwing a sedimentary gap at the base of the Silurian caused by glacially-induced sea-level fall renewed sedimentation started in a moderately shallow environment which may have lasted until the very beginning of the Wenlock. This is testified for example in sample no.11 indicating a bioturbated wackestone with algae and lumachelles suggesting a very shallow to intertital environment. During the following Wenlock time there is a progressing transgressive tendency. However, at the Wenlock/Ludlow boundary some strata are missing.

During deposition of the Cardiola Formation an pelagic off-shore environment is indicated by radiolarian-bearing black marly inderbeds and pelagic limestones containing a diverse Cardiola community. The following Alticola Lst. reflects stable conditions in a pelagic setting which terminated in a short regressive pulse at sample no. 40, i. e. laminated grainstones with lumachelles. A further transgressive trend can be assumed at the base of the Megaerella Limestone. For more details see L. H. KREUTZER in H. P. SCHÖNLAUB 1994.

*

Graptolites have been known in the Alps since the first discovery of G. STACHE in 1872. The pure graptolitic facies is best exposed in the so-called "Graptolithengraben" north of the upper Bischofalm in the central Carnic Alps. Lithologically, the graptolite-bearing rocks form a monotonous sequence of interbedded radiolarian bearing cherts and alum shales. The first dominate in the Llandovery and Wenlock part of the succession, the latter prevail in the upper part. The intermediate green and grey shales yield only few graptolites in tiny layers.

The composite thickness of the graptolite-bearing Silurian to Lochkov sequence ranges from 50 to 100 m. It is thus an extremely condensed sequence due to a very low but nevertheless continuous rate of deposition. This conclusion is supported by the very complete graptolite zonal succession. The environmental conditions were extremely euxinic except for a short interval when the Middle Bischofalm Shale was deposited (Fig. 4).

Graptolites and few conodonts on bedding planes are the only fossils to be found in this facies. The graptolites are common in many layers both in the alum shales and in the cherts. Some intervals, however, are almost barren of graptolites.

Due to intense Variscan and Alpine tectonics larger undisturbed sections are very rare. By far the best exposed and least disturbed section is displayed in the "main section", named the Hauptprofil and has been studied in great detail bei H. JAEGER starting in 1965. The tectonic block is almost 20 m thick and covers the interval from the vulgaris Zone of the Ludlow to the Lower Devonian hercynicus Zone. In the vicinity of the section older strata are as well exposed but they are fault-bounded with the main section.

The main graptolite section is virtually undisturbed except for a fault at the critical horizon between the *M. uniformis* and the *M. transgrediens* Zones , i. e. at the Silurian/Devonian boundary. By comparison with other sections it is concluded that there is no significant loss of strata at this fault.

According to H. JAEGER in H. W. FLÜGEL et al. 1977 the following points are of more than local interest:

- The Silurian/Devonian boundary is within a homogeneous black shale facies. Obviously, there was no physical break at this boundary.
- A distinct change in facies from green and grey shales to black shales preceded the faunal change at the boundary by one graptolite zone.
- There is no evidence that *M. transgrediens* and *M. uniformis* overlap.
- The Middle Bischofalm Shales occupy the same stratigraphic position as the non-graptolitic Ockerkalk of Thuringia and presumably also of Sardinia.

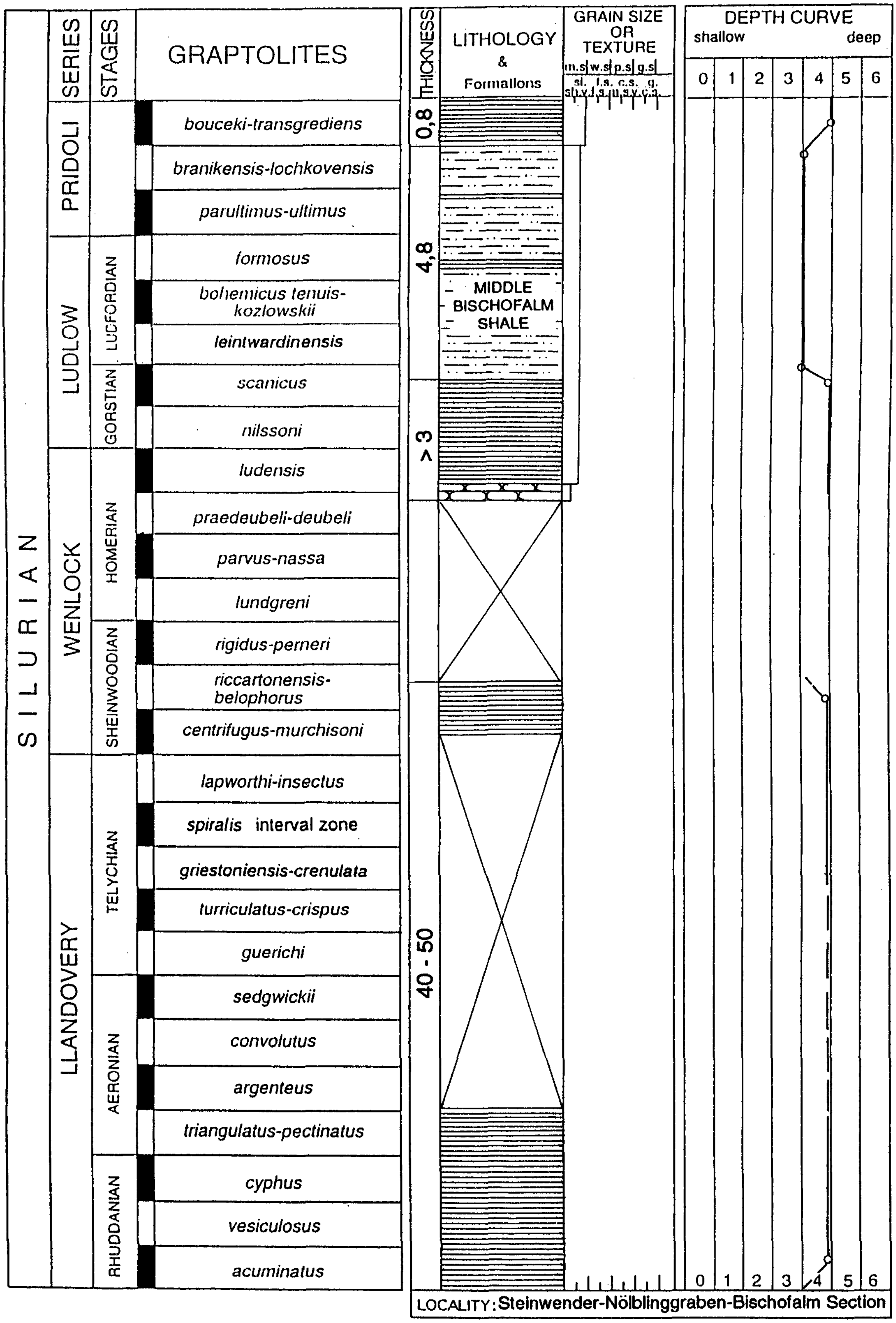

Fig. 4. Composite section of the Silurian Bischofalm facies at Steinwender Hütte, Nölblinggraben and north of upper Bischofalm with indication of lithology, grain size and depth.

The intermediate facies between the foregoing shallow water and basinal settings is best developed at the section Oberbuchach (Fig. 5). This facies is termed "Findenig facies". The Silurian strata represent a mixed argillaceous-calcareous lithology named Nölbling Formation. The almost 50 m thick sequence of Llandovery to Ludlow age are underlain by the Upper Ordovician Uggwa Lst. and the 10 m thick clastic Plöcken Fm. of Hirnantian age. This formation is overlain by interbedded laminated pyritic sandstones, black bedded chert layers and black argillaceous shales containing a graptolite fauna of the zone of *M. gregarius*, subzone of *M. triangulatus* of early Aeronian age (= early Middle Llandovery). Yet, it is not clear whether the equivalents of the Lower Llandovery are missing at this section or whether this portion is barren of fossils.

In the late Llandovery a second horizon of graphitic sandstones occur; its age is inferred from diagnostic conodonts of the *Pterospathodus celloni* Zone in limestones overlying the clastic member. These limestones are followed by an alternating sequence of dark argillaceous limestones, black argillaceous graptolite shales and cherts ranging through the Wenlock to the Ludlow. In this interval conodonts are associated with index graptolites of uppermost Llandovery to Wenlock age. In the shales above graptolites occur at several levels starting off with the zone of *Monograptus riccartonensis* in the Sheinwoodian Stage and ending in the zone of *Monograptus nilssoni* at the base of the Gorstian Stage, i. e. at the beginning of the Ludlow. The Wenlock/Ludlow boundary may thus be placed some 40 m above the base of the graptolite bearing sequence.

At this locality other fossils than graptolites and conodonts are very rare. Conodonts are dominated by simple tooth-shaped cones like *Dapsilodus* and *Decoriconus* whereas ramiform elements only occur in the lower portion of the section.

Strata corresponding to the remaining part of the Ludlow and Pridoli Series consist of up to 20 m thick, lithologically very distinct grey and almost unfossiliferous pyritiferous limestones showing a very characteristic weathered surface which may have originated from solution processes.

*

The Rauchkofel Boden section represents the Silurian Wolayer facies which is characterized by the Upper Ordovician cystoid bearing Wolayer Lst. overlain by highly fossiliferous Middle to Upper Silurian limestones (Fig. 6). Strata corresponding to the Hirnantian Stage of the late Ordovician and Lower Silurian respectively are missing in this facies. The sedimentary gap may be ascribed to the glacial-induced end-Ordovician eustatic sea-level fall and the inherited topography.

The Wolayer Lst. is disconformably overlain by grey fossiliferous cephalopod bearing limestones, named "Orthoceras Lst." and being equivalent to the Kok Limestone. Besides the dominating nautiloids trilobites and bivalves are quite common (H. R. v. GAERTNER 1931, H. RISTEDT 1968, J. KRIZ 1979, H. P. SCHÖNLAUB, ed., 1980). In addition conodonts occur fairly abundant and represent the *Ozarkodina sagitta* Zone of the Wenlock Series (basal Homerian Stage). About 1.20 m above the unconformity the index conodont *Kockelella variabilis* appears suggesting the base of the Ludlow Series by comparison with Bohemia (H. P. SCHÖNLAUB in J.

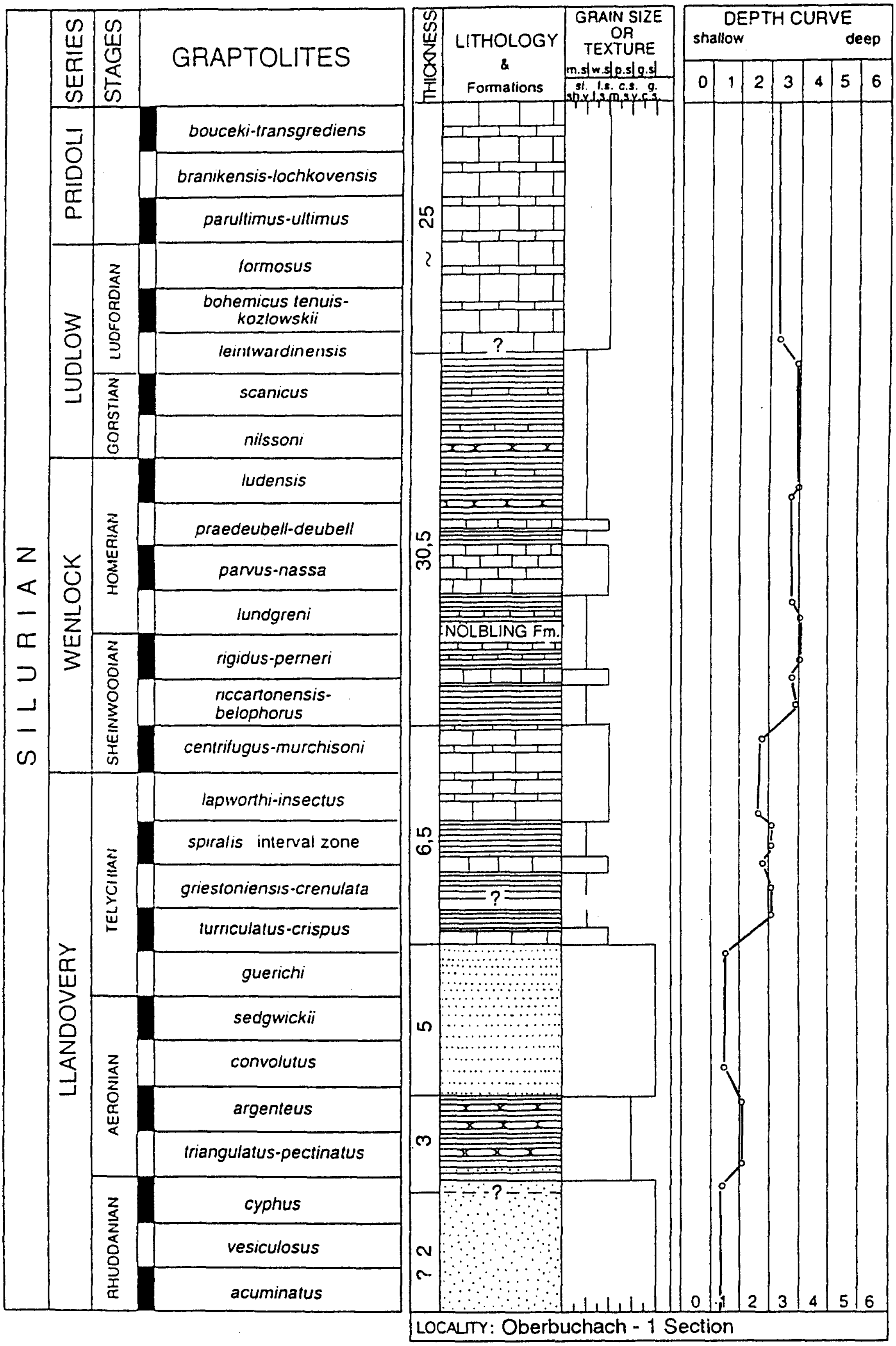

Fig. 5. Section Oberbuchach 1 representing the mixed carbonate - graptolitic shale facies of the Carnic Alps with indication of graptolite biostratigraphy, lithology, grain size and depth curve.

KRIZ et al. 1993). The following equivalent of the Cardiola Fm. corresponds to the *Polygnathoides siluricus* conodont Zone of the Cellon section. It is succeeded by pinkish and greyish limestones corresponding to the Alticola and Megaerella Limestones. However, diagnostic conodonts have yet not been found except in the uppermost level which contains *Scyphocrinites* sp. and common representatives of *Ozarkodina remscheidensis eosteinhornensis*. Based on new field data recently acquired by an international team including J. KRIZ, A. FERRETTI, C. HISTON, O. BOGOLEPOVA and the author the Silurian/Devonian boundary is suggested on top of the *Scyphocrinites* bed, i. e. at the base of the reference sample no. 199.

Preliminary paleoecological and paleogeographical analysis of the Wenlock to Pridoli succession have indicated a local hydraulic behaviour in a transgressive shallow water regime controlled by the South Equatorial Current who may have been responsible for the exchange of faunas between widely separated areas such as northern Sibiria, Perunica, the Carnic Alps and Sardinia (J. KRIZ & O. BOGOLEPOVA 1995). Indeed, there is a preferable trend in the orientation of orthoconic cephalopods from SW to NE in the Kok Lst. changing to a N-NE to S-SW direction in the overlying Lochkov strata (O. BOGOLEPOVA in H. P. SCHÖNLAUB & L. H. KREUTZER 1994).

The Gurktal Nappe

The Gurktal Nappe is composed of a several 100 m thick succession of volcanic and clastic rocks with intercalations of limestones. Strata corresponding to the Silurian comprise coral-bearing organodetritic limestone lenses at the passage from the Llandovery to the Wenlock and a few occurrences of 5 to 10 m thick limestones and dolomites of Late Silurian age. Due to lack of fossils and weak exposures it is as yet not possible to reconstruct a composite Silurian section. However, the facies development suggests a subdivision into a carbonate dominated and a carbonate-poor facies (M. F. BUCHROITHNER 1979, F. EBNER et al. 1990, H. P. SCHÖNLAUB & H. HEINISCH 1994).

The Lower Paleozoic sequences of the Gurktal Nappe System are also characterized by volcanic activities. Volcanism occurred at different times, varying intensities and different geochemical behaviour reflecting different paleotectonic settings (J. LOESCHKE & H. HEINISCH 1993).

The surroundings of Graz

The Palaeozoic history of the area of Graz is best displayed in the sequence of the Rannach Nappe which represents the uppermost nappe of the Graz Thrust Complex. The Silurian part of the sequence is dominated by alkaline mafic lavas and pyroclastics which suggest an initial rift stage. These volcano- and siliciclastics are succeeded by progressive carbonate production during the late Silurian and Devonian.

According to H. FRITZ & F. NEUBAUER 1988, F. NEUBAUER 1989 in the Silurian Kehr Fm. sedimentation was mainly controlled by volcanism. During the early Ludlow a more eastern area was characterized by a proximal shallow water setting with lavas and coarse lapilli tuffs while the western section represented the distal facies

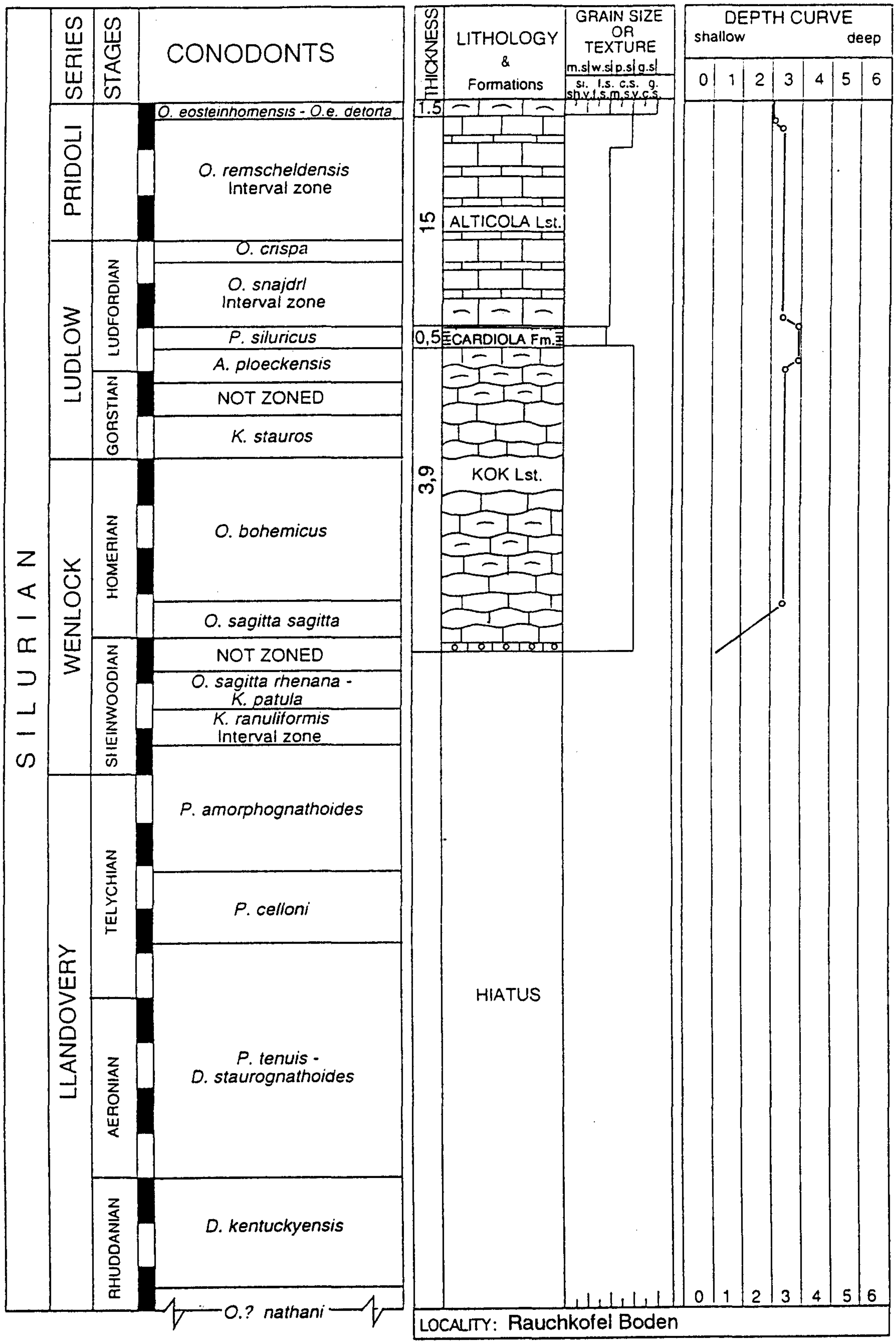

Fig. 6. The Silurian part of the Rauchkofel Boden section with indication of conodont stratigraphy, lithology, grain size and depth curve.

exhibiting cinerites with intercalations of lapilli-rich beds, agglomerates, shales and pelagic limestones. The interesting Kehr Agglomerate consists of 1 to 3% quartzites, dolomites, cherts and reworked limestones.

During the upper Silurian the volcanic centers were buried by fossiliferous carbonates consisting of approx. 4 m thick bedded dolomites with lenses of bioclastic (crinoids, brachiopods, trilobites, nautiloids) dolomitic limestones interbedded with tuffs and tuffitic shales. Based on conodonts for this sequence the Ludlow (Ludfordian) to Pridoli age is concluded (F. EBNER 1994).

Overall similar environmental conditions are suggested for the upper Silurian of the other nappes of the Graz Paleozoic in which pelagic nodular limestone sedimentation persisted from the Upper Silurian to the Devonian.

Lithostratigraphy, Biostratigraphy, Depositional Environment

In the Eggenfeld section the Silurian history of the Graz Paleozoic is best displayed (Fig. 7). In this area the distribution of upper Silurian and lower Devonian sediments is controlled by the Silurian volcanism. In spite of poor outcrops a well constrained lithostratigraphic framework can be established which includes the following rocks (F. EBNER 1994, Fig. 7):

- Massive green diabases interfingering with pinkish to greenish tuffs
- First horizon of well bedded dark dolomites (D/1) containing common crinoids, brachiopods, nautiloids and tabulate corals (*Favosites* sp.)
- Tuffs and tuffitic shales
- Second horizon of well bedded dark dolomites (D/2) with lenselike bioclastic accumulations of crinoids, brachiopods, trilobites, nautiloids and few corals (*Syringaxon* sp.)
- Tuffs and tuffitic shales with intercalations of dark dolomitic beds (D/3) with bioclastic accumulations of crinoids, brachiopods, trilobites and nautiloids.

Biostratigraphic important macro- and microfossils include conodonts and brachiopods. Conodonts are fairly abundant in all carbonatic levels. Diagnostic species include *Polygnathoides siluricus, Polygnathoides emarginatus* and *Kockelella variabilis* in the dolomites immediately overlying the diabases and thus indicate a Ludfordian or earlier age for the end of the basic volcanism. In the second carbonate level (D/2) *Ozarkodina snajdri* has been identified which represents the *Ozarkodina snajdri* Interval zone of the Ludfordian Stage. The index conodont is associated with *Ozarkodina remscheidensis eosteinhornensis*. In addition, at this level there is a common occurrence of the brachiopod species *Septatrypa subsecreta* which, however, also occurs in small carbonate layers intercalated in the overlying tuffitic shales. Based on the occurrence of *Icriodus woschmidti* the latter, however, belong to the lowermost Lochkovian. Yet, index conodonts of the *Pedavis latialata* and *Ozarkodina crispa* zones were not recorded.

The Eggenfeld section is of particular importance for the proof and dating of Silurian volcanic activity in the Eastern Alps. Based on its fossil record this section represents an excellent example of a volcanic island surrounded and buried by

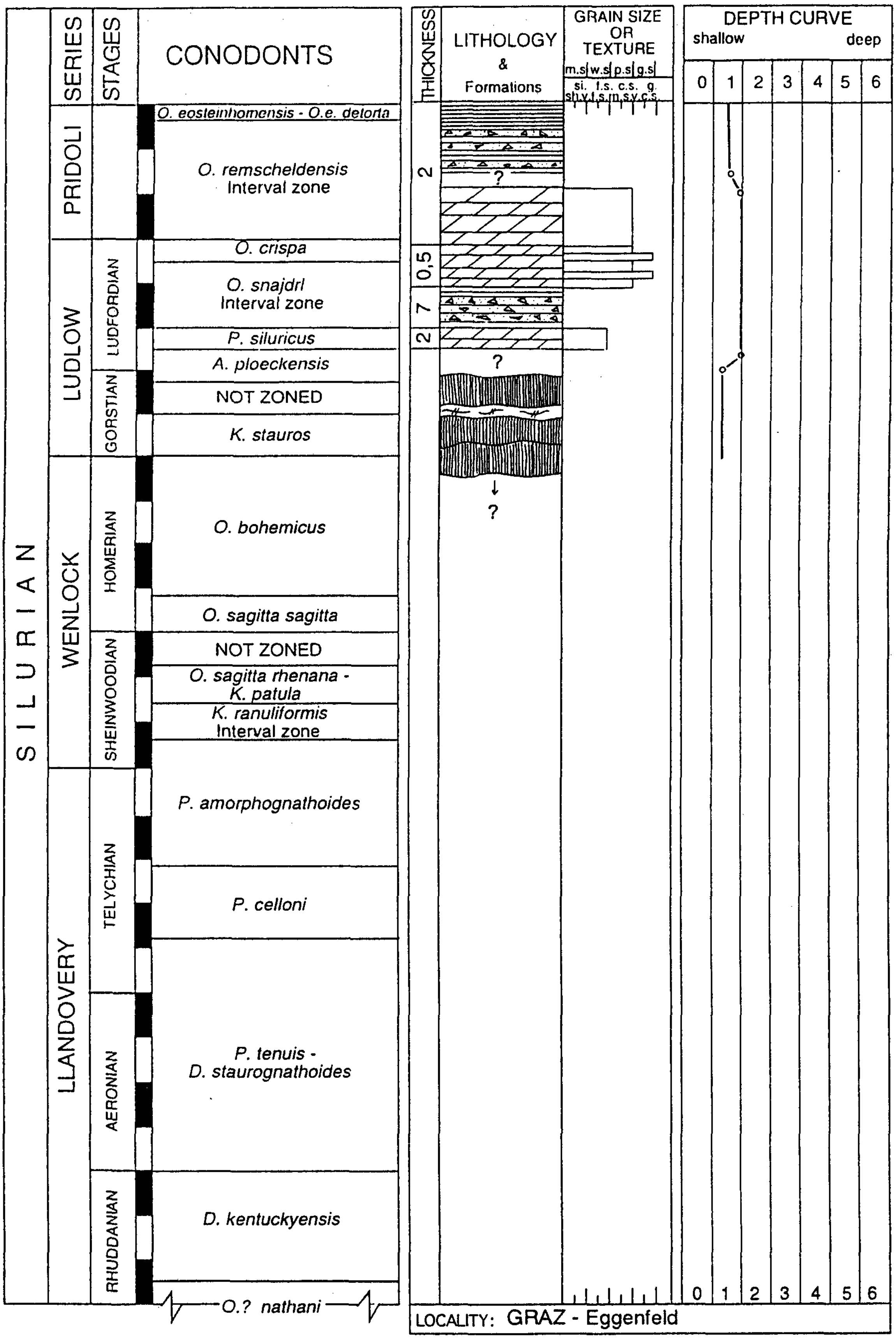

Fig. 7. The Eggenfeld section north of Graz with indication of conodont biostratigraphy, lithology, grain size and depth curve.

bioclastic carbonate accumulations during the upper Silurian. Carbonate production and volcanism progressed during the Devonian.

The Graywacke Zone

According to H. P. SCHÖNLAUB 1979 and H. P. SCHÖNLAUB & H. HEINISCH 1994 the Silurian part of the thick Lower Paleozoic succession of the Graywacke Zone of Styria exhibits a distinct facies differentiation which ranges from some 50 m thick crinoid and nautiloid bearing limestones to black graptolitic shales. Vertically and also laterally, they grade into interbedded limestones and shales followed by a pure limestone development during the Late Ludlow and Pridoli. Locally intercalations of basic volcanics of Llandovery age occur near its southern margin.

The above mentioned facies heterogenity seems to be valid also for the Tyrol and Salzburg segments of the Graywacke Zone. According to H. HEINISCH 1988 within short distances two distinct facies can be distinguished. They are preserved in two nappes named Wildseeloder and Glemmtal Unit, respectively. In the Silurian, the general facies pattern ranges from black shales with local occurrences of graptolites to cherts, siliceous pelagic limestones, condensed cephalopod limestones and even dolomitic rocks.

The Wildseeloder Unit is characterized by a thick pile of the Upper Ordovician Blasseneck Quartzporphyry which is overlain by several meters of pelagic limestones in the middle and upper Llandovery followed by the so-called "Dolomit-Kieselschiefer-Komplex" (Bedded Dolomite-Chert Fm.). In the upper Silurian a carbonate platform developed which lasted until the early Upper Devonian.

The Glemmtal Unit comprises more than 1000 m of mainly siliciclastic sequences which are summarized as Wildschönau Group. Locally up to 50 m thick intercalations of condensed pelagic limestones, marls, interbedded cherts, siliceous shales and basaltic layers occur which have been named Klingler Kar Formation. Based on conodonts for the lower part an upper Silurian age is indicated. Laterally this facies grades into a turbiditic facies named Löhnersbach Fm. In the latter, however, age assignments are as yet missing.

Lithostratigraphy, Biostratigraphy, Depositional Environment

With few exceptions from Styria the Silurian succession of the Graywacke Zone of Tyrol and Salzburg is fairly well known due to occurrences of conodonts and some other fossils such as graptolites. Yet, no detailed biostratigraphic data are available concerning the exact placement of the Ordovician/Silurian boundary.

The Spießnägel section south of Kirchberg/Tyrol is one of the few relevant sections in which the transition of presumably late Ordovician graywackes into basal Silurian strata is exposed. According to N. AL-HASANI & H. MOSTLER 1969 the Silurian sequence starts with 0.85 m thick arenaceous and tuffitic limestones containing diagnostic conodont of the *Pterospathodus celloni* Zone. The lower part of these limestones comprises bioturbated mudstones with varying amount of clastic and tuffaceous material. Some 0.70 m above the base they grade into wackestones. Of special interest is the occurrence of superficial ooids in the upper part of this bed. Their nucleus is formed by crinoid-stems or shell debris which were superficially coated.

The basal part is succeeded by 1.10 m of well bedded limestones with interbedded shale layers containing thin lenses of limestones. This part represents packstones with lumachelle-like debris of bivalves, brachiopods, ostracods and echinoderms. They exhibit a sharp contact to the overlying greyish laminated dolomites which are assigned to the *Kockellella patula* Zone of the lower Wenlock.

The sequence mentioned above corresponds to the interval from the *Ptersopathodus celloni* to the *Pterospathodus amorphognathoides* Zone, i. e., they reflect the environment of the upper Llandovery and the basal Wenlock in this segment of the Graywacke Zone.

Another important lower Silurian section has long been known as "Lachtal-Grundalm section" near the village of Fieberbrunn. The graptolite bearing sequence represents one of the classical outcrops of the Silurian of the Graywacke Zone. It comprises a mixed shale-limestone succession known in the literature as "Lydit-Kieselkalk-Komplex" at the base and the 5 m thick "Dolomit-Kieselschiefer-Komplex" above (H. MOSTLER 1966, Fig. 8).

The basal cherty formation is formed by black massive cherts known as "Lydite" in the Alpine terminology, radiolarian bearing dolomites and reddish cherty limestones which grade vertically into crinoidal limestones. The total thickness does not exceed 5 m. The accompanying microfauna consists of remains of ostracods, foraminifers, brachiopods, radiolarians, conodonts and echinoderms. In addition bivalves, solitary corals, trilobites and orthocone nautiloids sparsely occur in the lower part of the 1.40 m thick crinoid limestone member. Based on conodonts the lower 2.10 m of the limestone succession can be assigned to the *Pterospathodus celloni* Zone; the upper part belongs to the *Pterospathodus amorphognathoides* Zone.

According to H. JAEGER 1978 the only identifyable graptolites occur in the upper part of the Lachtal-Grundalm section known as "Dolomit-Kieselschiefer-Komplex". The lithology resembles the Nölbling Fm. of the Silurian of the Carnic Alps. Representatives of *Monograptus bohemicus* are most abundant in an upper horizon. They are characteristic for the *Monograptus nilssoni* Zone at the base of the Gorstian Stage of the lower Ludlow Series. Co-occurring conodonts are long ranging elements which permit no further age assignment. Other graptolites are *Monograptus dubius* cf. *frequens* and *Monograptus* sp. indet. ex gr. *colonus.*

In the Tyrolean part of the Graywacke Zone the "Dolomit-Kieselschiefer-Komplex" is overlain by dolomitic rocks and magnesites. According to H. MOSTLER 1966 the base of these carbonates can be assigned to the conodont zone of *Ozarkodina crassa* or to the base of the following *Ancoradella ploeckensis* Zone, i. e. to the boundary between the Gorstian and the Ludfordian Stages of the Ludlow Series.

In summary, the available data from the Lachtal-Grundalm section represent a composite succession through the major part of the Silurian. Biostratigraphically dated rocks start in the middle Llandovery and can be followed up through the Wenlock to the middle of the Ludlow Series. In the Tyrolean part of the Graywacke Zone no

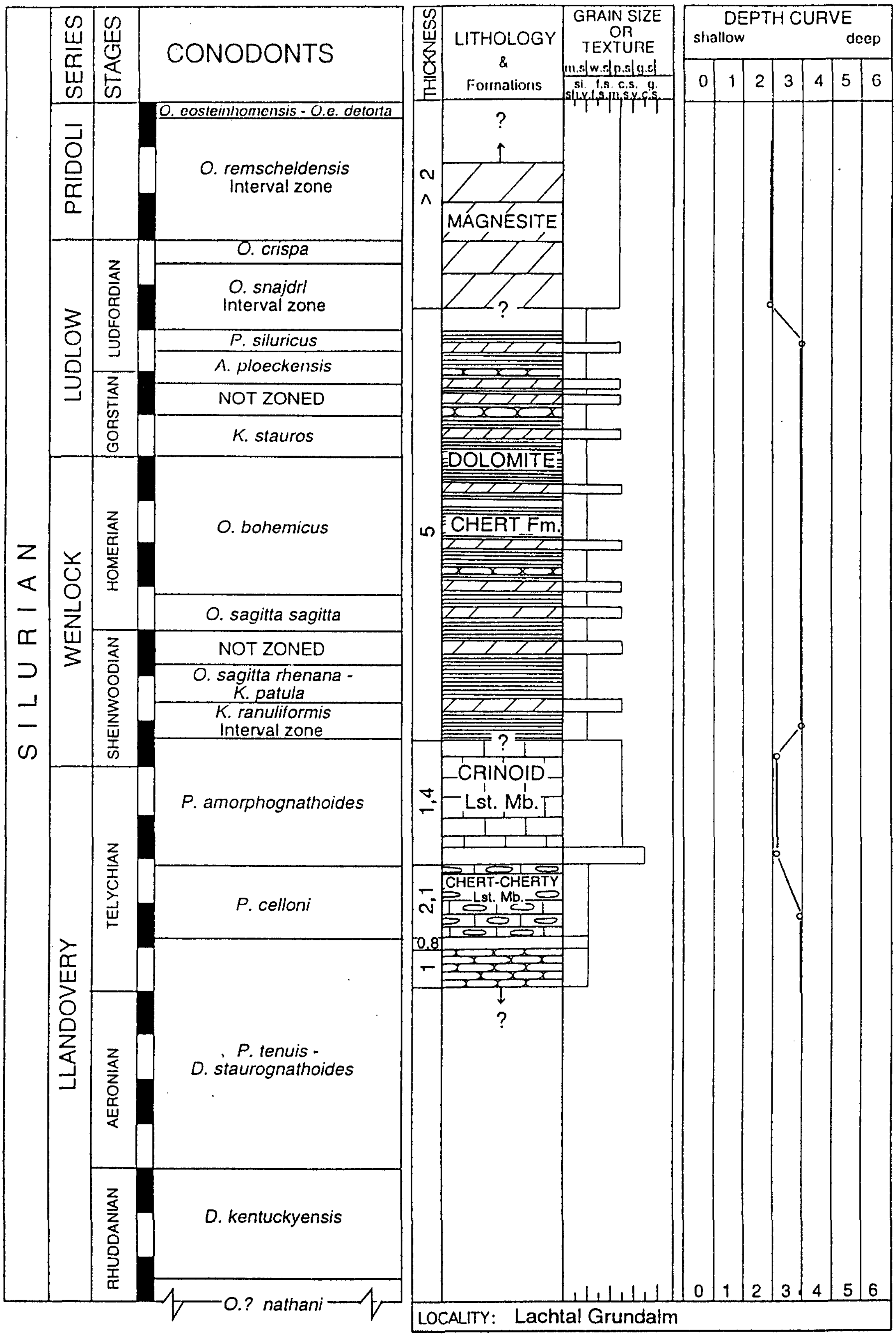

Fig. 8. The Lachtal Grundalm section south of the village Fieberbrunn/Tyrol with indication of conodont stratigraphy, lithology, grain size and depth curve.

records from the Pridoli Series are yet available which, however, may be represented by recrystallized dolomites.

Faunal relationships and climatic implications

As mentioned in the chapters before the Silurian Period is characterized in the Alps by a wide range of different lithofacies. The corresponding strata are locally very fossiliferous and contain each a distinct faunal assemblage consisting of varying abundances of nautiloids, trilobites, bivalves, brachiopods, graptolites as well as conodonts, foraminifera, acritarchs, chitinozoans and ostracods. During the last decades most but by far not all groups have been revised or are being studied presently. The available data suggest a complete but considerably condensed succession in the carbonate-dominated facies and a continuous record in the Silurian graptolite-bearing sequences. In particular this is true for the Carnic and Karawanken Alps; in other areas, however, continuity has as yet not been demonstrated and it seems uncertain to assess this aim due to bad preservation, lack of fossils and metamorphic overprints.

Silurian faunas following the end-Ordovician mass extinction are generally regarded as cosmopolitans and hence provide only little evidence to reconstruct the latitudinal position of individual plates. In combination with lithic data and a highly diversified fossil assemblage, however, this matter may be improved.

Conodont evidence from the Silurian of the Alps suggests a close affinity to coeval faunas from central, southern and southwestern Europe. Britain and Gotland occupied a more equatorial position and, hence, corresponding conodonts are more diversified.

The distribution of acritarchs suggest an intermediate position between the high latitude *N. carminae* and the tropical *Domasia-Deunffia* biofacies. The available data on chitinozoans show close relationships to those from Bohemia the connection of which is even stronger supported in upper Ludlow to lower Lochkov deposits (P. DUFKA 1992, J. KRIZ 1992, J. KRIZ et al. 1986, F. PARIS & J. KRIZ 1984).

Silurian trilobites from the Carnic Alps are closely related to Bohemia and other central European regions. Affinities to Morocco exist but are as yet not studied in detail.

According to W. B. N. BERRY 1979 Silurian graptolites show only little endemism suggesting that interplate dispersal was possible. Their distribution may have mainly been controlled by the surface water and oceanic currents which operated between the individual Silurian microcontinents and volcanic islands. As noted by H. JAEGER (1976, 1988) during the Ludlow and Pridoli an essentially uniform graptolite fauna developed in Europe. The changing environment of this time is portrayed in a contemporaneously shifting lithofacies between Africa and Baltica which displays a characteristic vertical change from black graptolitic shales to limestones and back to shales. Sea-level rise and fall are considered to have been responsible for these changes.

Beginning in the Upper Llandovery nautiloids became the dominating organisms in the carbonate facies of the Alps with rich abundances of orthoceratids in the

Wenlock and Ludlow and decreased numbers in the Pridoli (H. RISTEDT 1968, 1969). The diversified fauna seems closely related to Bohemia and Sardinia (J. KRIZ & E. SERPAGLI 1993). Ongoing studies have also shown that the Silurian cephalopod biofacies reflects even close links to northern Sibiria. Supposedly, this relationship resulted from the South Equatorial Current that operated during the Silurian along the southern margin of Sibiria and Laurussia (J. KRIZ & O. BOGOLEPOVA 1995).

The distribution of other mollusks, in particular bivalves resembles grossly that of nautiloids. According to J. KRIZ (1979) Silurian cardiolids from the Carnic Alps and the western Graywacke Zone inhabitated a warm equatorial belt or were dispersed through currents.

J. KRIZ (1996 in press) recognized in the Carnic Alps the oldest Silurian Bivalvia dominated community of the *Cardiola* Community Group, i. e. the *Carnalpia nivosa* Community in the rigidus Biozone (Wenlock). Other recurring communities of the *Cardiola* Community Group are also known from Bohemian Prague Basin and from other regions in Europe. In the Wenlock (lundgreni Biozone) of the Rauchkofel section the *Slava fibrosa* Community occurs which is closely related to the *Cardiola agna* Community known from other European regions.

The Cardiola Formation is characterized by the *Cardiola docens* Community, which is known from the Prague Basin (Bohemia), Sardinia, Eastern Serbia, Montagne Noire (France), Spain and Morocco.

At the base of the Prídolí (parultimus Biozone) in the Cellon section the *Cardiolinka bohemica* Community occurs known also from Nagelschmieddpalfen near Dienten in the Graywacke Zone of Tyrol, from the Prague Basin (Bohemia) and Elbersreuth, Frankenwald (Germany). In the uppermost Prídolí of the Rauchkofel Section the *Dualina - Patrocardia* Community occurs which is related to the Lower Devonian (Lochkovian) *Patrocardia evolvens evolvens* Community of the *Patrocardia* Community Group known from the Prague Basin in Bohemia, from Sardinia and from the South Armoricain Domain (La Meignanne) in France.

The *Cardiola* Community Group is characterized by epibyssate bivalves which were adapted to the cephalopod limestone biofacies indicating a temporally ventilated, relatively shallow bottom (Boucot´s Assemblage 2 - 3). The *Patrocardia* Community Group is characterized by epibyssate (*Patrocardia*), infaunal and reclining (*Dualina*) forms living also in the temporally ventilated cephalopod limestone biofacies.

In our view Silurian corals from the Alps were prominent constituents of a shallow water environment in the broader tropical belt (Fig. 9). During the early Silurian only weak indications of provincialism is indicated among tabulate and rugose corals at the generic level. However, long-living teleplanic larvae might also have been transported by ocean currents over long distances (J. W. PICKETT 1975, R. A. McLEAN 1985, D. L. KALJO & E. KLAAMANN 1973, A. E. H. PEDDER & W. A. OLIVER 1990).

Rugose and tabulate corals occur in the late Llandovery of Middle Carinthia, in the Upper Silurian (Ludlow) of Graz and very rare in shallow water and locally superficial ooid bearing limestones in the late Llandovery of the Graywacke Zone of Tyrol (H. P.

SCHÖNLAUB 1994, with additional references). Recently, the working team on cephalopod limestones has discovered also in the Carnic Alps a yet undescribed pioneer rugose coral fauna in rocks of Ludlow and Pridoli age.

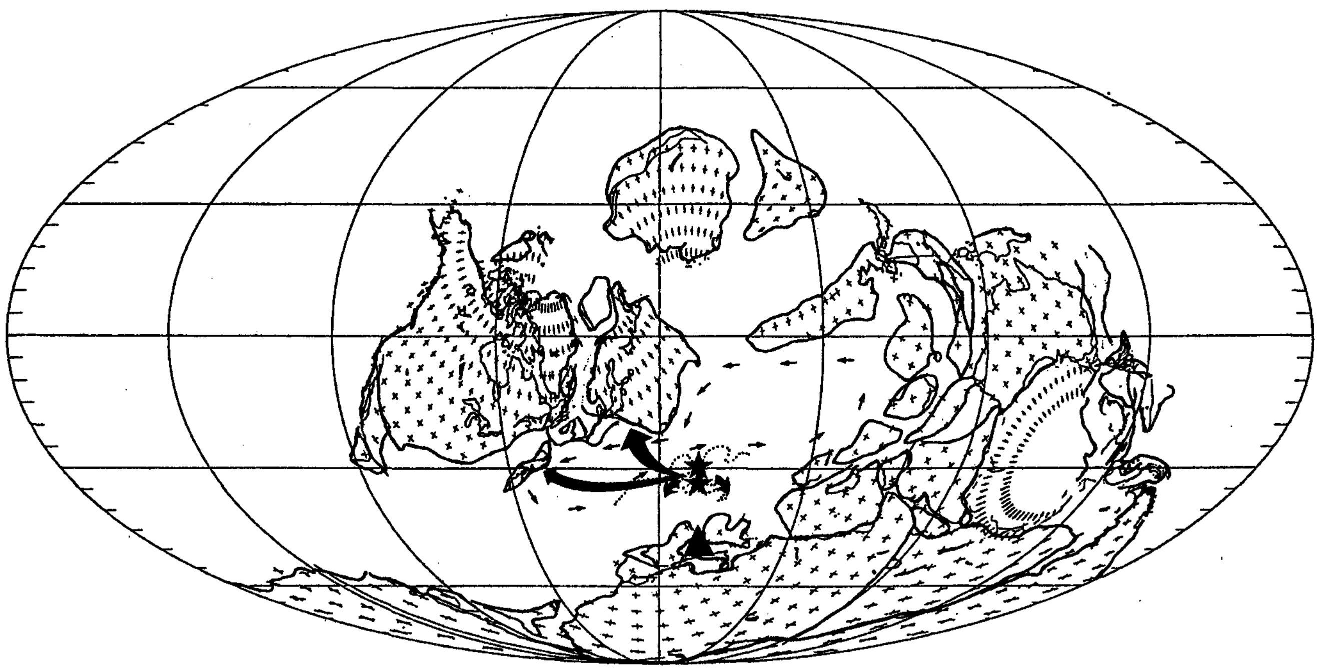

Fig. 9. Middle Silurian (Wenlockian) paleogeography with indication of latitudinal settings of Silurian rocks in the Alps shown as stars. Faunal relationships are shown by heavy arrows, the oceanic current system in the mid-European ocean by small arrows. Triangle represents position of the Alps as suggested by C. R. SCOTESE & W. S. McKERROW (1990). From H. P. SCHÖNLAUB (1992).

In summarizing, we believe that the above mentioned lithic and faunistic data of the Alps can be used to infer not only the climatic conditions during the Silurian but also provide some insights into such parameters as light, temperature, salinity, water agitation and other agents controlling the distribution of different organims. Hence, it is concluded that during the Silurian Period the Alpine occurrences continued to shift from higher to lower latitudes. Paleomagnetic data from Gondwana seem to support the assumption of rather rapid northward plate movements. Based on the evidences presented above we thus estimate for the Alpine occurrences of Silurian deposits a position at approx. 30 to 40° southern latitude. During this period close faunal relations existed to northern Europe but minor links were also directed to southern Europe (see Fig. 9).

References

AL-HASANI, N., and MOSTLER H., 1969, Zur Geologie der Spießnägel südlich Kirchberg (Nördliche Grauwackenzone, Tirol): Veröffentl. Univ. Innsbruck, 9, Alpenkundl. Stud., 5, 5 - 26.

BOGOLEPOVA, O. K., and KRIZ, J., 1995, Ancestral forms of Bohemian type Bivalvia from the lower Silurian of Siberia (Tungusskaja Syneclise, Russia): Geobios, 28, 6, 691 - 699.

BUCHROITHNER, M. F., 1979, Biostratigraphie und fazielle Untersuchungen im Paläozoikum von Mittelkärnten: Carinthia II, 169, 71 - 95.
DUFKA, P., 1992, Lower Silurian Chitinozoans of the Prague Basin (Barrandian, Czechoslovakia). Preliminary Results: Rev. Micropaléont., 35/2, 117 - 126.
DULLO, W. C., 1992, Mikrofazies und Diagenese der oberordovizischen Cystoideenkalke (Wolayerkalk) und ihrer Schuttfazies (Uggwakalk) in den Karnischen Alpen: Jb. Geol. B. - A., 135, 317 - 333.
EBNER, F., 1994, Section 1, Silurian/Devonian boundary section of Eggenfeld/Paleozoic of Graz. In: Field Trip Program IUGS Subcomm. Silurian Stratigraohy, Field Meeting 1994: Ber. Geol. B. - A., 30/1994, 77 - 82.
EBNER, F., FENNINGER, A., GOLLNER, H., HOLZER, H. L., NEUBAUER, F., NIEVOLL, J., RATSCHBACHER, L., STATTEGGER, K., TSCHELAUT, W., THALHAMMER, O. , and ZIER, C., 1990, Stratigraphic Correlation Forms of Paleozoic units in Austria. In: Sassi, F. P., and Zanferrari, A., (eds.) Pre-Variscan and Variscan Events in the Alpine-Mediterranean Belts, Stratigraphic Correlation Forms: Rend. Soc. Geol. Ital., 12, 213 - 239.
FLÜGEL, H. W., JAEGER, H., SCHÖNLAUB H.P. , and VAI G. B., 1977, Carnic Alps. In: Martinsson A (ed) The Silurian-Devonian Boundary: IUGS Series A, No 5, 126 - 142
FRITZ, H. and NEUBAUER, F. , 1988, Geodynamic aspects of the Silurian and Early Devonian sedimentation in the Paleozoic of Graz (Eastern Alps): Schweiz. Mineral. Petrogr. Mitt., 68, 359 - 367.
GAERTNER, H. R. von, 1931, Geologie der zentralkarnischen Alpen: Denkschr. Österr. Akad. Wiss., 102, 113 - 199.
HAUER, F. von, 1847, Versteinerungen von Dienten in Salzburg: Haidingers Berichte, 1, X.
HEINISCH, H., 1988, Hinweise auf die Existenz eines passiven Kontinentalrandes im Altpaläozoikum der Nördlichen Grauwackenzone - Ostalpen: Schweiz. Mineral. Petrogr. Mitt., 68, 407 - 418.
JAEGER H., 1975, Die Graptolithenführung im Silur/Devon des Cellon-Profils (Karnische Alpen): Carinthia II, 165/85, 111 - 126.
JAEGER, H., 1978, Graptolithen aus dem Silur der Nördlichen Grauwackenzone (Ostalpen): Mitt. Österr. Geol. Ges., 69 (1979), 89 - 107.
JAEGER H., 1988, Devonian Graptoloidea. In: McMillan NJ, Embry AF, Glass DJ (eds) Devonian of the World. - Proc. 2nd Internat. Symp. Devonian System Calgary Canada, 3, 431 - 438.
JAEGER, H., and SCHÖNLAUB, H. P., 1980, Silur und Devon nördlich der Gundersheimer Alm in den Karnischen Alpen (Österreich): Carinthia II, 170/90, 403 - 444.
JAEGER H., and SCHÖNLAUB, H. P., 1994, Section 4 "Graptolithengraben" (graptolite gorge) north of Upper Bischofalm. In: Field Trip Program IUGS Subcomm. Silurian Stratigraphy, Field Meeting 1994: Ber. Geol. B. - A., 30/194, 97 - 100.
KALJO, D. L., and KLAAMANN, E., 1973, Ordovician and Silurian corals. In: Hallam A (ed) Atlas of Palaeobiogeography: Elsevier Amsterdam, 37 - 45
KRIZ, J., 1979, Silurian Cardiolidae (Bivalvia): Sb. Geol. VED Paleont., 22, 1 - 157.
KRIZ, J., 1992, Silurian Field Excursions. Prague Basin (Barrandian), Bohemia: Geol. Ser. Nat. Mus. Wales, 13, 111 p.
KRIZ, J. (1996, in press), Bivalvia dominated communities of Bohemian type from the Silurian and Lower Devonian carbonate facies: Cambridge Univ. Press.
KRIZ, J. and BOGOLEPOVA, O. (1995), *Cardiola signata* Community (Bivalvia) in cephalopod limestones from Tajmyr (Gorstian, Silurian, Russia): Geobios, 28, 573 - 583.
KRIZ, J., JAEGER, H., PARIS, F. & SCHÖNLAUB, H. P. (1986): Pridoli - the Fourth Subdivision of the Silurian: Jb. Geol. B. -A., 129/2, 291 - 360.
KRIZ, J., and SERPAGLI, E., 1993, Upper Silurian and lowermost Devonian Bivalvia from Western Sardinia: Boll. Soc. Paleont. Italiana, 32, 289 - 347.
KRIZ, J., DUFKA, P., JAEGER, H. and SCHÖNLAUB, H. P., 1993, The Wenlock/Ludlow Boundary in the Prague Basin (Bohemia): Jb. Geol. B. - A., 136/4, 809 - 839.

LOESCHKE, J, and HEINISCH, H. 1993, Palaeozoic Volcanism of the Eastern Alps and Its Palaeotectonic Significance. In: Pre-Mesozoic Geology in the Alps, J. F. von RAUMER and F. NEUBAUER, eds, Springer Verl., 441 - 455.

McLEAN, R. A., 1985, New Early Silurian rugose corals from the Panuara area, central New South Wales: Alcheringa, 9, 23 - 34.

MOSTLER, H., 1966, Zur Einstufung der "Kieselschiefer" von der Lachtal-Grundalm (Fieberbrunn, Tirol): Verh. Geol. B. - A., 1966, 157 - 170.

NEUBAUER, F., 1989, Lithostratigraphie und Strukturen an der Basis der Rannachdecke im zentralen Grazer Paläozoikum (Ostalpen): Jb. Geol. B. - A., 132, 459 - 474.

PARIS, F., and KRIZ, J., 1984, Nouvelles especes de chitinozoaires a la limite Ludlow/Pridolien Tchecoslovaquie: Rev. Palaeobot. Palyn., 43, 155 - 177.

PEDDER, A. E. H., and OLIVER, Jr., W. A., 1990, Rugose coral distribution as a test of Devonian palaeogeographic models. In: McKerrow W. S. and Scotese, C. R. (eds) Palaeozoic Palaeogeography and Biogeography: Geol. Soc. London, Mem., 12, 267 - 275.

PICKETT, J. W., 1975, Continental reconstructions and the distribution of coral faunas during the Silurian: J. Proc. Roy. Soc. New South Wales, 108, 147 - 156.

RISTEDT, H., 1968, Zur Revision der Orthoceratidae: Abhandlungen Akademie Wissenschaften Mainz, math. naturw. Kl., 1968 No 4, 213 - 287.

RISTEDT, H., 1969, Orthoceren als Leitfossilien des Silurs: Carinthia II, SH 27, 25 - 28.

SCHÖNLAUB, H. P., 1979, Die Nördliche Grauwackenzone. In: Das Paläozoikum von Österreich: Abh. Geol. B. - A., 33, 76 - 97.

SCHÖNLAUB, H. P., 1980, Carnic Alps. Field Trip A. In: Schönlaub, H.P. (ed) Second European Conodont Symposium ECOS II, Guidebook-Abstracts: Abh. Geol. B. - A., 35, 5 - 57.

SCHÖNLAUB, H. P. 1985, Das Paläozoikum der Karnischen Alpen. In: Arbeitstagung der Geologischen Bundesanstalt 1985: Geol. B. - A., 1985, 34 - 52.

SCHÖNLAUB, H. P., 1988, The Ordovician-Silurian boundary in the Carnic Alps of Austria. In: Cocks, L.R.M., and Rickards, R. B., eds., A global analysis of the Ordovician-Silurian boundary: Bull. Brit. Mus. Nat. Hist. (Geology), 43, 107 - 115.

SCHÖNLAUB, H. P., 1994, The Faunal Relationship of the Silurian of the Alps. In: IUGS Subcomm.Silurian Stratigraphy , H. P.Schönlaub and L. H. Kreutzer (eds.): Ber. Geol. B. - A., 30, 52 - 60.

SCHÖNLAUB, H. P., 1994, Section 2 Cellon Section, Lithology, Paleontology and Stratigraphy. In: Field Trip Program IUGS Subcomm. Silurian Stratigraphy, Field Meeting 1994: Ber. Geol. B. - A., 30/1994, 83 - 84.

SCHÖNLAUB, H. P. 1993, Stratigraphy, Biogeography and Climatic Relationships of the Alpine Palaeozoic. In: J.F. von Raumer and F. Neubauer, eds., Pre-Mesozoic Geology in the Alps: Springer Verlag, 65 - 91.

SCHÖNLAUB, H. P., and HEINISCH, H., 1994, The Classic Fossiliferous Palaeozoic Units of the Eastern and Southern Alps. In: IUGS Subcomm. Silurian Stratigraphy, Field Meeting 1994: Ber. Geol. B. - A., no. 30/1994, 6 - 51.

SCHÖNLAUB, H. P., and KREUTZER, L. H., eds., 1994, Subcommission on Silurian Stratigraphy Field Meeting Eastern + Southern Alps, Austria 1994, Guidebook + Abstracts: Ber. Geol. B. - A., no. 30, 1 - 156.

STACHE, G., 1872, Entdeckung von Graptolithenschiefer in den Südalpen: Verh. Geol. R. - A., 1872, 234 - 235.

WALLISER, O. H., 1964, Conodonten des Silurs: Abh. hess. L. Amt Bodenf., 41, 1-106.

The Devonian of Austria[3]

by

Lutz H. Kreutzer, Hans P. Schönlaub and Bernhard Hubmann[4]

with 9 figures

Summary

Fossil bearing strata of Devonian age have been recognized in the Alps as early as 1843. Such classic regions comprise the surroundings of the city of Graz in Styria and its eastward continuation to southern Burgenland, the Carnic and Karawanken Alps at the Italian/Slovenian border, the Graywacke Zone of Styria, Salzburg and Tyrol and rather small occurrences of the so-called Gurktal Nappe of Middle Carinthia and parts of Styria (Fig. 1). Furthermore, based on rare microfossil occurrences and geochronologic data it may be concluded that a considerable part of the pre-Alpine crystalline complexes was also deposited during this time. However, this sedimentary and volcanogenic sequence of unknown thickness was affected by greenschist and amphibolite-grade metamorphism attributed to the Variscan orogeny of the late intra-Devonian.

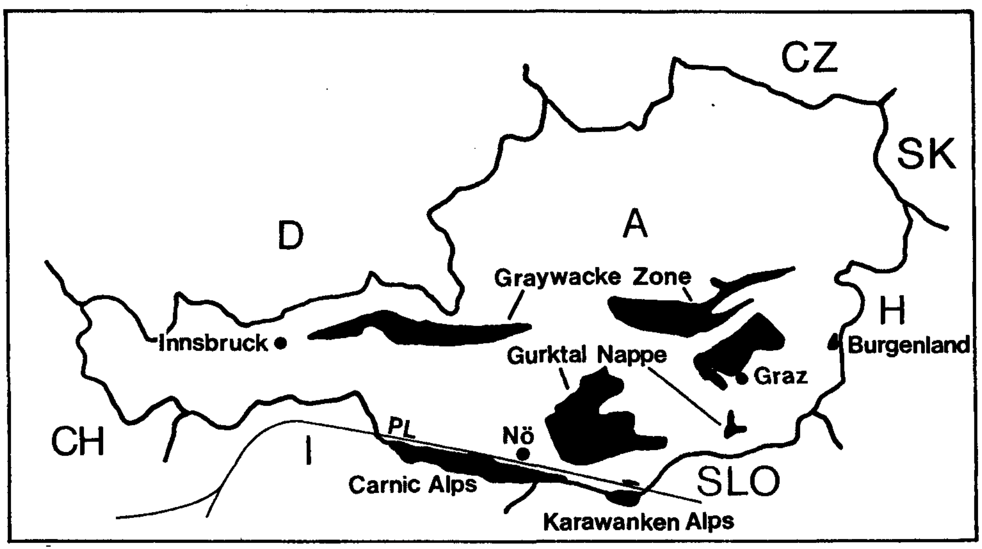

Fig. 1. Main regions with fossiliferous Paleozoic strata in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Nötsch).

In the Alps the equivalents of the Devonian Period are characterized by abundant shelly fossils and carbonate as well as clastic sequences of varying thicknesses. In addition some basic volcanics occur in the Graz Paleozoic and in the Graywacke Zone. The limestone development ranges from true reefs and carbonate buildups to slope and condensed cephalopod limestones of an open marine offshore environment on the sea-side and platform and coastal deposits on the land-directed other

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side. In the Carnic Alps, for example, the relationship between shallow water limestones and contemporary goniatite limestones is approx. 12 : 1 indicating an extensional regime of enhanced mobility accompanied in some areas by rifting related basic volcanism in the Lower and Middle Devonian prior to the climax of the Variscan perturbations.

For the Devonian strata of the Alps the analysis of climate sensitive lithologies suggests a setting within the tropical belt of 30° southern latitude. Biogeographically, close relations exist to coeval faunas and floras of Bohemia, the Urals, Kazachstan, Altai and Tienshan and less pronounced to the Eifelian Hills, the Ardennes and Northern Africa for the Lower Devonian. From the Middle to the Upper Devonian cosmopolites are dominating like ammonoids, trilobites, brachiopods, corals and algae which reflect an overall uniform character and are only of limited use to reconstruct old pathways (Schönlaub 1992 and Fig. 2). Whether or not several distinct Devonian microcontinents are assembled in an Alpine collage is yet not fully understood

In more detail the biogeographically relevant data from the Alps reflect the following relationships (Fig. 2):

- Lower Devonian faunal and floral affinities (brachiopods, corals, gastropods, trilobites, algae) exist with central and northern Europe and the Ural - Tienshan regions;
- Loose contacts are with northern Africa;
- During the Middle and Upper Devonian cosmopolites dominate;
- The Devonian is characterized by thick carbonate deposits and buildups with abundant shelly fossils;
- Volcanic events reflect a rifting stage;
- Locally (e. g., surroundings of Graz) a hypersaline environment developed..

In conclusion,

- ➢ for the Devonian of the Alps a paleolatitudinal position within the tropical belt of some 30° S or less is inferred;
- ➢ mobile basins were affected by extensional tectonics; the oceanic circulation system aided the dispersal of many organic groups;
- ➢ two terranes or microcontinents may have existed in the Alps suggesting latitudinal differences between the Southern Alps and the Graz Paleozoic;
- ➢ during the Devonian the relative plate motion of Africa changed resulting in a southward shift of Africa relative to the South Pole ("loop" of APWP).

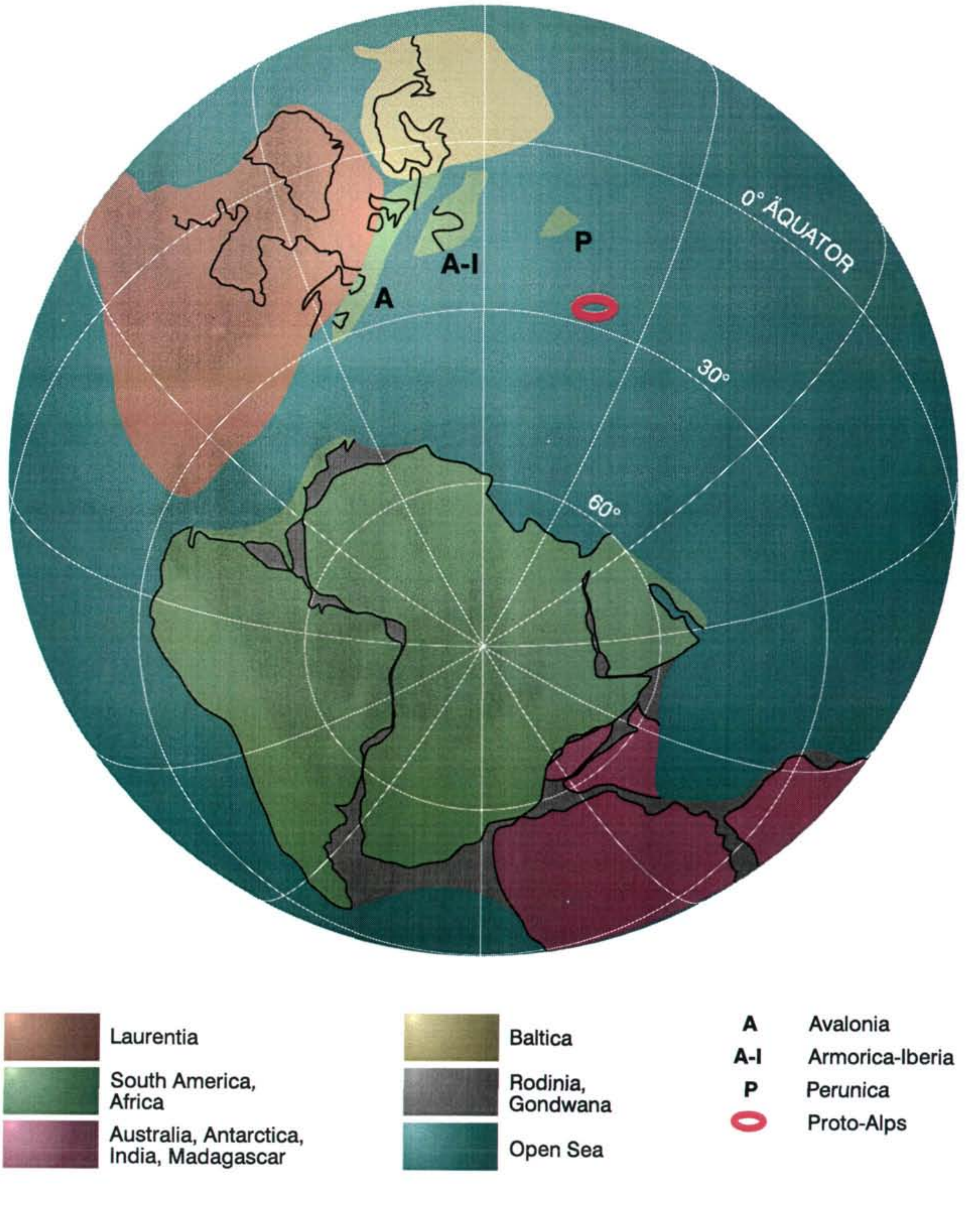

Fig.2.
Late Devonian (c. 360 Ma) paleogeographic reconstructions of the Atlantic bordering continents (after V. BACHTADSE et al. 1995, modified).

The Devonian of the Carnic and Karawanken Alps of Carinthia

The Paleozoic Units of the Carnic and the Karawanken Alps represent the basement of the Southern Alps. They are separated from the Central Alps by the Periadriatic Fault system (Fig.1). The Carnic Alps extend in West-East-direction over 140 km from the village of Sillian in Eastern Tyrol to Arnoldstein in Carinthia. In the following Western Karawanken Alps the Variscan sequence is almost completely covered by rocks of Alpine age. To the east, however, the Lower Paleozoic sequence is well exposed in the Seeberg area south of the city of Klagenfurt. In this Eastern Karawanken region Lower Paleozoic rocks occur on both sides of the Periadriatic Fault. They are subdivided into a small northern and a more prominent southern part, the latter extending beyond the stae boundary to Slovenia.

The Carnic Alps

The Paleozoic of the Carnic Alps represents one of the very few places in the world in which an almost continuous fossiliferous sequence has been preserved (Fig. 3). Ongoing geological and paleontological research started in the middle of the last century. More recent investigations in the Devonian sequences were carried out during the last 30 years by Bandel (1969, 1972, 1974), Ebner (1973), Kreutzer (1989, 1990, 1992a/b), Oekentorp-Küster & Oekentorp (1992), Schönlaub (1979, 1985, 1992), Schönlaub et al. (1992), Schönlaub & Heinisch (1993), Schönlaub & Flajs (1975) on the Austrian part of the mountain range and by Ferrari & Vai (1965), Galli (1985), Schönlaub & Kreutzer (1993), Spalletta & Vai (1984), Spalletta et al. (1983, 1994) on the Italian side.

According to Kreutzer 1992a,b in the Carnic Alps the Devonian Period is characterized by the development of five north-northeast to south-southwest directed facies belts (Fig. 4). During the Variscan orogeny these belts were transformed into strongly deformed nappes which from top to base can be subdivided into the following tectono-stratigraphic units:

1: Southern shallow water facies (Cellon-Kellerwand nappe)
  a : Intertidal subfacies (Biegengebirge, Gamskofel)
  b : Back reef subfacies (Upper Kellerwand, Hohe Warte, Biegengebirge)
  c : Reef subfacies (Hohe Warte, Upper Kellerwand)
  d : Reef debris subfacies (Hohe Warte, Upper Kellerwand)
2: Transitional facies (Cellon nappe)
3: Pelagic limestone facies (Rauchkofel nappe)
4: Offshore pelagic basinal facies (Bischofalm nappe)
5: Northern shallow water facies (Feldkogel nappe)

During the Caradoc Series of the Ordovician sedimentation was dominated by siliciclastic deposits. Already in the following Ashgill Series a weak differentiation of facies is indicated by the development of different cool water limestones. According to Dullo (1992) the Wolayer limestone (south position) represents a near-shore parautochtoniuos cystoid facies and the Uggwa Limestone (north position) an off-shore basinal debris facies. However, the Ordovician reef evolution never exceeded a pioneer faunal stage with crinoids suggesting a biostromal tendency with low topographic differences. This setting together with the contemporary faunal relationships with neigbouring regions may correspond to a position of about 45° southern latitude (Schönlaub 1992).

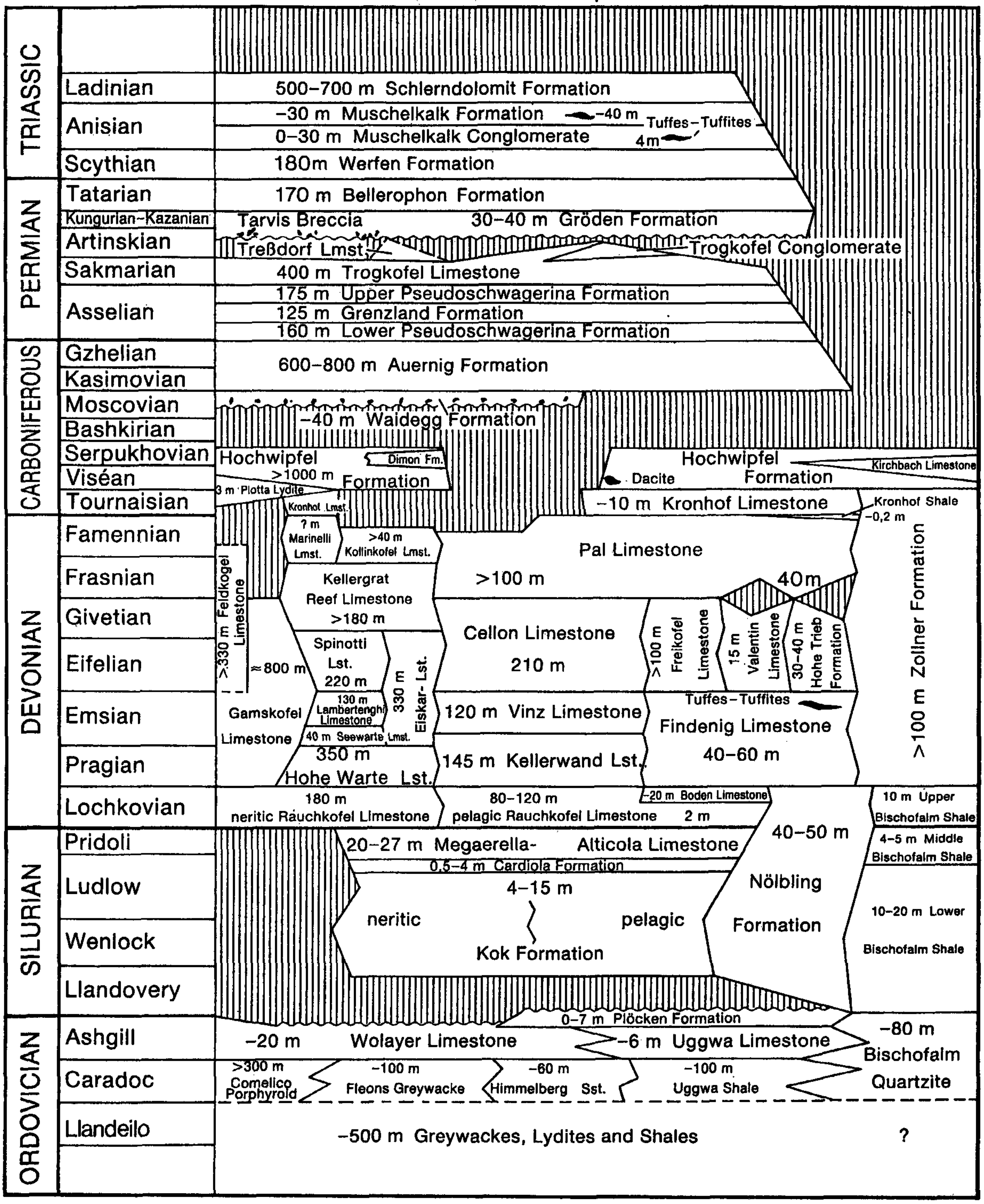

Fig. 3: Stratigraphy of the Paleozoic sequences of the Carnic Alps after Schönlaub (1986), modified by Kreutzer (1992b).

In agreement with other regions in the Carnic Alps the passage from the Ordovician to the Silurian is characterized by a regressive-transgressive relationship. The first is related to the retreat of the sea coupled with the glacial event in the Southern hemisphere during parts of the Hirnantian Stage while the latter may indicate the rising sea level following an abrupt end of the glaciation. Thus, in the Llandovery the transgressive Kok-Formation disconformably overlies the late Ordovician Plöcken Formation in all sections dominated by limestones (for example in the famous Cellon section representing a southern paleogeographic position). In other sections, e.g. in the Wolayer facies of the Seekopf section the Silurian sequence is considerably reduced; it represents a more northern position. According to Schönlaub (1992) the paleogeographical position of the Silurian is estimated at about 30 degrees southern latitude. Similar to the Ordovician development, the Silurian carbonate buildups suggest a rather low relief.

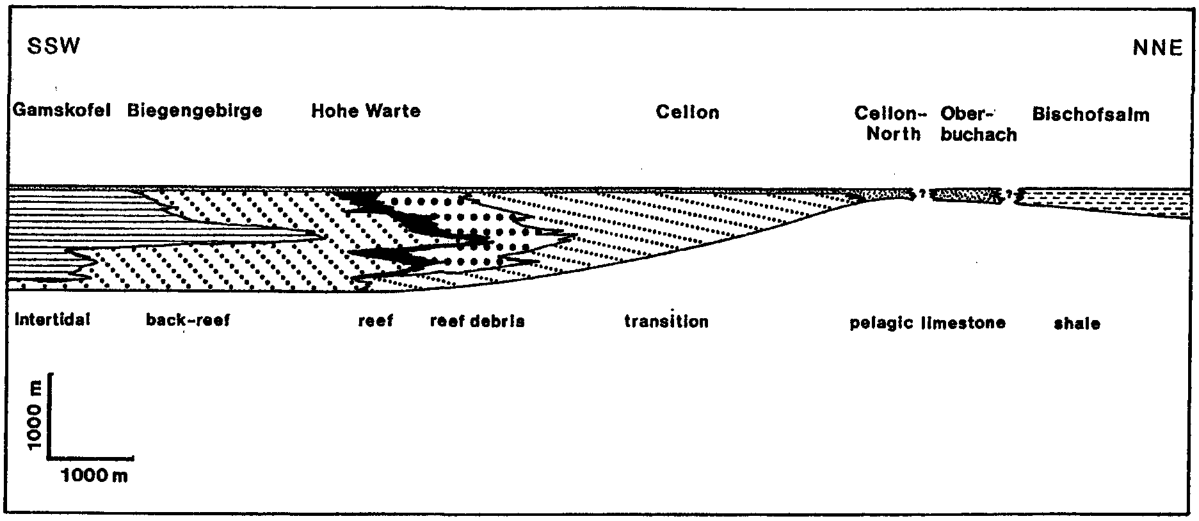

Fig. 4. Palinspastic profile of the Carnic Alps at the Devonian/Carboniferous boundary (Kreutzer 1992a). Gamskofel, Biegengebirge, Hohe Warte: Southern shallow water facies (Kellerwand nappe); Cellon: Transitional facies (Cellon nappe); Cellon-North, Oberbuchach: Pelagic limestone facies (Rauchkofel nappe); Bischofalm: Offshore pelagic basinal facies (Bischofalm nappe). Somewhere to the north the northern shallow water facies of the Feldkogel nappe occurs.

During the Lochkovian and Pragian Stages corals and stromatoporoids slowly proceeded and first patch reefs started to grow. At the same time in the southern realm of the Kellerwand nappe a shallow water subfacies developed. Schönlaub (1992) estimated the global position of the Carnic Alps in the Middle Devonian at about 30 degrees southern latitude.

In the Carnic Alps the prominent and more than 1300 m high cliffs of the Kellerwand and of the Hohe Warte (altitude 2784 m above sea level) represent the centres of the Devonian reefs (Fig. 5) having their climax in the Givetian and Frasnian Stages. The strongly varying thicknesses of the facies belts during the Devonian (see Fig. 5) indicate a differently subsiding mobile basin in an extensional regime which contrasts with the foregoing Silurian Period. In fact, during the time from the Lochkovian to the Frasnian in the facies belt 1 about 1100 metres of shallow water limestones were deposited (Kreutzer, 1990). They correspond to coeval pelagic cephalopod limestones with markedly reduced thicknesses of some 100 m of facies belt 3. Between this two facies belts a transitional environment with changing thicknesses is developed representing the facies belt 2. In conclusion, the different lithologies of the limestone development can be attributed to at least 13 microfacies types (Kreutzer 1990, 1992a/b).

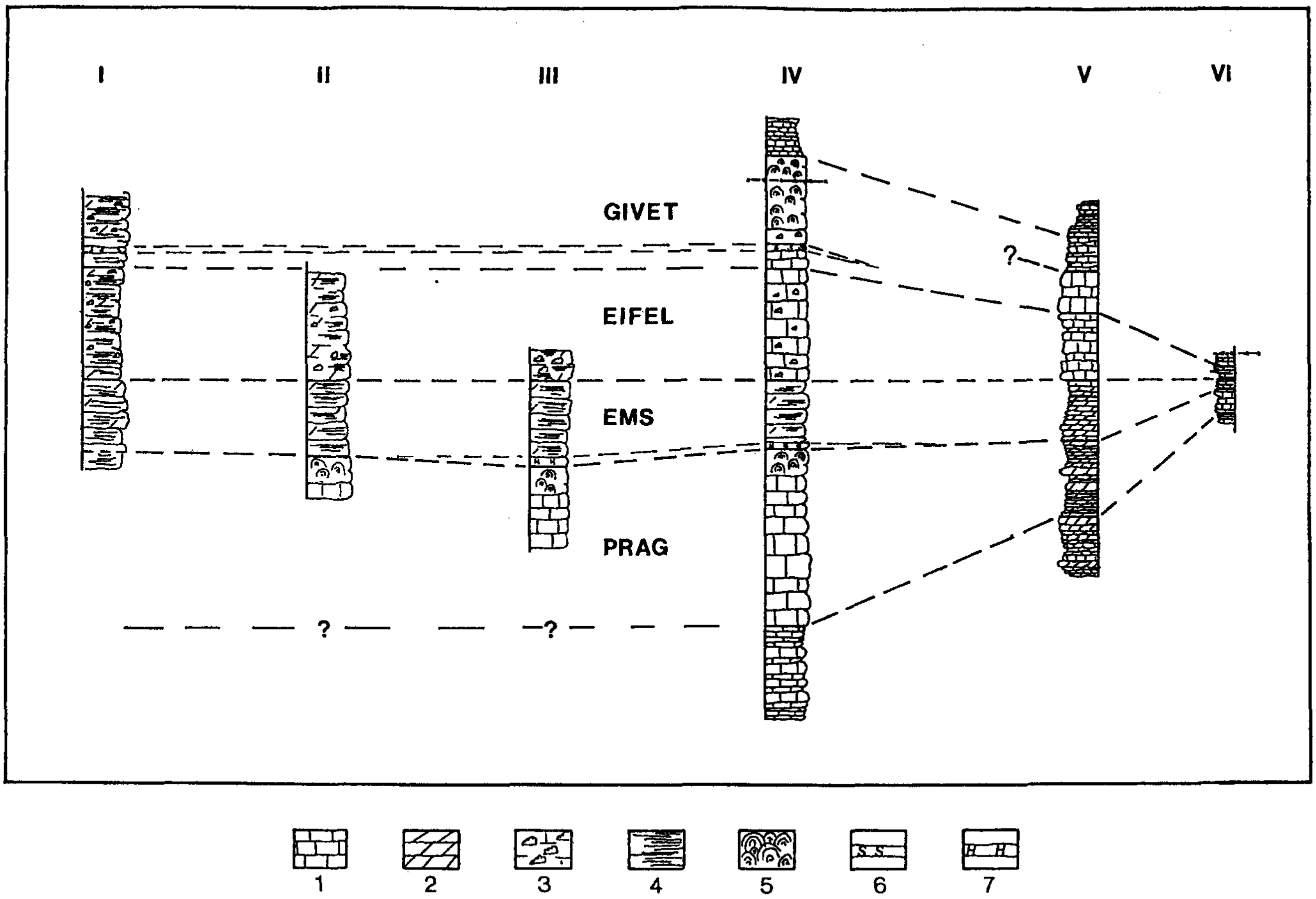

Fig. 5: Correlation of Devonian sequences in the Carnic Alps (Kreutzer 1992a).
Southern shallow water facies: I = Gamskofel; II = Biegengebirge (Austriascharte); III = Biegengebirge (Seekopf); IV = Hohe Warte, Upper Kellerwand
Transitional facies: V = Lower Kellerwand, Cellon
Pelagic limestone facies: VI: Oberbuchach
1: Bedded limestone; 2: Dolomite; 3: Birdseye limestone; 4: Laminite; 5: Reef buildups; 6: *Stringocephalus* layer; 7: *Hercynella* layer

The reef development ended in the upper *gigas* Zone (Kreutzer 1990, 1992a/b). During the following Famennian Stage the environment reflects a general trend towards a uniform pelagic setting which was finally established at the beginning of the Carboniferous Period (Fig. 3). The Lower Carboniferous Kronhof Limestones represents such a cephalopod-trilobite bearing wackestone.

The forementioned pelagic limestones facies grades to the north-northeast into the coeval siliciclastic Zollner Formation of facies belt 4. At the base of the Pragian Stage this lithology succeeded the Silurian to Lochkovian graptolite bearing Bischofalm Formation and continued into the Lower Carboniferous. Yet, only few localities are known in which interbedded limestones and siliciclastic layers occur (Dellachalm Shale). Schönlaub (1985) interpreted these green shales as a transition between the phacoid Findenig Limestone and the Zollner Formation.

The Karawanken Alps

The Devonian outcrops in the Karawanken Alps occur within a tectonic window called "Seeberg Aufbruch" (Rolser & Tessensohn 1974, Fig. 6) and "Eisenkappel Aufbruch", respectively, the latter being located close to the Periadriatic Fault (Fig. 1). Along the river Trögern the Eisenkappel Aufbruch ranges from the Upper Ordovician to the Permian. The Ordovician limestones resemble those from the Carnic Alps. According to Tessensohn (1983) the Silurian succession exhibits rich occurrences of biostratigrahically important faunas which is closely related to coeval faunas of the Carnic Alps. With regard to the Devonian reef environment, the Seeberger Aufbruch represents the most important structure of the whole Karawanken Alps. In this area the following tectonic units can be subdivided from top to base (Fig. 6):

- Triassic of Steiner Alpen
- Reef Unit ("Riffkalkeinheit" - pelagic, near reef and reef core and volcanic Devonian)
- Banded limestone Unit ("Bänderkalk" - Upper Devonian to Lower Carboniferous striated banded limestones)
- Basal Unit (exposed in the "Seeberg - Fenster" - Upper Carboniferous shales and limestones)

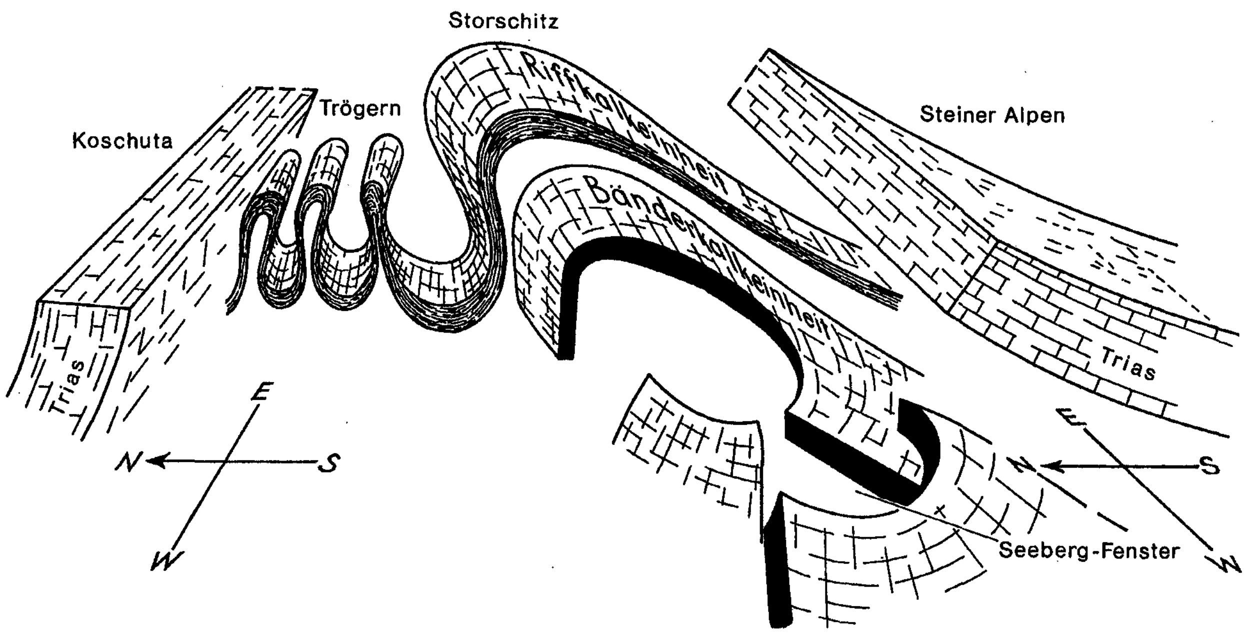

Fig. 6. The main tectonic units of the Seeberg area of the Eastern Karawanken Alps (after Rolser & Tessensohn 1974).

A revision of older stratigraphic data and introduction of new methods including study of the petrofacies were carried out by Kupsch et al. (1971) and Tessensohn (1974a,b). According to these authors the Seeberg realm represents Paleozoic sediments which range from the Silurian to the Permian. More recently, Rantitsch (1992) studied the relationship between the different Devonian lithologies and in particular the reef limestone development wich were strongly dislocated by Alpine tectonics.

The Devonian limestone sequences comprises the Devonian to Carboniferous banded limestone ("Bänderkalk") and the reef limestone unit forming an anticlinal structure. Both units are underlain and covered by clastic rocks. According to Tessensohn (1974a, 1983) the limestone sequences of the reef unit comprises an environment which ranges from reef buildups to reddish pelagic phacoidal limestones of Devonian to Lower Carboniferous age. The main reef environment is exposed in the centre of the Seeberg Aufbruch at the localities "Storschitz", "Gut Haller"and "Christophorus-Rock" and is represented by massive limestones. Recently these strata were restudied by Rantitsch (1992) who confirmed 8 different types of microfacies for the near reef realm of the back-reef, the reef-core and the debris facies. As the centre of the reef-core he identified a Stromatoporoid-*Renalcis* facies with a debris area in front. On the back side of the reef core lagoonal and platform carbonates are developed. Rantitsch concluded a reef system in which the facies belts interfinger within short distances. According to Tessensohn 1983 southwest of the locality Sadonig-Höhe clastic rocks occur within the Reef unit. In the shales and greywackes basic to intermediate tuffs as well as some phacoidal limestone beds are intercalated. Based on conodonts a Middle Devonian age has been demonstrated for these beds by Loeschke & Rolser (1971).

In addition to the main reef development in the Karawanken Alps also an inter reef mudstone facies can be recognized suggesting a simultaneous sedimentation between single reef cores. Such a pattern may be compared with modern days atoll reefs (Rantitsch 1992).

Comparison and Conclusions:

The facial environment of the Devonian of the Karawanken Alps and its different microfacies types (Rantisch 1992) display many similarities with coeval strata of the Carnic Alps by Kreutzer (1990, 1992a,b). In both areas the biohermal reef growth lasted from the Lower Emsian to the Frasnian (Kreutzer 1990, Tessensohn 1974 a,b, 1983).

Rantitsch determined a carbonate content between 95 and 100 % indicating a very low terrigeneous influence. Similar conditions were concluded by Kreutzer (1990) for the Carnic Alps. According to Tessensohn (1794a, 1983) and Rantitsch (1992) the fauna of the reef and back-reef area are dominated by representatives of *Favosites, Heliolites, Thamnopora, Renalcis, Amphipora, Thamnophyllum.* The same association occurs in the Carnic Alps (Kreutzer 1990, 1992a,b, Oekentorp-Küster & Oekentorp 1992). In the Devonian of the Carnic Alps Kreutzer estimated the transition from intertidal flats to the pelagic limestone facies within a distance of less than 9 km. A short transition was also postulated by Rantitsch for the facial belts of the Karawanken Alps. In addition Rantitsch proposed a model with atoll reefs in the Devonian of the Karawanken Alps. According to Kreutzer (1990) in some areas of the Carnic Alps reef core sedimentation is interrupted by low energy sediments. Yet, the only proof of volcanic activity in the Devonian of the Carnic Alps are layers resembling tuffites which are intercalated in the Lower Devonian Findenig Limestone. Finally, with consideration to the very low terrestrail influx of the limestone sequences the intertidal realm of the Biegengebirge area of the Carnic Alps suggests an island setting.

In conclusion, during the Devonian the Carnic and the Karawanken Alps exhibit a closely similar environment. According to new investigations carried out in the past 30 years, a barrier reef belt is suggested which grades to the north into a basinal areas and to the south into a back reef lagoon or platform development. Yet, any indication of a nearby land area is missing from which a clastic input may be derived. In conclusion, the microfacial environment and the facial belts of the Carnic and Karawanken Alps closely correspond to the "model for reef and shallow water platform" of Machel and Hunter (1994).

The Graz Palaeozoic

The Graz Palaeozoic, part of the Upper Austroalpine nappe system, comprises an outcropping area of approx. 1250 km^2. Presumably, the Ordovician to Carboniferous sequences overly a metamorphic basement which is well preserved in a marginal position: In the northern and western part fossiliferous Paleozoic rocks are overthrust upon the Middle Austroalpine Unit, i. e. the Gleinalm crytalline complex and in the eastern part upon the Lower Austroalpine Unit, i.e. the Raabalpen complex. In its western sector the Palaeozoic succession is unconformly overlain by the Upper Cretaceous Kainach Gosau. To the south it is covered by Neogene sediments of the "Styrian Basin".

The Graz Paleozoic represents a pile of nappes. These nappes are composed of different facies or a mixing of several facies (Flügel and Neubauer 1984). Considering lithological similarities, the tectonic position, and metamorphic superposition, a lower, an intermediate, and an upper group of nappes can be differentiated (Fig. 7):

(1) The Lower Nappe System (Upper Silurian to Lower Devonian) comprises the 'Schöckl-Group', the 'Passail-Group' and the 'Anger Crystalline Complex'. Besides the common Alpine (Early to Late Cretaceous) deformation of the Graz Paleozoic in this basal nappe system minor Variscan deformation under upper greenschist-grade overprints with exceptionally occuring amphipolite-grade conditions have been documented. Generally, volcanoclastics dominate the Late Silurian to Early Devonian, and carbonates the Middle Devonian time span.

(2) The Intermediate Nappe System (Early Silurian to Upper Devonian) consists of the 'Laufnitzdorf-Group' and the 'Kalkschiefer-Group' (Early to Upper Devonian). Both nappe groups occur in different structural levels. The former development pelagic limestones, shales and volcanoclastics are the dominating lithologies, in the latter limestones and siliciclastics.

(3) The Upper Nappe System (Upper Silurian to Upper Carboniferous) comprises the 'Rannach- and Hochlantsch-Group'. Both groups display a comparable development of facies, in particular from the Emsian to the Givetian Stages.

With regard to the palaeogeographical interpretation of the entire Palaeozoic succession, the 'Rannach- and Hochlantsch group' are considered as a nearshore development, while the 'Laufnitzdorf group' may represent an offshore setting. According to Hubmann 1993 the 'Schöckl group' occupies an intermediate position.

The overall lithologies reflect a sedimentary regime changing from a passive continental margin with a continental breakup (alkaline volcanism) to shelf and platform geometries during Silurian and Devonian times (Fritz et al. 1992). During this period the lithologic development, i.e. the alternation of dolostones and limestones (Hubmann 1993) and the occurrences of stratigraphic gaps and mixed conodont faunas (Ebner 1978) may be attributed to sea-level changes and probably also synsedimentary tectonics. An overview of the lithologic development is shown in Fig. 7. In this figure traditional lithostratigraphic names are still used although a revision is in preparation (Flügel in prep.).

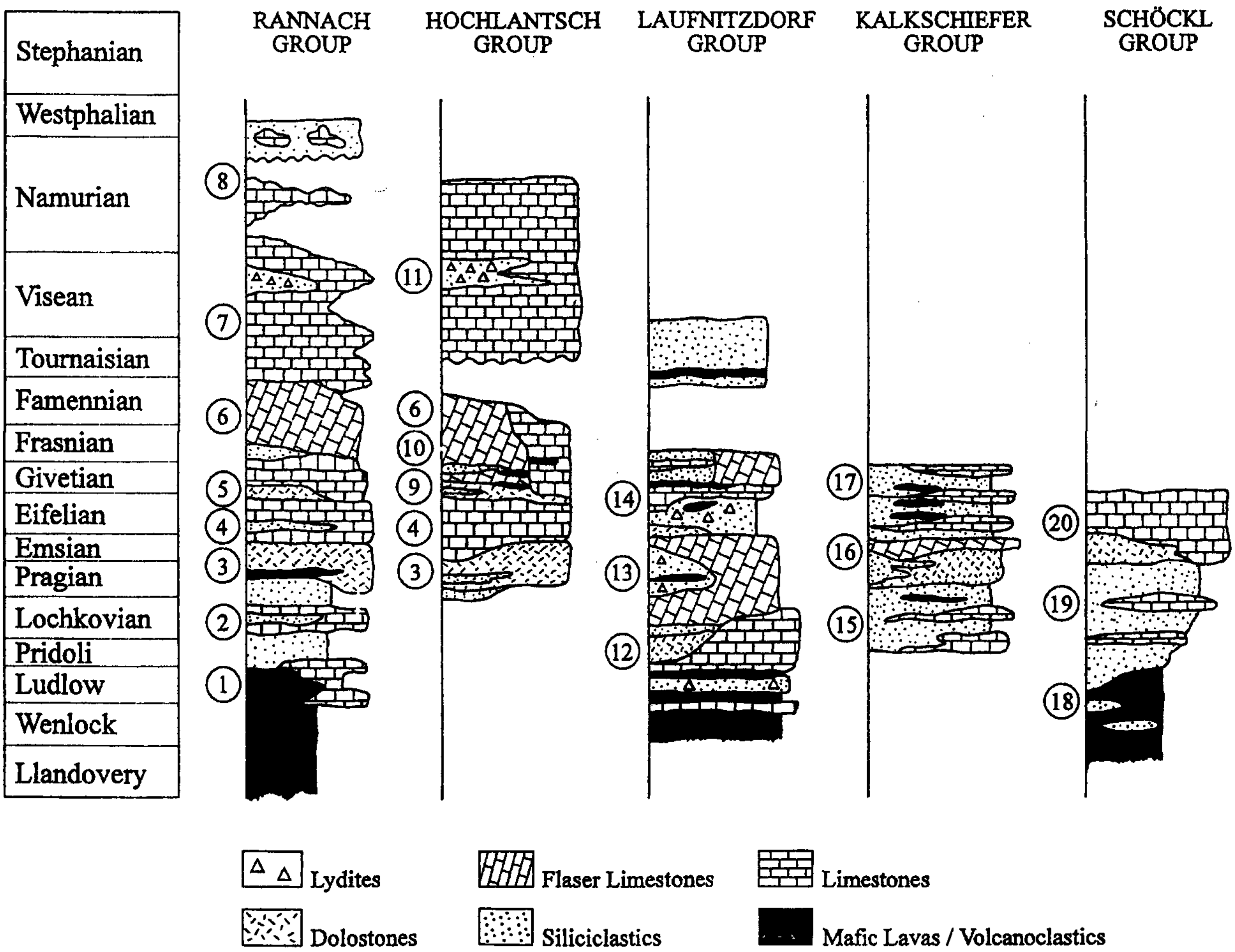

Fig. 7: Schematic stratigraphic development of the Graz Paleozoic after Hasenhüttl (1994) and Hubmann & Hasenhüttl (1995).
1 Kher Formation, 2 Parmasegg Formation, 4 Barrandei Limestone, 5 Kanzel Limestone, 6 Steinberg Limestone, Platzlkogel Formation, Höllererkogel flaser limestone, Grösskogel flaser limestone, 7 Sanzenkogel Limestone, 8 Dult Formation 9 Tyrnaueralm Formation, 10 Hochlantsch Limestone, 11 Mixnitz Formation, 12 Hackensteiner Formation, 13 Harrberger Formation, 14 Schattleitner Formation, Dornerkogel Formation, 15 Kogler Formation, 16 Heuberg Formation, Sommeralm complex, 17 Gschwendt Formation, 18 Passail Formation, Waldstein Formation, 19 Arzberg Formation, 20 Schöckl Limestone, Hochschlag Limestone.

Efforts to demeonstrate the faunal relationships between the Paleozoic of Graz and other remnants of the Paleozoic of Central Europe, especially the Rhenohercynian zone date back to the pioneering phase of paleontological research in the surroundings of Graz. In particular the very fossiliferous late Emsian to Eifelian formations of the Graz Paleozoic e.g., the Barrandei Limestone-Formation are well suited for faunal relations due to its diversified and abundant list of fossils (Flügel 1975). However, there is a strong need to revise older identifications and to demonstrate its potential for comparison beyond such a limited geographic area like the Alps. For example, the taxonomy of some Green Algae and tabulate corals was recently the subject of detailed studies (Hubmann 1990, 1991, in prep.) to demeonstrate rather close biogeographic links with the Rhenohercynian Zone, the Moravian Karst and the Cantabrian Mountains (Hubmann 1991, 1995, Herrmann & Hubmann 1994).

The Paleozoic of southern Burgenland

Since the last century rocks of presumably Devonian age have been known from southern Burgenland. They comprise shales, limestones and dolomites of unknown cumulative thickness which occur in some scattered outcrops near the villages of Hannersdorf and the town of Güssing, respectively. A newly discovered fossil assemblage of conodonts, rugose and tabulate corals and crinoid debris clearly indicates an Upper Emsian age for at least parts of the carbonate sequence. Based on these new biostratigraphic data as well as the general facies development in this region an original close connection with the neighbouring fossiliferous sequences in the surroundings of Graz seems well established (Schönlaub 1994). This conclusion is strongly supported by frequently occurring dolomitic rocks of Lower Devonian age in the subsurface of the Tertiary Basin of eastern Styria (Ebner 1988).

The Gurktal Nappe

The Gurktal Nappe represents one of the uppermost tectonic units within the pile of nappes of the Eastern Alps. It covers a wide area in Middle Carinthia but extends beyond the provincial boundary to parts of western Styria. The whole sequence comprises a variety of greenshist-grade metamorphic rocks of volcanic and sedimentary nature, such as basic and acid volcanics of mainly Ordovician and Silurian age, siliciclastics and carbonate rocks, the latter being of predominantly Devonian age (Fig. 8). Already in the first half of this century from a few localities fossils of Lower Paleozoic age were recorded indicating the above mentioned age assignments and thus an almost equivalent facies with parts of the Graywacke Zone in the northern Alps.

After application of research methods for microfossils, in particular conodonts many new data have been provided which are summarized in Fig. 8 . Apart from some brachiopods and crinoids occuring in marbles of the underlying "Phyllite Complex", strata equivalent to the Devonian comprise bedded limestones, nodular limestones and dolomitic rocks with intercalations of shales and graywackes.

Based on the available biostratigraphic and lithological data in the central part of the Gurktal Nappe two distinct Devonian facies occur. The first one named "Althofen facies" is dominated by different types of up to 100 m thick shallow-water and partly bioclastic limestones, the other one named "Magdalensberg facies" by mostly pelitic rocks with rather small lenticular accumulations of limestones. One of the best examples for the Devonian limestone dominated succession is displayed at the famous quarry "Aich" near Treibach-Althofen showing a complete record through the Devonian except for parts of the Middle Devonian (Schönlaub 1971). The opposing pelitic facies is dominated by fine and coarse grained clastics with some tuffaceous and limestone intercalations the tickness of which varies from 2 to 9 m. Based on conodonts different levels within the Lower, Middle and Upper Devonian (up to the Frasnian Stage) have been recognized (Buchroithner 1979, Neubauer & Pistotnik 1984).

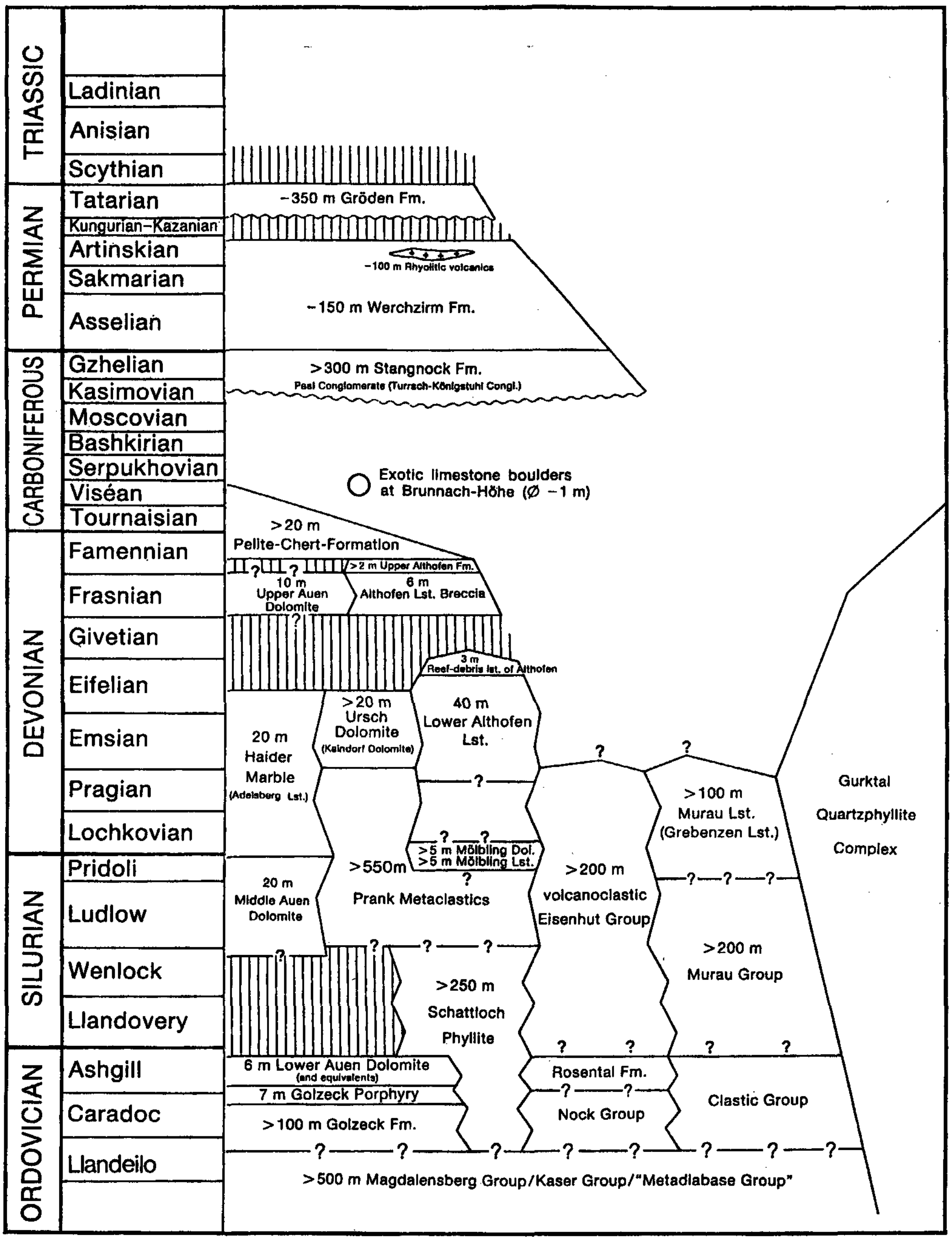

Fig. 8. Stratigraphy of the Variscan sequence of the Gurktal Nappe of Middle Carinthia and the surroundings of Murau (SW Styria). Modified from Buchroithner (1979) and Neubauer & Pistotnik (1984). (From H. P. SCHÖNLAUB 1992).

The Graywacke Zone

The Graywacke Zone represents the Paleozoic basement of the Northern Limestone Alps. The West-East-directed belt of Lower Paleozoic and Carboniferous rocks extends over a distance of some 450 km and a maximum width of 23 km from the Province of Vorarlberg in the west to the town of Ternitz in Lower Austria in the east. In the following Vienna Basin the eastern continuation is covered by sedimentary rocks of Tertiary age.

Although in the Graywacke Zone fossil remains have been found as early as 1847 main progress towards a modern biostratigraphic framework was not achieved until the early 1960s when conodont studies were first employed in the Styrian and Tyrolean part of this zone. Since then a great deal of new and fundamental data were supplied accompanied by analysis of facies, geochemical analysis of volcanics and new maps (see summary by Schönlaub & Heinisch 1993).

In the Eastern Graywacke Zone limestone sedimentation passed without any breaks from the Silurian into the Devonian. Different from other regions in the Alps splitting of facies is less pronounced in the Devonian. Generally, the equivalents of the Lower Devonian are charakterized by platy limestones which laterally pass into dacryoconarid bearing reddish limestones with marly and bioclastic interbeds.

In the eastern part of the Graywacke Zonethe majority of the Devonian sections end at or close to the Lower/Middle Devonian boundary. At few localities, however, strata equivalent to the Frasnian and basal Famennian overly unfossiliferous rocks suggesting that sedimentation may have lasted through the entire Devonian. During this time 200 to 300 m limestones were deposited. The Devonian sequence is disconformably overlain by a limestone breccia and the 100 to 150 m thick clastic Eisenerz Formation of Lower to Middle Carboniferous age (Fig. 9).

In the western Graywacke Zone of Tyrol and Salzburg an obvious heterogenity of facies has recently been recognized. According to Heinisch et al. (1988) within short distances two distinct facies are developed which comprise the Wildseeloder and the Glemmtal Unit, respectively (Fig. 9). In the first in the Upper Silurian a carbonate platform formed which lasted until the early Upper Devonian. It consists of shallow water lagoonal dolomites, a local reef development and pelagic limestones of Frasnian age (Mostler 1970, Schönlaub 1979). The Glemmtal Unit is distributed to the south of the former. The Devonian part consists of siliciclastic sediments with intercalations of condensed cephalopod limestones and interbedded cherts and black siliceous shales named Klingler Kar Formation. In addition, in the Pragian and presumably also in the Middle and Upper Devonian (?)2 to several hundred meters thick intercalations of basic magmatites occur ranging from lavas, pyroclastic rocks and tuffites. Based on trace elements they are of intraplate origin. They also interfinger with medium to fined grained sandstones, siltstones and shales termed Löhnersbach Formation. Both the clastic and limestone sequences are overlain by the unfossiliferous Schattberg Formation. In conclusion, during the Silurian and the Devonian in the western segment of the Graywacke Zone the shallow water platform regime of the Wildseeloder Unit existed contemporaneously to the basin and "seamount" facies of the Glemmtal Unit. The only connecting link was the Ordovician Blasseneck Porphyry which, however, also reflects some lithological differences in both tectonic units.

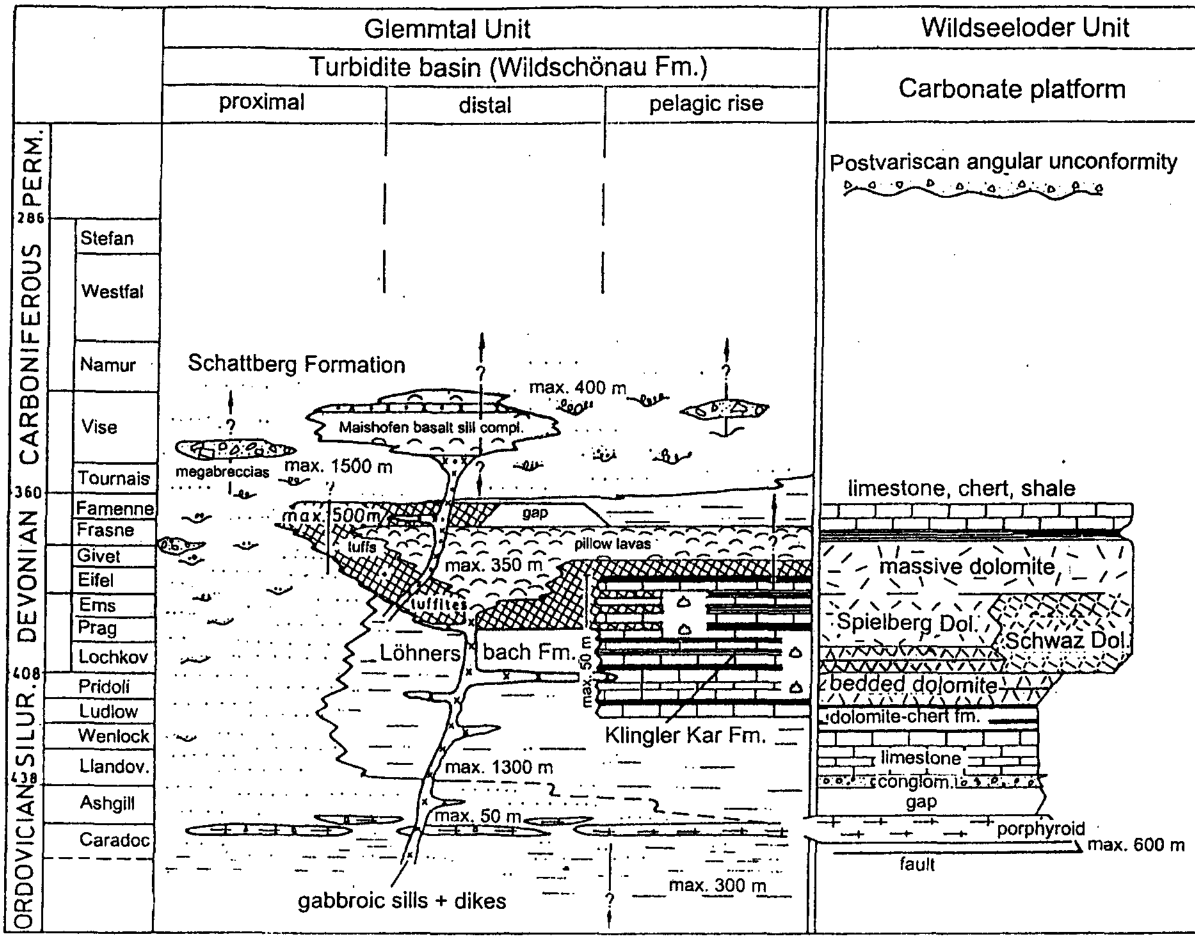

Fig. 9. Stratigraphy of the Graywacke Zone in the surroundings of Kitzbühel and Saalbach (after H. Heinisch 1988).

References

BACHTADSE, V., TORSVIK, T. H., TAIT, J. A. & SOFFEL, H. C. (1995): Paleomagnetic Constraints on the Paleogeographic Evolution of Europe During the Paleozoic. In: Pre-Permian Geology of Central and Eastern Europe, Dallmeyer et al. (eds.), 567 - 578.

BANDEL, K. (1969): Feinstratigraphische und biofazielle Untersuchungen unterdevonischer Kalke am Fuß der Seewarte (Wolayer See, Zentrale Karnische Alpen).- Jb. Geol. B.-A., 112: 197-234, Wien.

BANDEL, K. (1972): Palökologie und Paläogeographie im Devon und Unterkarbon der Zentralen Karnischen Alpen.- Palaeontographica, 141, Abt. A: 1-117, Stuttgart.

BANDEL, K. (1974): Deep-water limestones from the Devonian-Carboniferous of the Carnic Alps, Austria.- Spec. Publs. Int. Ass. Sediment., 1974/1: 93-115, Oxford.

BUCHROITHNER, M. F. (1979): Biostratigraphische und fazielle Untersuchungen im Paläozoikum von Mittelkärnten. - Carinthia II, 169/89: 71-95, Klagenfurt.

DULLO, W.-C. (1992): Mikrofazies und Diagenese der Oberordovizischen Cystoideen-Kalke (Wolayerkalk) und ihrer Schuttfazies (Uggwakalk) in den Karnischen Alpen.- Jb. Geol. B.-A., 135/1: 317-333, Wien.
EBNER, F. (1973): Foramminiferen aus dem Paläozoikum der Karnischen Alpen.- Mitt. Abt. Geol. Paläont. Bergb. Landesmus. Joanneum, 34: 3-24, Graz.
EBNER, F. (1978): Stratigraphie des Karbon der Rannachfazies im Paläozoikum von Graz, Österreich.- Mitt. Österr. Geol. Ges., 69: 163-196, Wien.
EBNER, F. (1988): Das Paläozoikum in den RAG-Bohrungen Blumau 1, 1a und Arnwiesen 1 (Oststeirisches Tertiärbecken). - Jb. Geol. B.-A., 131, 563 - 573, Wien.
FERRARI, A. & VAI, G.B. (1965): Richerche stratigraphiche e paleoechologiche al Monte Zermula.- Giorn. Geol., 33: 389-406, Bologna.
FLÜGEL, H.W. & NEUBAUER, F. (1984): Steiermark. Erläuterungen zur Geologischen Karte der Steiermark.- Geol. B.-A., 1-127, Wien.
FLÜGEL, H.W. (1975): Die Geologie des Grazer Berglandes.- Mitt. Abt. Geol. Bergbau Landesmus. Joanneum, 1: 1-288, Graz.
FRITZ, H., EBNER, F. & NEUBAUER, F. (1992): The Graz Thrust-Complex (Paleozoic of Graz).- Alcapa-Field Guide, IGP/KFU: 83-92, Graz.
GALLI, G. (1985): Depositional Environments in the Devonian Limestone Succession of the Cima Ombladet (Carnic Alps, Italy).-Facies, 12: 97-112, Erlangen.
HASENHÜTTL, C. (1994): Eine Wärmegeschichte des Grazer Berglandes.- Unpubl. Doctoral Thesis Univ. Graz: 1-165 + i-xvii, Graz.
HEINISCH, H. (1988): Hinweise auf die Existenz eines passiven Kontinentalrandes im Altpaläozoikum der Nördlichen Grauwackenzone. - Schweiz. Mineral. Petrogr. Mitt., 68, 407 - 418.
HEINISCH, H., SPRENGER, W. & WEDDIGE, K. (1987): Neue Daten zur Altersstellung der Wildschönauer Schiefer und des Basaltvulkanismus im ostalpinen Paläozoikum der Kitzbüheler Grauwackenzone (Österreich). - Jb. Geol. B.-A., 13: 163-173, Wien.
HERRMANN, R. & HUBMANN, B. (1994): Devonian Udoteacean Green Algae from the Cantabrian Mountains (Santa LucŸa Formation), NW-Spain.- Rev. Espanola Paleont., 9/2: 195-202, Oviedo.
HUBMANN, B. - (1991): Alveolitidae, Heliolitidae und Helicosalpinx aus den Barrandeikalken (Eifelium) des Grazer Devons.- Jb. Geol. B.-A., 134/1: 37-51, Wien.
HUBMANN, B. (1990): Udoteaceen (Grünalgen) aus dem Grazer Paläozoikum/Österreich (Barrandeikalke, Eifelium).- Facies, 22: 147-158, Erlangen.
HUBMANN, B. (1993): Ablagerungsraum, Mikrofazies und Palöoökologie der Barrandeikalk-Formation (Eifelium) des Grazer Paläozoikums.- Jb. Geol. B.-A., 136/2: 393-461, Wien.
HUBMANN, B. (1995): Middle Devonian shallow marine deposits of the Graz Paleozoic: fact and fiction for deposition under ecological stress.- Beitr. Paläont., 20: 107-112, Wien.
HUBMANN, B. & HASENHÜTTL, C. (1995): Zur Entwicklung der hohen Deckengruppe des Grazer Paläozoikums. Exkursionspunkte zu ausgewöhlten Profilen.- Exkursionsführer 2. Tagung Österr. Paläont. Ges., 1-43, Graz.
KREUTZER, L.H. (1989): Reef-basin distance in the Devonian of the Carnic Alps.- Ann. Soc. Geol. Belg., 112: 159-163, Liège.
KREUTZER, L.H. (1990): Mikrofazies, Stratigraphie und Paläogeographie des Zentralkarnischen Hauptkammes.- Jb. Geol. B.-A., 133/2: 275-343, Wien.
KREUTZER, L.H. (1992a): Palinspastische Entzerrung und Neugliederung des Devons in den Zentralkarnischen Alpen aufgrund von neuen Untersuchungen.- Jb. Geol. B.-A.; 135/1, 261 - 272, Wien.
KREUTZER, L.H. (1992b): Photoatlas zu den variszischen Karbonat-Gesteinen der Karnischen Alpen (Österreich/Italien). - Abh. Geol. B.-A., 47: 1-129, Wien.
KUPSCH, F., ROLSER, J. & SCHÖNENBERG, R. (1971): Das Altpaläozoikum der Ostkarawanken.- Z. dt. geol. Ges., 122: 89-96, Hannover.
LOESCHKE, J. & ROLSER, J. (1971): Der altpaläozoische Vulkanismus in den Karawanken (Österreich).- Zt. dt. geol. Ges., 122: 145-156, Hannover.

MACHEL, H.G & HUNTER, I.G. (1994): Facies Models for Middle to Late Devonian Shallow-marine Carbonates, with Comparisons to Modern Reefs: a Guide for Facies Analysis.- Facies, 30:155-176, Erlangen.
MOSTLER, H. (1970): Struktureller Wandel und Ursachen der Faziesdifferenzierung an der Ordoviz/Silur-Grenze in der Nördlichen Grauwackenzone (Österreich). - Festbd. Geol. Inst. 300-Jahr Feier Univ. Innsbruck: 507-522, Innsbruck.
NEUBAUER, F. & PISTOTNIK, J. (1984): Das Altpaläozoikum und Unterkarbon des Gurktaler Deckensystems (Ostalpen) und ihre paläogeographischen Beziehungen. - Geol. Rdsch.,73, 149-174, Stuttgart.
OECKENTORP-KÜSTER, P. & OECKENTORP, C. (1992): Rugose Korallenfaunen des Mittel- und Ober-Devons der zentralen Karnischen Alpen.- Jb. Geol. B.-A., 135/1: 233 - 260, Wien.
RANTITSCH, G (1992): Fazies und Diagenese devonischer Riffkalke des Seeberger Aufbruchs (Kärnten, Österreich).- Jb. Geol. B.-A., 135/1: 273-285, Wien.
ROLSER, J. & TESSENSOHN, F. (1974): Alpidische Tektonik im Variszikum der Karawanken und ihre Beziehung zum Periadriatischen Lineament.- Geol. Jb., A25: 23-53, Hannover.
SCHÖNLAUB, H. P. (1971): Die Althofener Gruppe - eine neue stratigraphische Einheit im Devon Mittelkärntens (Österreich). - N. Jb. Geol. Paläont., Mh., 1971: 288-305, Stuttgart.
SCHÖNLAUB, H.P. (1979): Das Paläozoikum in Österreich.- Abh. Geol. B.-A., 33: 3-124, Wien.
SCHÖNLAUB, H.P., ed. (1985): Arbeitstagung der Geologischen Bundesanstalt 1985, Kötschach-Mauthen.- Geol. B.-A., 1-87, Wien.
SCHÖNLAUB, H.P. (1992): Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its Implications for Plate Movements.- Jb. Geol. B.-A., 153/1: 381-418, Wien.
SCHÖNLAUB, H. P. (1994): Das Altpaläozoikum im Südburgenland. - Jub. Schrift 20 Jahre Geol. Zusammenarbeit Österreich-Ungarn, Teil 2, Geol. B.-A., 365-377, Wien.
SCHÖNLAUB, H.P., ATTREP, M., BOECKELMANN, K., DREESEN, R., FEIST, R., FENNINGER, A., HAHN, G., KLEIN, P., KORN, D., KRATZ, R., MAGARITZ, M., ORTH, C.J., SCHRAMM, J.-M. (1992): The Devonian/Carboniferous boundary in the Carnic Alps (Austria) - A multidisciplinary approach. - Jb. Geol. B.-A., 135/1: 57-98, Wien.
SCHÖNLAUB, H.P. & FLAJS, G. (1975): Die Schichtfolge der Nordwand der Hohen Warte (Mt. Coglians) in den Karnischen Alpen (Österreich).- Carinthia II, 165/85: 83-96, Klagenfurt.
SCHÖNLAUB, H.P. & HEINISCH, H. (1993): The Classic Fossiliferous Paleozoic Units of the Eastern and Southern Alps.- In: J. F. von RAUMER & F. NEUBAUER, eds.) Pre-Mesozoic Geology in the Alps: 395 - 422. - Springer Verl. Berlin.
SCHÖNLAUB, H.P. & KREUTZER, L.H. (1993): Lower Carboniferous Conodonts from the Cima di Plotta Section (Carnic Alps, Italy).- Jb. Geol. B.-A., 136/1: 247-269, Wien.
SCOTESE, C. R. & McKERROW, W. S. (1990): Revised World maps and introduction. In: McKERROW, W. S. & SCOTESE, C.R. (Eds.): Paleozoic Palaeogeography and Biogeography. - Geol. Soc. Mem, 12: 1-21, London.
SPALLETTA, C., PERRI, M.C. & VAI, G.B. (1983): Pattern of conodont reworking in the Upper Devonian of the Alps: palaeoenvironmental and palaeotectonic implications.- Lethaia, 16: 51-66; Oslo.
SPALLETTA, C. & VAI, G.B. (1984): Upper Devonian intraclast parabreccias interpreted as seismites.- Marine Geology, 55: 133-144, Amsterdam.
SPALLETTA, C. & VENTURINI, C. (1994): Late Devonian-Early Carboniferous syn-sedimentary tectonic evolution of the Palaeocarnic domain (Southern Alps, Italy). - Giorn. Geol., 56/2: 211-222, Bologna.
TESSENSOHN, F. (1974a): Zur Fazies paläozoischer Kalke in den Karawanken.- Verh. Geol. B.-A., 1974: 89-124, Wien.

TESSENSOHN, F. (1974b): Schichtlücken, Diskordanzen, Mischfaunen. Neue stratigraphische Ergebnisse zu einer Faziesanalyse im Devon der Karawanken.- Carinthia II, 164: 137-160, Klagenfurt.

TESSENSOHN, F. (1983): Eisenkappler und Seeberger Paläozoikum.- In: Erläuterungen zur Geologischen Karte der Karawanken 1:25.000, Ostteil. - Geol. B.-A., 32 - 45, Wien.

The Biogeographic Relationships of the Carboniferous of Austria[5]

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with 4 figures

The Carboniferous Period of the Alps is generally subdivided into the final Variscan series representing a Lower Carboniferous pelagic development in the Tournaisian and succeeding flysch deposits of Visean and Namurian age, and the post-Variscan transgressive cover sediments of Late Carboniferous and Permian age. Both groups of rocks are separated by the Variscan unconformity. Based on new and revised data on conodonts and fusulinids in the Southern Alps the pre-Variscan strata were deformed between the late Namurian *Gastrioceras*-Zone and the Upper Miatchkovian of the late Middle Carboniferous in the Russian terminology (F.KAHLER 1983, H.P. SCHÖNLAUB, unpubl.), the latter corresponding to the West European Westfalian D Substage.

From the older cycle only few biogeographically relevant data are yet available which mostly comprise cosmopolitan groups like goniatites and some pelagic trilobites. According to D. KORN (in H.P. SCHÖNLAUB et al. 1988) and D. KORN 1992 across the Devonian/Carboniferous boundary a complete succession of ammonoids occur which indicate continuous pelagic sedimentation in an open marine pelagic environment comparable to many other places in the world, e.g., Rhenish Massif, Sauerland, Moravia, Southern France or South China. Similarly, trilobites are related to Cornwall and north Devon as well as to the Rhenish Massif, Frankenwald, Montagne Noire, the Sudetes, Poland, the Urals, Kazakhstan and southeast China (R. FEIST 1992). Some of these faunas are characterized by blind or reduced eyes indicating benthonic forms of moderately deep waters; some, however, represent fully blind trilobites yet not known from elsewhere in the Variscan basin (G. HAHN & R. KRATZ 1992). Nevertheless, loose relations do exist to Sauerland, Thuringia, Poland and England.

Floras from the Culmian Hochwipfel flysch of the Carnic Alps are of little biogeographic significance. According to H. W. J.van AMEROM et al. 1984 these new discoveries indicate similarities to the Erzgebirge (Chemnitz), Silesia, Thuringia, CZ, the Black Forest, France and Scotland.

In contrast to these reports and, hence, of special interest is the so-called "Carboniferous of Nötsch" from north of the Gail valley and west of Villach in Carinthia (Fig. 1). With regard to its lithology and the rich and diversified fossil content the Carboniferous of Nötsch has long been regarded as being unique and distinct for the whole Alps. The latest Visean or, more probably, Early Namurian fossil assemblage (H.P.SCHÖNLAUB 1985, G. SCHRAUT 1996) comprises brachiopods, trilobites, gastropods, bivalves, crinoids, corals, bryozoans, foraminifera, ostracods, plants and algae; yet, only a small part has been studied.

[5] Updated version of a chapter from the author's original paper of 1992 (Jb. Geol. B.-A., 135, 381 - 418).

According to G. & R. HAHN 1973 the trilobite fauna is characterized by its special Tethyan aspect with some similarity to coeval occurrences in the Veitsch Nappe of the Graywacke Zone of Styria. Subsequently this view was rejected by G. HAHN & R. HAHN 1987 when they recovered additional trilobites showing a strong relationship with the Kohlenkalk of Belgium. They then concluded a mixing of Asiatic-Australian, i.e., Tethyan and West-European trilobites. Based on additional rich material, however, G. SCHRAUT 1990, 1996 finally emphasized a strong affinity of trilobites to the Western European Kohlenkalk facies of Belgium and England ("European Province" of R. M. OWENS & G. HAHN 1993) and even to North America, and less close similarities to Russia, Asia and Australia. Even ostracods follow these suggested pathways and are closely related to the Kohlenkalk region and in particular to the north America Midcontinent. Different from trilobites, in eastern direction they show strong affinities to the Urals, Sibiria, China, Japan and Kazakhstan.

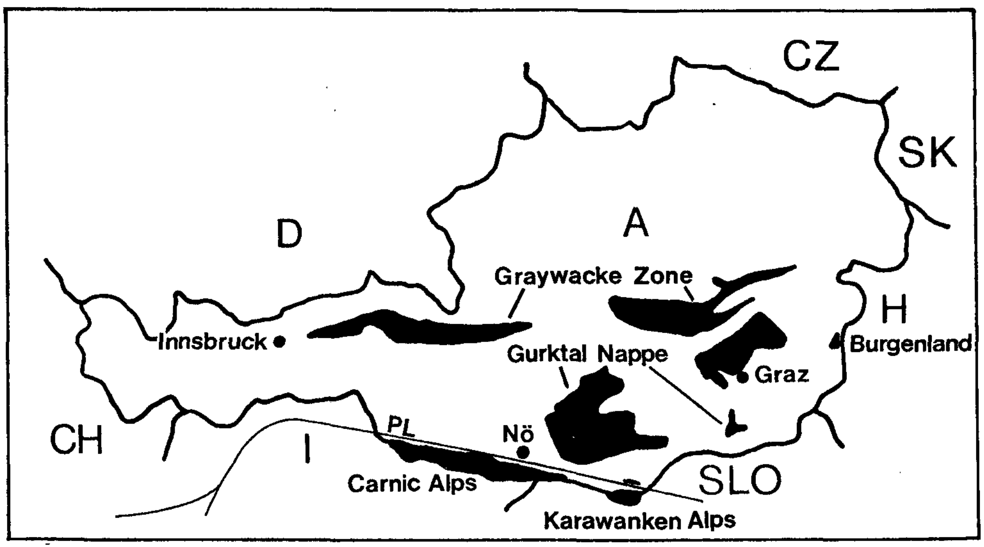

Fig. 1. Main regions with fossiliferous Paleozoic strata in the Eastern and Southern Alps (PL = Periadriatic Line, Nö = Nötsch).

The rich faunal and floral association of the Carboniferous of Nötsch represents a shallow water environment characterized by full marine conditions, agitated water, penetration of light and significant nutrient supply. Temporary, however, this environment was replaced by thick gravity flows named Badstub-Breccia which were formed as proximal inner fan or slope deposits along an active plate margin (H.P.SCHÖNLAUB 1985, K. KRAINER & A. MOGESSIE 1991, K. KRAINER 1992).

Such an inferred plate margin position seems strongly corroborated by other evidence. According to E.FLÜGEL & H.P.SCHÖNLAUB 1990 in the Carboniferous of Nötsch as well as in the Hochwipfel Formation of the Southern Alps (Carnic Alps) there occur exotic limestone clasts of varying microfacies-types. They indicate a shallow carbonate water setting of an open marine and restricted shelf environment during the Visean (Fig. 2). Presumably, this platform development existed north of the Gailtal Line and adjacent to a supposed land area. Yet, no relics of this platform have been preserved. The only records are some limestone clasts and paleoenvironmentally significant fossils such as the heterocoral *Hexaphyllia mirabilis* (DUNCAN), the algae *Pseudodonezella tenuissima* (BERCHENKO), the foraminifera

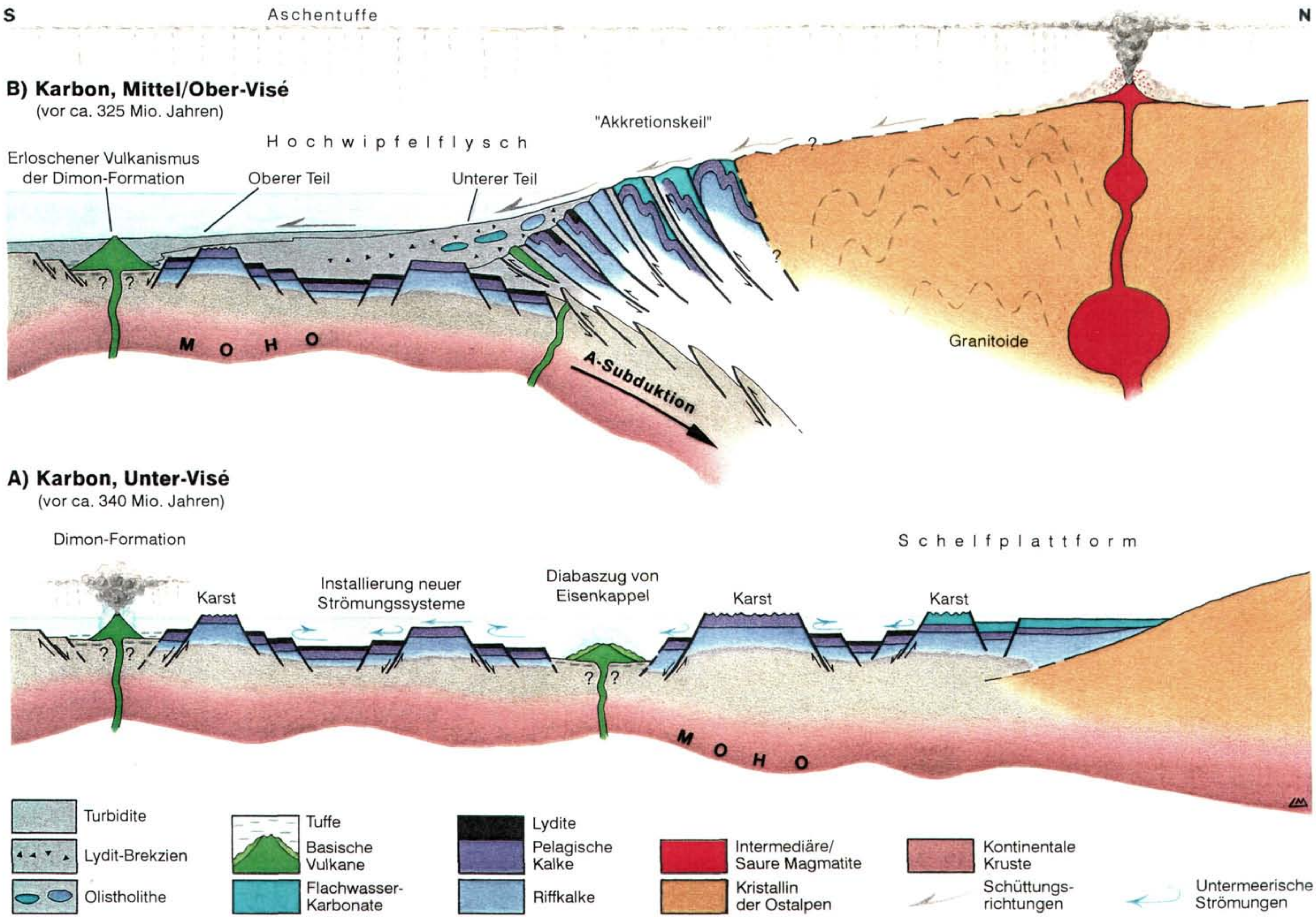

Fig. 2.
Geodynamic model of the tectonic and sedimentary history of the Southern and Central Alps in the Lower Carboniferous (after A. LÄUFER et al. 1993, modified).

Howchinia bradyana (HOWCHIN) and abundant conodont faunas corresponding to the *Eumorphoceras*-Stage E2 of the basal Namurian. Recently in other parts of Carinthia apparently coeval limestone clasts of boulder size were found (H.SCHLÖSER et al. 1990).

Litho- and biofacies of the forementioned exotic limestone clasts exhibit strong affinities to the Kohlenkalk Facies of various parts of Europe (Belgium, France, England, Poland), but also to Hungary, the eastern and southern Carpathians, the Pyrenees, southern Spain, northern Africa, the Donets Basin and the Urals (E. POTY 1981, H.-G.HERBIG 1986, E.FLÜGEL & H.-G.HERBIG 1988, F. EBNER 1990, D.HENNINGSEN & H.-G.HERBIG 1990, H. SCHLÖSER et al. 1990). Moreover, the supposed setting on an active continental margin and its formation through successive erosion of an accretionary wedge during a collision of two different plates reflect a remarkable coincidence between the Eastern Alps and the western part of the Mediterranean (see A. LÄUFER, J. LOESCHKE & B. VIANDEN 1993).

Besides the lowermost Carboniferous during which the end-Devonian climate prevailed, the available paleoclimatic data from the Southern Alps, the Carboniferous of Nötsch and the Veitsch Nappe of the Graywacke Zone suggest an increase of temperature and humidity during the Visean. Of particular significance is a widespread emersion that occurred in the lengthy *Scaliognathus anchoralis*-conodont-Zone, i.e., at the Tournaisian/Visean boundary prior to the deposition of transgressive cherts and the succeeding flysch deposits. It resulted in a variety of buried paleokarst features like an extensive relief and small-scale disconformities, mixed faunas, coated fissures, collapse breccias, caves with internal fillings and mineralizations which recently have been recognized in the Carnic Alps and most probably also occurred in the Graywacke Zone and the surroundings of Graz (H. P. SCHÖNLAUB et al. 1991, H. P. SCHÖNLAUB et al. 1980, F. EBNER 1976, see Fig. 3).

In the Southern Alps Late Paleozoic sediments unconformably overlie the Variscan flysch and other basement rocks of varying age, i.e., different Silurian and Devonian strata. According to F. KAHLER 1983 the oldest transgressive sediments are Middle Carboniferous in age and, more precisely, correspond to the *Fusulinella bocki*-Zone of the Upper Miatchkovo of the Moscow Basin. This Late Paleozoic cover comprises clastic and calcareous shallow marine sediments of the Auernig Formation in the Upper Carboniferous (Kasimovian and Ghzelian Stages) followed by various Lower Permian shelf and shelf edge deposits. They represent differentially subsiding platform and outer shelf settings and are characterized by transgressive-regressive cycles that lasted from the Westfalian to the Artinskian Stage of the Lower Permian.

Upper Permian sediments rest disconformably upon the Lower Permian and its equivalents in the Dolomites, or, farther west on phyllites of the Variscan basement. They indicate a transgressive regime starting with red beds of the Gröden Formation and followed by the Bellerophon Formation of the Late Permian. This formation represents a carbonate ramp which gently dips to the southeast, but is located far east from the Permian shoreline exposed in the Dolomites of Northern Italy in the west.

Even more restricted was the extent of the sea in the Late Carboniferous. In the Upper Miatchkovo the westernmost transgressive sediments were deposited near Lake Zollner in the central Carnic Alps. From there the transgression continuously

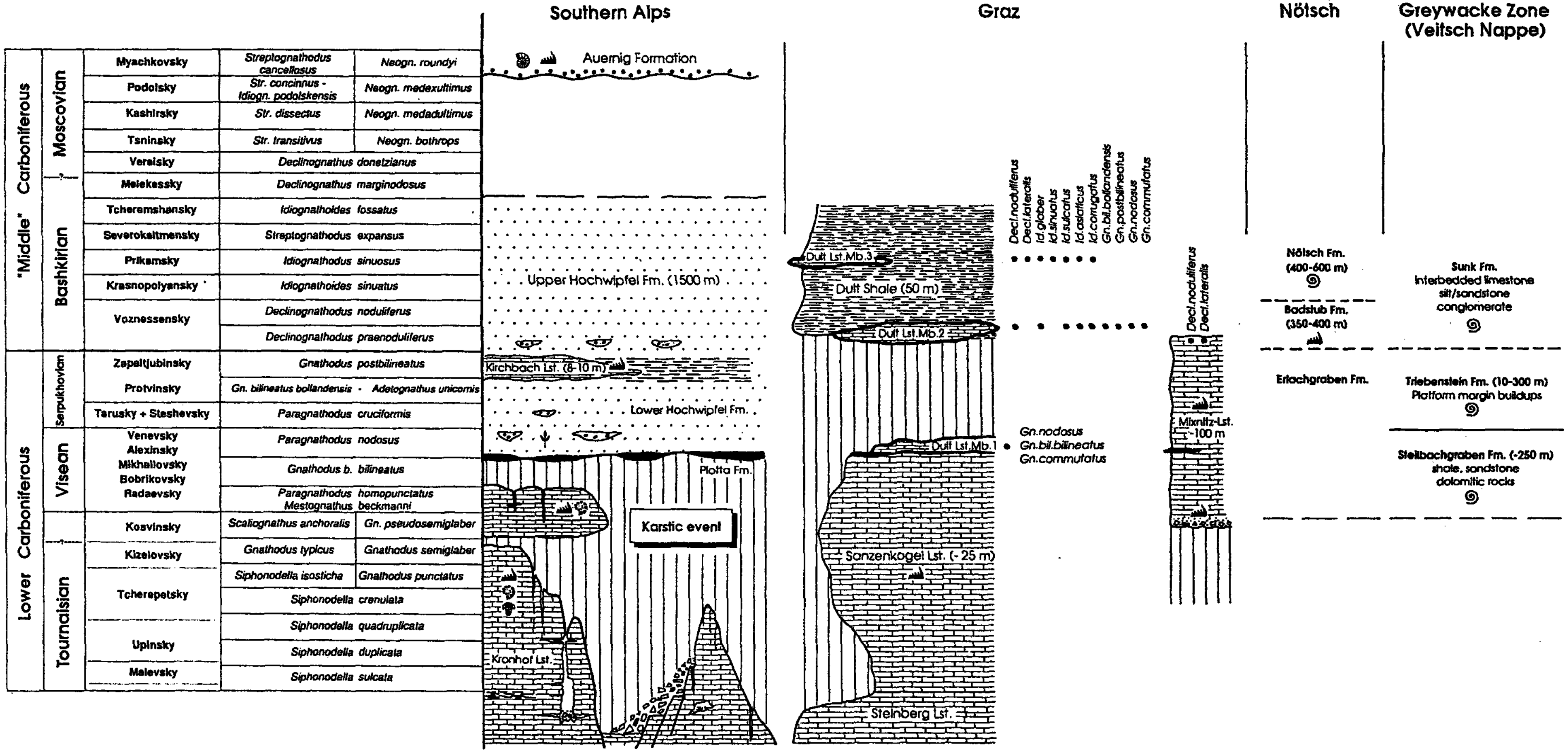

Fig. 3. Correlation of Lower Carboniferous sequences of the Southern and Central Alps.

progressed in western direction to reach Forni Avoltri and the region of the Seikofel north of the Sexten Dolomites during the Upper Carboniferous.

This whole area is very close to segments of the Periadriatic Fault Zone in the Lesach and Gail Valleys, immediately in the north. The prominent fault separates the predominantly marine post-Variscan sequences of the Southern Alps from clastic terrigenous Upper Carboniferous and Permian sediments of the Central Alps.

The marine post-Variscan sequences of the Southern Alps have long been famous for their abundant and highly diverse fossil groups. During the last few years the major part of the fauna and flora has been reinvestigated and new material was collected. Based upon these studies the following conclusions can be drawn: Fusulinids are of typical "Paleotethyan" and thus, apparently of cosmopolitan aspect showing similarities with coeval faunas in many other parts of the world, e.g., the Dinarides (Serbia, Velebit, Montenegro, Albania), the Bükk Mountains of Hungary, northern Africa (Tunis), Turkey (Anatolia), Iran (Elburs), Afghanistan, Indochina, South China, Japan as well as to the Moscow and Donets Basins, the Urals, Ferghana, Mongolia, Pamir, Greenland, northern California and Texas (F.KAHLER 1939, 1955, 1974, 1983, F. & G.KAHLER 1982); trilobites are closely related to the Karawanken Alps and the Cantabrian Mountains of northern Spain and less close to the Urals, the Moscow and Donets Basins (G. & R. HAHN 1987, G. HAHN & R. HAHN 1977, 1989); brachiopods are equally related to these regions as they have many species in common as opposed to the weak links with North America (K.L. GAURI 1965, A. RAMOVS 1972, C.F. WINKLER PRINS 1971, 1983, 1984); the ostracod fauna too suggests a close similarity with the Cantabrian Mountains of Asturia and reflects a shallow marine and low energy environment (G. RUGGIERI 1966, B. FOHRER 1990, 1991, G. BECKER 1978); sphinctozoans appear well comparable to those from New Mexico, Texas and the Cantabrian Mountains (H.-W. KÜGEL 1987); the rich coral faunas have yet not been revised but it appears that it is closely related to Russia, East Asia and China (F.HERITSCH 1936, 1943); in addition, Lower Permian faunas are of low diversity (W. HOMANN 1971); calcareous algae often occur as massive algal wackestones attributed to lense-shaped algal mud-mounds which consist of low diversity phylloid algae *(Epimastopora, Archaeolithophyllum, Eugonophyllum)* and the dasycladacean *Anthracoporella* and others (E. BUTTERSACK & K. BÖKKELMANN 1984, K. BÖCKELMANN 1985, K. KRAINER 1992) which appear of no biogeographic significance.

During the last twenty years in the Eastern Alps more than 60 localities with Upper Carboniferous and Early Permian plants were studied together with revisions of old collections (for summary see Y.G. TENCHOV 1980, A. FRITZ & M. BOERSMA 1986, 1990, M. BOERSMA & A. FRITZ 1990, A. FRITZ & K. KRAINER 1994). Besides implications for the paleoclimate and for the local facies development no distinct paleofloristic-biogeographic relationships can be inferred. Yet, its main importance is the potential for correlating West-European continental with Tethyan marine sequences which for a good deal has been demonstrated from floras of the Carnic Alps.

Conclusions

As a response to the Variscan Orogeny dramatic changes affected the Alps during the Carboniferous Period (see Fig. 2). In the Southern Alps the climax of deformation occurred between the Late Namurian and the Late Westphalian Stages, or, in the Russian terminology, between the Early Bashkirian and the Middle or Late Moscovian Stages.

In the Central Alps, however, deformation and metamorphism evidently occurred earlier. This conclusion seems well founded from radiomatric ages and from the transgressive molasse-type sediments within the Gurktal Nappe, the Carboniferous of Nötsch and the Veitsch Nappe of the Graywacke Zone. Moreover, we presented evidence that these scattered occurrences might represent the last remains of an originally vast shelf characterized by various platform sediments as opposed to the Southern Alps with contemporary flysch deposits.

During the Carboniferous this northern development was biogeographically more closely related to Western Europe and even to North America than to Eastern Europe or Asia. In particular, there appears a striking similarity with the Cantabrian Mountains, the western Mediterranean and to the "Kohlenkalk" regions of England, Belgium and Poland.

Consequently, we suspect that the Southern and Central Alps represented two different microplates during the Lower Carboniferous. This assumption confirms the suggested fragmentation of the predecessors of the Alps which has already been concluded elsewhere from the analysis of older rocks and faunas. If at all and how much they were separated is presently difficult to decide. Yet, it is worth mentioning that reworked amphibolite clasts in the Badstub Breccie of the Carboniferous of Nötsch are metamorphosed tholeiitic ocean floor basalts (T. TEICH 1982, K. KRAINER & A. MOGESSIE 1991) suggesting sometimes during the Paleozoic an enigmatic oceanic crust in this area of the Alps.

Soon after collision and amalgamation of the two plates the biogeographic patterns of the Southern Alps began to match those from the former settings in the Central Alps indicating migration of faunas and floras into the newly established Southern Alps domain where they found remarkably favourable environmental conditions. F. & G. KAHLER noted already 1982 that this new sedimentary cycle started approximately at the same time as sedimentation of the marine fusulinid-bearing strata of the Cantabrian Mountains ceased. In the light of new research, however, marine rocks of Stephanian age and *Triticites* bearing Late Kasimovian strata have been recognized there (E. MARTINEZ-GARCIA & R.H.WAGNER 1971, 1984, E. MARTINEZ -GARCIA 1984).

Most if not all suggested faunal and floral migration paths of fusulinids and other groups along the northern shelf margin of the Tethys Sea, the Ural Sea and the Arctic region to North America as well as to analogous occurrences on the southern shelf appear well constrained by the revised World Maps of C. R.SCOTESE & W. S. McKERROW for the Late Carboniferous. Possibly, dispersal of planctic groups was aided by warm subequatorial gyres which were blocked and deflected at the contact between Laurussia and Gondwana (A.M. ZIEGLER et al.1981, C.A. ROSS & J.R.P. ROSS 1985, P.H. KELLEY et al. 1990).

Potentially useful climate-sensitive sediments of Carboniferous age comprise in the Veitsch Nappe of the Graywacke Zone several tens of metres of graphite and related rocks as well as limestones and dolomites which supposedly formed in a

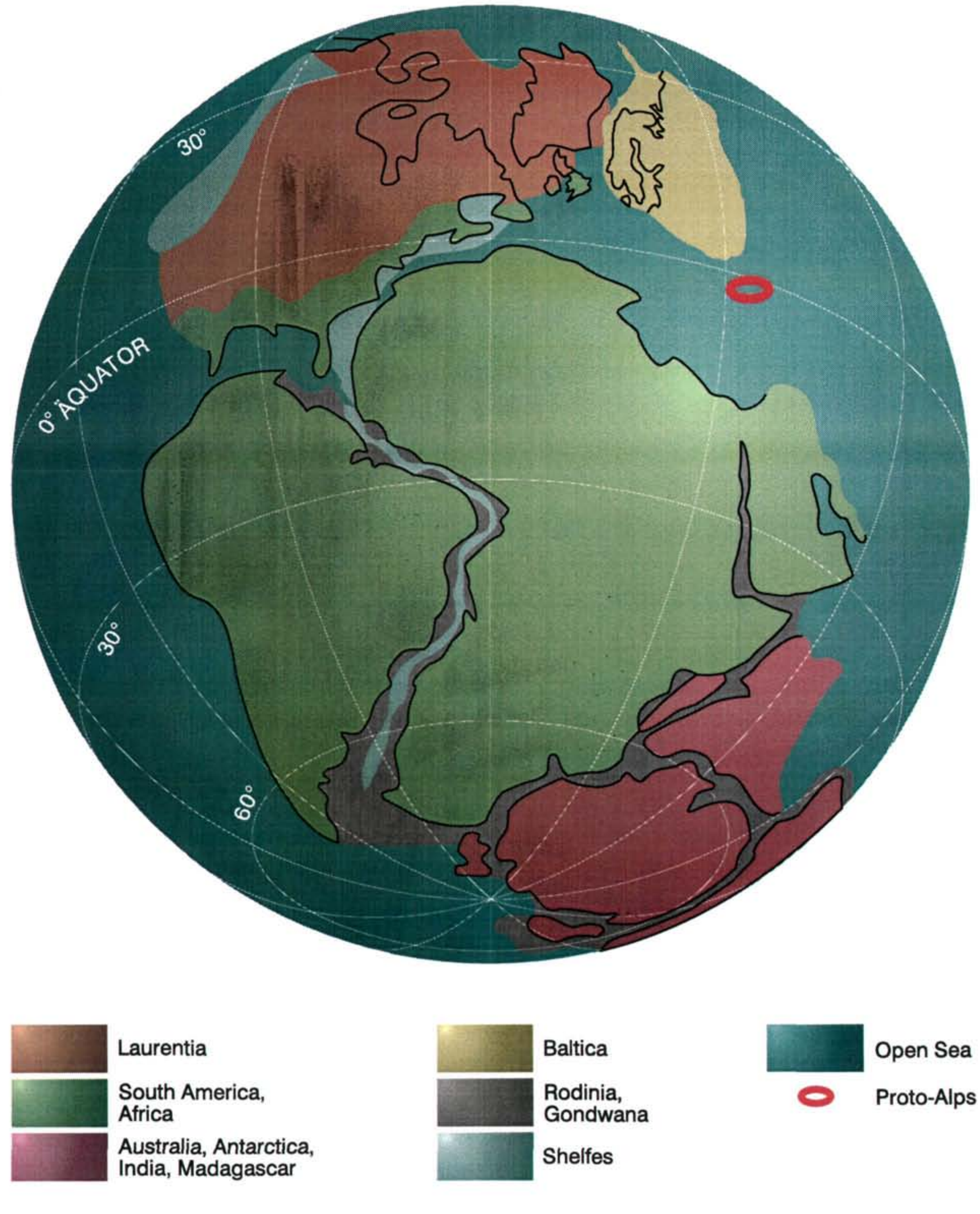

Fig. 4.
Paleogeographic reconstruction of the supercontinent Pangea in the Upper Permian at c. 260 Ma (after I. W. D. DALZIEL 1995, position of European plate strongly modified).

temporary hypersaline environment (R. RATSCHBACHER 1984). Furthermore, at many localities plants occur in rich abundances and diversity; up to a few metres thick coal seams, however, are mainly restricted to the Carnic Alps and the Gurktal Nappe. In the former they are interbedded with locally rich occurrences of corals, fusulinids, algal mud-mounds and oncoid limestones consistent with the inferred low latitudinal position close to the equator and humid climatic conditions for the Middle and Late Carboniferous of the Alps. Nonetheless, it should be kept in mind that the O_2-concentration of the Carboniferous atmosphere is still unsettled and may have varied between 13 and 35% of the present 21% level (H.D. HOLLAND 1990). Other major perturbations concern its anomalous carbon, oxygen and sulfur isotopic composition and the low CO_2 content (see T. J. ALGEO et al. 1995, H. P. SCHÖNLAUB 1996, R. A. BERNER 1997). The latter reached almost present-day values. Moreover, nutrients levels varied considerably during the Carboniferous with significant implications for the marine and terrestrial biosphere (R. MARTIN 1996).

According to J. C. CROWELL 1978, M. J. HAMBREY & W. B.HARLAND 1981, M. V. CAPUTO 1985, M. V.CAPUTO & J. C. CROWELL 1985, J. J.VEEVERS & C. Mc POWELL 1987, J. N. J. VISSER 1990, J. LANG et al. 1991, A. BOUROZ et al.1978 T. J. CROWLEY & S. K. BAUM 1991, G. GONZALEZ-BONORINO & N. EYLES 1995, N. EYLES et al. 1995, R. A. GASTALDO et al. 1996 and others the continental glaciation in the Southern Hemisphere started diachronously in the Tournaisian and Visean[6]. With varying intensities this climatic alteration caused high-latitude cooling and contemporary equatorial warming episodes which lasted until the Lower Permian. According to P. H. KELLEY et al.1990 the cooling event resulted in changes of latitudinal diversity patterns coupled with migration of different organisms, for example brachiopods. The well known "Auernig-cyclicity" in the Upper Carboniferous of the Carnic Alps may certainly be explained as a glacial rebound (K. KRAINER 1991) although alternative proposal have also been made (e.g., G.M. FRIEDMAN 1989); evidently, it was of no consequence to the biogeographic distribution of faunas and floras of that region.

At the beginning of the Carboniferous the apparent polar wander path (APWP) shows a change in the drift direction from a Devonian southward movement to a continuous and rapid northward drift of Gondwana with minimum drift rates of 10 cm a^{-1} (R. VAN DER VOO 1988, D.E. KENT & R.VAN DER VOO 1990, V.BACHTADSE & J.C. BRIDEN 1990). This rapid movement of Africa over the South Pole is hold responsible for the final disappearance of the Mid-European or Rheic Ocean besides several other oceans and the collision between Gondwana and Laurussia in the Namurian (e.g., W. S. McKERROW & A. M. ZIEGLER 1972, J. NEUGEBAUER 1988, C. R.SCOTESE & W. S.McKERROW 1990). As mentioned above the collision of the Southern Alps with the central part of the Eastern Alps can also be related to this motion; it occurred, however, slightly later at the end of the Namurian or at the beginning of the Westfalian Stage, i.e. in the Bashkirian or early Moscovian.

Fig. 4 illustrates the paleogeography of the supercontinent Pangea in the Upper Permian at c. 260 Ma. The organisation of plates resembles that from the Upper Carboniferous.

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[6] However, according to M. V. CAPUTO (pers. comm. at the James Hall Symp. Rochester, N. Y., 1996), tillites occur already in pre-expansa-Zone old deposits, i. e. in the Famennian in the Amazonas and Parnaiba Basins of Brasil; older tilltes may even be assigned to the Frasne/Famenne boundary but are as yet not dated.

References

ALGEO, T. J., BERNER, R. A., MAYNARD, J. B. & SCHECKLER, S. E. (1995): Late Devonian Oceanic Anoxic Events and Biotic Crises: "Rooted" in the Evolution of Vascular Land Plants? - GSA Today, 5/3, 63 - 66.

AMEROM, H. W. J. VAN, FLAJS, G. & HUNGER, G. (1984): Die "Flora der Marinelli Hütte" (Mittleres Visé) aus dem Hochwipfelflysch der Karnischen Alpen (Italien). - Med. Rijks Geol. Dienst, 37-3, 1 - 41.

BACHTADSE, V. & BRIDEN, J. C. (1990): Palaeomagnetic constraints on the position of Gondwana during Ordovician to Devonian times. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 43 - 48.

BECKER, G. (1978): Flachwasser-Ostracoden aus dem hohen Westfal Asturiens (Kantabrisches Gebirge, N-Spanien). 1. Palaeocopida. - Senck. leth., 59, 37 - 69.

BERNER, R. A. (1997): The Rise of Plants and Their Effect on Weathering and Atmospheric CO2. - Science, 276, 544 - 546.

BOECKELMANN, K. (1985): Mikrofazies der Auernig-Schichten und Grenzland-Bänke westlich des Rudnig-Sattels (Karbon/Perm, Karnische Alpen). - Facies, 13, 155 - 174.

BOERSMA, M. & FRITZ, A. (1990): Die Paläofloren Kärntens: Ober-Karbon/Unter-Perm. - Carinthia II, 180/49, 133 - 172.

BOND, G. C., NICKESON, P. A. & KOMINZ, M. A. (1984): Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories. - Earth Planet. Sc. Letters, 70, 325 - 345.

BOUROZ, A., EINOR, 0. L., GORDON, M., MEYEN, S. V. & WAGNER, R. H. (1978): Proposals for an international chronostratigraphic classification of the Carboniferous. - Huitième Congr. Intern. Stratigr. Geol. Carbonif., Compte Rendu 1, 36 - 52.

BUTTERSACK, F. & BOECKELMANN, K. (1984): Palaeoenvironmental Evolution during the Upper Carboniferous and the Permian in the Schulter-Trogkofel Area (Carnic Alps, Northern Italy). - Jb. Geol. B.- A., 126, 349 - 358.

CAPUTO, M. V. (1985): Late Devonian glaciation in South America. - Palaeogeography, Palaeoclimatology, Palaeoecology, 51, 291 - 317.

CAPUTO, M. V. & CROWELL, J. C. (1985): Migration of glacial centers across Gondwana during Palaeozoic Era. - Geol. Soc. Amer. Bull., 96, 1020 - 1036.

CROWELL, J. C. (1978): Gondwanan glaciation, cyclothemes, continental positioning, and climate change. - Amer. J. Sci., 278, 1345 - 1372.

CROWLEY, T. J. & BAUM, S. K. (1991): Modeling late Paleozoic glaciation. - Geology, 20, 507 - 510.

EBNER, F. (1976): Die Schichtfolge an der Wende Unterkarbon/Oberkarbon in der Rannachfazies des Grazer Paläozoikums. - Verh. Geol. B. - A., 1976, 65 - 93.

EBNER, F. (1990): Circummediterranean Carboniferous preflysch sedimentation. - In: VENTURINI, C. & KRAINER, K. (eds.): Field workshop on Carboniferous to Permian sequence of the Pramollo-Nassfeld Basin (Carnic Alps). - Proceedings, 20 - 32.

EYLES, N., GONZALEZ-BONORINO, G., EYLES, C. H., FRANCA, A. B. & LOPEZ, P. O. (1995): Hydrocarbon-bearing late Paleozoic glaciated basins of South America (A. J. TANKARD et al., eds.). - Amer. Ass. Petrol. Geol., Mem.

FEIST, R. (1992): Trilobiten aus dem Devon/Karbon-Grenzprofil an der Grünen Schneid, zentrale Karnische Alpen, Österreich. - Jb. Geol. B. - A., 135, 21 - 47.

FLÜGEL, E. & HERBIG, H. - G. (1988): Mikrofazies karbonischer Kalkgerölle aus dem Paläozoikum des Rif (Marokko): Ein Beitrag zur Paläogeographie der westmediterranen Paläotethys im Karbon. - Facies, 19, 271 - 300.

FLÜGEL, E. & SCHÖNLAUB, H. P. (1990): Exotic limestone clasts in the Carboniferous of the Carnic Alps and Nötsch. - In: VENTURINI, C. & KRAINER, K. (eds.): Field workshop on Carboniferous to Permian sequence of the Pramollo-Nassfeld Basin (Carnic Alps). - Proceedings, 15 - 19.

FOHRER, B. (1990): Verkieselte Flachwasser-Ostracoden und ihre Begleitfauna und -flora aus dem Oberkarbon der Karnischen Alpen (Nassfeld-Region, Kärnten, Österreich). Diplomarb. Inst. Paläont. Univ. Erlangen-Nürnberg, 1 - 170.
FOHRER, B. (1991): Verkieselte Flachwasserostracoden und ihre Begleitfauna und -flora aus dem Oberkarbon der Karnischen Alpen (Naßfeld-Region).- Abh. Geol. B.- A., 46, 1 - 107.
FRIEDMAN, G. M. (1989): Recent developments in Carboniferous geology: some comments. - Proc. Geol. Ass., 100, 239 - 240.
FRITZ, A. & BOERSMA, M. (1986): Fundberichte über Pflanzenfossilien aus Kärnten 1986, Beitrag 11: Tomritschrücken (Unter-Stefan), Karnische Alpen. - Carinthia II, 176, 69 - 85.
FRITZ, A. & BOERSMA, M. (1990): Die steinkohlenzeitliche Pflanzenwelt Kärntens in ihrer fossilen Überlieferung. - Carinthia II, 180, SH 49, 15 - 108.
GASTALDO, R. A., DiMICHELE, W. A. & PFEFFERKORN, H. W. (1996): Out of the Icehouse into the Greenhouse: A Late Paleozoic Analog for Modern Global Vegetational Change. - GSA Today, 6/10, 1 - 7.
GAURI, K.L. (1965): Uralian stratigraphy, trilobites and brachiopods of the Western Carnic Alps (Austria). - Jb. Geol. B.- A., SB 11, 1 - 94.
GONZALEZ-BONORINO, G. & EYLES, N. (1995): Inverse relation between ice extent and the late Paleozoic glacial record of Gondwana. - Geology, 23, 1015 - 1018.
HAHN, G. & HAHN, R. (1973): Trilobiten aus dem Unter-Karbon (Dinantium) von Nötsch (Österreich). - Geologica et Palaeontologica, 7, 135 - 146,
HAHN, G. & HAHN, R. (1977): Trilobiten aus dem Unter-Karbon der Veitsch (Steiermark, Österreich). - N. Jb. Geol. Paläont. Mh. 1977, 137 - 143.
HAHN, G. & HAHN, R. (1987): Trilobiten aus dem Karbon von Nötsch und aus den Karnischen Alpen Österreichs. - Jb. Geol. B.- A., 129, 567 - 619.
HAHN, G., HAHN, R. & SCHNEIDER, G. (1989): Neue Trilobitenfunde aus der Waidegg-Formation (hohes Oberkarbon) der Karnischen Alpen (Österreich). - Jb. Geol. B.- A., 132, 645 - 664.
HAMBREY, M. J. & HARLAND, W. B. (eds. 1981): Earth's Pre-Pleistocene Glacial Record. - Cambridge (Cambridge Univ. Press).
HENNINGSEN, D. & HERBIG, H.- G. (1990): Die karbonischen Grauwacken der Malagiden und Menorcas im Vergleich (Betische Kordillere und Balearen, Spanien). - Z. Dt. Geol. Ges., 141, 13 - 29.
HERBIG, H.- G. (1986): Rugosa und Heterocorallia aus Obervisé-Geröllen der Marbella-Formation (Betische Kordillere, Südspanien). - Paläont. Z., 60, 189 - 225.
HERITSCH, F. (1936): Die Karnischen Alpen. - Monographie einer Gebirgsgruppe der Ostalpen mit variszischem und alpidischem Bau. - 1 - 205, Graz (Geol. Inst. Univ. Graz).
HERITSCH, F. (1943): Das Paläozoikum. - In: Die Stratigraphie der geologischen Formationen der Ostalpen 1. - 1 - 681, Berlin (Borntraeger).
HOLLAND, H.D. (1990): Origins of breathable air. - Nature, 347, 17.
HOMANN, W. (1971): Korallen aus dem Unter- und Mittelperm der Karnischen Alpen. - Carinthia II, SH 28, 97 - 143.
HOMANN, W. (1972): Unter- und tief-mittelpermische Kalkalgen aus den Rattendorfer Schichten, dem Trogkofel-Kalk und dem Tressdorfer Kalk der Karnischen Alpen (Österreich). - Senck. leth., 53, 135 - 313.
KAHLER, F. (1939): Verbreitung und Lebensdauer der Fusuliniden-Gattung *Pseudoschwagerina* und *Paraschwagerina* und deren Bedeutung für die Grenze Karbon/Perm. - Senck. leth., 21, 169 - 215.
KAHLER, F. (1955): Entwicklungsräume und Wanderwege der Fusuliniden im euroasiatischen Kontinent. - Geologie, 4, 178 - 188.
KAHLER, F. (1974): Fusuliniden aus T'ien-schan und Tibet - Mit Gedanken zur Geschichte der Fusuliniden-Meere im Perm. - Repts. Sc. Exp. NW Prov. China under Leadersh. Sv. Hedin, Publ. 52, V. Inv. Palaeont., 4, 1 - 148, Sven Hedin Found. Stockholm.

KAHLER, F. (1983): Fusuliniden aus Karbon und Perm der Karnischen Alpen und der Karawanken. - Carinthia II, SH 41, 1 - 107.
KAHLER, F. & KAHLER, G. (1982): Beiträge zur Kenntnis der Fusuliniden der Ostalpen: Oberkarbonische Fusuliniden der Karnischen Alpen. - Palaeontographica A, 177, 89 - 128.
KELLEY, P. H., RAYMOND, A. & LUTKEN, C. B. (1990): Carboniferous brachiopod migration and latitudinal diversity: a new palaeoclimatic method. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 325 - 332.
KENT, D. V. & VAN DER VOO, R. (1990): Palaeozoic palaeogeography from palaeomagnetism of the Atlantic-bordering continents. - In: McKERROW, W. S. & SCOTESE, C. R. (eds.): Palaeozoic Palaeogeography and Biogeography.- Geol. Soc. Mem., 12, 49 - 56.
KORN, D. (1992): Ammonoideen vom Devon/KarbonGrenzprofil an der Grünen Schneid, Karnische Alpen, Österreich. - Jb. Geol. B. - A., 135, 7 - 19.
KRAINER, K. (1991): Neue Erkenntnisse zur geologischen Erforschung Kärntens: Nadstubbreccie (Karbon von Nötsch) und Auernigschichten (Oberkarbon der Karnischen Alpen). - Carinthia II, 181, 95 - 108.
KRAINER, K. (1992): Fazies, Sedimentationsprozesse und Paläogeographie im Karbon der Ost- und Südalpen. - Jb. Geol. B.- A., 135, 99 - 193.
KRAINER, K. & MOGESSIE, A. (1991): Composition and Significance of Resedimented Amphibolite Breccias and Conglomerates ("Badstubbreccia Complex") in the Carboniferous of Nötsch (Eastern Alps, Carinthia, Austria). - Jb. Geol. B. - A., 134, 65 - 81.
KÜGEL, H.- W. (1987): Sphinctozoen aus den Auernigschichten des Naßfeldes (Oberkarbon, Karnische Alpen, Österreich). - Facies, 16, 143 - 156.
LANG, J., YAHAYA, M., EL HAMET, M. O., BESOMBES, J. C. & CAZOULAT, M. (1991): Depots glaciaires du Carbonifère inférieur à l'Ouest de l'Air (Niger). - Geol. Rdsch., 80/3, 611 - 622.
LÄUFER, A., LOESCHKE, J. & VIANDEN, B. (1993): Die Dimon-Serie der Karnischen Alpen (Italien) - Stratigraphie, Petrographie und geodynamische Interpretation. - Jb. Geol. B. - A., 136, 137 - 162.
MARTIN, R. (1996): Secular Increase in Nutrient Levels Through the Phanerozoic: Imlications for Productivity, Biomass, and Diversity of the Marine Biosphere. - Palaios, 11, 209 - 219.
MARTINEZ-GARCIA, E. (1984): Outline of Paleozoic Stratigraphy and Structure of the Eastern Cantabrian Mountains (Northwest Spain). - In: SUTHERLAND, P.K. & MANGER, W.L. (eds.): Compte Rendu 2, 329 - 344, 9th Congr. Intern. de Stratigraphie et de Géologie du Carbonifère. Washington - Champaign - Urbana.
MARTINEZ-GARCIA, E. & WAGNER, R. H. (1971): Marine and continental deposits of Stephanian age in Eastern Asturias (NW Spain). - In: "The Carboniferous of Northwest Spain", Pt 1. - Trab. Geol., 3, 285 - 305.
MARTINEZ-GARCIA, F. & WAGNER, R. H. (1984): The Post-Asturian Marine Basin of Late Stephanian Age in Northwest Spain. - In: SUTHERLAND, P.K. & MANGER, W.L. (eds.). - Compte Rendu 2, 508 - 516, 9th Congr. Intern. de Stratigraphie et de Géologie du Carbonifère. - Washington - Champaign - Urbana.
McKERROW, W. S. & ZIEGLER, A. M. (1972): Palaeozoic Oceans. - Nature, 240, 92 - 94.
OWENS, R. M. & HAHN, G. (1993): Biogeography of Carboniferous and Permian trilobites. - Geologica et Palaeontologica, 27, 165 - 180.
NEUGEBAUER, J. (1988): The Variscan plate tectonic evolution: an improved "lapetus model". - Schweiz. Mineral. Petrogr. Mitt., 68, 313 - 333.
POTY, E. (1981): Recherches sur les Tétracoralliaires et les Hétérocoralliaires du Viséen de la Belgique. - Med. Rijks Geol. Dienst, 35, 1 - 161.
RAMOVS, A. (1972): Mittelpermische Klastite und deren marine Altersäquivalente in Slowenien, NW Jugoslawien. - Verh. Geol. B.- A., 1972, 35 - 45.

RATSCHBACHER, R. (1984): Beitrag zur Neugliederung der Veitscher Decke (Grauwackenzone) in ihrem Westabschnitt (Obersteiermark, Österreich). - Jb. Geol. B.- A., 127, 423 - 453.
ROSS, C. A. & ROSS, J. R. P. (1985): Carboniferous and Early Permian biogeography. - Geology, 13, 27 - 30.
RUGGIERI, G. (1966): Nuovo genere di ostracode del Carbonifero superiore delle Alpi Carniche. - Riv. It. Paleont., 72, 1 - 8.
SCHLÖSER, H., KULLMANN, J. & LOESCHKE, J. (1990): Korallenführendes Unterkarbon auf der Brunnachhöhe (Nockgebiet, Gurktaler Decke, Österreich). - Carinthia II, 180, 643 - 650.
SCHÖNLAUB H. P. (1996): Scenarios of Proterozoic and Paleozoic Catastrophes: A Review. - Abh. Geol. B. - A., 53, 59 - 75.
SCHÖNLAUB, H. P. (1985b): Das Karbon von Nötsch und sein Rahmen. - Jb. Geol. B.- A., 127, 673 - 692.
SCHÖNLAUB, H. P. & KREUTZER, L. H. (1993): Lower Carboniferous Conodonts from the Cima di Plotta Section (Carnic Alps, Italy). - Jb. Geol. B. - A., 136, 247 - 269.
SCHÖNLAUB, H. P., G. FLAJS & F. THALMANN (1980): Conodontenstratigraphie am Steirischen Erzberg (Nördliche Grauwackenzone). - Jb. Geol. B. - A., 123, 169 - 229.
SCHÖNLAUB, H.P., FEIST, R. & KORN, D. (1988): The Devonian/Carboniferous Boundary at the section "Grüne Schneid" (Carnic Alps, Austria): A preliminary report. - Cour. Forsch. Inst. Senckenberg, 100, 149 - 167.
SCHÖNLAUB, H. P., KLEIN, P., MAGARITZ, M. RANTITSCH, G. & SCHARBERT, S. (1991): Lower Carboniferous Paleokarst in the Carnic Alps (Austria, Italy). - Facies, 25, 91 - 118.
SCHÖNLAUB, H. P., ATTREP, M., BOECKELMANN, K., DREESEN, R., FEIST, R., FENNINGER, A., HAHN G., KLEIN, P., KORN, D., KRATZ, R., MAGARITZ, M., ORTH, C. & SCHRAMM, J.- M. (1992): Die Devon/Karbon-Grenze in den Karnischen Alpen (Österreich) - Eine Fallstudie interdisziplinärer Zusammenarbeit. - Jb. Geol. B. - A., 135, 57 - 98.
SCHRAUT, G. (1990): Neue Trilobiten und andere Fossilien aus dem Karbon von Nötsch. - Diplomarb. (Teil 1) Fachbereich Geowiss. Univ. Marburg, 1 - 62.
SCHRAUT, G. (1991): Die Arthropoden aus dem Unterkarbon von Nötsch (Kärnten/Österreich). - Abh. Geol. B. - A., 51, 1 - 193.
SCOTESE, C. R. & McKERROW W. S. (1990): Revised World maps and introduction. - In: McKERROW, W.S. & SCOTESE, C.R. (eds.): Palaeozoic Palaeogeography and Biogeography. - Geol. Soc. Mem., 12, 1 - 21.
SPALLETTA, C. & VENTURINI, C. (1994): Late Devonian - Early Carboniferous syn-sedimentary tectonic evolution of the Paleocarnic domain (Southern Alps, Italy). - Giorn. Geol., 56, 211 - 222.
TEICH, T. (1982): Zum Chemismus der Badstubbrekzie im Unterkarbon von Nötsch in Kärnten. - Carinthia II, 162, 91 - 96.
TENCHOV, Y. G. (1980): Die paläozoische Megaflora von Österreich. Eine Übersicht. - Verh. Geol. B.-A., 1980, 161-174.
VAI, G. B. (1991): Palaeozoic strike-slip rift pulses and paleogeography in the circum Mediterranean Tethyan realm. - Palaeogeography, Palaeoclimatology, Palaeoecology, 87, 223 - 252.
VAN DER VOO, R. (1988): Palaeozoic paleogeography of North America, Gondwana and intervening displaced terranes: comparisons of paleomagnetism with paleoclimatology and biogeographical patterns. - Geol. Soc. Amer. Bull., 100, 311 - 324.
VEEVERS, J. J. & MCPOWELL, C. (1987): Late Palaeozoic glacial episodes in Gondwanaland reflected in transgressive-regressive depositional sequences in Euramerica. - Geol. Soc. Amer. Bull., 98, 475-487.
VISSER, J. N. J. (1990): The age of the late Palaeozoic glacigene deposits in southern Africa. - S. Afr. J. Geol., 93, 366-375.

WINKLER PRINS, C. F. (1971): Connections of the Carboniferous brachiopod faunas of the Cantabrian Mountains (Spain). In: WAGNER, R.H. (Ed.): The Carboniferous of Northwest Spain., Pt 11. - Trab. Geol., 4, 687 - 694.

WINKLER PRINS, C. F. (1983): A general review of the Carboniferous Brachiopods from the Cantabrian Mountains (North Spain). - In: LEMOS DE SOUSA, M.J. (Ed.): Contributions to the Carboniferous Geology and Palaeontology of the Iberian Peninsula, 69-91.

WINKLER PRINS, C. F. (1984): Brachiopods and the Main Classification of the Carboniferous. - In: SUTHERLAND, P. K. & MANGER, W. L. (eds.): Compte Rendu 2 - Biostratigraphy, 47 - 51, 9th ICC, Carbondale - Edwardsville (Southern Ill. Univ. Press).

ZIEGLER, A. M., BAMBACH, R. K., PARRISH, J. T., BARRETT, S. F., GIERLOWSKI, E. H., PARKER, W. C., RAYMOND, A. & SEPKOSKI, J. J. Jr. (1981): Palaeozoic biogeography and climatology. In: NIKLAS, K.J. (Ed.): Paleobotany, Paleoecology and Evolution. - 231 - 266, New York (Praeger).

The Distribution of the Chitinozoans in the Cellon Section (Hirnantian - Lower Lochkovian). - A Preliminary Report.

by

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with 1 figure

Introduction

The investigations of the chitinozoans from the Cellon section [Ashgill - Lochkovian] were part of a project with the goal of examining the geographic and stratigraphic distribution of the palynomorphs within the different facies of the Upper Ordovician to Lower Devonian strata in the Carnic Alps.

These are: the shallow water facies with mainly calcareous deposits, the siliciclastic basin facies and the transitional facies mediating between the former two.

In none of these facies *spores* could be observed. The *acritarchs* turned out to be strongly influenced by the local environments. Their only remarkable occurrence was in the Lower Silurian of the Cellon section which belongs to the calcareous facies [PRIEWALDER, 1987]. However, the *chitinozoans* proved to be the geographically and stratigraphically widest distributed group of the palynomorphs.

Concerning the chitinozoans, 79 samples from the siliciclastic and transitional facies have been examined so far by spot checks: 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 [= 51%] yielded chitinozoans.

As the chitinozoans were opaque to transmitting light the investigations had to be done 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 only on gross determinations. Detailed studies have yet to be carried out and will result in more diverse chitinozoan associations at many horizons of the section.

In the Cellon section, the chitinozoans are restricted to four formations [fig.1]:

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

- the sequence from the upper part of the Alticola *Limestone* to the lowermost *Rauchkofel Limestone* [***Ludlow/Pridoli boundary - lowermost Lochkovian***].

Chitinozoans of the Upper Ordovician

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

Stratigraphically the chitinozoans occur for the first time at the base of the Plöcken Formation [sample ***126***] with a few representatives of *Conochitina EISENACK 1931* and probably also *Tanuchitina JANSONIUS 1964*. Further numerous melanosklerits with a strong resemblance to chitinozoans can be observed, as well as chitinozoan-like graphitic particles.

In the uppermost part of the Plöcken Formation a few samples [***128*** , ***129*** , ***45***] contain taxa which are diagnostic for the Ashgill: *Armoricochitina nigerica (BOUCHÉ 1965)* and *Tanuchitina elongata (BOUCHÉ 1965)*. Furthermore *Desmochitina minor EISENACK 1931*, which does not range across the Ordovician/Silurian boundary, and representatives of *Conochitina*, *Rhabdochitina (?) EISENACK 1931*, *Spinachitina SCHALLREUTER 1963* and the first specimen of the *Ancyrochitininae* with broken processes have been extracted.

The chitinozoan assemblages of this succession suggest the Hirnantian ***Tanuchitina elongata*** **- Biozone** (PARIS 1990).

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

Chitinozoans of the upper Llandovery

Sample ***46A*** at the very base of the Kok Formation [= upper Llandovery], which unconformably overlies the Plöcken Formation, yields a completely different chitinozoan fauna with a great number of individuals: numerous representatives of *Lagenochitinidae* and *Ancyrochitininae*, which cannot be determined exactly; *Ancyrochitina* gr. *ancyrea (EISENACK 1931)*, *A.* cf. *diabolo (EISENACK 1937)*, *Cyathochitina caputoi DA COSTA 1971* and *Eisenackitina dolioliformis UMNOVA 1976* which is very characteristic of this sample.

Samples ***47*** , ***130*** and ***131*** contain many specimens of *Bursachitina TAUGOURDEAU 1966* and *Conochitina* [e.g. *C.sp. cf. emmastensis NESTOR 1982*], further *E. dolioliformis*, as well as *A. cf. nigerica* and *Laufeldochitina ? sp.*, which are reworked taxa of upper Ordovician age.

This part of the sequence may be assigned to the upper Aeronian - lower Telychian ***Eisenackitina dolioliformis*** **- Biozone** [VERNIERS et al. 1995].

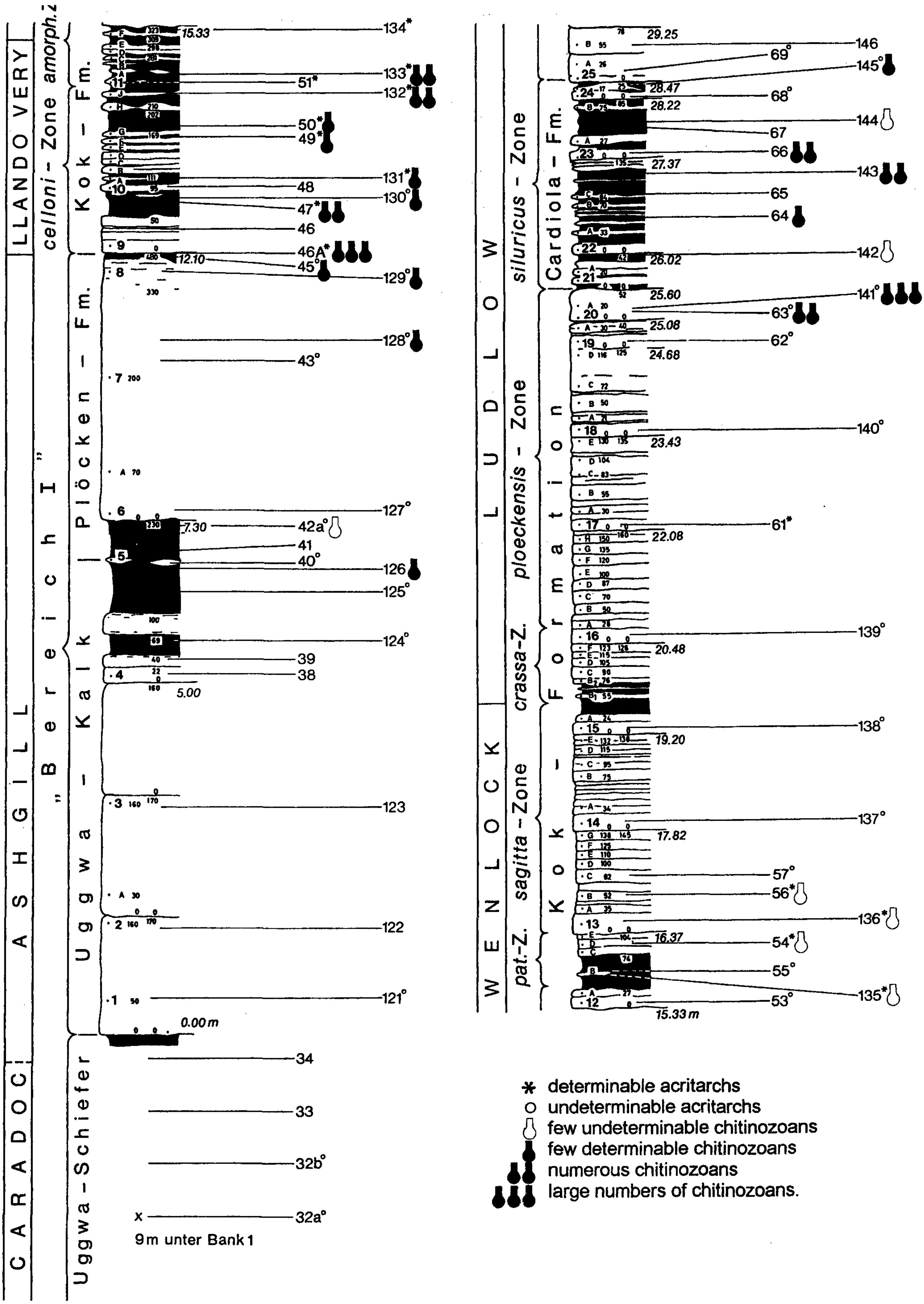
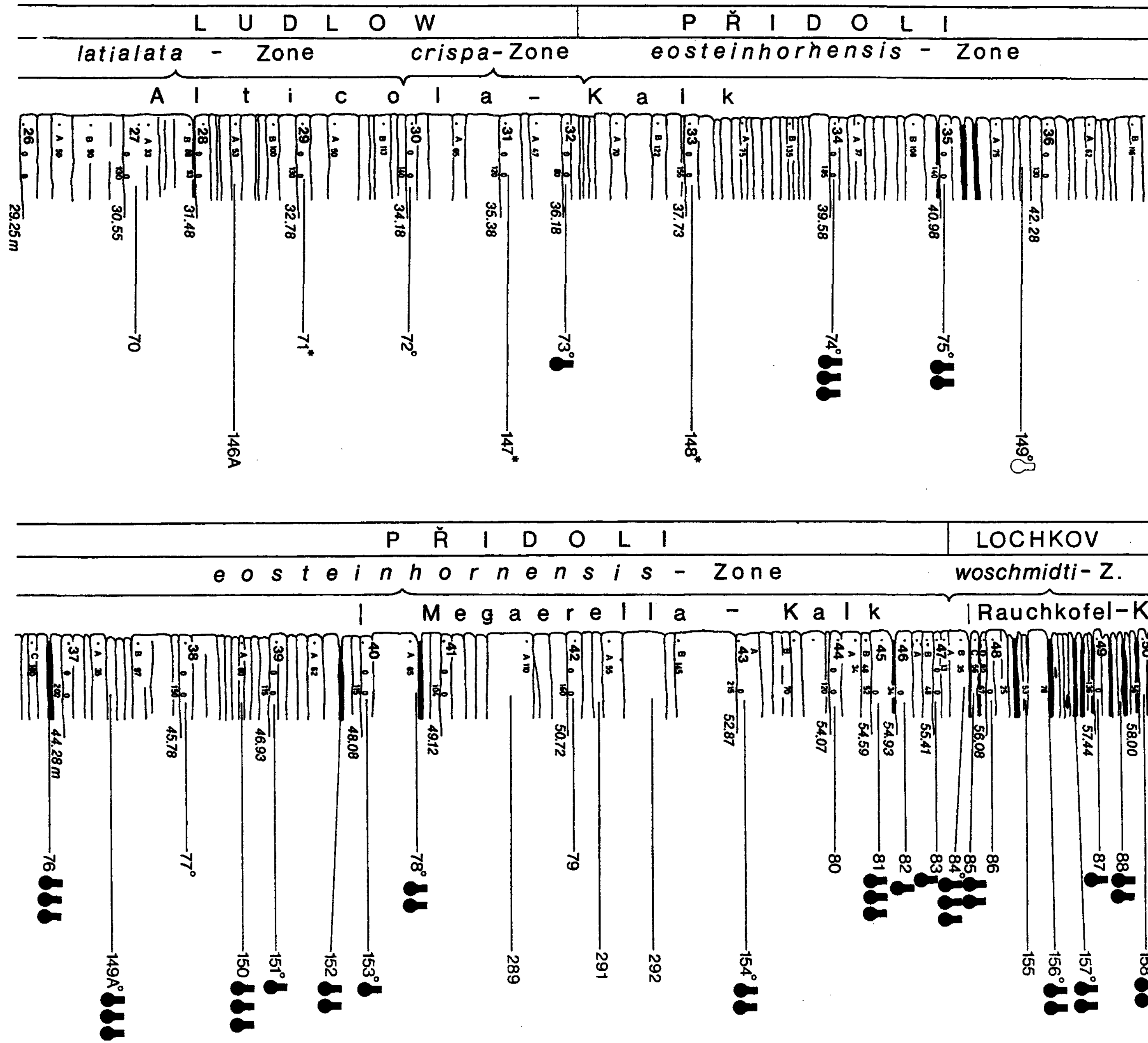


Fig.1: The location of the samples in the Cellon-section (drawing of the section after SCHÖNLAUB 1985).


L U D L O W
P Ř I D O L I
latialata - Zone
crispa-Zone
eosteinhorhensis - Zone
A l t i c o l a - K a l k
29.25 m
30.55
31.48
32.78
34.18
35.38
36.18
37.73
39.58
40.98
42.28
70
71*
72°
73°
74°
75°
146A
147*
148*
149°
P Ř I D O L I
LOCHKOV
e o s t e i n h o r n e n s i s - Zone
woschmidti- Z.
M e g a e r e l l a - K a l k
Rauchkofel-K.
44.28 m
45.78
46.93
48.08
49.12
50.72
52.87
54.07
54.59
54.93
55.41
56.08
57.44
58.00
76
77°
78°
79
80
81
82
83
84°
85
86
87
88
89*
149A°
150
151°
152
153°
289
291
292
154°
155
156°
157°
158

In sample ***49,*** an *Angochitina* species appears which is similar to *A. longicolla EISENACK 1931*, the index species of the following ***Angochitina longicollis* - Biozone** [VERNIERS et al.1995] of upper Telychian age.

The upper part of the Llandoverian strata of the Kok Formation [samples ***50, 132***] is characterized by chitinozoans which closely resemble *Conochitina proboscifera EISENACK 1937*, a typical species of the upper Telychian/lower Sheinwoodian period; *Conochitina* spp. [e.g. *C.* sp. cf. *C. armillata TAUGOURDEAU & DE JEKHOWSKI 1960, C.* sp. cf. *C.edjelensis elongata TAUGOURDEAU 1963*], *Eisenackitina sp.* and *Lagenochitina sp.* occur less frequently.

The uppermost Llandovery sample [***133***] yields only badly preserved individuals resembling *Angochitina longicolla*, as well as *Conochitina* sp., *Cyathochitina* sp., *Eisenackitina* sp. and *Sphaerochitina* sp..

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.

Chitinozoans of the Wenlock - lower Ludlow

hroughout the Wenlock, the strata of which attain a thickness of only 5 meters indicating extreme condensation [SCHÖNLAUB 1994], and also in the lower Ludlow, associations of determinable chitinozoans are missing. Only sporadic and badly preserved fossils are present: Sample ***135***: one fragment of *Belonechitina* sp.; sample ***54***: the internal moulds of *Conochitinidae* indet.; sample ***136***: fragments of *Conochitinidae* indet. and *Lagenochitinidae* indet., sample ***56***: *Bursachitina* sp., *Lagenochitinidae* indet., *Conochitinidae* indet..

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.

At the base of this sequence [samples ***63***, ***141***] abundant and diverse *Angochitina EISENACK 1931* [e.g. *A. echinata EISENACK 1931* and a fragment similar to *A. elongata EISENACK 1931*], *Sphaerochitina EISENACK 1955* [e.g. *S.*sp. cf. *impia LAUFELD 1974*], *Conochitina EISENACK 1931* and a few *Bursachitina* sp. and *Eisenackitina* sp., as well as some *Ancyrochitina* sp. appear.

Above this level a fragment of *Linochitina EISENACK 1968* [sample ***142***] is found.

Some *Cingulochitina* cf. *convexa (LAUFELD 1974)*, *Sphaerochitina* spp. and *Angochitina* spp. [like in samples ***63*** , ***141***] and a few *Ancyrochitininae* indet. are found in sample ***64.***

The middle part is dominated by numerous *Conochitina and Belonechitina JANSONIUS 1964. C.*sp. cf. *tuba EISENACK 1932* occurs in sample ***143***. Sample ***66*** yields *Belonechitina* sp. cf. *latifrons (EISENACK 1964)* and *B.*sp. cf. *lauensis (LAUFELD 1974)* and rare *Sphaerochitina* sp..

Finally, in the last sample of this succession [***145***] a few *Cingulochitina* sp. and *Ancyrochitininae* indet. are present.

The chitinozoans of this sequence seem thus to be referred to the upper Gorstian - lower Ludfordian ***Angochitina elongata* - Biozone** [VERNIERS et al. 1995].

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

From the base of the Alticola Limestone up to the end of the Ludlow the examined samples yield no chitinozoans.

Chitinozoans of the uppermost Ludlow to the lower Lochkovian

A rich development of chitinozoans is documented from sample ***73*** of the Ludlow/ Pridoli boundary beds and persists through the Pridoli up to the end of the section in the lower Lochkovian [sample ***89***]. It comprises the upper part of the Alticola Limestone, the Megaerella Limestone and the lowermost part of the Rauchkofel Limestone.

Three samples at the base of this succession [***73*** = uppermost Ludfordian sample; ***74***, ***75*** = lower Pridolian samples] contain numerous *Eisenackitina barrandei PARIS & KRIZ 1984, E. granulata (CRAMER 1964), E. intermedia (EISENACK 1955), Urnochitina* gr. *urna (EISENACK 1934),* and some *Sphaerochitina* cf. *sphaerocephala (EISENACK 1932), Ancyrochitina* gr. *ancyrea (EISENACK 1931), Angochitina* sp., *Bursachitina* sp. and *Gotlandochitina* sp..

E. barrandei is the index-fossil of the ***Eisenackitina barrandei* - (total range) - Biozone** [VERNIERS et al.1995] which is restricted to the uppermost Ludfordian. At the global stratotype section of the Ludlow/Pridoli-boundary at Pozáry Quarry of the Prague Basin, Bohemia, *E. barrandei* ranges a few decimeters into the Pridoli, where it coexists within a very short distance with atypical representatives of *Urnochitina* gr. *urna* [typical specimens are present in the higher parts of the Pridoli]. The latter is an index species of the Pridoli appearing in the Prague Basin within an interval of a few centimeters below to a few centimeters above the Ludlow/Pridoli-boundary [PARIS in KRIZ et al.1986].

Compared to the ranges in the Cellon section an obvious difference exists: here *E. barrandei* ranges relatively high up into the Pridoli [almost 5 meters]; moreover, in this interval it coexists with atypical *U.* gr. *urna*. Detailed studies will have to settle this discrepancy.

The next sample [*149*] reveals a very low fossil content consisting of only some *Eisenackitina* sp., *Angochitina* sp. and *Ancyrochitina* ? sp..

The development of typical *Urnochitina urna* starts suddenly and with a great number of specimens in sample ***76***. As already described in the literature the fauna here too is of almost monospecific composition with the exception of only rare representatives *of Desmochitinidae* indet..

The following sample [***149A***] displays a special feature: *U. urna* becomes numerically unimportant, whereas large quantities of *Bursachitina krizi (PARIS & LAUFELD 1980)* are present. The residue consists almost entirely of representatives of the latter species.

Sample ***150*** is dominated by *U. urna; in addition*, only very few individuals of *B. krizi* and *Desmochitinidae* indet. occur.

The next three samples [***151***, ***152***, ***153***] yield insignificant associations with various *Lagenochitinidae* indet., a fragment of *B.krizi* [?], some *Angochitina* similar to *A. chlupaci (PARIS & LAUFELD 1980)* and *Sphaerochitina* sp..

The only taxon in the following sample ***78*** is *E. granulata* with a few well preserved individuals. It is still present in sample ***154***, but there accompanied by rare *B. krizi*, *Linochitina klonkensis PARIS & LAUFELD 1980* and *Ancyrochitina* sp..

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

At about this level of the section the chitinozoan fauna starts to rearrange: *U. urna* occurs with more and more decreasing numbers of individuals, while *Angochitina EISENACK 1931*, *Cingulochitina PARIS 1981*, *Gotlandochitina LAUFELD 1974*, *Linochitina EISENACK 1968*, *Sphaerochitina EISENACK 1955* and especially *Ancyrochitina EISENACK 1955* occur more frequently.

The most abundant species in sample ***81***, from which large quantities of chitinozoans could be extracted, represents *Ancyrochitina* sp. A, provided with simple processes with very broad basis. Other taxa are *L. klonkensis*, *Calpichitina corinnae JAGLIN 1986*, *Sphaerochitina* cf. *sphaerocephala (EISENACK 1932)*, *Gotlandochitina* ? sp. and *U. urna* with very few specimens.

Samples ***82*** and ***83,*** the uppermost Pridolian samples, contain only poor associations: very few *U. urna*, *Ancyrochitina* sp. A and *S.* cf. *sphaerocephala.*

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 [***Fungochitina kosovensis* -, *Margachitina elegans* - and *Anthochitina superba* - Biozones**, VERNIERS et al.1995] could not be identified at Cellon.

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

The chitinozoan assemblage of sample ***85***, in which the number of individuals is rather low, is dominated by *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]. Co-occurring taxa are a few *Angochitina* aff. *chlupaci, Cingulochitina* sp., *Desmochitinidae* indet. and *Lagenochitinidae* indet..

In sample ***156*** *A. chlupaci* is present with several unequivocal individuals together with a few *Angochitina* sp. and *Desmochitinidae* indet..

The remaining samples in the section [***157***, ***87***, ***88***, ***158*** and ***89*** with a large quantity of chitinozoans] are dominated by numerous *Ancyrochitina* [at least 5 species]. Moreover they yield numerous diverse representatives 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 taxa; thinner-walled individuals are often more or less strongly collapsed.

Conclusions.

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

In several samples (46A, 141, 74, 76, 149A, 150, 81, 84, 89) they occur with large numbers of individuals and usually great diversity.

◆ The chitinozoan assemblages of the upper Ashgill and upper Llandovery strata separated by a gap of two stages are easily to distinguish.

The boundaries between the Llandovery and Wenlock, and the Wenlock and Ludlow, respectively, cannot be established by the aid of chitinozoans as these fossils are missing throughout the Wenlock and also in the lower Ludlow.

With regard to the chitinozoans, the position of the base of the Pridoli in the Cellon section is not yet clear and needs further investigations.

However, the base of the Lochkovian is well documented by diagnostic chitinozoan associations.

<u>Several chitinozoan biozones can be identified:</u>
- 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.

◆ Obviously, environmental conditions were more favourable for the chitinozoans in the upper part of the section than in the lower. Starting with the topmost layer of the Kok Formation [upper Ludlow] up to the lower Lochkovian they show greater diversities and larger numbers of individuals and also better preservation than in the lower part.

Presently, the reasons for the occurrence 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.

◆ 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.

Because of the palaeogeographic vicinity of the two depositional areas, the Silurian-Lower Devonian chitinozoans of the studied section are very similar to those from Bohemia which is especially true for the upper Ludlow to lower Lochkovian sequence [DUFKA, 1992; 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 yield no 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 [e.g. high hydrodynamic regime in a shallow sea, at least temporary; oxidation] in the sedimentary environment of the Cellon section.

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References

ACHAB,A., BERTRAND,R. & VAN GROOTEL,G.: Chitinozoan Contribution to the Ordovician and Lower Silurian Paleobiogeography.- J.Geol., 100, 621-629, 5 fig., Chicago, 1992.

BOUCHÉ, P.M.: Chitinozoaires du Silurien s.l. du Djado (Sahara nigérien).- Rev. Micropaléont., 8, 151-164, 3 tab., 3 pl., Paris, 1965.

CRAMER, F.H.: Microplankton from three Paleozoic formations in the province of León (NW Spain). - Leidse Geol.Meded., 30, 255-361, 56 fig., 24 pl., Leiden, 1964.

CRAMER, F.H.: Chitinozoans of a composite section of Upper Llandovery to basal Lower Gedinnian sediments in northern León, Spain. A preliminary report. - Bull. Soc. belge Géol., 75, 69-129, 7 fig., 5 pl., Brussels, 1967a.

DUFKA,P.: Lower Silurian Chitinozoans of the Prague Basin (Barrandian, Czechoslovakia). Preliminary Results.- Rev.Micropaléont., 35, 117-126, 1fig., 3 tab., 3 pl., Paris, 1992.

EISENACK, A.: Neotypen baltischer Silur-Chitinozoen und neue Arten. - N.Jb.Geol.Paläont., Abh., 108, 1-20, 4 fig., pl.1-3, Stuttgart, 1959.

EISENACK, A.: Neotypen baltischer Silur-Chitinozoen und neue Arten. - N.Jb.Geol.Paläont., Abh., 114, 291-316, 8 fig., 1 tab., pl.14-17, Stuttgart, 1962.

EISENACK, A.: Mikrofossilien aus dem Silur Gotlands, Chitinozoen. - N.Jb.Geol.Paläont.: Abh., 120, 308-342, 9 fig., 7 tab., pl.26-30, Stuttgart, 1964.

EISENACK, A.: Über Chitinozoen des baltischen Gebietes. - Paläontographica A, 131, 137-198, 13 fig., 2 tab., pl. 24-32, Stuttgart, 1968.

EISENACK, A.: Beiträge zur Chitinozoen-Forschung.- Paläontographica A, 140, 117-130, 1 fig., pl. 32-37, Stuttgart, 1972.

ELAOUAD-DEBBAJ, Z.: Chitinozoaires Ashgilliens de l'Anti-Atlas (Maroc). - Geobios, 17, 45-48, 5 fig., 3 pl., Lyon, 1984.

GRAHN, Y.: Chitinozoan stratigraphy in the Ashgill and Llandovery. - In COCKS, L.R.M. & RICKARDS,R.B. (eds.): A Global Analysis across the Ordovician - Silurian boundary.- Bull.Br.Mus.nat.Hist.(Geol.), 43, 317-323, 27 fig., London, 1988.

JAGLIN, J.C.: Chitinozoa from the late Ordovician glacio-marine deposits from North Africa. - Chit.Newsletter, 8, 5-6, Uppsala, 1987.

JENKINS,W.A.M. & LEGAULT, J.A.: Stratigraphic ranges of selected Chitinozoa. - Palynology, 3, 235-264, 6 fig., Dallas, 1979.

KREUTZER, L.H.: Photo-Atlas of the Variscan Carbonate Sequences in the Carnic Alps (Austria/Italy). - Abh.Geol.B.-A., 47, 129 p., 9 fig., 3 tab., 46 pl., Wien, 1992.

KREUTZER, L.H.: Cellon Section. Facial differentiation and bathymetric environment.- In SCHÖNLAUB, H.P. & KREUTZER, L.H. (eds.): IUGS Subcomm.Silurian Stratigraphy, Field Meeting 1994. - Ber.Geol.B.A., 30, 85-88, Wien, 1994.

KRIZ, J.: Silurian Field Excursions. Prague Basin (Barrandian), Bohemia. - Geol.Ser.Nation.Mus.Wales, 13, 111 p., 86 fig., 4 pl., Cardiff, 1992.

KRIZ, J., DUFKA, P., JAEGER, H. & SCHÖNLAUB, H.P.: The Wenock/Ludlow Boundary in the Prague Basin (Bohemia). - Jb.Geol.B.-A., 136, 809-839, 18 fig., 1 tab., 3 pl., Wien, 1993.

KRIZ, J., JAEGER, H., PARIS, F. & SCHÖNLAUB, H.P.: Pridoli - the Fourth Subdivision of the Silurian. - Jb.Geol.B.-A., 129, 291-360, 44 fig., 1 tab., 6 pl., Wien, 1986.

LAUFELD, S.: Silurian Chitinozoa from Gotland. - Fossils and Strata, 5, 130 p., 78 fig., Oslo, 1974.

LAUFELD, S.: Biogeography of Ordovician, Silurian and Devonian Chitinozoans. - In GRAY, J. & BOUCOT, A.J. (eds.): Historical Biogeography, Plate Tectonics, and the Changing Environment, 75-90, 14 fig., (Oregon State University Press), o.O., 1979.

MOLYNEUX, S.G. & PARIS, F.: Late Ordovician Palynomorphs.- In THUSU, B.T. & OWENS, B. (eds.): The Palynostratigraphy of Northeast Libya. - J.Micropalaeont., 4, 11-26, 7 pl., London, 1985.

NESTOR, V. & K.: Correlation of the East-Baltic and Gotland Silurian by Chitinozoans. - In KALJO, D. & KLAAMAN, E. (eds.): Ecostratigraphy of the East Baltic Silurian. - Acad.Sci.Estonian S.S.R., 89-96, 3 fig., Tallinn, 1982.

NESTOR, V.: Silurian Chitinozoans. - In KALJO, D. & NESTOR, H.N.(eds.): An excursion guidebook, 80-83, fig. 15, pl. 14, 15, Tallinn, 1990.
NESTOR, V.: Chitinozoan diversity dynamics in the east Baltic Silurian. - Proc.Estonian Acad.Sci.Geol., 41, 215-224, 5 fig., 2 tab., Tallinn, 1992.
NESTOR, V.: Early Silurian Chitinozoans of Estonia and North Latvia. - Academia, 4, 163 p., 29 fig., 32 pl., 3 tab., Tallinn, 1994.
PARIS, F.: Les Chitinozoaires dans le Paléozoique du sud-ouest de l'Europe. - Mém.Soc.géol.minéral.Bretagne, 26, 412 p., 134 fig., 45 tab., 41 pl., Rennes, 1981.
PARIS, F.: Chitinozoans. - In HOLLAND, C.H. & BASSETT, M.G. (eds.): A GlobalStandard for the Silurian System. - Geol.Ser.Nation.Mus Wales, 9, 280-284, fig. 174, 175, Cardiff, 1989.
PARIS, F.: The Ordovician chitinozoan biozones of the Northern Gondwana Domain. - Rev. Palaeobot.Palynol., 66, 181-209, 4 fig., Amsterdam, 1990.
PARIS, F.: Application of chitinozoans in long-distance Ordovician correlations. - In: WEBBY, B.D. & LAURIE, J.R. (eds.): Global Perspectivs on Ordovician Geology, 23-33, 3 fig., (Balkema), Rotterdam, 1992.
PARIS, F.: Evolution paléogéographique de l'Europe au Paléozoiqe inférieur: le test de Chitinozoaires. - C.R.Acad.Sci.Paris, t.316, Ser.II, 273-280, 4 fig., Paris, 1993.
PARIS, F.: Chitinozoan Biostratigraphy and Palaeoecology. - In JANSONIUS, J. & McGREGOR; D.C. (eds.): Palynology: Principles and Applications, vol.2, 531-552, 9 fig., 3 pl., Salt Lake City, (Publishers Press), 1996.
PARIS, F. & GRAHN, Y.: Chitinozoa of the Silurian-Devonian boundary sections in Podolia, Ukraine. - Palaeontology, 39, 629-649, 4 fig., 4 pl., London, 1996.
PARIS, F. & KRIZ, J.: Nouvelles especes de chitinozoaires a la limite Ludlow/Pridoli en Tchecoslovaquie. - Rev.Palaeobot.Palynol., 43, 155-177, 8 fig., 3 pl., Amsterdam, 1984.
PARIS, F., LAUFELD, S. & CHLUPÁC, I.: Chitinozoa of the Silurian-Devonian boundary stratotypes in Bohemia. - S.G.U., Avh., Ser.Ca., 51, 1-28, 10 fig., 3 pl., Uppsala, 1981.
PARIS, F. & ROBARDET, M.: Early Palaeozoic palaeobiogeography of the Variscian regions. - Tectonophysics, 177, 193-213, 5 fig., 1990.
PRIEWALDER; H.: Acritarchen aus dem Silur des Cellon-Profils, Karnische Alpen, Österreich. - Abh.Geol.-B.-A., 40, 121 p., 39 fig., 24 pl., Wien, 1987.
PRIEWALDER, H.: Chitinozoans of the Cellon Section (Upper Ordovician - Lower Devonian). A Preliminary Report. - In SCHÖNLAUB, H.P. & KREUTZER, L.H. (eds.): IUGS Subcomm.Silurian Stratigraphy, Field Meeting 1994. - Ber.Geol.B.A., 30, 61-69, 1 fig., Wien, 1994.
RAUSCHER, R.: Recherches micropaléontologiques et stratigraphiques dans l'Ordovicien at le Silurien en France. Etude des Acritarches, des Chitinozoaires et des Spores. - Mém.Sci.Géol., 38, 224 p., 46 fig., 31 tab., 12 pl., Strasbourg, 1973.
SCHÖNLAUB, H.P.: Das Paläozoikum der Karnischen Alpen. - In: Arbeitstagung der Geologischen Bundesanstalt, 1985, 34-52, fig. 10-15, Wien, 1985.
SCHÖNLAUB, H.P.: The Ordovician-Silurian boundary in the Carnic Alps of Austria.- In COCKS, L.R.M. & RICKARDS, R.B. (eds.): A Global Analyses of the Ordovician-Silurian boundary. - Bull.Br.Mus.nat.Hist. (Geol), 43, 107-115, 4 fig., London, 1988.
SCHÖNLAUB, H.P.: Stratigraphy, Biogeography and Paleoclimatology in the Alpine Paleozoic and its Implications for Plate Movements. - Jb.Geol.B.-A., 135/1, 381-418, 16 fig., Wien, 1992.
SCHÖNLAUB, H.P.: The Faunal Relationship of the Silurian of the Alps.- In SCHÖNLAUB, H.P. & KREUTZER, L.H. (eds.): IUGS Subcomm.Silurian Stratigraphy, Field Meeting 1994. - Ber.Geol.B.A., 30, 52-60, 1 fig., Wien, 1994.
SCHÖNLAUB, H.P.: Cellon Section. Lithology, Paleontology and Stratigraphy.- In SCHÖNLAUB, H.P. & KREUTZER, L.H. (eds.): IUGS Subcomm.Silurian Stratigraphy, Field Meeting 1994. - Ber.Geol.B.A., 30, 83-84, Wien, 1994.
SCHÖNLAUB, H.P. & HEINISCH, H.: The Classic Fossiliferous Palaeozoic Units of the Eastern and Southern Alps. - In SCHÖNLAUB, H.P. & KREUTZER, L.H. (eds.): IUGS

Subcomm.Silurian Stratigraphy, Field Meeting 1994. - Ber.Geol.B.A., 30, 6-51, 18 fig., Wien, 1994.

SCHWEINEBERG, J.: Silurische Chitinozoen aus der Provinz Palencia (Kantabrisches Gebirge, N-Spanien). - Göttinger Arbeiten zur Geologie und Paläontologie, 33, 94 p., 24 fig., 13 pl., Göttingen, 1987.

SUTHERLAND, S.J.E.: Ludlow Chitinozoans from the Type Area and Adjacent Regions. - Monogr.Palaeontogr.Soc., Publ.594, 104 p., 57 fig., 18 pl., London, 1994.

TAUGOURDEAU, P.: Étude de quelques espèces critiques de Chitinozoaires de la Région d'Edjelé et compléments à la faune locale. - Rev.Micropaléont., 6, 130-144, 3 pl., 4 tab., Paris 1963.

TAUGOURDEAU, P. & DE JEKHOWSKY, B.: Répartition et description des Chitinozoaires Siluro-dévoniens de quelques sondages de la C.R.E.P.S., de la C.F.P.A. et de la S.N. REPAL au Sahara - Rév.Inst.Franc.Pétrol., 15, 1199 - 1260, 19 fig., 13 pl., Paris 1960.

VERNIERS, J.: The Silurian of the Mehaigne Valley (Brabant Massif, Belgium): Biostratigraphy (Chitinozoa). - Rev.Palaeobot.Palynol., 34, 165-174, 1 fig., 2 pl., Amsterdam 1981.

VERNIERS, J.: The Silurian Chitinozoa of the Mehaigne Area (Brabant Massif, Belgium). - Prof.Pap.Geol.Dienst Belgie, 1982/6, 192, 76 p., 10 fig., 9 pl., Gent, 1982.

VERNIERS, J., NESTOR, V., PARIS, F., DUFKA, P., SUTHERLAND, S. & VAN GROOTEL, G.: A global Chitinozoa biozonation for the Silurian. - Geol.Mag., 132, 651-666, 6 fig., Cambridge, 1995.

WALLISER, O.H.: Conodonten des Silurs. - Abh.Hess.L.-Amt Bodenforsch., 41, 106 p., 10 fig., 2 tab., 32 pl., Wiesbaden, 1964.

WRONA, R.: Upper Silurian - Lower Devonian Chitinozoa from the Subsurface of Southeastern Poland. - Palaeont.Polonica, 41, 103-165, 111fig., 13 tab., pl. 24-37, Warsaw, 1980.

The Field Trip Programme

Stop 1: Cellon Section

by
Hans P. Schönlaub, Lutz H. Kreutzer, Helga Priewalder,
Kathleen Histon & Bernd Wenzel

Lithology, Paleontology and Stratigraphy
(H.P. Schönlaub)

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.

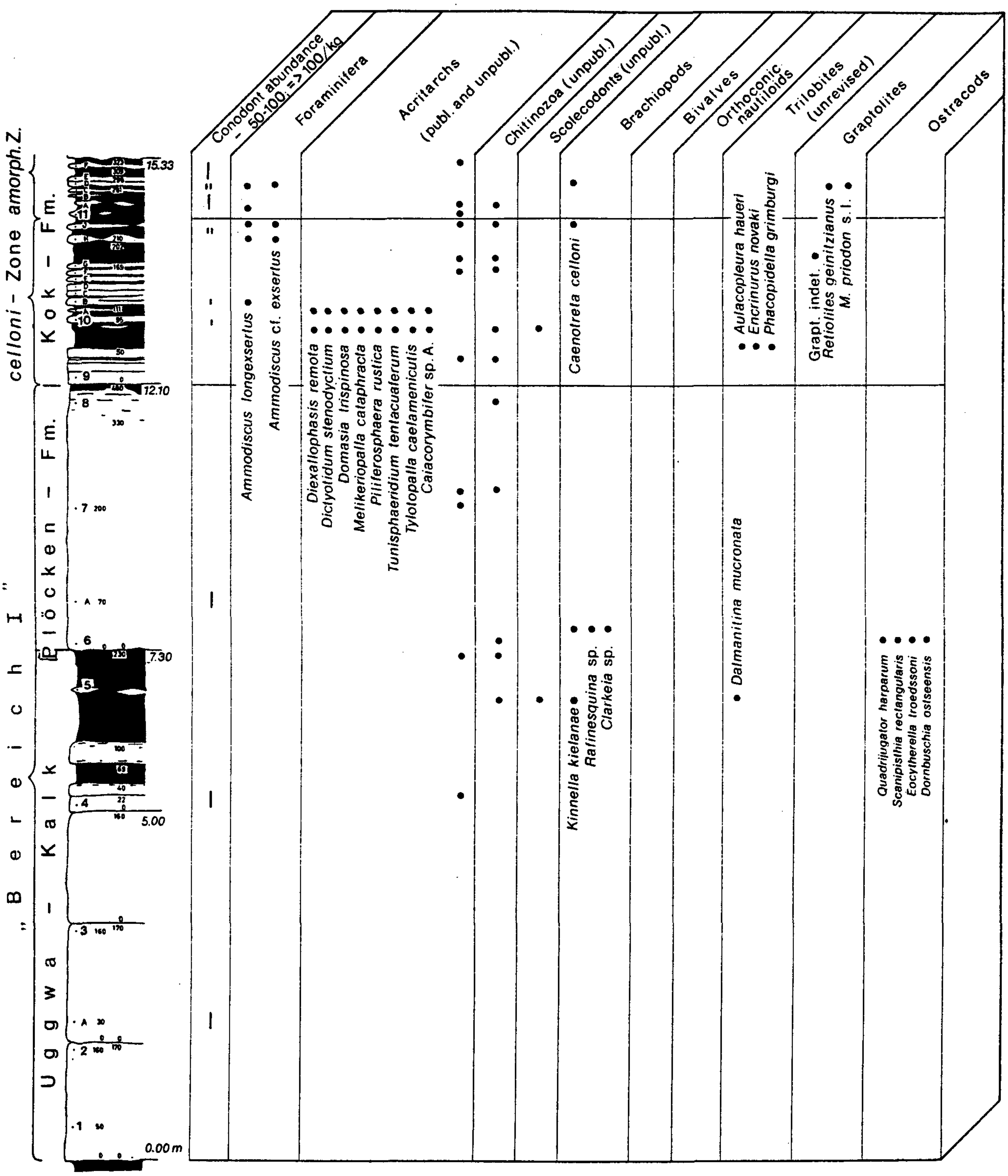
The Silurian part of the Cellon section is best exposed in a narrow gorge cut by avalanches. Thus, the German name for the section is "Cellonetta Lawinenrinne".

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 G.GEYER first described the rock sequence. In 1903 it was presented to the 9th IGC which was held in Vienna. According to H. R. v. GAERTNER (1931) who studied the fossils and rocks in great detail, the 60 m thick continuously exposed Upper Ordovician to Lower Devonian section could be subdivided into several formations. Since O. H. 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 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 (see Figs. 1A-D on the following pages):

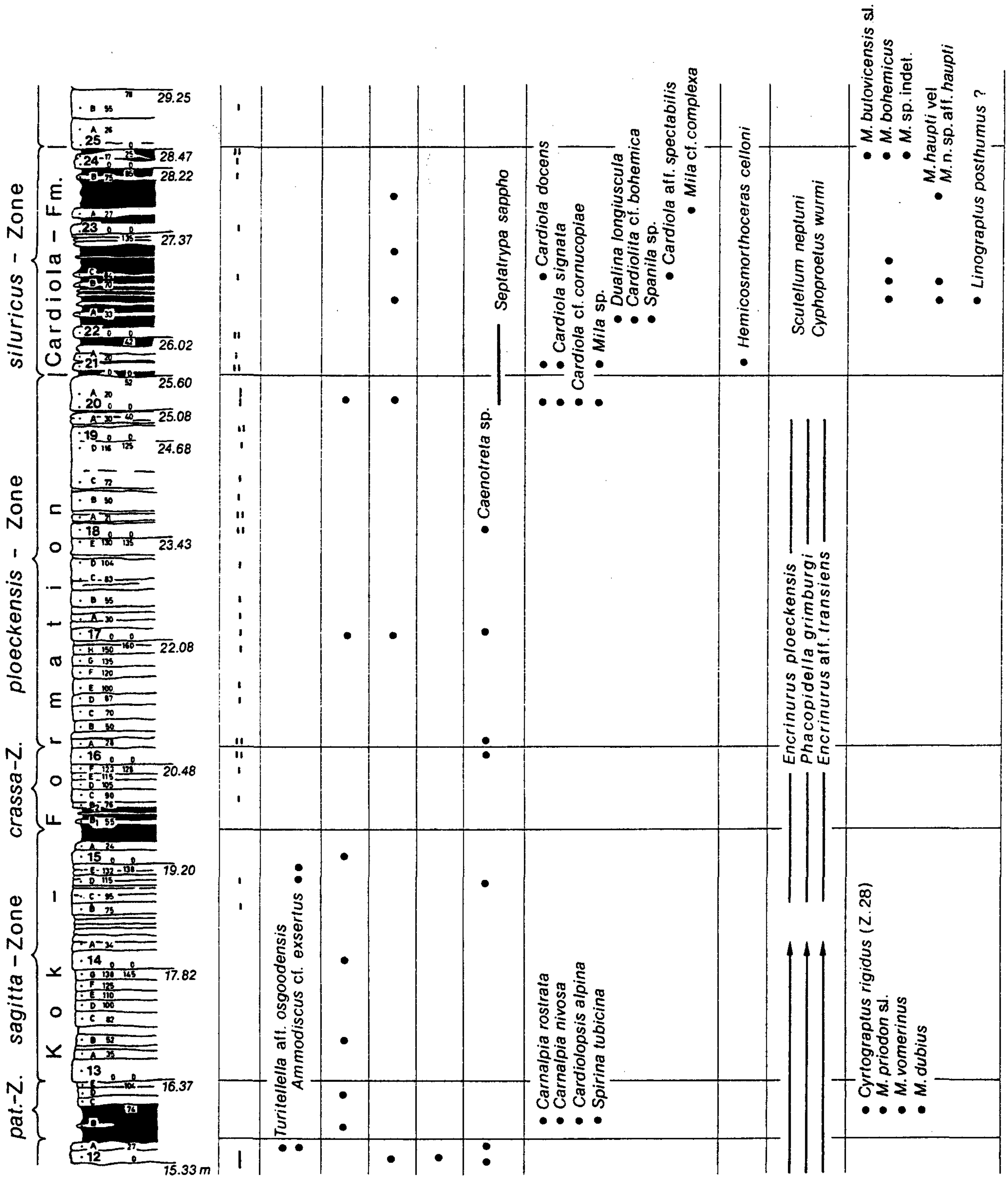
Top:

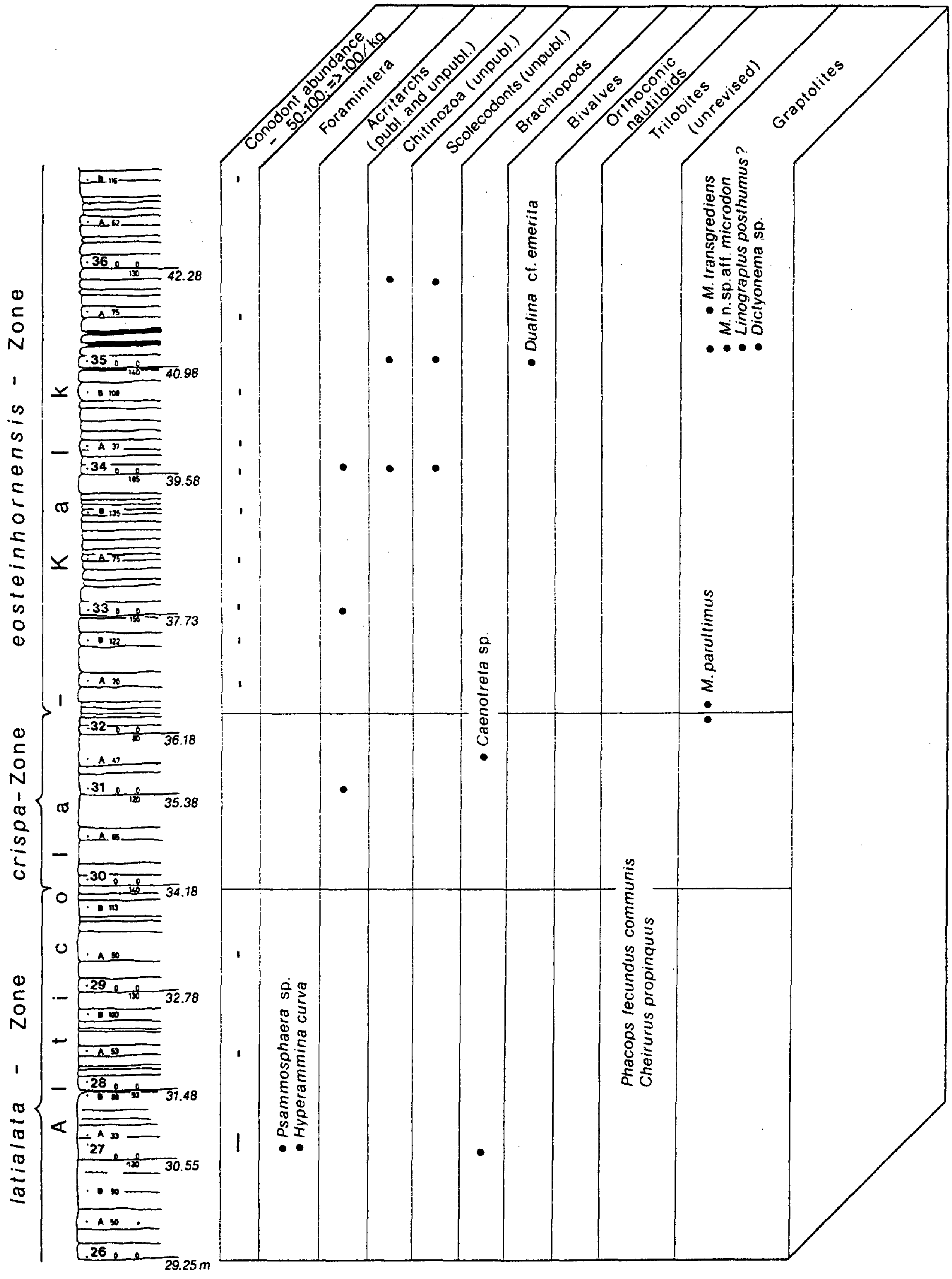
80.0	m Rauchkofel Limestone (dark, platy limestone; Lochkovian)
8.0	m Megaerella Limestone (greyish and in part fossiliferous limestone; Pridoli)
20.0	m Alticola Limestone (grey and pink nautiloid bearing limestone; Ludlow to Pridoli)
3.5	m Cardiola Formation (alternating black limestone, marl and shale;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

According to H. P.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

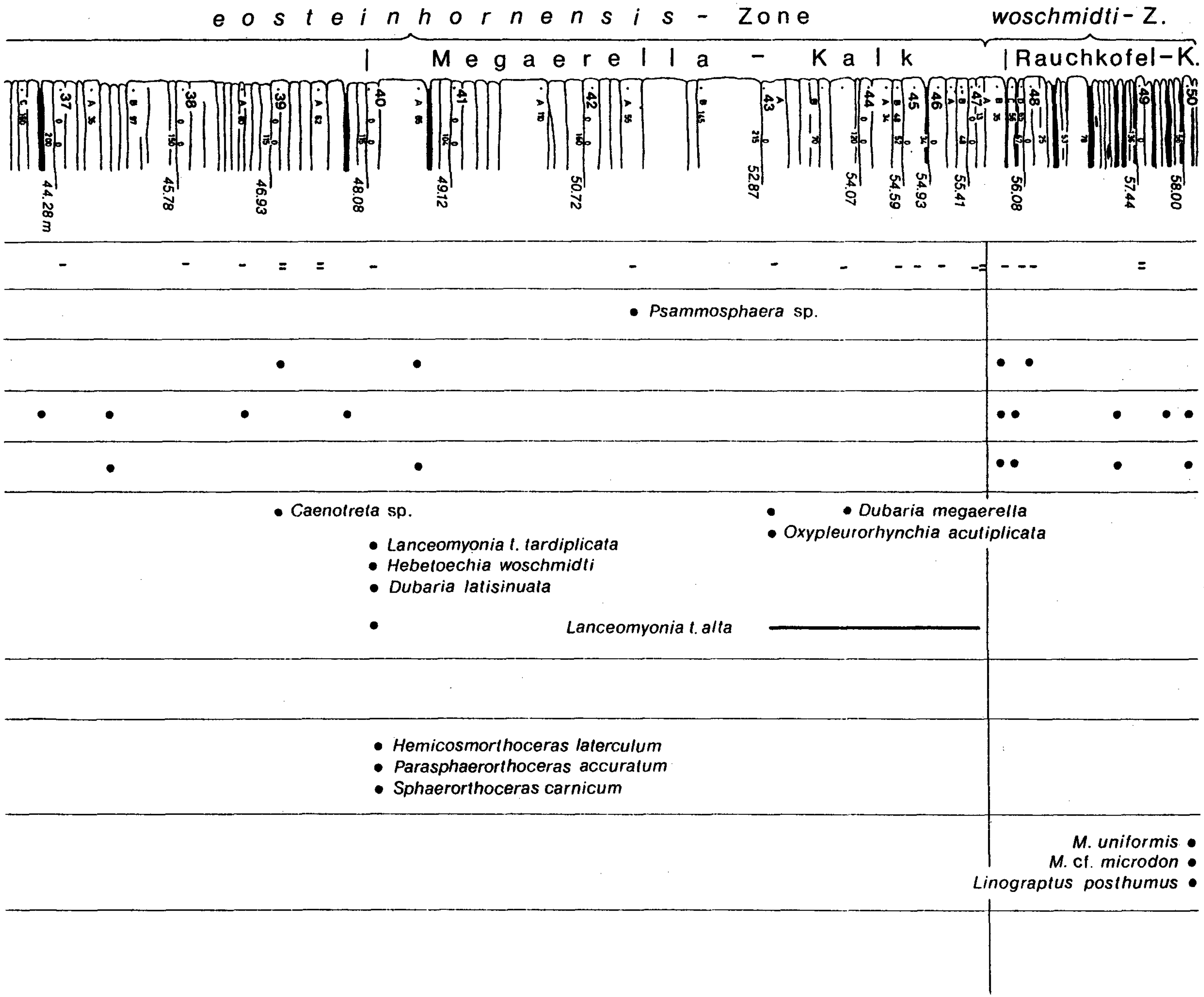


Figs. 1A - B. The Upper Ordovician to Lower Devonian portion of the Cellon section (after H. P. SCHÖNLAUB 1985, modified).


pat.-Z.
sagitta - Zone
crassa-Z.
ploeckensis - Zone
siluricus - Zone
K o k - F o r m a t i o n
Cardiola - Fm.
15.33 m
16.37
17.82
19.20
20.48
22.08
23.43
24.68
25.08
25.60
26.02
27.37
28.22
28.47
29.25
Turritellella aff. osgoodensis
Ammodiscus cf. exsertus
Caenotreta sp.
Septatrypa sappho
Carnalpia rostrata
Carnalpia nivosa
Cardiolopsis alpina
Spirina tubicina
Cardiola docens
Cardiola signata
Cardiola cf. cornucopiae
Mila sp.
Dualina longiuscula
Cardiolita cf. bohemica
Spanila sp.
Cardiola aff. spectabilis
Mila cf. complexa
Hemicosmorthoceras celloni
Encrinurus ploeckensis
Phacopidella grimburgi
Encrinurus aff. transiens
Scutellum neptuni
Cyphoproetus wurmi
Cyrtograptus rigidus (Z. 28)
M. priodon sl.
M. vomerinus
M. dubius
M. bulovicensis sl.
M. bohemicus
M. sp. indet.
M. haupti vel
M. n. sp. aff. haupti
Linograptus posthumus ?



Figs. 1C - D. The Upper Ordovician to Lower Devonian portion of the Cellon section (after H. P. SCHÖNLAUB 1985, modified).



e o s t e i n h o r n e n s i s - Zone
woschmidti - Z.
Megaerella - Kalk
Rauchkofel-K.
44.28 m
45.78
46.93
48.08
49.12
50.72
52.87
54.07
54.59
54.93
55.41
56.08
57.44
58.00
Psammosphaera sp.
Caenotreta sp.
Lanceomyonia t. tardiplicata
Hebetoechia woschmidti
Dubaria latisinuata
Lanceomyonia t. alta
Dubaria megaerella
Oxypleurorhynchia acutiplicata
Hemicosmorthoceras laterculum
Parasphaerorthoceras accuratum
Sphaerorthoceras carnicum
M. uniformis
M. cf. microdon
Linograptus posthumus

age.These strata represent the culmination of the end-Ordovician regressive cycle known from many places in the world (H. P. SCHÖNLAUB 1988).

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

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

According to H. P. SCHÖNLAUB in J. 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 an upper 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 (H. P. SCHÖNLAUB in J. 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 Pridolian part of the sequence 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.

Cephalopod Limestones

(Kathleen Histon)

General Remarks on the Silurian Nautiloid Fauna from the Carnic Alps.

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), von 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 (as listed in Fig. 2) . A more recent generic assignment of the species is tentatively given where known). 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 and a total of 18 nautiloid species were described (GNOLI & HISTON, in prep.).

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.*

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

New detailed collecting from both the Cellon and Rauchkofel 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 (1991) from Sardinia. 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.

Species	Kok Fm.	Cardiola Fm.	Alticola Lst.	Megaera Lst.
Orthoceras apollo Barr.	*			
O.argus Barr.		*	*	*
O.currens Barr. (Michelinoceras ?)	*			
O.extenuatum barr.	*			
O.firmum Barr.	*	*	*	
O.germanum Barr.	*			
O.gruenewaldti Barr. (Plagiostomoceras?)	*			
O.littorale Barr.	*		*	
O.lineare Barr.			*	
O.michelini Barr. (Michelinoceras?)	*		*	
O.migrans Barr.	*			
O.potens Barr.	*	*		
O.praevalens Barr.	*			
O.truncatum (Sphooceras?)	*			
Geisonoceras alticola Frech (non Barr.)	*		*	
G.amoenum Barr.	*	*	*	*
G.arion Barr.		*		
G.carinatum Münster			*	
G.cavum Barr.		*		
G.transiens Barr (Pseudocycloceras?)	*			
G. reductum Barr.			*	
G.pelagium Barr.	*		*	
G.placens Barr.			*	
Kionoceras cf. bacchus Barr.	*			
K.dorulites Barr.			*	*
K.aff. electum Barr.	*		*	
K.neptunium Barr.			*	
K.pulchrum Barr			*	
K.striatopunctatum Münster			*	
K.tiro Barr.	*		*	*
Protobactrites acuarium Münster			*	
P.acus Barr.			*	
P.perlongum Barr.	*			
P.pleurotomum Barr.	*	*	*	
Dawsonoceras aff. agassizi Barr.	*			
D.dulce Barr	*	*	*	
D.aff.inchoatum Barr.	*			
D.lunaticum Barr.	*			
D.lynx Barr. (Orthocycloceras?)			*	
D.cf.pauper Barr.		*		
D.praecox Barr.		*		
D.subannulare Münster	*	*	*	*
D.venustulum Barr.	*			
Paractinoceras cf.severum Barr.			*	
Cyrtoceras circumflexum Barr.			*	
C.cycloideum Barr.			*	
C.imbelle Barr.	*			
C. sp.	*	*	*	*
Trochoceras carinthiacum Stache	*			
Barrandeoceras sacheri Barr.	*			
Total - 52 species	32	11	26	6

Fig. 2

Taphonomy. A detailed study of the taphonomy of the nautiloid fauna from the Kok Fm. has been carried out and the field observations are illustrated in Fig 3. The abundance, dimension, orientation, preservation, morphology and structural strenghts of the fauna have been observed for each level as defined by WALLISER (1964) in his study of the conodonts from this section. In some cases these divisions have been subdivided on the basis of the taphonomy of the fauna observed.The study is still in progress and will be continued during 1997 with main emphasis on the Cardiola Fm. and the remaining Upper Silurian.

Kok Formation

Base of the Silurian sequence - Bed 9

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

Bed 10

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

Bed 11 Llandovery - Wenlock Transition

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

Bed 12

Again a series of shales and limstone levels with more carbonate levels than before.There is an abundant trilobite fauna of large dimensions at the base with associated brachiopods and nautiloids. A crinoid fauna is more apparent higher in the sequence. Nautiloids are parallel to bedding with both body chamber and apexes preserved. There are upper and lower 'crusts' around the carbonate levels. Nautiloids are relatively abundant in the carbonate levels towards the top of the sequence whereas previously they were more abundant in the shales.

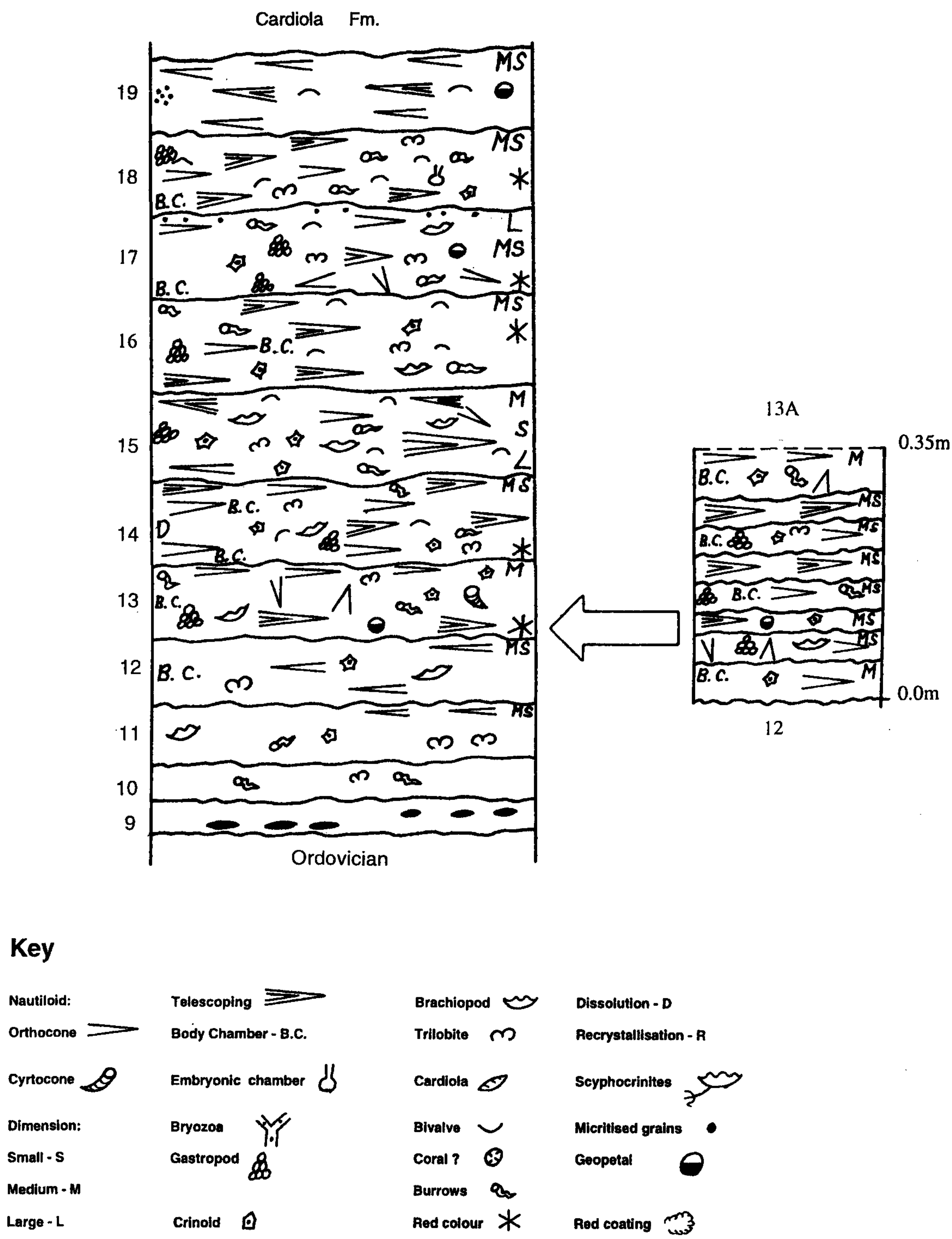


Fig. 3. Cellon section: Taphonomy - preliminary field observations. Bed numbers after WALLISER (1964).

Bed 13

Grey-red iron rich limestone with abundant nautiloids dominantly parallel to bedding. There are various cycles within this bed which show minor changes in the energy levels of the depositional environment (A detail of the base of the base of bed no. 13 is given in the illustration). Telescoping is prevalent at the base then progressing to random orientation followed by parallel orientation at the top of the sequence. Geopetals parallel to bedding have been noted at the base. The internal sediment of the nautiloids sometimes appears finer grained than the surrounding matrix so there may be some reworking of this fauna. Nautiloids have both internal and outer iron rich coating. Burrowing is also seen at the base and top of the sequence. The associated fauna consists of both coiled and spired gastropods, crinoids (articulated stem fragments), brachiopods and a cyrtocone at the base with trilobites becoming common upwards in the sequence. A certain amount of recrystallisation and gradation may also be noted up the sequence. Crusts occur between each cycle and iron rich 'layers' which have an uneven lateral development - sometimes appear to be only a surface feature: sometimes shows internal sedimentary layering.

Bed 14

This is similar to bed 13 but the cycles are less frequent and there is less iron in the bed overall with some dissolution effects. There is a slight developement of a juvenile brachiopod-bivalve-nautiloid fauna in one layer midway in the bed. Burrows only seem to occur in the iron-rich layers. Nautiloids start to be 'trapped' within crusts at top of cycles and are mainly medium in size.

Beds 13 and 14 represent a series of brown ferriginous limestones, a grey-red iron rich limestone with abundant nautiloids dominantly parallel to bedding. There are various cycles within these beds which show minor changes in the energy levels of the depositional environment. Telescoping is prevalent at the base then progressing to random orientation followed by parallel orientation at the top of the sequence. Geopetals parallel to bedding have been noted at the base. However, sediment within the nautiloids sometimes appears finer grained than the surrounding matrix so there may be some reworking of this fauna. Nautiloids have both an internal and outer iron rich coating.

Crusts occur between each cycle and iron rich 'layers' which have an uneven lateral development - sometimes appear to be only a surface feature: but sometimes also show internal sedimentary layering. As we go up the section the cycles are less frequent and there is less iron in the bed overall with some dissolution effects being evident

Bed 15

This bed shows a definite change in lithology with less iron content and development of an encrinitic level and a small fauna level as seen previously.The base is marked by the presence of large nautiloids within cycles as seen before and a juvenile fauna layer. Then there is the development of shales and the crinoid levels which also have a rich nautiloid fauna parallel to bedding.Towards the middle of the formation there is a definite change in lithology with less iron content and development of an encrinitic level above which, as at the Rauchkofel section, the nautiloid fauna is again abundant.

The top levels of the bed return to the previous cycles seen in beds 13 and 14 - iron rich and with medium nautiloids forming the top of the level showing telescoping.

Bed 16

This bed shows an increased frequency of cycles and of faunal abundance: iron layers and crusts are also developed together. There are also juvenile fauna layers which are quite distinctive and are easy to trace. Telescoping occurs at both the base and top of the bed but there is no concentration of larger dimensions at the top of the bed as seen previously. There is an increase in burrows and also in their dimension.

Bed 17

This bed is similar to bed 16 in the frequency of cycles and the faunal content but we start to have gradation up the cycles and the appearance of micritised grains particularly at the top of this bed. There is also a concentration of large nautiloids towards the top of the bed. A small fauna layer is apparent also near the top of the bed.

Bed 18

The fauna and cyles are as before but there is a definite increase in the variety of nautiloid fauna as we see large siphuncles, variety of apical angles and width of septa and embryonic chambers. Both the body chambers and apexes are preserved. There is a concentration of medium nautiloids at the top of the bed. This is probably a slightly deeper environment than the beds before.

Bed 19

There is a gradation upwards in the bed and more frequent development of crusts between thin carbonate levels. Faunal content not apparent but nautiloids parallel to bedding at top of bed and trapped between crust layers in the middle part of this bed. Burrows not evident in this bed. At the top of the bed the carbonate layers have an undulating appearance between thinly laminated shales similar to Bed 12.

Summary. In general in the Kok Formation in both the Cellon and Rauchkofel Boden sections we can note the changing energy and oxygen levels within the sequence and that there are many accumulated levels with intermittent changes in sea level particularly towards the top of the sequence. The data for the structural limits of the nautiloids is quite general at this stage of the study based on a ratio of conch diameter to septal spacing but the indications are for a mixed fauna in the lower beds of the formation becoming dominated by stronger fauna higher in the formation. A detailed study of the septal strengths of the nautiloids using the methods of HEWITT & WESTERMANN (1996) will be done when sampling of the sections is completed.

This study is still in its preliminary stages but it is hoped by comparing the results of the taphonomy and bathymetric indications for the nautiloid fauna from both sections to identify various taphofacies as has been done by BRETT (1989, 1990, 1991, 1995) for the Silurian of North East America.

The preliminary data for the nautiloid fauna at the Cellon section indicates a possible placement for the lower beds of the Kok Formation in Taphofacies 4 and the upper beds in Taphofacies 2 but this is still work in progress.

The depositional environment

(Lutz H. Kreutzer & Hans P. Schönlaub)

The first facial investigation at the Cellon section was carried out by H. FLÜGEL (1965). K. BANDEL (1972) studied the facies development of the Lower and Middle Devonian in the central part of the Carnic Alps. Middle and Upper Devonian and Lower Carboniferous strata (exposed as steep cliffs and on top of Cellon) were investigated by L. H. KREUTZER (1991). Photomicrographs with detailed interpretation from the Ordovician to Lower Carboniferous sequences comprising the whole Cellon section was published by L. H. KREUTZER (1992b).

In this volume a revised analysis of 64 thin sections of the Cellon gorge is presented. The following list shows the facial characteristics of each formation with the sample numbers according to O. H. WALLISER (1964).

Ordovician: Uggwa Formation
Age: Ashgill
Facies: Uggwa Facies
Character: (a:) grey to coloured pelagic Flaser limestone with (b:) ostracod-echinodermal debris layers.
Skeletal grains: brachiopods, filaments, ostracods, parathuramminaceae, cephalopods, styliolinids, trilobites, acritarchs
Thickness: 7,3 m
Outcrop: Cellon section, layer 1 - 5 (WALLISER 1964)
DUNHAM (1962): a: wackestone; b: pack-/grainstone
SMF-type acc. to WILSON (1975): (a:) 9; (b:) 12

Ordovician: Plöcken Formation
Age: Ashgill, Hirnantian Stage
Facies: Uggwa Facies
Character: echinodermal and bivalve debris
Skeletal grains: echinoderms, ostracods, bivalves, algae
Thickness: 4,8 m
Outcrop: Cellon section, layer 6 - 8 (WALLISER 1964)
DUNHAM (1962): grainstone
SMF-type acc. to WILSON (1975):12

Silurian: Kok Formation
Age: Upper Llandovery to Middle Ludlow
Facies: Plöcken Facies
Character: grey to greyish black micritic limestones with many stylolites
Skeletal grains: filaments, trilobites, ostracods, gastropods, brachiopods, echinoderms, algal crusts
Thickness: 13 m

Outcrop: Cellon section, layer 9 - 20 (WALLISER)
DUNHAM (1962): Mud-/wackestone
SMF-type acc. to WILSON (1975): 9

Silurian: Cardiola Formation
Age: Upper Ludlow
Facies: Plöcken Facies
Character: grey limestones with marly layers
Skeletal grains: nautiloids, ostracods, trilobites, parathuramminaceae, radiolarians
Thickness: 3,5 m
Outcrop: Cellon section, layer 21 - 24 (WALLISER 1964)
DUNHAM (1962): wackestone
SMF-type acc. to WILSON (1975): (3/9)

Silurian: Alticola Limestone
Age: Ludlow to Pridoli
Facies: Plöcken Facies
Character: dolomitic grey to greyish pink micrites
Skeletal grains: nautiloids, filaments, trilobites
Thickness: 20 m
Outcrop: Cellon section, layer 25 - 39 (WALLISER 1964)
DUNHAM (1962): wackestone
SMF-type acc. to WILSON (1975): 3

Silurian: Megaerella Limestone
Age: Pridoli
Facies: Plöcken facies
Character: a) light to grey micrites with b) biosparites
Skeletal grains: a) ostracods, filaments, trilobites; b) ostracods, filaments, echinoderms
Thickness: 8 m
Outcrop: Cellon section, layer 40 - 47A (WALLISER 1964)
DUNHAM (1962): a) wackestones; b) pack-/grainstones
SM F-type acc. to WILSON (1975): a) 3; b) 2

Devonian: Rauchkofel Limestone
Age: Lochkov
Facies: Transition facies (KREUTZER 1992a)
Character: a) dark grey to black platy limestone and shales with shell debris and layers of b) crinoidal debris grainstones
Skeletal grains: a) tentaculites, cephalopods, ostracods, parathuramminaceae, filaments, trilobites, few echinoderms; b) rounded echinodermal fragments, bivalves
Thickness: 80 m
Outcrop: Cellon section, layer 47B and >
DUNHAM (1962): a) wacke-/packstone; b) grainstone
SMF-type acc. to WILSON (1975): 9

Single beds can be characterized as follows (see Figs. 1A-D):

51:	Peloid-grainstone with echinodermal fragments and lumachelles
50, 49:	Laminated peloid-shell-grainstone
48A, 48:	Laminated grainstone with lumachelles
47C:	Laminated grainstone with echinodermal fragments and lumachelles
46B:	Peloid-grainstone with lumachelles
46, 45:	Laminated grainstone with lumachelles
44A, 44:	Bioclastic wackestone with nautiloids, trilobites and filaments

43:	Grainstone with lumachelles
42B, 42, 41A:	Bioclastic wackestone with nautiloids, filaments, parathuram- minacea
41:	Wacke-/packstone, dolomitized, bioturbated
40A:	Mud-/wackestone, few echinodermal fragments
40:	Laminated grainstone with lumachelles
39:	Wackestone with parathuramminacea, dolomitized
38:	Wackestone with nautiloids, parathuramminacea
37, 36, 35, 34, 33, 32:	Bioturbated wackestone, parathuramminacea, nautiloids, filaments, trilobites, ostracods
31:	Bioclastic wackestone, partly dolomitic matrix, trilobites
30:	Graded bedding (pack-/wackestone, above secondary dolomite) in a wackestone
29:	Iron-rich pack-/grainstone with nautiloids, dacryoconarids, filaments
28:	Iron-rich bioclastic packstone, trilobites, surrounded by algal crusts, filaments, ostracods
27:	Bioclastic wacke-/packstone, nautiloids, filaments, ostracods
26:	Secondary dolomite, bioclastic wackestone
25:	Bioclastic wackestone, nautiloids, trilobites, filaments
24:	Finely laminated lithoclastic shaly limestone, pyrite
23:	Bioturbated shaly limestone with radiolarians, above shell grainstone with ostracods
22:	Bioclastic wackestone with nautiloids, filaments, trilobites
20:	Laminated grainstone with lumachelles, pyrite
19:	Bioclastic wackestones with nautiloids
18C:	Packstone, nautiloids, brachiopod shells, conodonts
18:	Lithoclastic layer with shells
17:	Bioclastic wacke-/packstone with trilobites, nautiloids, bioturbated
16:	Pack-/grainstone with lumachelles
15B:	Grainstone, lumachelles, pyrite
15, 14, 13, 12:	Bioclastic wacke-/packstone with nautiloids, trilobites, ostracods, filaments, iron-rich
11D:	Strongly bioturbated wackestone with algae, lumachelles, quartz
7:	Packstone with edged echinoderm fragment clasts, few shells and bryozoan fragments
6:	Grainstone with ehinoderms and shells
5:	Grainstone with echinoderms and shells changing with clay rich laminated clast layers, pyrite
4:	Lithoclastic pack-/floatstone with reworked components from layer 3
3, 2, 1:	Bioclastic wackestone with nautiloids, trilobites, filaments

The remaining part of the Variscan carbonate succession at Cellon and the surrounding area is described in L. H. KREUTZER 1992b.

The bathymetric environment for the Silurian sequence can be described as follows (see Fig. 4):

As early as in the Ordovician a facial differentiation can be recognized for the carbonates. The Cellon section with its Uggwa Limestone development (sample 1-5) represents the late Ordovician Uggwa facies which is time-equivalent to the Wolayer Limestone of the Himmelberg facies exposed, e. g., at the Rauchkofel-Boden section. Based on conodonts the Uggwa Limestone is well dated as being Ashgillian in age. According to W. C. DULLO (1992), the two formations represent the near-shore parautochthonouos cystoid facies (Wolayer Limestone) and an off-shore basinal debris facies (Uggwa Limestone), respectively.

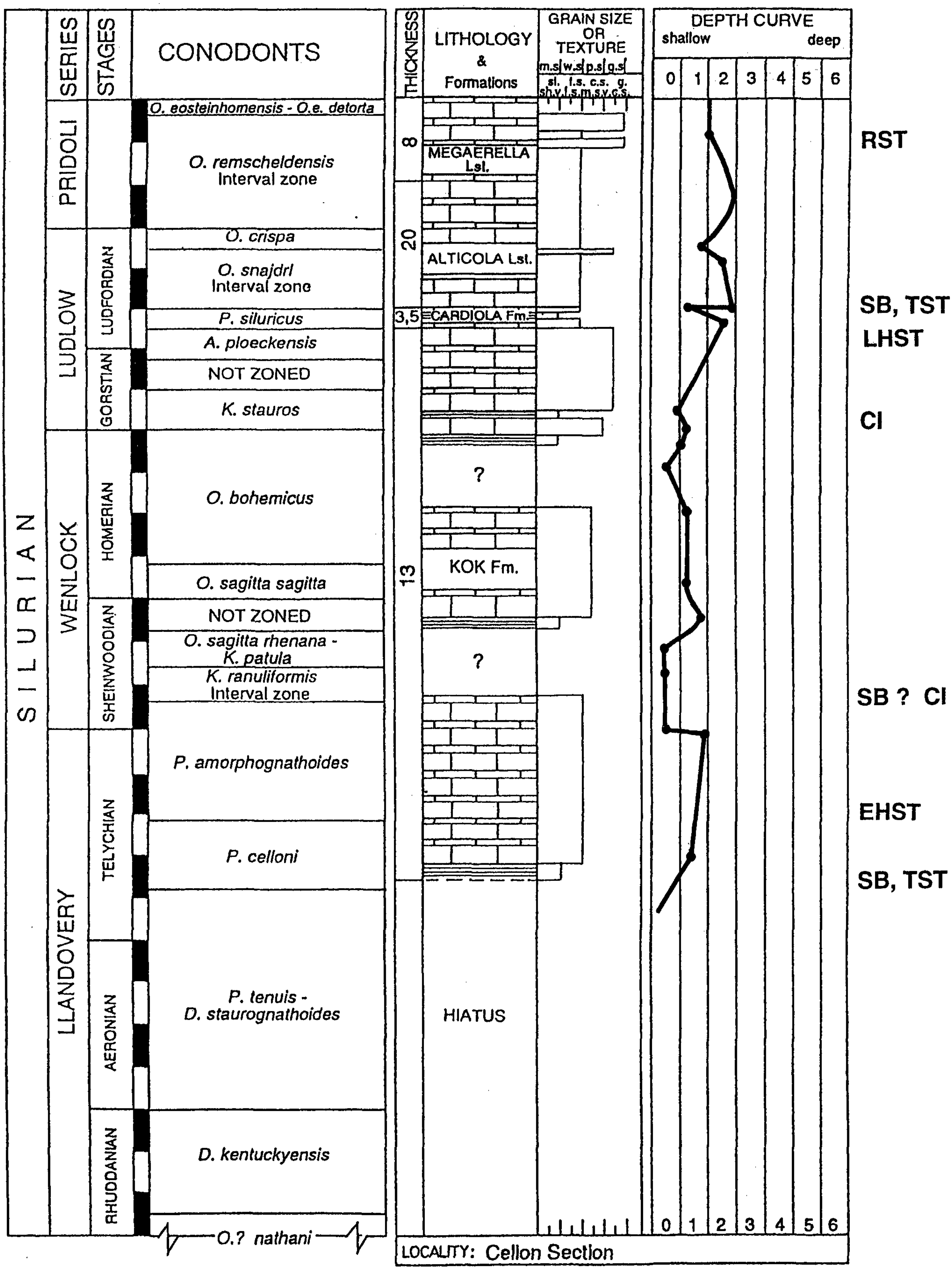


Fig. 4. Conodont stratigraphy, lithology, grain size and depth curve of the Silurian portion of the Cellon section (CI - condensed interval, EHST - early highstand system tract, LHST - late highstand (regressive) system tract, RST - regressive system tract, TST - transgressive system tract, SB - sequence boundary).

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

Transgression of the Kok Formation started in the Cellon section in the Upper Llandovery (bed no. 9). In contrast to the Cellon section the Rauchkofel section located some 8 km to the northwest exhibits a considerably reduced sequence. At Cellon the basal Silurian succession represents a moderately shallow environment which may have lasted until the Llandovery/Wenlock boundary or until the very beginning of the Wenlock. Sample 11 exhibits a very shallow to intertidal environment thus confirming the biostratigraphic considerations of an extrem condensation or more probably a gap in sedimentation. Based on lithofacies criteria for the remaining part of the Wenlock a sea-level rise is indicated. However, at the Wenlock/Ludlow boundary (bed nos. 15A - F) some strata may also be missing reflecting either submersion or another level of reduced sedimentation.

During deposition of the Cardiola Formation (bed nos. 21 - 24) contemporrary non-deposition (due to currents ?) may have occurred. Black limestone and shale beds with radiolarians alternate with pelagic limestone beds indicating an offshore environment of a late highstand system (RST - regressive system tract).

In terms of sequence stratigraphy the boundary between the Cardiola Fm. and the overlying Alticola Lst. represents a sequence boundary (SB) with a sharp erosive contact between the two formations. At the base of the Alticola Lst. a "transgressive systems tract" (TST) of the following deepening cycle is developed. The succeeding beds up to no. 39 reflect overall stable conditions in a pelagic environment which was interrupted by a short-term regressive pulse (bed no. 40). With the onset of the Megaerella Limestone (nos. 41-47A) a further transgressive trend followed by a regressive (late) highstand system can be inferred.

Starting in the Lochkovian Stage (bed 47B and >; Rauchkofel Limestone) and ranging to the Upper gigas Zone of Frasnian age (top region of the Cellon cliff) the Devonian transitional facies represents a fore-reef facies. While this slope facies accumulated at Cellon, only a few kilometers to the palinspastic SSW (today seen at the Kellerwand region) more than 1000 meters of Devonian shallow-water limestones were deposited (Fig. 5). Moreover, coeval carbonates of pelagic origin, i. e. pelagic limestone facies of the Rauchkofel nappe) with a markedly reduced thickness of not more than 100 meters were deposited within short distances to the NNE (SCHÖNLAUB 1979, 1985; KREUTZER 1990, 1992a, b).

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

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

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

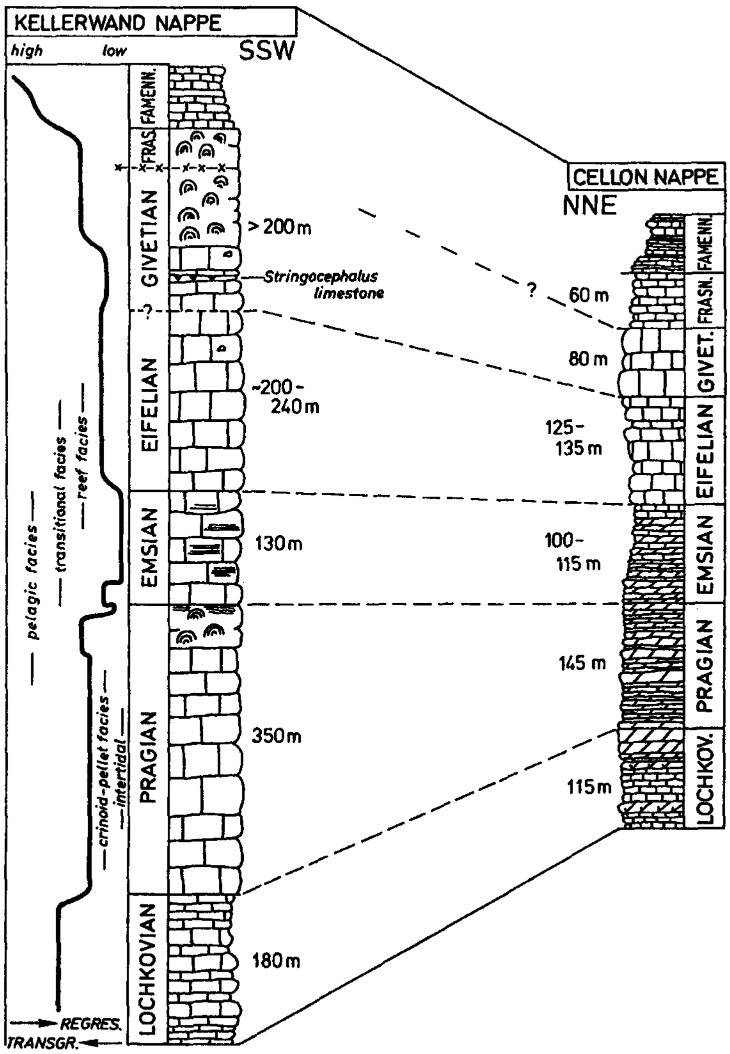


Fig. 5. Comparison of the Devonian sequences between the Kellerwand and the Cellon Nappes (after L. H. KREUTZER 1990).

A short distance to the west of the peak of Cellon at the famous Grüne Schneid section the Devonian/Carboniferous boundary beds are excellently exposed (Fig. 6). The detailed distribution of conodonts, goniatites and trilobites as well as the lithology and major and trace element content has recently been studied by an international working group (see H. P. SCHÖNLAUB et al. 1992).

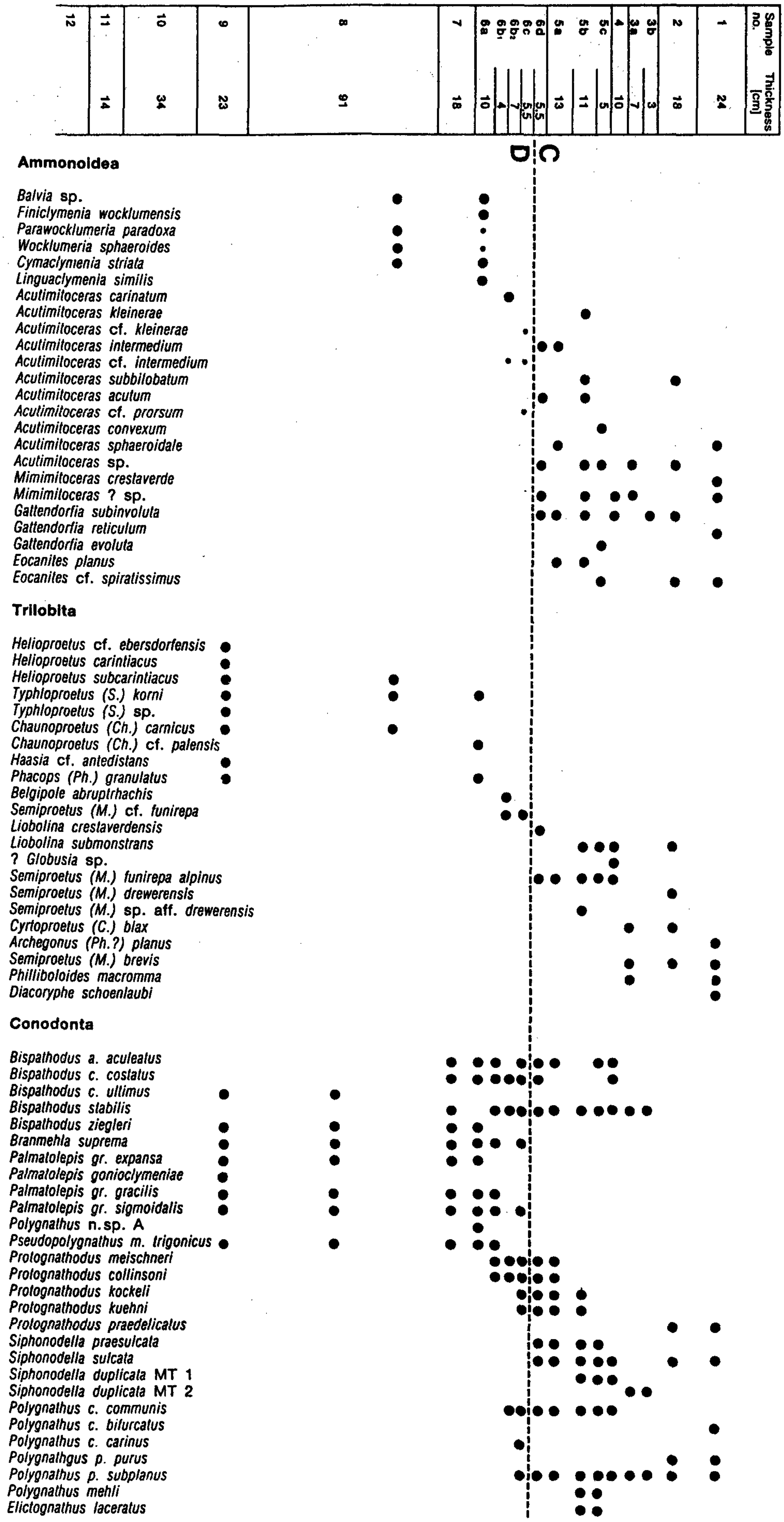


Fig. 6.
Distribution of conodonts, ammonoids and trilobites at the Grüne Schneid section.

Stable Isotope Data of the Silurian of the Carnic Alps[7]
(Bernd Wenzel)

Carbon isotope data were obtained from carbonate whole rock samples and the sedimentary organic carbon content (TOC) for several Silurian sections of the Carnic Alps. The sampled sections comprise pelagic graptolite shales of the Bischofalm facies, the transitional Findenig facies of interbedded black shales and carbonates and the pelagic Plöcken as well as the neritic Wolayer facies. The isotope data can not only be used for stratigraphic correlation but permit also further implications for the depositional environment.

The Silurian part of the Cellon section (Fig. 7)

At Cellon the Silurian carbonates are characterized by more or less uniform $\delta^{13}C$- values. Slightly increased values occur in the late Ashgill (Hirnantian Stage) and in the lowermost part of the Alticola Lst. corresponding to the latialata conodont Zone of

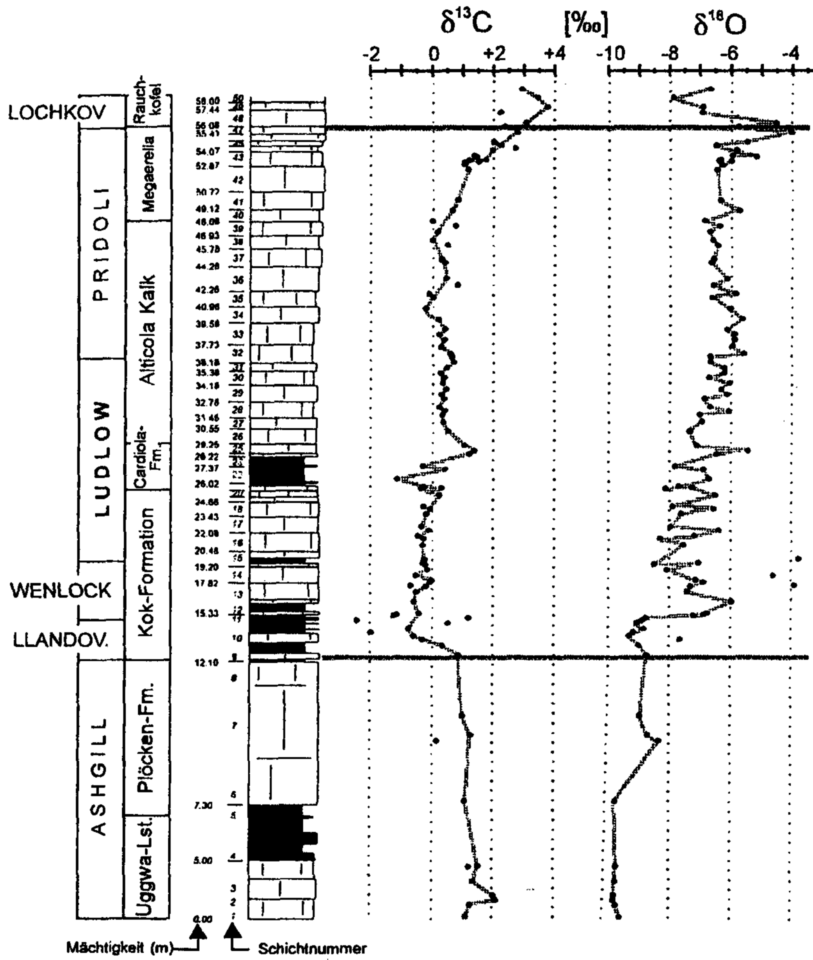


Fig. 7. Stratigraphy, lithology and isotope data for the Cellon section (Upper Ordovician to Lower Devonian). Black = C_{org} rich carbonates and shales. Isotope data from dolomitized horizones are excluded (after B. WENZEL, in press).

[7] The originally German text was provided by B. WENZEL (Erlanger Geol. Abh., 129, in press) and translated by Hans P. Schönlaub.

the Ludfordian Stage (upper Ludlow). However, these positive excursions are less pronounced than in the Baltic region. Moreover, the postive $\delta^{13}C$ signal in strata of the lower Wenlock riccartonensis graptolite Zone of Gotland can not be confirmed at Cellon suggesting either a gap or a strongly condensed interval in this part of the section. This suspicion is supported by data from the Oberbuchach 1 section a few kilometers to the east of Cellon in which a distinct positive signal has clearly been recognized in strata corresponding to the riccartonensis Zone presumably missing at Cellon.

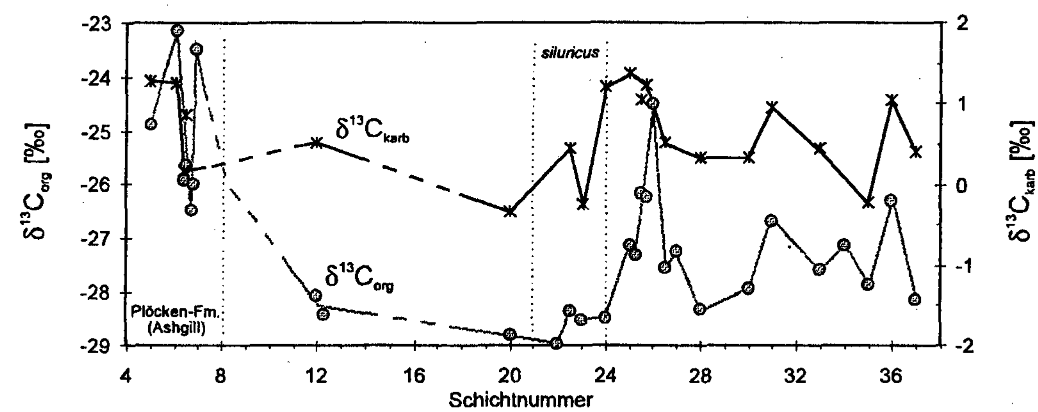


Fig. 8. $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ data for the Cellon section. For sample numbers compare Fig. 7. Note that positive $\delta^{13}C_{org}$ excursions are paralleled by positive $\delta^{13}C_{carb}$ excursions for the Ashgillian, the latialata Zone of the upper Ludlow and within the Pridolian part of the sequence.

The measurements of the isotope signal of the organic carbon displays a parallel trend (Fig. 8). The Plöcken Fm. of the Hirnantian Stage is characterized by high $\delta^{13}C_{org}$-values similar to the Hirnantian of Estonia and South China. A second high signal is reflected in the lower latialata conodont Zone of the basal Alticola Lst. which can be correlated with the Eke and Burgsvik Beds of the Gotland succession. Similar to the $\delta^{13}C_{carb}$-signal the $\delta^{13}C_{org}$-values for the lower Wenlock suggest a break in sedimentation as the corresponding positive $\delta^{13}C$ excursions of the Baltic region (and of the Oberbuchach 1 section) are missing.

Stop 2: Rauchkofel Boden Section

by

Hans P. Schönlaub, Kathleen Histon, Annalisa Ferretti, O. Bogolepova, Bernd Wenzel

Lithology and Paleontology

(Hans P. Schönlaub)

This section is exposed on the southwestern slope of Mount Rauchkofel west of p.2175 m. It represents a continuously exposed and conformable limestone succession ranging from the Ashgillian to the Lower Devonian (Pragian). The major part of Lower Silurian strata, however, are missing at this section (Fig. 9).

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". A detailed description was published by H. R. v. GAERTNER 1931 and H. P. SCHÖNLAUB 1970, 1980. The fauna was studied by H. RISTEDT 1968 (orthoconic nautiloids), W. HAAS (trilobites, unpubl.), J. KRIZ (bivalves), and H.P. SCHÖNLAUB (conodonts).

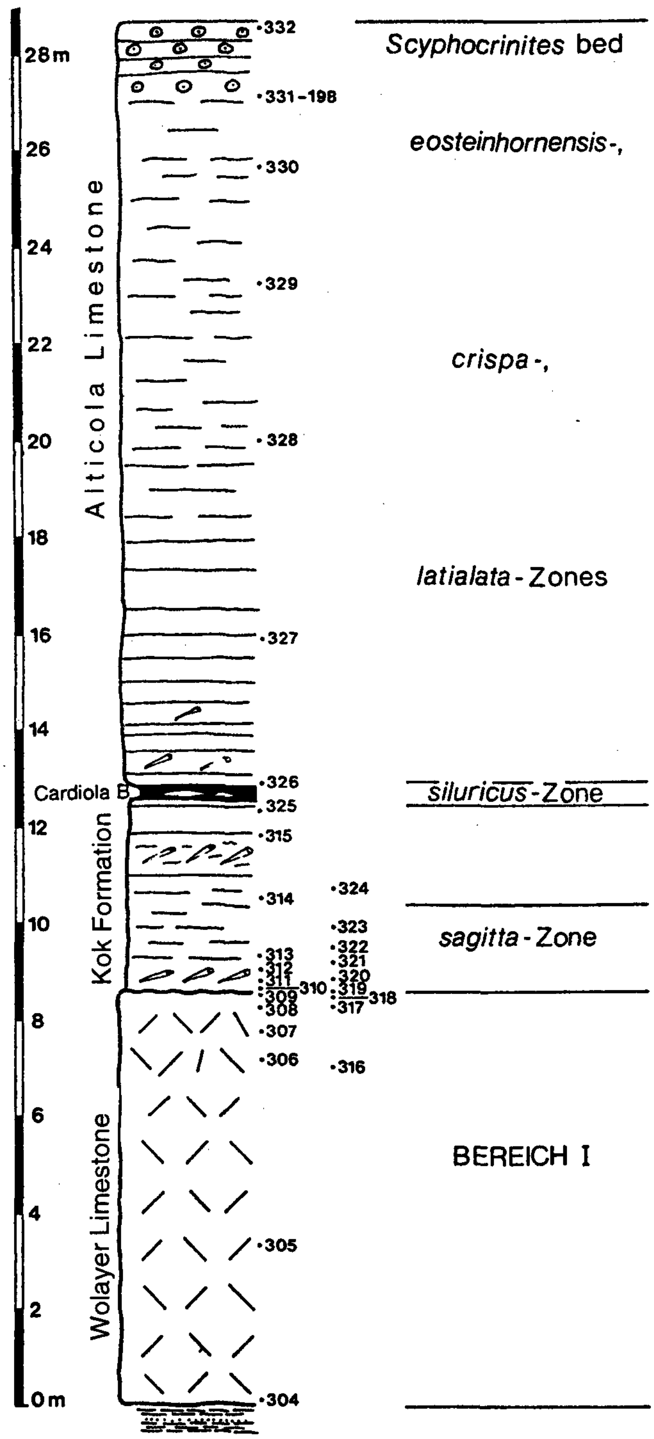


Fig. 9. The Rauchkofel Boden section (Upper Ordovician to Silurian part) after H.P. SCHÖNLAUB et al. (1980).

The Upper Ordovician is represented by a 8.60 m thick cystoid bearing massive limestone horizon, the so-called Wolayer Limestone. Its lithology was recently studied. According to W. C. DULLO 1992 it was deposited in a shallow water environment with low energy in a moderate climatic setting. Besides undescribed cystoids and trilobites conodonts are fairly abundant suggesting a late Ordovician age within the Ashgillian Series.

The Wolayer Lst. is disconformably overlain by 3.90 m thick grey fossiliferous cephalopod limestones (*"Orthoceras* Lst."). The macrofauna includes the following nautiloids and bivalves (sample nos. 310-315, 319-324):

Michelinoceras (?) sp.
Sphaerorthoceras n.sp.
Merocycloceras declivis RISTEDT
Parasphaerorthoceras sp.
Isiola lyra KRIZ (nos. 319, 322, 325-65 cm)
Slava fibrosa (no.325-105 cm)
Cardiola aff. *signata* BARR. (322)
Cardiola contrastans (no. 325-105 cm)
Spanila sp. (322)

W. HAAS from Bonn University reported the following trilobites from the basal part (approx. 1.5 m) of the cephalopod limestone:

Aulacopleura haueri
Kielania n.sp.
"Odontopieura" ovata
Eodrevermannia n.subg. n.sp.
Otarion (O.) sp.
Scharyia n.sp.
Leonaspis cf. *minuta*
Xanionurus n.sp.
Koneprusia n.sp.

In the middie part he found:

Kosovopeltis n.sp.
Otarion (O.) sp.
Leonaspis cf. *minuta*
Raphiophorus rouaulti

The upper part of the cephalopod limestone contains:

Raphiophorus rouaulti
Prionopeltis striatus
Otarion (O.) sp.
Leonaspis cf. *minuta*

The 10 cm thick black limestones bed above no. 325 (badly exposed in the trench from the war) yielded the following bivalves (J. KRIZ):

Cardiola docens BARR.
Cardiola consanguis BARR.
Cardiola cf. *signata* BARR.

Mila complexa BARR.
Spanila aspirans BARR.

W. HAAS found in the Cardiola Fm. *Aulacopieura* cf. *muensteri.* The fauna above the Cardiola Fm. has not been restudied in detail yet. H. R. v. GAERTNER and F. HERITSCH 1943 reported the following taxa:

Base of Alticola Lst. (sample nos. 326-328):

Spirigera canaliculata BARR.
Spirigera obovata SOW.
Retzia ? umbra BAAR.
Maminca italica GORT.
Dualina plicata MSTR.
Dualina cf. *sedens* BARR.
Tenka cf. *bohemica* BARR.
Loxonema commutatum PER.
Holopella compressa MSTR.
Holopella trochleata MSTR.
Platyceras otiosum BARR.
Platyceras praepriscum BARR.

Sample nos. 329-332:

Encrinurus nilssoni BARR.
Encrinurus transiens BARR.
Proetus romanicus GAERTNER
Petraia laevis POCTA
Holopella subcompressa MSTR.
Orthoceras tiro BARR.
Scyphocrinus sp.

According to W. HAAS (unpubl.) the following trilobites occur at the edge of the steep slope (sample no. R 5):

Goldillaenus nilssoni
Cornuproetus (C.) cf. *vertumnus*
Encrinurus subvariolaris
Encrinurus ploeckensis
Bohemoharpes n.sp.
Bohemoharpes cf. *crassifrons*
Cerauroides cf. *propinquus*
Phacopidella n.sp.
Ananaspis grimburgi
Ceratonurus sp.

In the late Wenlock and the Upper Silurian conodonts are fairly abundant. A rich fauna representing the *O. sagitta* Zone occurs from the base of the *Orthoceras* Lst. up to sample no. 313, i.e. 1.20 m above the base (fig. 12). 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 (H.P. SCHÖNLAUB in J. KRIZ et al. 1993).

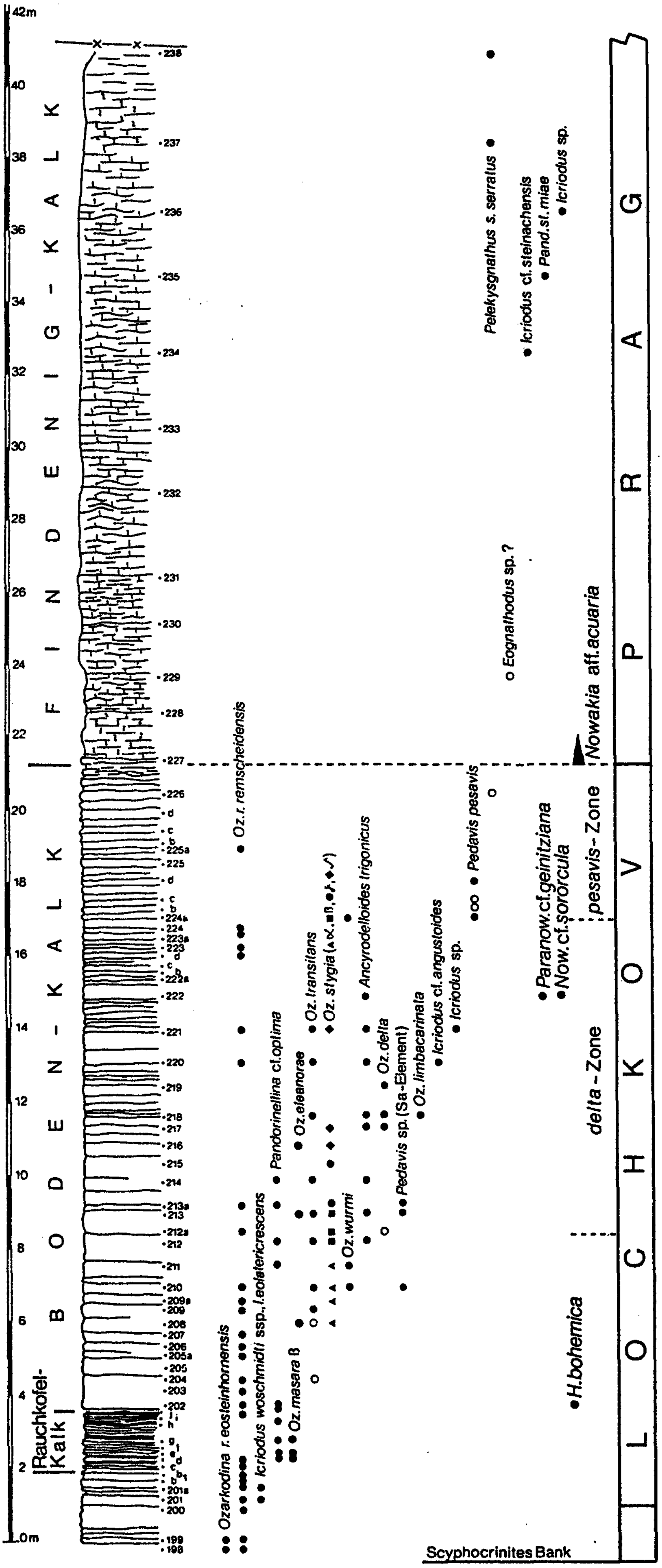


Fig. 10. Rauchkofel Boden section, Lower Devonian part with basal 1.80 m thick pelagic Rauchkofel Lst., followed by Boden Lst. and Findenig Lst. (after H. P. SCHÖNLAUB et al. 1980, modified).

The following Cardiola Fm. corresponds to the *P. siluricus* Zone of the stratotype at Cellon. 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 Silurian/Devonian boundary is drawn at the base of grey and blackish platy crinoidal limestones containing *Scyphocrinites* (sample no. 331=198). At this horizon abundant loboliths of *Scyphocrinites* can be found. 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 (Fig. 10) seems to be extremely condensed. 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 were 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. 10 showing its lithology and faunal content. The exposed 40 m thick undisturbed section is subdivided into the following formations:

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

Cephalopod Limestones

(Annalisa Ferretti & Kathleen Histon)

Microfacies and Taphonomy. The Rauchkofel section offers pictoresque expositions of Silurian cephalopod limestones, among which different limestone types may be recognised. A global study of the Silurian strata at this section by a research team (O. BOGOLEPOVA, A. FERRETTI, K. HISTON, J. KRIZ & H. P. SCHÖNLAUB) is in progress based on observations of the abundance, dimension, orientation, colour and the preservation of all organisms composing the fauna, in particular the nautiloid fauna, together with lithologic and sedimentological data. The data here reported and summarised in Fig. 11 are just preliminary results by two members of the group. A distinction of the outcrop into three parts was attempted (Inner trench, exposed towards the south, median trench and outer trench, exposed to the north) and a correlation made between them. Iron-oolitic concentrations which may mark the limit of depositional cycles have been identified at certain levels. A brief outline of previous work on these limestones in the Carnic Alps and the taphonomic parameters used in this study is given in this volume in the chapter on the Cellon Section.

Kok Formation (Bed nos. 310 to 315 and 319 to 325)

The Kok Formation consists of a of dark grey-reddish micritic limestone showing a variety of bed thickness which in general decreases upwards.Possible dropstones have been noted at the Ordovician - Silurian boundary on the upper surface of the Ordovician Cystoid limestone. The contact with the lighter Ordovician limestone is easily recognizable in all the exposures being marked by an iron-oolitic concentration. The lowermost samples are mostly represented by a bioclastic wackestone to packstone with cephalopods inside a sorted matrix of small bioclasts (trilobites, crinoid fragments, simple valves of bivalves, ostracods and gastropods). Recrystallisation is common. The base of the formation is relatively barren in nautiloid fauna with respect to the upper beds. The majority of them are apparently oriented parallel to bedding and some telescoping is seen although there seems to be a very regular cyclicity to the occurence of telescoping of specimens, usually occuring at the top of individual beds. Body chambers have not been observed but the apex is usually present. In some cases the nautiloids are seen to have an outer dark red oxidised coating of the shell which may represent dissolution of the shell wall itself as in some cases the nautiloid may be removed from this external casing.

An encrinitic packstone of crinoid debris is present towards the middle of the formation (level 323/314). Above it what may be called "an abundant nautiloid fauna" occurs for the first time in this formation (base 324/ mid 314).

This level is followed by thinly developed cyclic micritic limestone beds of bioclastic accumulations separated by thinly laminated iron-rich layers or 'crusts' with sometimes iron-oolitic concentrations. These crusts may represent sedimentation breaks or hardgrounds in the carbonate sequence. A rich nautiloid fauna is preserved, the nautiloids sometimes being apparently trapped within the crusts. The nautiloids are varied in dimension from 1 - 5cm diameter but larger diameters are also seen in vertical orientation and these sometimes traverse the bedding layers.

The orientation of the nautiloids varies within individual beds but alternating trends from parallel to random may be noted with telescoping also occurring in certain beds. Dissolution of the conch wall is also often evident where specimens are enclosed within the "crusts".

Higher in this series of beds the external red oxidised coating of the lower beds is not so obvious but an iron-rich lining of cameral chambers and siphuncle is often seen. Pyrite development also occurs towards the top of this sequence.

Concentrations of apparently juvenile and equidimensional articulate brachiopods and nautiloids and small gastropods alternating with the nautiloid beds occur from about mid-way to the top of the sequence (top 324 / 315). and have a distinctive red-pink appearance. These bio-accumulations seem to have major thickness in front of the middle trench.

At the top of the formation bordering the war trench, spectacular cephalopod limestone beds are exposed and may be distinguished from the previous nautiloid layers by the greyer appearance of the limestone and the obvious variety of the nautiloid fauna (325 /315). The limestone is represented by a cephalopod wackstone to packstone with gastropods, echinoderms, trilobites and ostracods. No sorting or

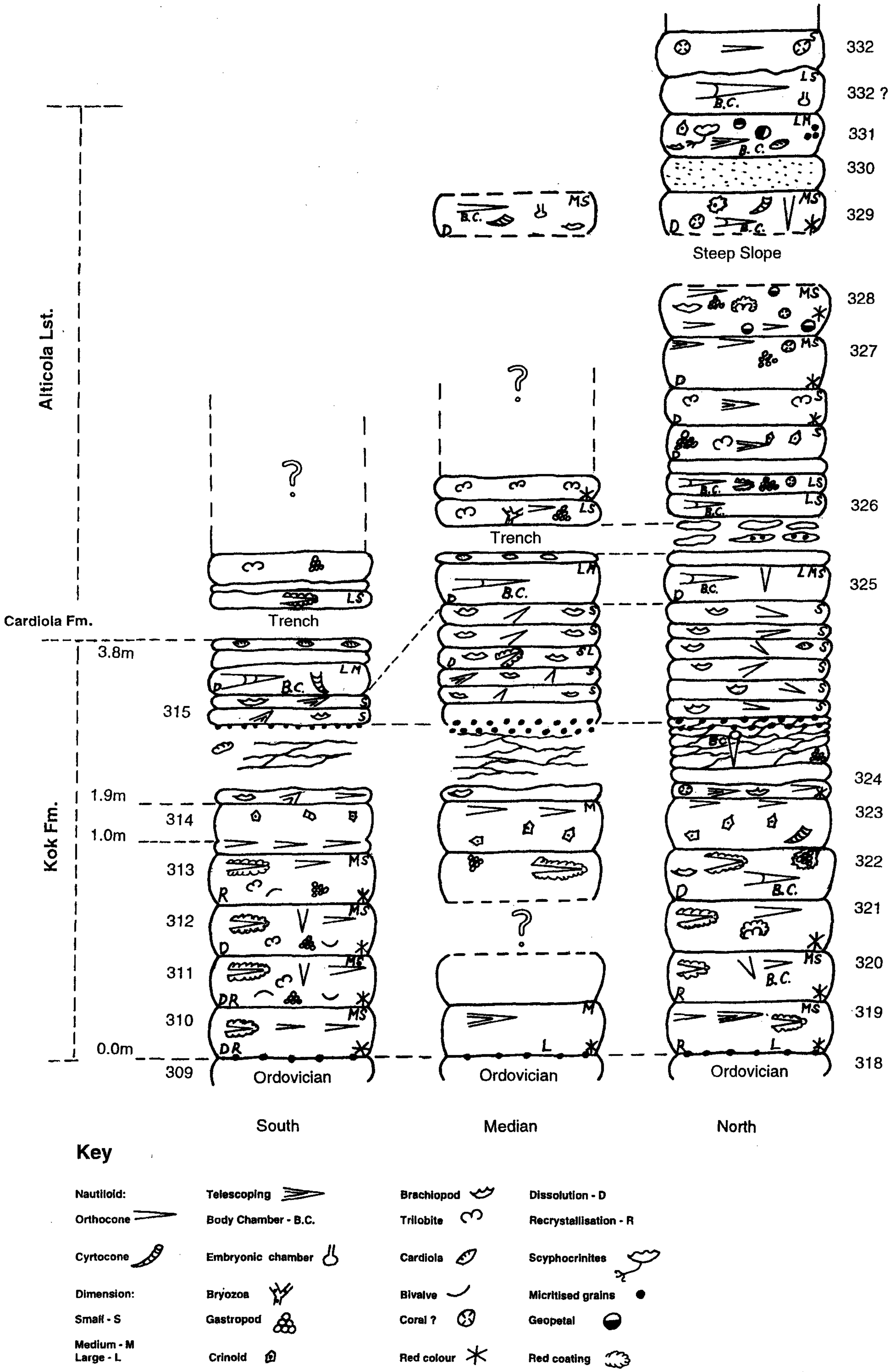


Fig. 11. Rauchkofel Boden section: Microfacies and Taphonomy - preliminary field observations. Bed numbers after SCHÖNLAUB et al. (1980).

gradation was observed. The abundance of the nautiloid fauna is at first deceptive due to the undulating exposure of the underlying layers but the fauna is nevertheless quite rich particularly with regard to form and dimension. Dimensions range from 1-5cm in diameter in general with the smaller forms being dominant. They are usually oriented parallel to bedding with some vertically oriented specimens also being present. The specimens are also less fragmented in these upper levels.

Dissolution of the conch wall and body chamber has also been noted and is particularly shown by the contrast of the relief of the remaining secondary cameral and siphuncle deposits on the bedding surface.

The iron-rich coatings and infillings of the fauna in certain levels together with the observed dissolution of shell material indicate the changing oxygen levels in the environments. The iron-rich crusts seen between the beds in the upper part of the formation have also been noted in condensed beds in the Devonian of Morocco (WENDT 1988) and have been interpreted there as hardgrounds or breaks in sedimentation. BRETT (1995) discusses the importance of these condensed beds and sedimentation breaks for sequence stratigraphy and how the overall cycles may be used for correlation purposes. The data for the structural limits of the nautiloids is quite general at this stage of the study but the indications are for a mixed fauna in the lower beds of the formation becoming dominated by stronger fauna or deeper water fauna higher in the formation. Therefore for the Kok Formation at the Rauchkofel section we see that the fauna becomes dominantly abundant and larger in size up the sequence with iron content also decreasing but dissolution being more evident.

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 fauna that there are many accumulated levels with intermittent changes in sea level particularly towards the top of the sequence. 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 an indication of high energy. Thus a high energy environment may be indicated for bed nos. 319, 324 and some levels of 315. The preservation of the conchs 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 bed nos. 320, 322, some levels of 315 and 325.

It is still too early in the study to make more conclusive comments on the environmental setting of the formation.

Cardiola Formation

The overlying Cardiola Formation, Ludlow in age, is comparable with the well-known cephalopod limestone which was deposited in Bohemia and along the North Gondwana margin. It is represented by a thinly developed dark limestone which is badly exposed in the war trench and shows lateral variation in its outcrop. It overlies the Kok Fm. appearing now as loose blocks or lenses which are buried in an earthy deteriorated layer. Cephalopods are the dominant fauna in this micritic limestone. Iso-oriented bioclasts, frequently coated by micrite, are quite common in the matrix.

Below the Cardiola Fm., just at the top of bed 315 at one side of the trench, a 10cm thick level with an upper undulate surface was exposed. This horizon is rich in Cardiolids and was distinguished from the true Cardiola Fm. of the trench.

With regard to the nautiloids there is an abundant fauna apparently oriented parallel to bedding which acts as a fixed substrate for the *Cardiola* bivalve fauna. The specimens are generally small in size with diameters of 1-3cm and are longiconic in form. 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. An interesting level overlies the Cardiola Fm. which bears a spectacular concentration of large nautiloids. Determinations and measurements of the specimens are in progress.

Alticola Limestone (Bed nos. 326 to 331)

The Alticola Lst., Pridoli in age, is a fine grey micritic limestone the beds of which vary in thickness and colour becoming darker and thinner towards the top but with an abundant nautiloid fauna throughout the formation. The preservation of the nautiloid fauna is similar to that of the Kok Formation. The associated fauna includes trilobites, brachiopods, echinoderms and relatively big gastropods. Solitary corals are visible in bed nos. 327 and 328 - lamination of the matrix and bioturbation were observed - the limestone becomes more micritic towards the top. A *Scyphocrinites* bed bearing complete specimens caps the formation. Micritised bioclasts are abundant in the matrix.

As may be seen from the data given (Fig. 2) this formation has a rich and varied fauna both of nautiloid and other groups. The base and top of the formation are marked by the occurrence of large orthocones oriented both parallel and perpendicular to bedding but which also show definite trends on the bedding surface itself. Telescoping and orientation to bedding are again good indicators of energy levels as is the fragmentation of the associated crinoid and trilobite fauna in some levels of bed nos. 326, 327 and 331. The amount of dissolution of the fauna appears to be quite significant in some beds particularly nos. 326 and 327 as is the development of thin crusts within these beds: these may be indicative of changing sea and oxygen levels. 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. The presence of Oncocerid nautiloids in Bed 329 also indicates a quite shallow setting.

Orientation of Cephalopods
(Olga Bogolepova)

With regard to the orientation of orthoceracone cephalopods in the Rauchkofel Boden section O. BOGOLEPOVA is adding some preliminary data based on a study in 1993:

Many examples of orthoceracone cephalopod orientation and the use of the latter as indicator or paleocurrents have been published. Theoretical considerations indicate that orthoceracone cephalopods (like other elongate objects) are aligned parallel with a current. Though there are a number of publications based on the application of hydrodynamic modelling in experiments, which produce different and at times conflicting results, the author following the majority of the investigators, holds to the opinion that most orthocone shells of orthoceratids, tentaculites and high-spired gastropods found on bedding planes in mass accumulation are oriented by their apices against the current. A strong current orients orthocones in such a way that their apices point against the current. However, the discussion of the paleoflumenology problems, the merits and demerits of this method, the ways for different interpretation of the results and so on will be the subject of a future article. The task of the author here is to present preliminary data which were obtained as the result of measurements of cephalopod orientation at the Rauchkofel Boden section during a visit in 1993.

Orthoceracone cephalopods are abundant in the Kok Lst., the Cardiola Fm. and the *Scyphocrinites* bearing bed of the Alticola Limestone. The highest concentration of orthocones occurs in bed 2 (lower and upper part) of the authors subdivision, bed 4 (lower part), bed 6 and bed 8 (see Fig. 12). Orientations were measured on bedding planes (one or a few in each layer) and the condition of the majority of cones was noted. All measurements were done by the umbonal part of cephalopods. In each layer the orientation of each individual was plotted on the bar graph and then on the rose-diagram. All orientation measurements within 15 degrees were placed in one class.

Bed 2: In the lower part of the layer the orientation of 36 orthocones shows two trends, from SW to NE, and from W to E. The number of measurements does not allow to conclude any major preferable trend in the orientation of cephalopods. In the upper part of the bed on a different bedding plane the orientation of 187 orthocones was measured. The rose-diagram of layer 2, upper part shows the orientation of all measured cephalopods. There is one clear trend from SW to NE (between 30-45 degrees).

Bed 4: The orientation of 39 orthocones was measured. Most of the cones are oriented between 60 and 75 degrees indicating a direction from SW to NE.

Bed 6: The orientation of 82 orthocones was measured. They reflect one major trend from SW to NE (between 45 and 75 degrees) and minor secondary trends.

Bed 8: (Lower Devonian, Lochkov): The orientation is based on measurements of 85 cephalopods. The major direction runs from N-NE to S-SW (between 180 and 195 degrees).

On the illustrated figure the main results of this preliminary study are summarized showing the main tendency of preferred orientation of cephalopods in the Rauchkofel Boden section. C. HOLLAND (1984) noted many published examples of so-called "Orthoceras" limestones and wrote that "more observations could be quoted and new ones must be made, but the variety of situations is perhaps sufficient to inspire caution". Our data allow us to make the first very preliminary and careful conclusion about the existence of two major trends of a paleocurrent: a current running from south-west to north-east in the Upper Silurian and a Lower Devonian one prevailing a north-northeastward direction.

Comment by H.P. SCHÖNLAUB: Regardless whether the current-direction hypothesis against the apex or in the opposite direction is preferred, the statistics from orthocone cephalopod measurements from both the Carnic Alps and Bohemia show striking similarities with regard to shell alignement in the Silurian (J. KRIZ 1992, p. 24, 43, 55: Silurian Field Excursions, Prague Basin (Barrandian), Bohemia. National Mus. Wales, Geol. Series No.13, Cardiff). During the Lower Devonian the current direction suggests minor changes towards a north direction. This northern gyre may be related to the South Equatorial Current which according to M. S. OCZLON 1990 operated along the southern margin of Laurussia in the Middle Devonian. During the interval from the Silurian to the Devonian this system may be held responsible for the distinct exchange of faunas between Siberia, the Urals and Central and Southern Europe. Also, it should be noted that during this time Siberia had an "upside-down position" with the Tajmyr Peninsula in a more southern position facilitating such an exchange (pers. comm. O.K. BOGOLEPOVA).

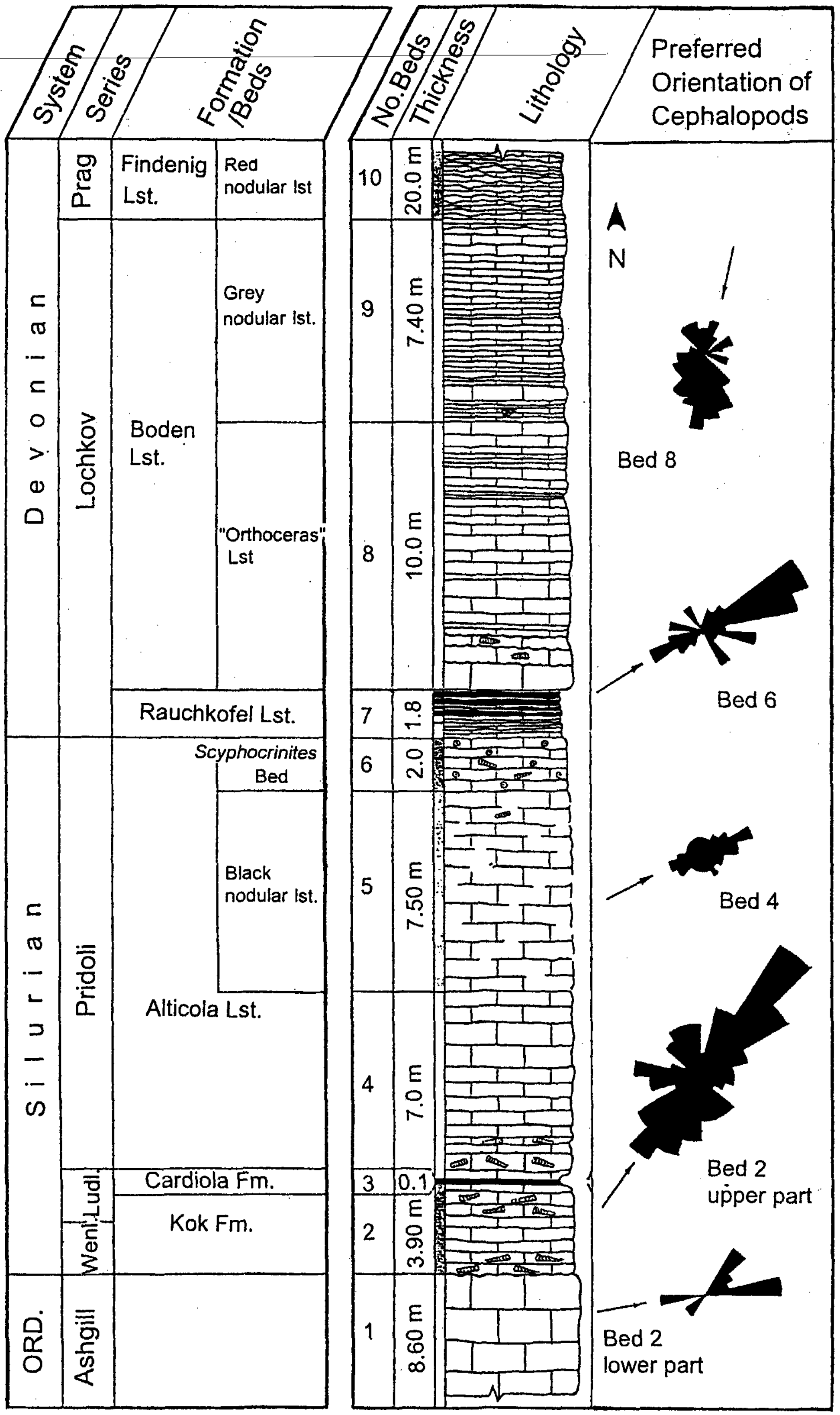


Fig. 12. The orientation of orthocone nautiloids in the Rauchkofel Boden section (after O. BOGOLEPOVA 1994)

Stable Isotopes at Rauchkofel Boden section

(Bernd Wenzel)

For the introduction part we refer to p.106. Not surprisingly, on either side of the contact between the Upper Ordovician Wolayer Lst. and the transgressive Kok Fm. of the Wenlock a sharp break in the $\delta^{13}C_{carb}$-values can be recognized (Fig. 13). The succeeding samples from the Kok Fm. are characterized by relatively uniform $\delta^{13}C$-values. In contrast in the overlying equivalents of the basal Alticola Lst. corresponding to the latialata conodont Zone of the upper Ludlow significantly enhanced $\delta^{13}C$-values occur which apparently reveal the same trend as observed at Cellon. Different from the Cellon section, however, the strongest signal occurs at the base of the *Scyphocrinites*-bearing bed and not at the base of the overlying Rauchkofel Lst. of lowermost Lochkovian age. In terms of thickness this level is 2 m below the base of the Rauchkofel Lst. at this section.

During the present study of C and O isotopes additional differences between the Cellon and Rauchkofel sections have been recognized (see Fig. 13): For example, the $\delta^{13}C$-values of the Wolayer Lst. are about 1‰ higher than those from the Plökken Fm. at Cellon. Similar differences have been found in samples from the Wenlock and the lower and upper Ludlow. Also, in the Upper Silurian of the Rauchkofel Boden section the variation of the $\delta^{13}C$-signal is significantly bigger than at Cellon.

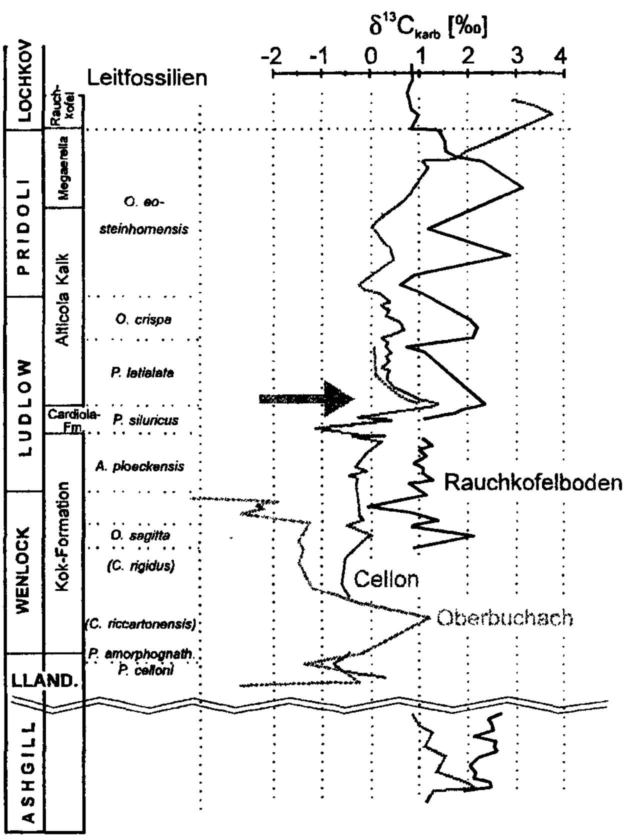


Fig. 13. $\delta^{13}C_{carb}$ curves for the sections Rauchkofel Boden, Cellon and Oberbuchach 1 correlated according to available biostratigraphic data. Note the upper Ludlow positive $\delta^{13}C$ excursion (arrow). After B. WENZEL (in press).

Stop 3: The Seewarte Section

by
Hans P. Schönlaub & Lutz H. Kreutzer

The oldest rocks of the Seewarte section are best exposed near the Valentin Törl (= Pass), a few meters to the west of the southern pass at an altitude of 2100 m (H.P. SCHÖNLAUB 1971, 1980).

The Ashgillian and Silurian part of this section represents a transitional facies between the Plöcken facies and the Wolayer facies. In the Ashgill neither the typical Uggwa Lst. nor the typical Wolayer Lst. are developed. Similarly, the Silurian is characterized by an intermediate facies of crinoid-brachiopod bearing limestones instead of the brownish nautiloid bearing Kok Lst.

At the base of the Silurian iron-manganese bearing black shales and Fe-Mn enriched hardground layers occur suggesting a condensation horizon which can also be inferred from the basal Silurian conodont fauna.

The fauna from the Ordovician limestone below indicates a coeval age with the Uggwa Lst. at Cellon as well as from other places in the Carnic Alps (E. SERPAGLI 1967). Although all elements of the multi-element of *Amorphognathus ordovicicus* have been found, the fauna is dominated by single cones such as *Acodus similaris, Oistodus niger* and *Distomodus europaeus.*

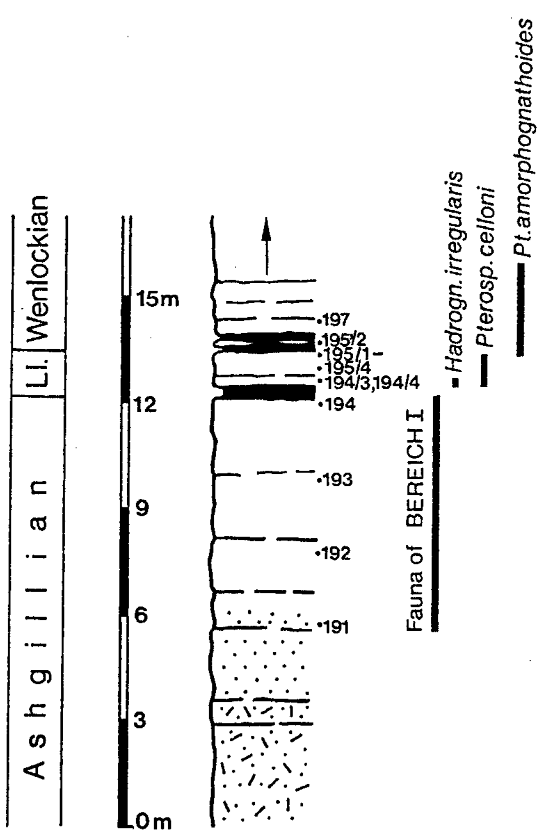


Fig. 14. Ordovician/Silurian boundary beds at the base of Mount Seewarte (from H. P. SCHÖNLAUB 1971).

The basal Silurian conodont fauna is mentioned in Fig. 14. Diagnostic elements indicate the presence of the *P. celloni* Zone (Upper Llandovery, Telychian) and the following *P. amorphognathoides* Zone at the passage from the Llandovery to the Wenlock. As at Cellon the corresponding sediments of the Lower and the major part of the Middle Llandovery are missing.

As far as the thickness is concerned the succeeding Wenlock and Ludlow sequence resembles the Cellon section. For example the equivalent of the Kok Lst. reaches a thickness of 12 m in comparison to 13,5 m at the Cellon section.

The main difference, however, is the lithology which reflects a more shallow environment dominated by crinoids and small brachiopods which have not yet been studied in detail.

At this locality the Silurian/Devonian boundary beds are not exposed. Instead, they are developed some 300 m to the west at the footwall of the Seewarte cliff near Lake Wolayer in a small ravine a few meters above the trail. The remaining section has a full exposure ranging through the Devonian to the Dinantian.

According to the "classical" studies of K. BANDEL 1969 and G. B. VAI 1967, 1971, 1977 (in H. W. FLÜGEL et al. 1977) the transition from the Silurian to the Devonian occurs in a very uniform facies. In fact, the boundary is defined only on paleontological evidence based on conodonts, brachiopods and trilobites.

The Megaerella Fm. of the Pridoli consists of greyish to blackish, medium to well-bedded crinoidal limestones in which fossils are rather rare. Index fossils are the conodont species *O. r. eosteinhornensis* and the brachiopods *Dubaria megaerella* and *Gracianella umbra*. The boundary itself can be drawn within a 7m-interval between sample nos. B298 and FV140.

The following subdivision of the Devonian sequence is based on detailed lithologic studies of K. BANDEL 1969, 1972, G. B. VAI 1967, 1971, S. POHLER 1982 and L. H. KREUTZER 1992a,b (see Figs. 15, 16). With regard to faunal and floral occurrences and their biogeographic significance we refer to the summary remarks of H. P. SCHÖNLAUB (1992).

The Lochkovian part of the Devonian succession represents the neritic Rauchkofel Limestone. This unit comprises interbedded coarse-bedded, greyish and partly dolomitized fossiliferous crinoidal limestones and greyish to black well-bedded pelletoidal limestones. Locally small patch-reefs occur for the first time. The faunal content is listed in the accompanying figure.

The neritic Rauchkofel Lst. grades into the 350 m thick massive Hohe Warte Limestone of Pragian to Lower Emsian age representing the southern shallow-water facies of L. H. KREUTZER (1992). It comprises light grey bioclastic to biohermal crinoidal limestones of the fore-reef and reef-core environment. This formation is locally very fossiliferous consisting mainly of frame-building organisms such as echinoderms, brachiopods, corals, stromatoporoids, algae, trilobites and gastropods (G. B. VAI 1967, 1973, K. BANDEL 1969).

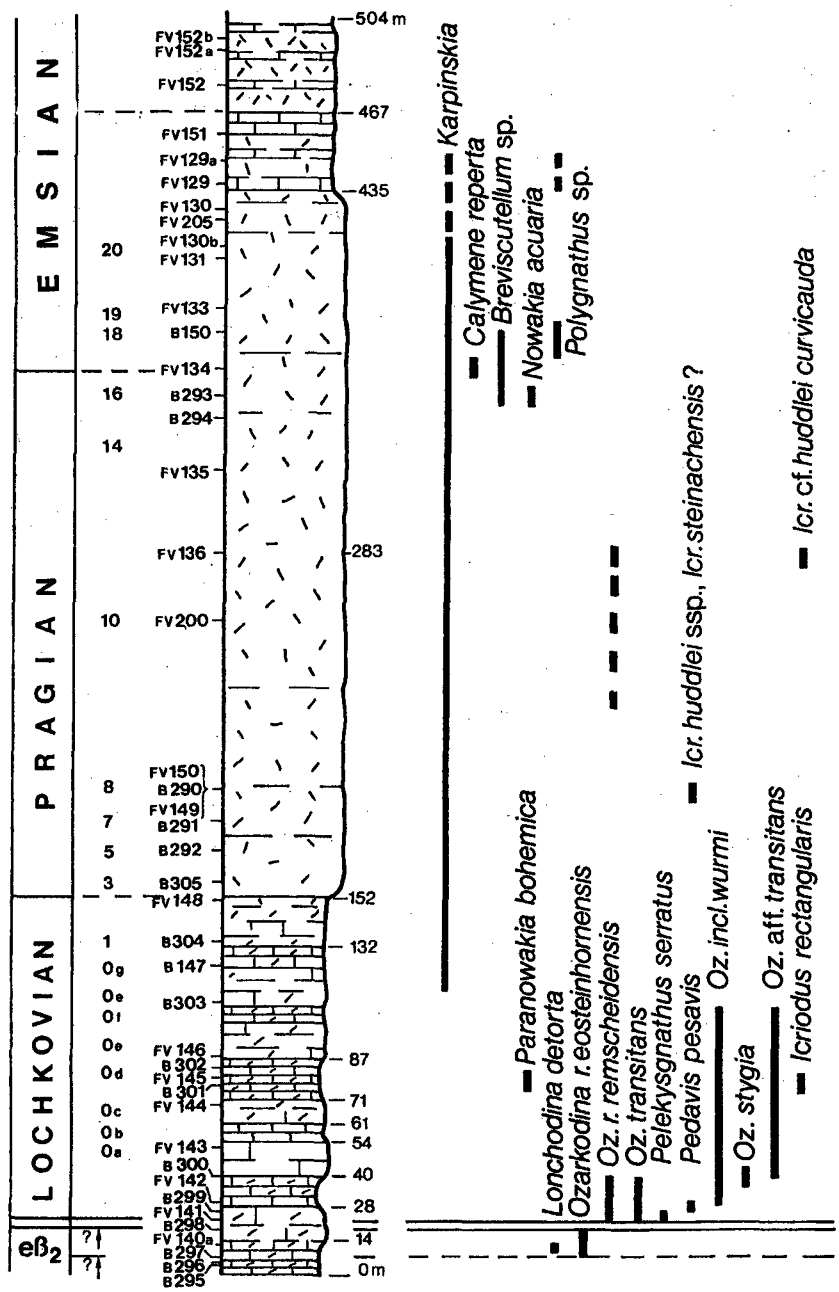


Fig. 15. The Lower Devonian section along the base of the northwestern cliff of Mount Seewarte (from G. B. VAI 1973, modified).

Fairly abruptly, the Hohe Warte Lst. is succeeded by the 40 m thick Seewarte Lst. (formerly named "Hercynella-Kalk") of Lower Emsian age. It consists of black bituminous algae, gastropod, bivalve and coral-bearing limestones being deposited in a restricted back-reef setting atop the former reefal development.

The following 130 m thick Upper Emsian Lambertenghi Lst. represents interbedded fenestral, grey limestones, reworked crinoidal limestones and microbial laminites. The skeletal grains consist of algae, gastropods, ostracods and parathuramminaceae in the laminites and bivalves, gastropods, corals, stromatoporoids and dasycladaceae in the organodetritic layers. Most probably it was deposited in a restricted subtidal and intertidal platform setting.

The overlying 220 m thick Spinotti Limestones of Eifelian to Lower Givetian age represents interbedded fenestral "birdseye"-type limestones, beds with debris of crinoids and Amphipora-bearing limestones. Fossils consist of bivalves, gastropods, echinoderms, amphiporids, stromatoporoids, corals, brachiopods and dasycladaceae. The Spinotti Lst. was formed in a temporary well agitated back-reef setting.

The top of the Seewarte cliff is formed by the more than 180 m thick Kellergrat Reef Limestone of Givetian to Frasnian age. It represents the repetition of the Devonian reef consisting of massive fossiliferous framestones and bafflestones with abundant stromatoporoids, corals, brachiopods, gastropods, echinoderms, calcispheres and *Renalcis turbidus.* According to L. H. KREUTZER the reef development ended in the Lower gigas conodont Zone.

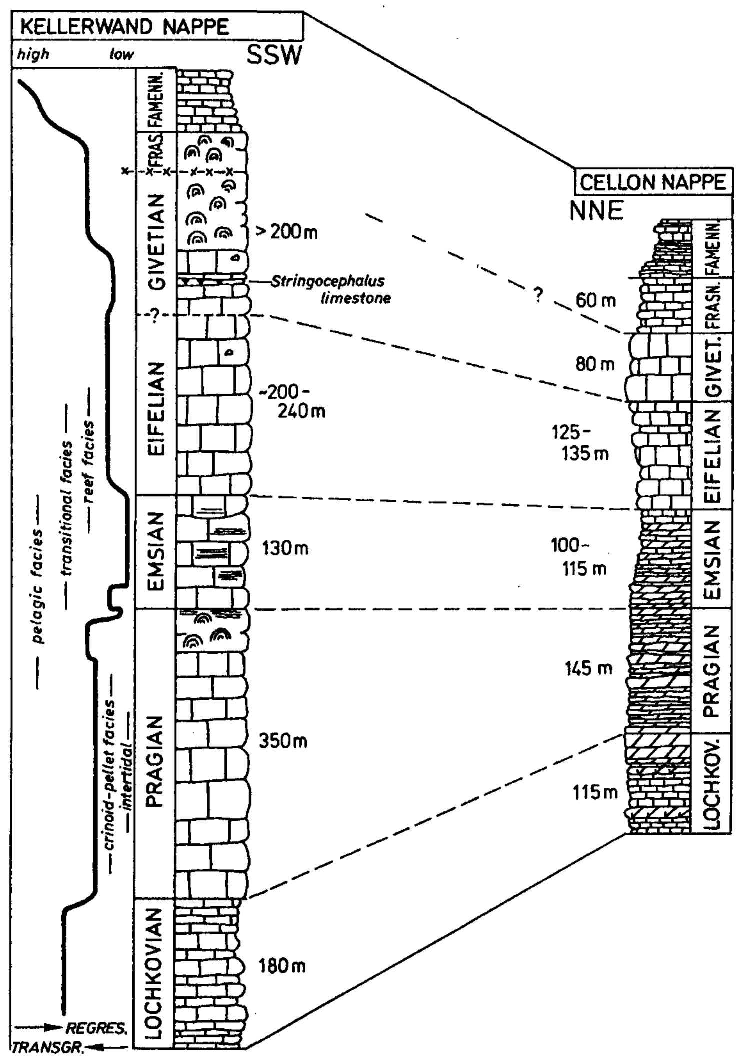


Fig. 16. Comparison of the Devonian sequences between the Kellerwand (Hohe Warte) and the Cellon Nappes (after L. H. KREUTZER 1990, modified).

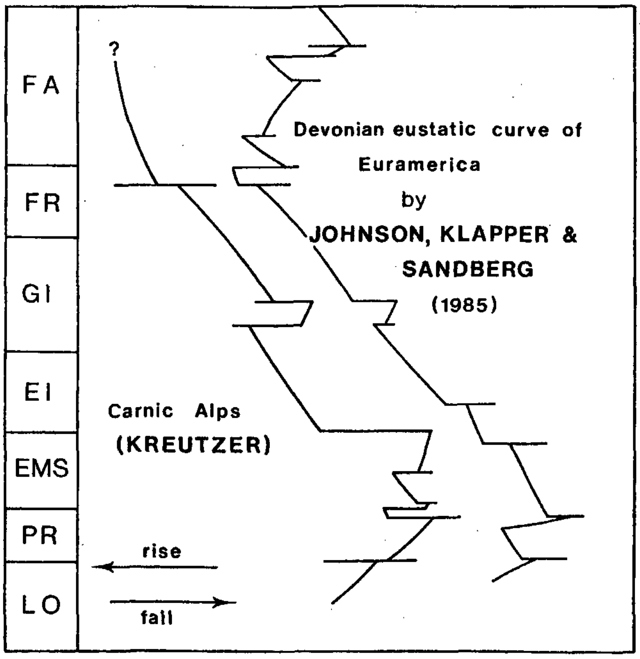


Fig. 17. Eustatic sea-level curve for the Devonian of Euramerica (simplified, after JOHNSON et al. 1985) and of the Carnic Alps (after L. H. KREUTZER 1990). Note similarity between the two curves except for the Upper Devonian.

The above mentioned reef limestones are locally overlain by the Marinelli and Kollinkofel Limestones, respectively, representing up to some 50 m thick shallow water crinoidal and rhynchonellid limestones of uppermost Frasnian to Famennian age.

So far, at this southern block any equivalents of the upper Famennian are apparently missing. Instead, the above mentioned strata are disconformably overlain by cephalopod and trilobite-bearing limestones of Lower Carboniferous age. Based on rich occurrences of fossils at the Plotta section on the Italian side of the mountain chain H. P. SCHÖNLAUB & L. H. KREUTZER 1993 concluded a lowermost Visean age for the uppermost limestone beds documenting thus the end of the continuous deposition of lime in the Variscan sequence of the Carnic Alps (Fig. 18).

This limestone sequence of the Plotta section is unconformably overlain by the cherty Plotta Formation which presumably represents a fossil soil. This horizon represents the base of the Southalpine equivalents of the Culm named here Hochwipfel Formation. Deposition of this siliciclastic sequence started in the Visean and may have lasted during the Serpukhovian and the major part of the Bashkirian.

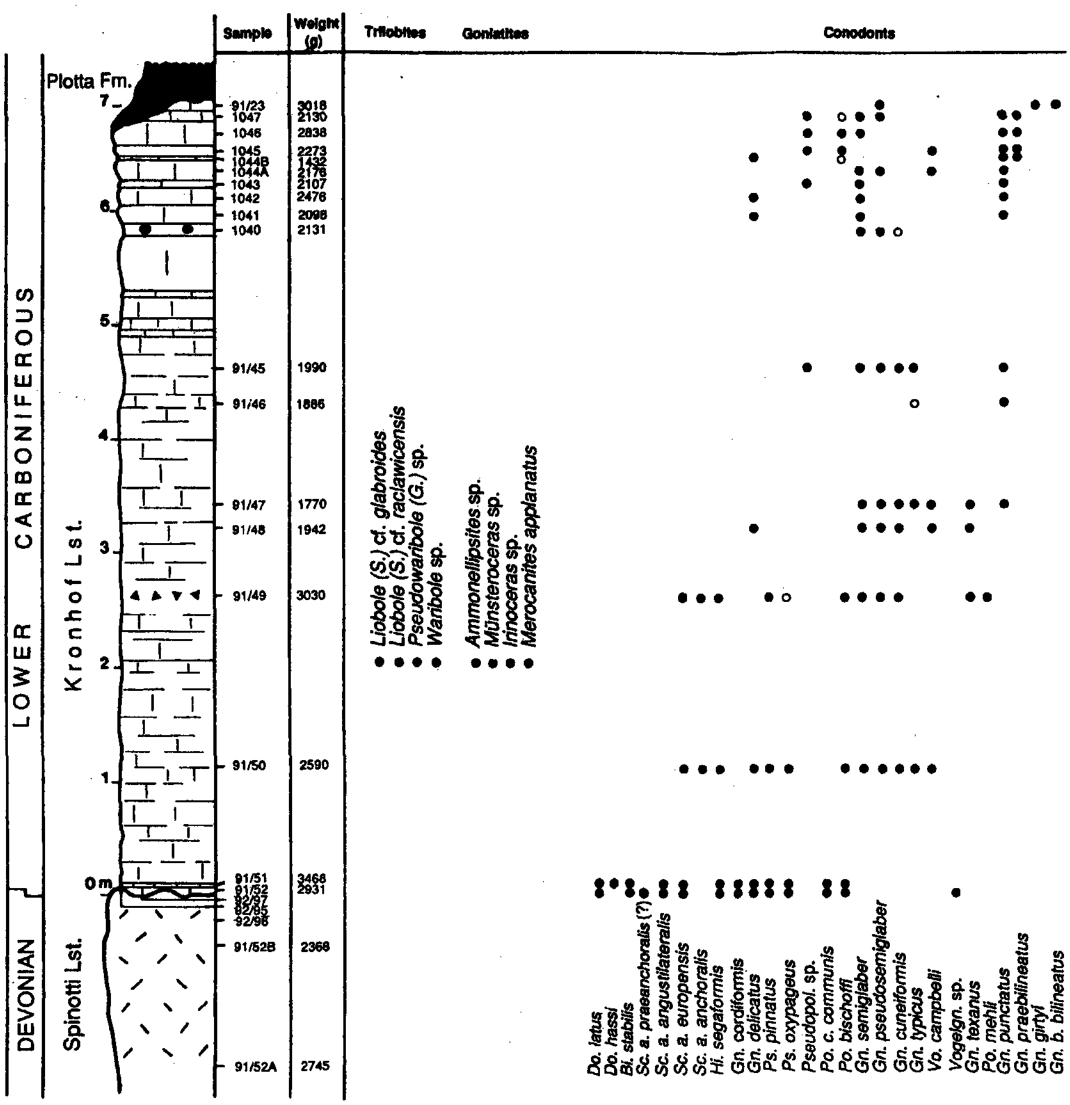


Fig. 18. Distribution of trilobites, goniatites and conodonts from the Kronhof Limestone at the Cima di Plotta section (after H. P. SCHÖNLAUB & L. H. KREUTZER 1993).

Stop 4: Wolayer "Glacier" Section

by

Hans P. Schönlaub, M. M. Joachimski, W. Buggisch & T. Anders

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. Of particular interest is the Frasnian/Famennian boundary the sedimentology, conodont stratigraphy and isotope geochemistry of which has been studied by B. GÖDDERTZ (1982), H. P. SCHÖNLAUB (1980, 1985, Fig. 19) and M. M. JOACHIMSKI et al. (1994, Fig. 20).

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.

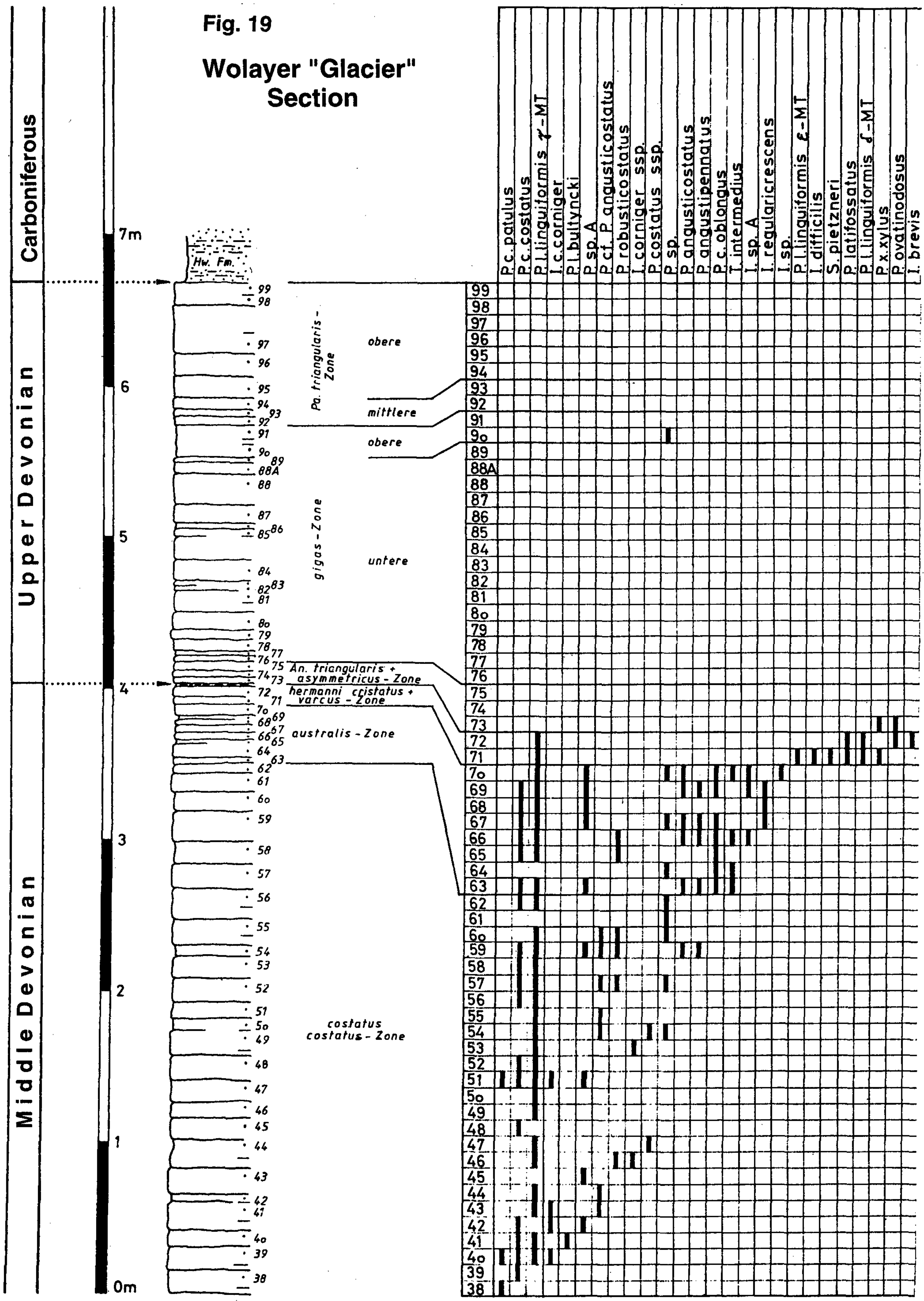
The Pal Lst. of Frasnian age is characterized by mudstones to wackestones with fragments of bivalves, ostracods, echinoderms, trilobites and rare occurrences of corals and styliolinids. Thin biosparitic and quartz-rich layers suggest distal turbidites. Of special interest is an up to 6 cm thick black shale horizon interpreted as an equivalent of the Lower Kellwasser Horizon (M. M. 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. 19). 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 M. M. JOACHIMSKI & W. BUGGISCH (1993) this characteristic twofold pattern can be recognized in many boundary sections around the globe.

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

Fig. 19

Wolayer "Glacier" Section



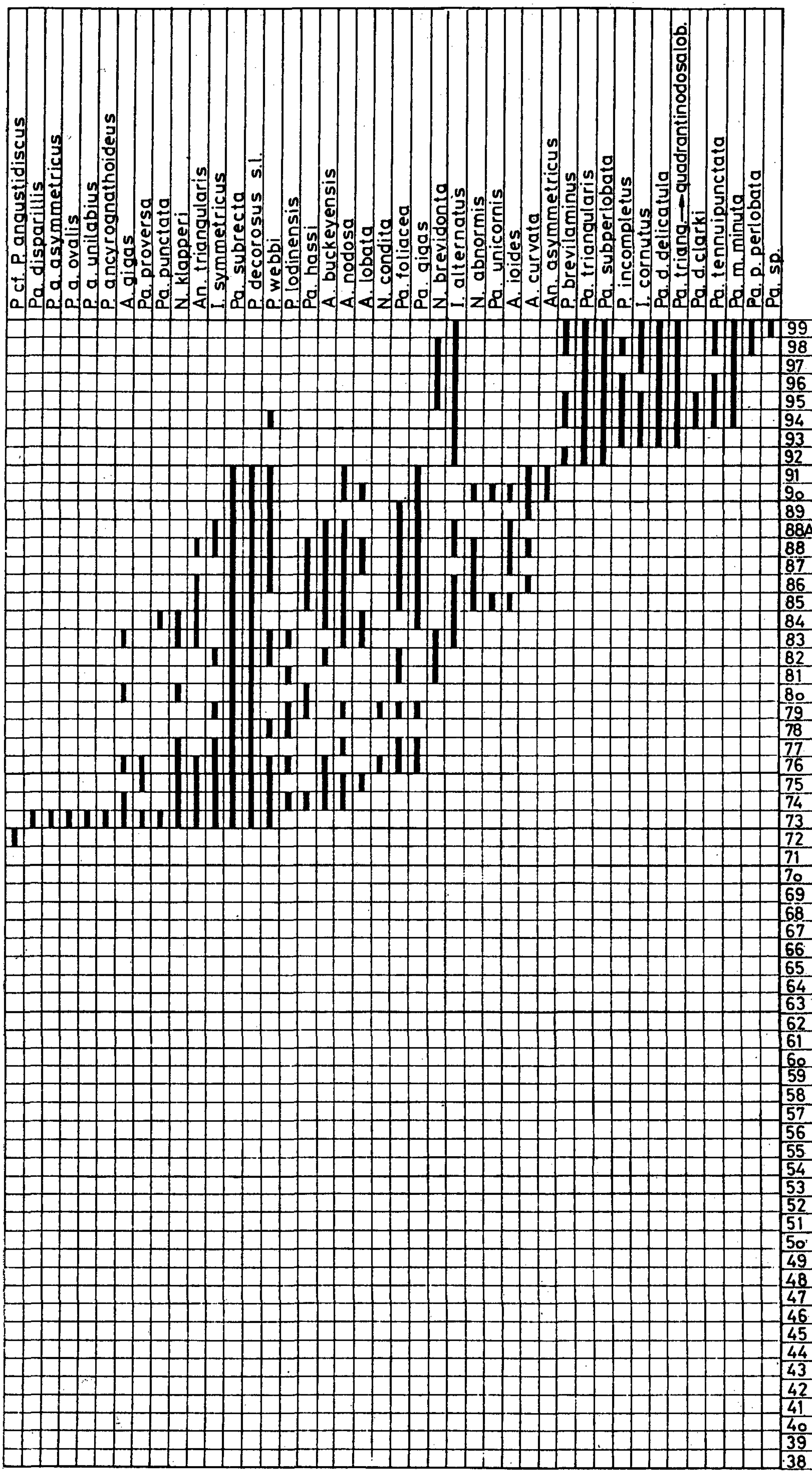


Fig. 19
Wolayer Glacier section.
Distribution of conodonts
in the Valentin and Pal. Lst.
(From B. GÖDDERTZ 1982).

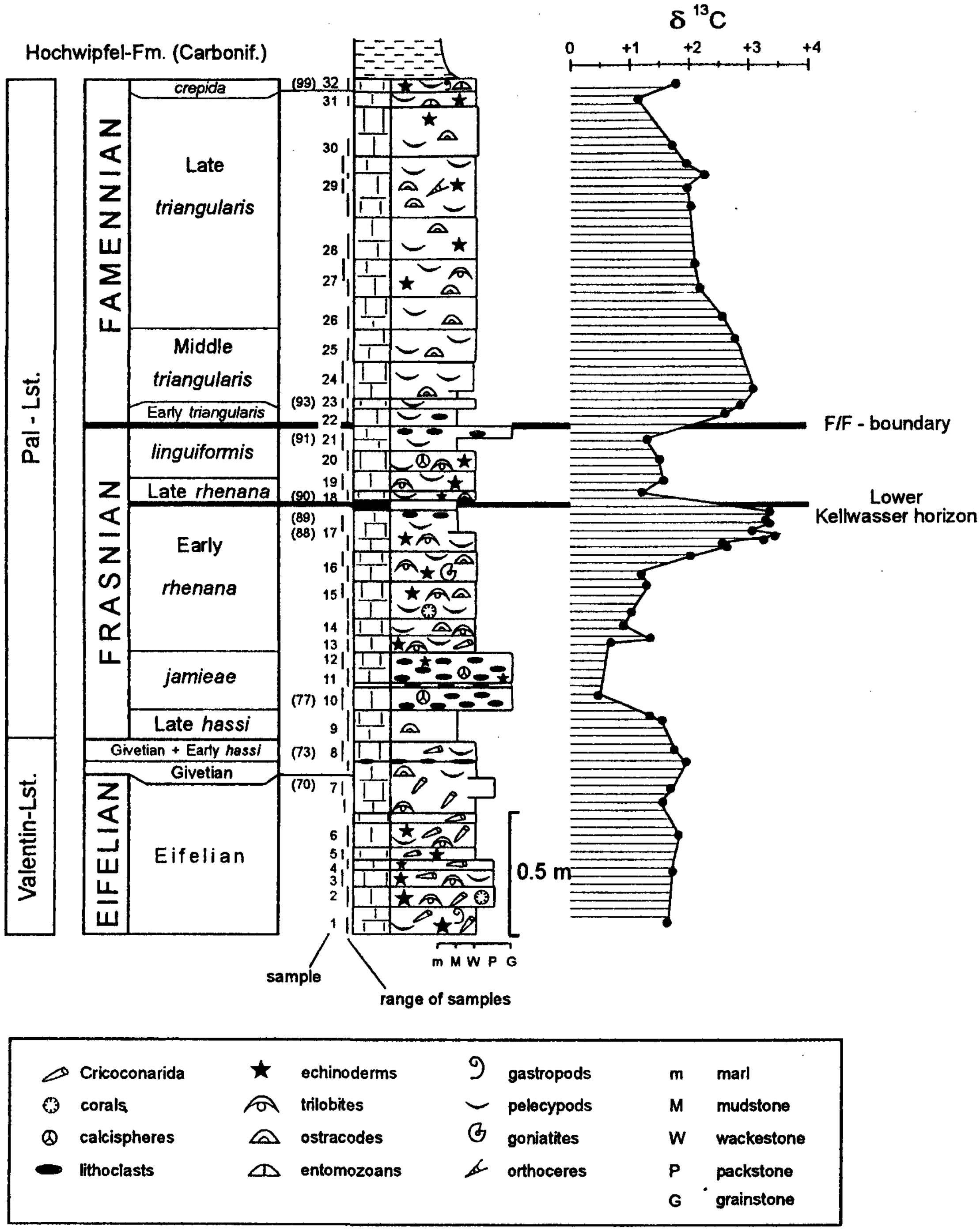


Fig. 20. Carbon isotope pattern across the Frasnian/Famennian boundary at the Wolayer Glacier section (modified from M. M. JOACHIMSKI, W. BUGGISCH & T. ANDERS 1994).

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

Stop 5: Valentintörl West
by
Hans P. Schönlaub & D. Korn

At this locality 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 Lst. of the Upper Devonian a rich ammonoid fauna was recorded by H. R. v. GAERTNER (1931). According to M. R. HOUSE & J. PRICE 1980 the varied fauna indicates the Famennian Hembergian Stage (Upper Devonian IIIα to β) and consists of the following taxa:

Pseudoclymenia dillensis (DREVERMANN)
Pseudoclymenia pseudogoniatites (SANDBERGER)
Prolobites delphinus (G. & F. SANDBERGER)
Sporadoceras (S.) muensteri (VON BUCH)
Rectoclymenia rotundata SCHINDEWOLF
Rectoclymenia subflexuosa (MÜNSTER)
Rectoclymenia acuta (PERNA)
Platyclymenia (Pl.) sandbergeri (WEDEKIND)
Platyclymenia (Pl.) pompeckii (WEDEKIND)

The above mentioned fauna supplemented by a rich new collection is presently revised (D. KORN).

References

BANDEL, K. (1969): Feinstratigraphische und biofazielle Untersuchungen unterdevonischer Kalke am Fuß der Seewarte (Wolayer See, zentrale Karnische Alpen). - Jb. Geol. B. - A., 112, 197 - 234.

BANDEL, K. (1972): Palökologie und Paläogeographie im Devon und Unterkarbon der Zentralen Karnischen Alpen. - Palaeontographica, Abt. A, 141, 1 - 117.

BRETT, C. E., GOODMAN, W. M. & LODUCA, S. T. (1990): Sequences, cycles and basin dynamics in the silurian of the appalachian foreland basin. - Sed. Geol., 69, 191 - 244.

BRETT, C. E., (1995): Sequence stratigraphy, biostratigraphy and taphonomy in shallow marine environments. - Palaios, 10, 597 - 616.

DULLO, W. C. (1992): Mikrofazies und Diagenese der oberordovizischen Cystoideenkalke (Wolayerkalk) und ihrer Schuttfazies (Uggwa-Kalk) in den Karnischen Alpen. - Jb. Geol. B. - A., 135, 317 - 334.

ECKERT, B. & BRETT, C. E., (1989): Bathymetry and paleoecology of silurian benthic assemblages, late Llandoverian, New York state. - Palaeogeogr., Palaeoclimatol., Palaeoecol., 74, 297-326.

FEIST, R. (1992): Trilobiten aus dem Devon/Karbon-Grenzprofil an der Grünen Schneid (Zentrale Karnische Alpen, Österreich). - Jb. Geol. B. - A., 135, 21 - 47.

FLÜGEL, H. (1965): Vorbericht über mikrofazielle Untersuchung des Silurs des Cellon-Lawinenrisses (Karnische Alpen). - Anz. Österr. Akad. Wiss., math. - naturw. Kl., 1965, 289 - 297.

FLÜGEL, H. W., JAEGER, H., SCHÖNLAUB, H. P. & VAI, G. B. (1977): Carnic Alps. In: The Silurian-Devonian Boundary (A. MARTINSSON Ed.). - IUGS Series A No. 5, 126 - 142.

FRECH, F. (1887): Über das Devon der Ostalpen nebst Bemerkungen ueber das Silur und einem palaeontologischen Anhang. - Zeitschr. d. Deutsch. geol. Ges. , 1887, 659.

FRECH, F. (1894) Die Karnischen Alpen. Ein Beitrag zur vergleichenden Gebirgstektonik. - Verl. Max Niemeyer, 514 pp.
GEYER, G. (1894): Zur Stratigraphie der paläozoischen Schichtserie in den Karnischen Alpen. - Verh. Geol. R. - A., 1894, 102 - 119.
GEYER, G. (1903): Exkursion in die Karnischen Alpen. IX INtern. Geol. Kongress Führer, 11, 4 - 51.
GAERTNER, H. R. von (1931): Geologie der Zentralkarnischen Alpen. - Denkschr. Österr. Akad. Wissensch., math.-naturw. Kl., 102, 113 - 199.
GNOLI, M. & HISTON, K.: Silurian Nautiloid cephalopods from the Carnic Alps: a preliminary investigation. In prep.
GNOLI, M. & SERPAGLI, E. (1991): Nautiloid assemblages from middle-late Silurian of Southwestern Sardinia: a proposal. - Boll. Soc. Paleont. Ital, 30, 187-195.
GÖDDERTZ, B. (1982): Zur Geologie und Conodontenstratigraphie der Rauchkofelböden und des Rauchkofel in den Zentralen Karnischen Alpen. - Unpubl. Dipl. Arb., Univ. Bonn, 1 - 88.
GORTANI, M. & VINASSA DE REGNY, P. (1909): Fossili Neosilurici del Pizzo di Timau e dei Pal nell' Alta Carnia. - Mem. R. Accad. Sc. Ist. Bologna, 183 - 217.
HERITSCH, F. (1929): Faunen aus dem Silur der Ostalpen. - Abh. Geol. B.- A, 23, 2, 1-183.
HERITSCH, F. (1943): Das Paläozoikum. In: Die stratigraphie der geologischen Formationen der Ostalpen, Bd. 1.. Verl. Gebr. Borntraeger, 1 - 681, Berlin.
HEWITT, R. A. & WESTERMANN, G. E. G. (1996): Post-mortem behaviour of early Paleozoic nautiloids and paleobathymetry. - Paläont. Z. , 70, 3/4, 405-425.
HOLLAND, C. H. (1984): Form and Function in Silurian cephalopoda. In Bassett, M.G. & Lawson, J.D. (eds.) Autecology of Silurian organisms : Special Papers in Palaeontology, 32, 151-164.
JAEGER, H. (1975): Die Graptolithenführung im Silur/Devon des Cellon-Profils (Karnische Alpen). - Carinthia II, 165, 111 - 126.
JOACHIMSKI, M. M., BUGGISCH, W. & ANDERS, T. (1994): Mikrofazies, Conodontenstratigraphie und Isotopengeochemie des Frasne-Famenne-Grenzprofils Wolayer Gletscher (Karnische Alpen). - Abh. Geol. B. - A., 50, 183 - 195.
KORN, D. (1992): Ammonoids from the Devonian/Carboniferous boundary section at Grüne Schneid (Central Carnic Alps, Austria). - Jb. Geol. B. - A., 135, 7 - 19.
KREUTZER, L. H. (1990): Mikrofazies, Stratigraphie und Paläogeographie des Zentralkarnischen Hauptkammes. - Jb. Geol. B. - A., 133, 275 -343.
KREUTZER, L. H. (1992a): Palinspastische Entzerrung und Neugliederung des Devons in den Zentralkarnischen Alpen aufgrund von neuen Untersuchungen. - Jb. Geol. B. - A., 135, 262 - 272.
KREUTZER, L. H. (1992b): Photoatlas zu sen Variszischen Karbonat-Gesteinen der Karnischen Alpen (Österreich/Italien). - Abh. Geol. B. - A., 47, 1 - 129.
KRIZ, J. (1979): Silurian Cardiolidae (Bivalvia). - Sbornik geol. ved., Paleontol., 22, 1 - 157.
KRIZ, J. (1992): Silurian Field Excursions. Prague Basin (Barrandian), Bohemia. - Geol. Ser. Nation. Mus. Wales, 13, 1 - 111.
KRIZ, J. , JAEGER, H., PARIS, F. & SCHÖNLAUB, H. P. (1986): Pridoli - the fourth Subdivision of the Silurian. - Jb. Geol. B. - A., 129, 291 - 360.
KRIZ, J., DUFKA, P., JAEGER, H. & SCHÖNLAUB, H. P. (1993): The Wenlock/Ludlow Boundary in the Prague Basin (Bohemia). - Jb. Geol. B. - A., 129, 291 - 360.
OCZLON, (1990): Ocean currents and unconformities: The North Gondwana Middle Devonian. - Geology, 18, 509 - 512.
POHLER, S. (1982): Die Entwicklung der Flachwasserkarbonate im Mittel- und Oberdevon der Zentralen Karnischen Alpen (Seewartesockel zum S-Abfall der Hohen Warte). - Unveröff. Diplomarb., Rhein. Friedr.-Wilh. Univ. Bonn, 1 - 134.
RISTEDT, H. (1968): Zur Revision der Orthoceratidae. - Abh. Akad. Wiss. Mainz, math. Naturw. Kl., 1968, Nr. 4, 213 - 287.
RISTEDT, H. (1969): Orthoceren als Leitfossilien des Silurs. - Carinthia II, 27, 25-28.
RISTEDT, H. (1971): Zum Bau der Orthoceriden Cephalopoden. - Palaeontographica, Abt. A, 137, 155-195.

SCHÖNLAUB, H. P. (1970): Vorläufige Mitteilung über die Neuaufnahme der silurischen Karbonatfazies der Zentralen Karnischen Alpen (Österreich). - Verh. Geol. B. - A., 1970, 306 - 315.
SCHÖNLAUB, H. P. (1971): Zur Problematik der Conodontenchronologie an der Wende Ordoviz/Silur mit besonderer Berücksichtigung der Verhältnisse im Llandovery. - Geologica et Palaeontologica, 5, 35 - 57.
SCHÖNLAUB, H. P. (1971):Palaeo-environmental studies at the Ordovician/Silurian boundary in the Carnic Alps. In: Colloque Ordovicien-Silurien Brest 1971. - Mem. B. R. G. M., 73, 367 - 377.
SCHÖNLAUB, H. P. (1979): Das Paläozoikum in Österreich. Verbreitung, Stratigraphie, Korrelation, Entwicklung und Paläogeographie nicht-metamorpher und metamorpher Abfolgen. - Abh. Geol. B. -A., 33, 1 - 124.
SCHÖNLAUB, H. P. (1980): Carnic Alps. Field Trip A. In: SCHÖNLAUB, H. P. (Ed.): Second European Conodont Symposium, ECOS II, Guidebook, Abstracts. - Abh. Geol. B. - A., 35, 5 - 57.
SCHÖNLAUB, H. P. (1985): Das Paläozoikum der Karnischen Alpen. - In: Arbeitstagung der Geologischen Bundesanstalt 1985, 34 - 52. - Geol. B. -A.
SCHÖNLAUB, H. P. (1988): The Ordovician-Silurian boundary in the Carnic Alps of Austria. - Bull. Brit. Mus. Nat. Hist. (Geol.), 43, 107 - 115.
SCHÖNLAUB, H. P. (1992): Stratigraphy, Biogeography and Paleoclimatology of the Alpine Paleozoic and its Implications for Plate Movements. - Jb. Geol. B. - A., 135, 381 - 418.
SCHÖNLAUB, H. P., KLEIN, P., MAGARITZ, M., RANTITSCH, G. & SCHARBERT, S. (1991): Lower Carboniferous Paleokarst in the Carnic Alps (Austria, Italy). - Facies, 25, 91 - 118.
SCHÖNLAUB, H. P., ATTREP, M., BOECKELMANN, K., DREESEN, R., FEIST, R., FENNINGER, A., HAHN, G., KLEIN, P., KORN, D., KRATZ, R., MAGARITZ, M., ORTH, C. J. & SCHRAMM, J. M. (1992): The Devonian/Carboniferous Boundary in the Carnic Alps (Austria) - a multidisciplinary appoach. - Jb. Geol. B. - A., 135, 57 - 98.
SCHÖNLAUB, H. P. & KREUTZER, L. H. (1993): Lower Carboniferous Conodonts from the Cima di Plotta Section (Carnic Alps, Italy). - Jb. Geol. B. - A., 136, 247 - 269.
SCHÖNLAUB, H. P. & KREUTZER, L. H. (1994) with contributions by M. M. JOACHIMSKI & W. BUGGISCH: Paleozoic Boundary Sections of the Carnic Alps (Southern Austria). - Erlanger geol. Abh., 122, 77 - 103.
SERPAGLI, E. (1967): I conodonti dell'Ordoviciano superiore (Ashgilliano) delle Alpi Carniche. - Boll. Soc. Paleont. Italiana, 6, 30 - 111.
SPEYER, S. E. & BRETT, C. E. (1991): Taphofacies controls. In. Allison, P. A. & BRIGGS, D. E. G. (eds.) Taphonomy: Releasing the Data locked in the fossil record. - Vol. 9 of Topics in Geobiology. Plenum Press, New York.
STACHE, G. (1879) Uber der Verbreitung der silurischen Schichten in den Ostalpen. - Verh. Geol. R. - A., 1879, 216 - 223.
TARAMELLI, T., (1870): Osservazioni stratigrafiche sulle valli del But e del Chiarsò in Carnia. - Ann. Scient. R. Ist. tecn. Udine, IV, p. 38.
TARAMELLI, T., (1881): Sulla recente scoperta di fossili siluriani nella provincia di Udine. - Rend. R. Ist. Lomb., XIV, p. 590.
TARAMELLI, T., (1895): Osservazioni sul Paleozoico delle Alpi Carniche. - Boll. Soc. Geol.It., 14, 277-280.
TIETZE, E. (1870): VIII. Beiträge zur Kenntnis der älteren Schichtgebilde Kärnthens. - Jb. Geol. R. - A., 20, 259 - 272.
VAI, G. B. (1967): Le Devonien inferieur biohermal des Alpes Carniques Centrales. - Coll. sur le Devonien inferieur (Rennes 1964). - Mem. B. R. G. M., 33, 28 - 30.
VINASSA DE REGNY, P. (1908): Nuove osservazioni geologiche sul nucleo centrale delle Alpi Carniche. - Proc. Verb. Soc. toscana Sc. nat. XVII, p. 40.
VINASSA DE REGNY, P. (1913): Ordoviciano e Neosilurico nei gruppi del Germula e di Lodin. - Boll. Soc. Geol. It., 445 - 450.
VINASSA DE REGNY, P & GORTANI, M., (1910): Le paléozoique des Alpes Carniques. - Compte Rendu du XI:e Congrès Géologique International, 1005 - 1012.

WALLISER, O. H. (1964): Conodonten des Silurs. - Abh. Hess. L.-Amt Bodenforsch., 41, 1 - 106.

WENDT, J. (1988): Condensed carbonate sedimentation in the Late Devonian of the eastern Anti-Atlas (Morocco). - Eclogae geol. Helv., 81, 155 - 173.