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

The Paleozoic of the Carnic Alps

Hans Peter SCHÖNLAUB, Kathleen HISTON, Susanne POHLER

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

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

Review of Stratigraphy

Ordovician

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

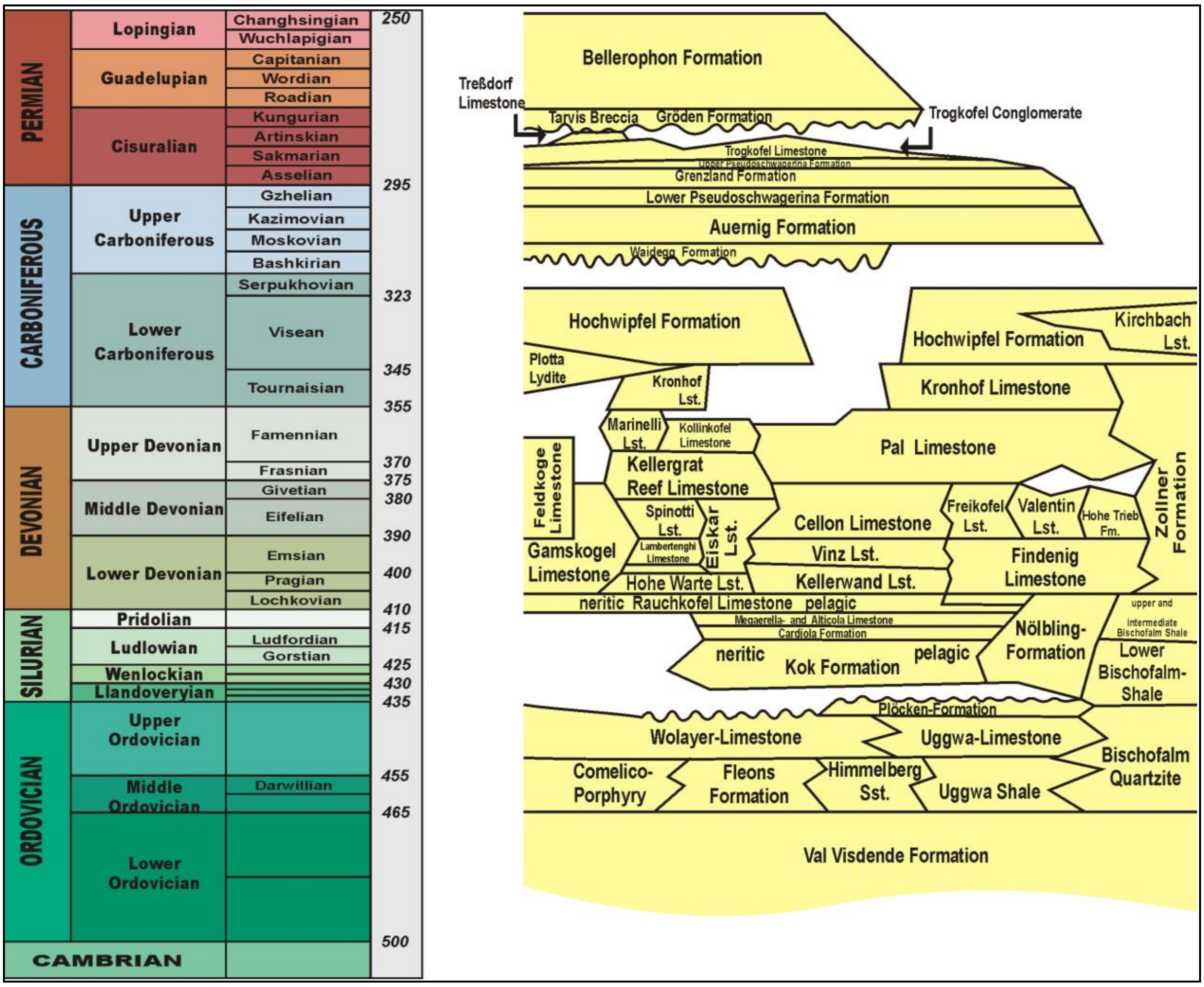

Fig. 3: Biostratigraphic scheme of the Paleozoic sequence of the Carnic Alps.
After SCHÖNLAUB, 1985, modified.

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

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

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

Silurian

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

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

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

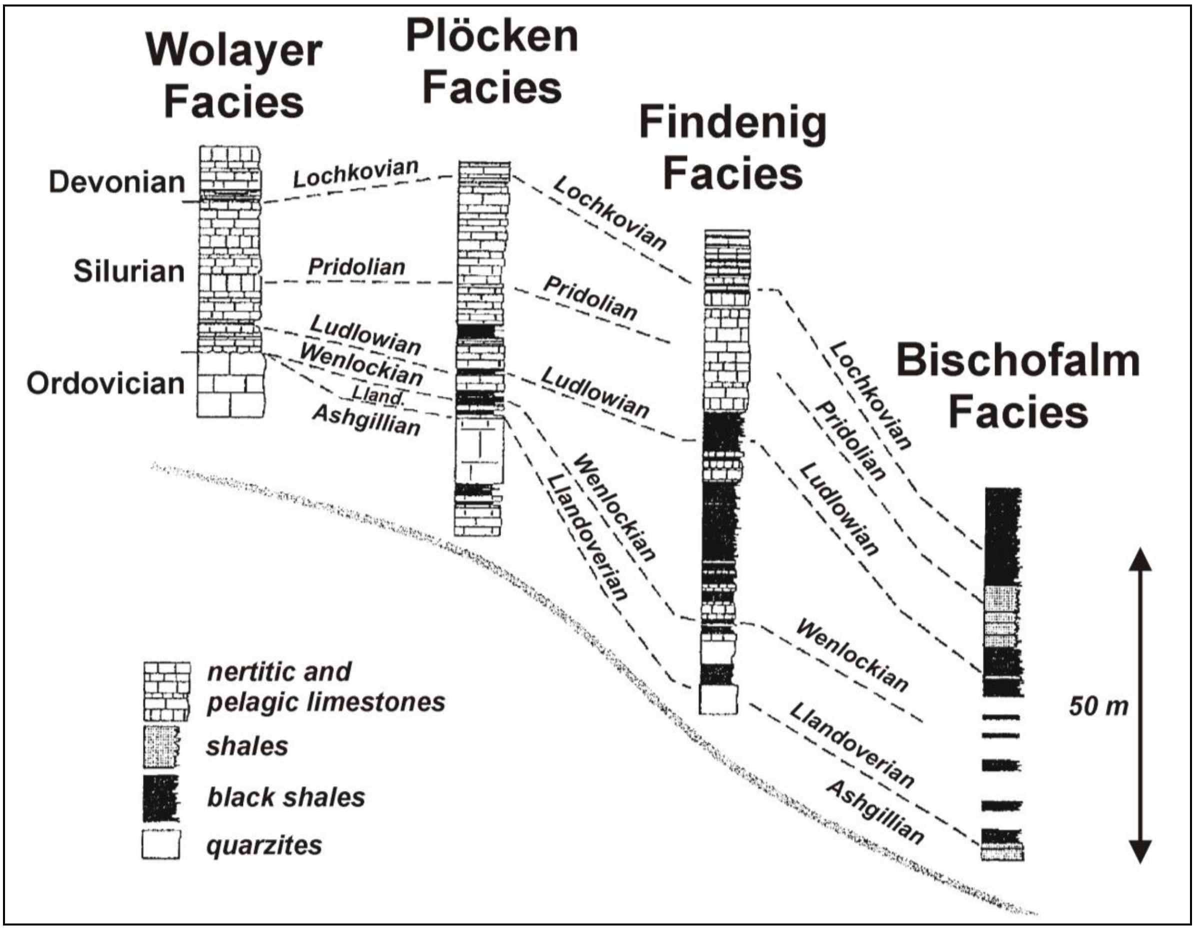

Fig. 4: Lithology of Silurian sediments of the four different lithofacies of the Carnic Alps. Brickstone: carbonates; black: C_{org} rich graptolite-bearing shales and cherts and C_{org} rich carbonates of the Wolayer Facies; light grey: C_{org} poor shales.
Columns from left to right show the sections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

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

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

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

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

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

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

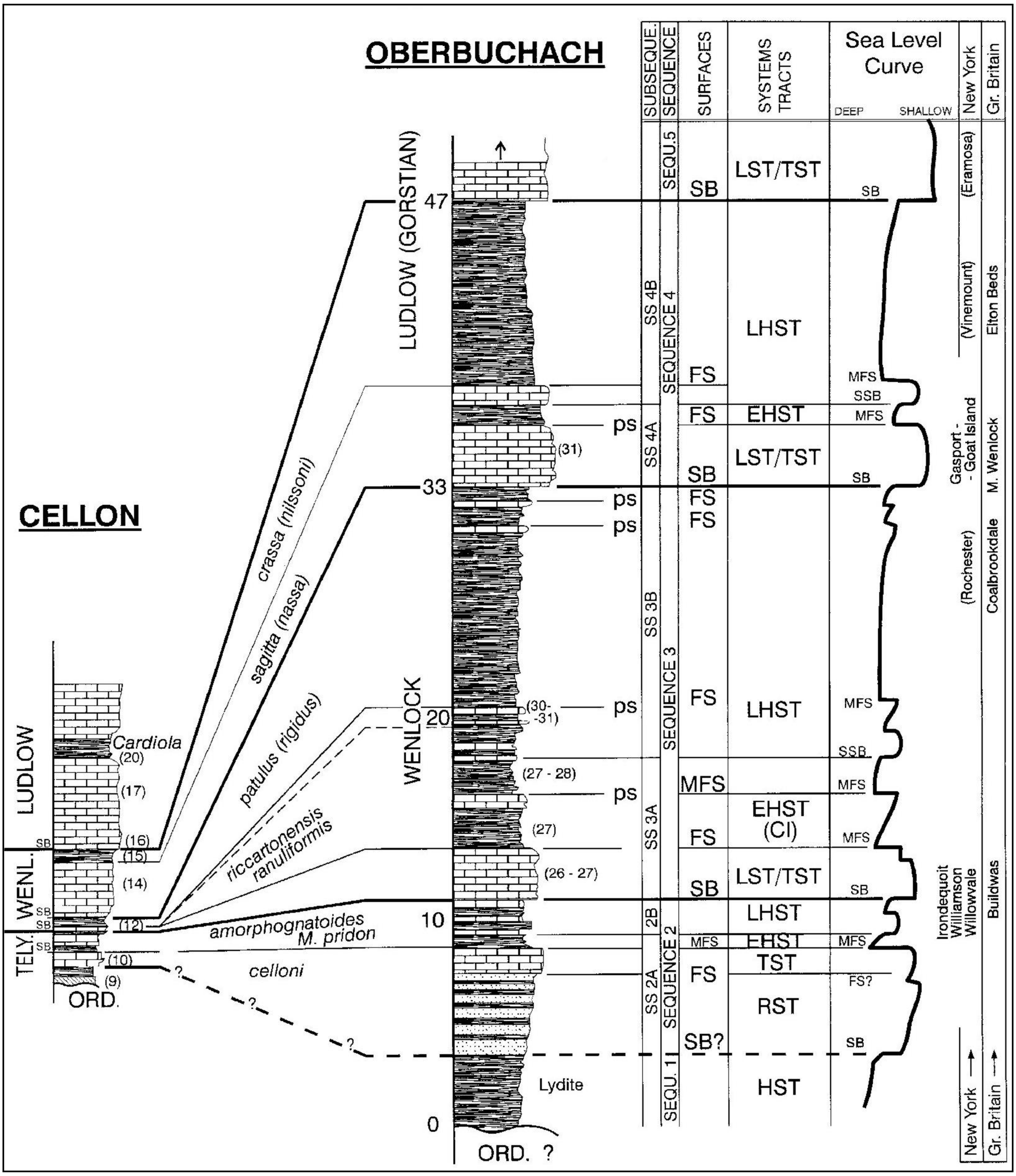

Fig. 5: Correlation and sequence interpretation Llandovery - Lower Ludlow, Carnic Alps. (BRETT & SCHÖNLAUB, 1998).

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

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

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

Devonian

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

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

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

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

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

Depositional Environments of the Devonian Carbonates
in the Central Carnic Alps

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

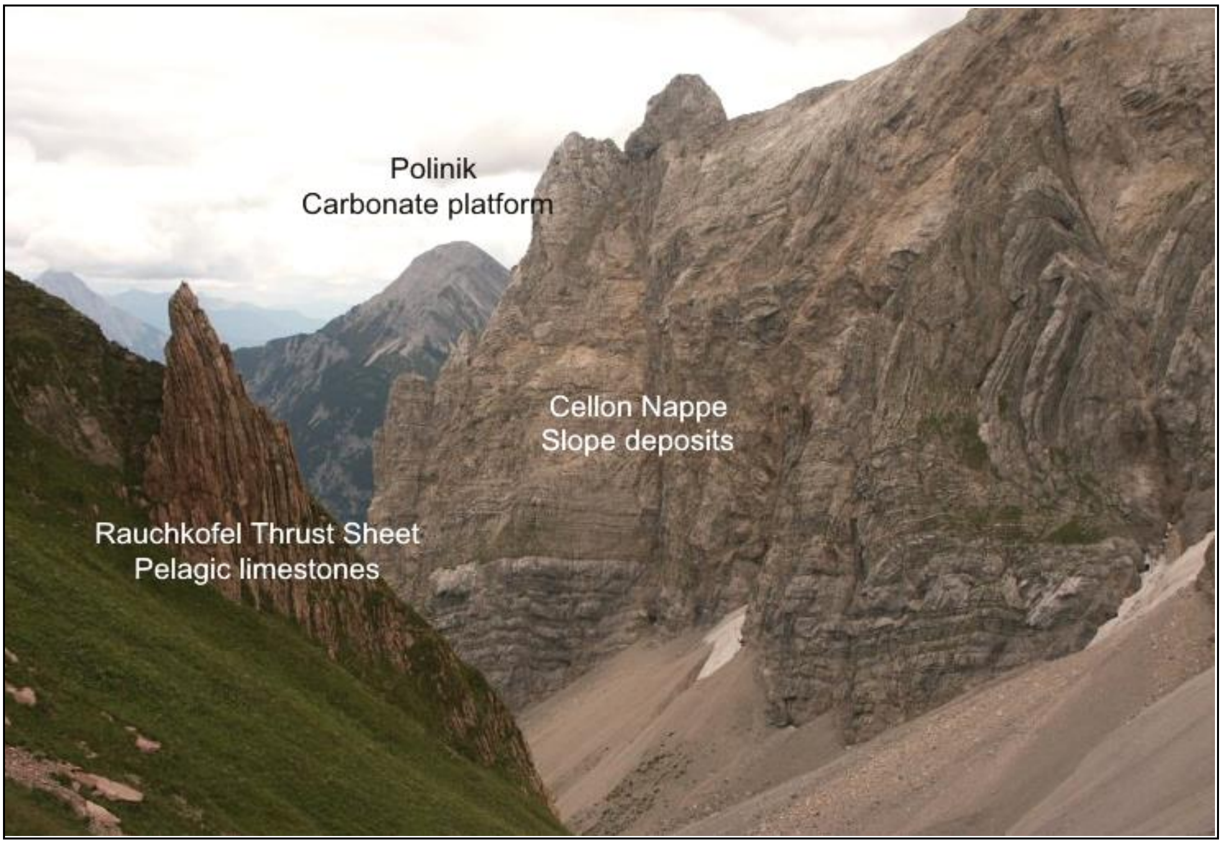

Fig. 6: View from Valentin Törl to the mountainous area in the east showing the proximity of the different depositional environments preserved in the Feldkogel, Cellon, and Rauchkofel Nappes.

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

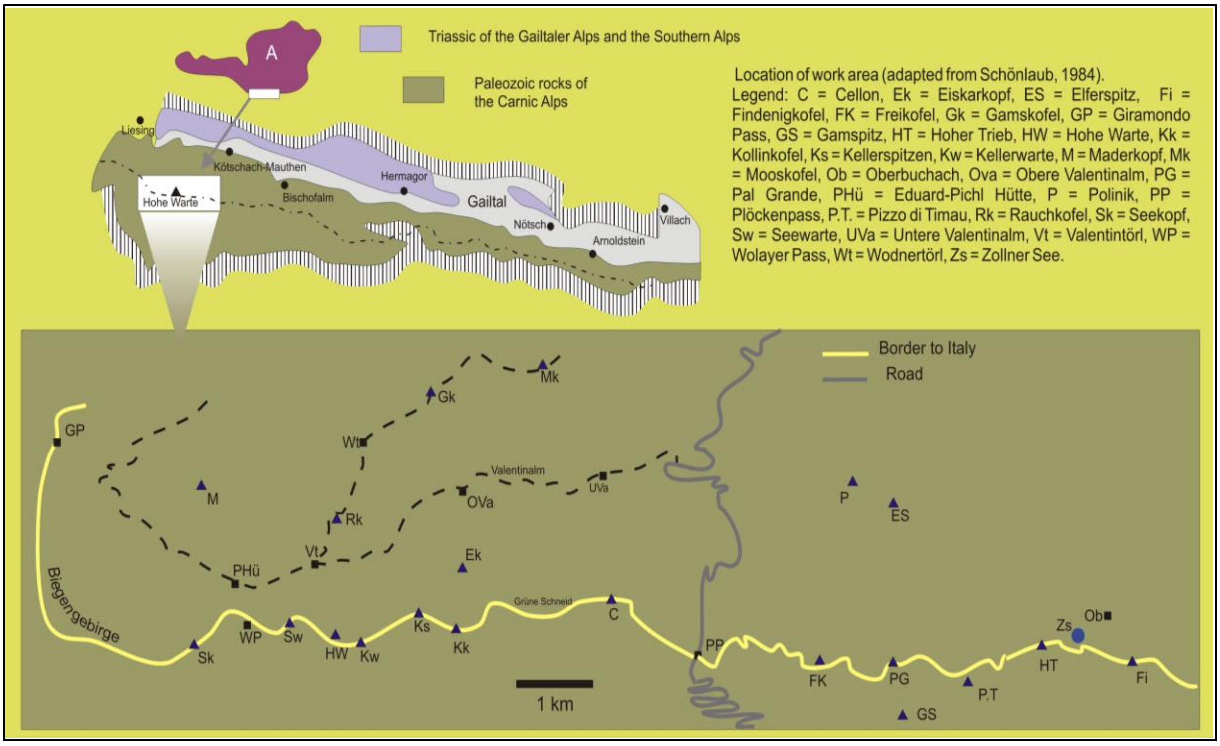

Fig. 7: Location of sections and localities discussed in the text.

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

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

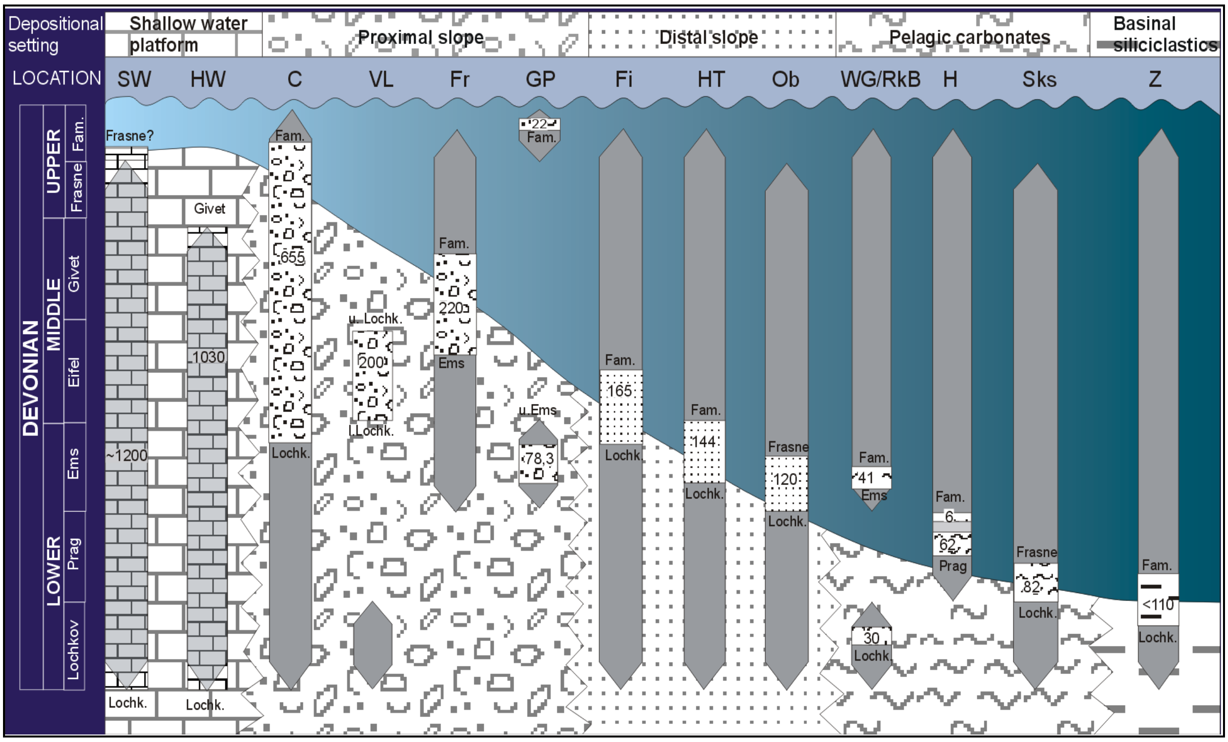

Fig. 8: Thicknesses and ranges of measured sections through the various sedimentary realms.
SW = Seewarte, HW = Hohe Warte, C = Cellon, VL = Valentintal, Fr = Freiko-fel, GP = Großer Pal, Fi = Findenigkofel, HT = Hoher Trieb, Ob = Oberbuchach, WG/RkB = Wolayer Glacier/ Rauchkofel Boden, H = Hütte, Sks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

Conodont Biostratigraphy

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

Southern Shallow Water Facies (Kellerwand Nappe)

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

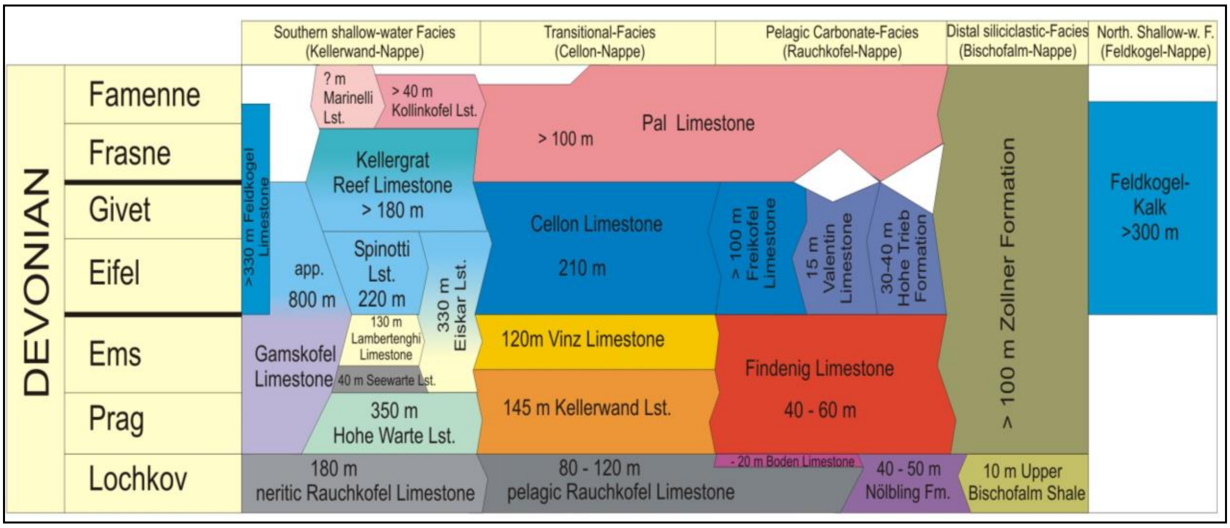

Fig. 9: Stratigraphy of the different Devonian lithofacies on a proximal (left) to distal (right) transect. To the right the northern shallow-water facies of the Feldkogel Nappe is indicated.
Adapted from SCHÖNLAUB, 1992.

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

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

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

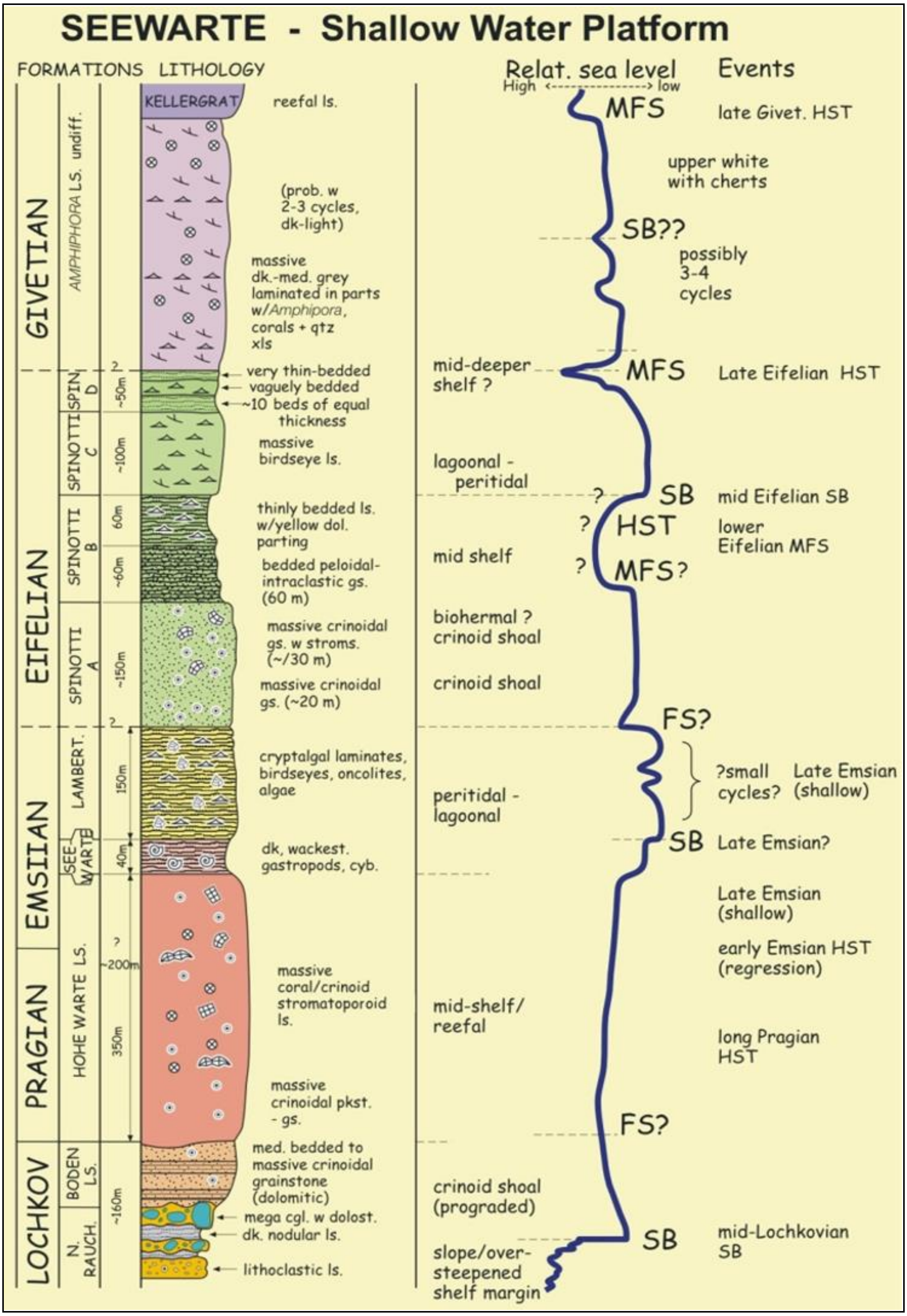

Fig. 10: Section through the southern shallow water facies (Kellerwand Nappe) measured at Mount Seewarte. Sequence stratigraphic interpretation by C. BRETT.

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

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

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

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

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

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

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

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

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

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

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

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

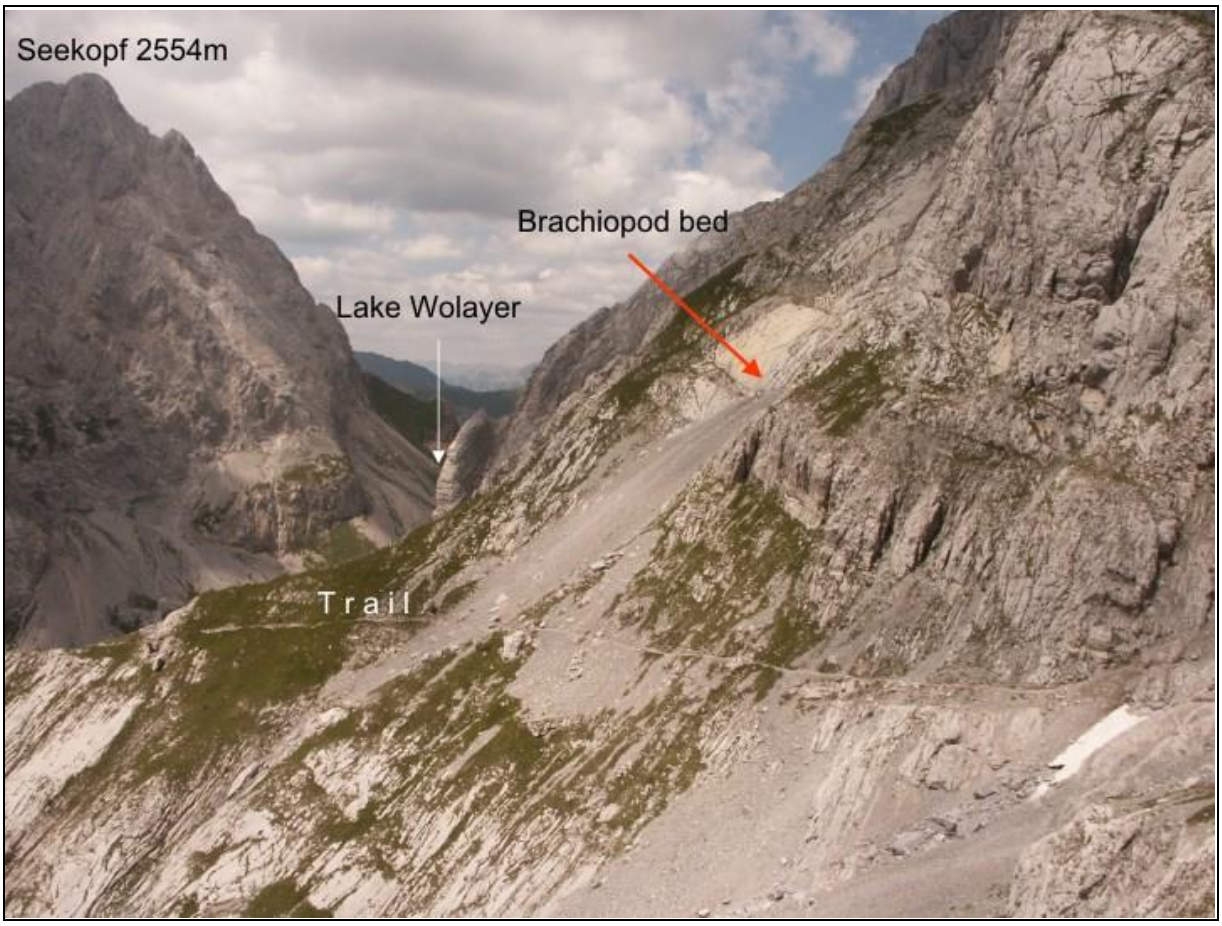

Fig. 12: The yellow bed above the Sentiero at elevation 2120 m.

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

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Foreslope/Slope Facies (Cellon Nappe)

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

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

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

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

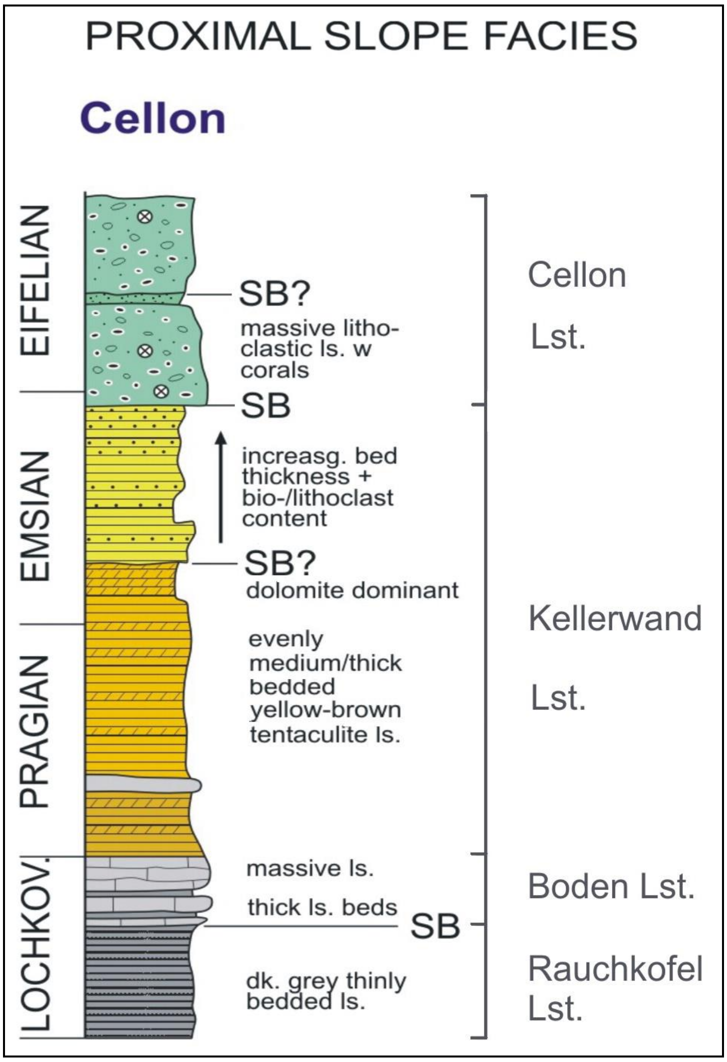

Fig. 15: Generalized section through the proximal slope facies (Cellon Nappe) measured at Mount Cellon.

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

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

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

Discussion

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

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

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

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

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

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

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

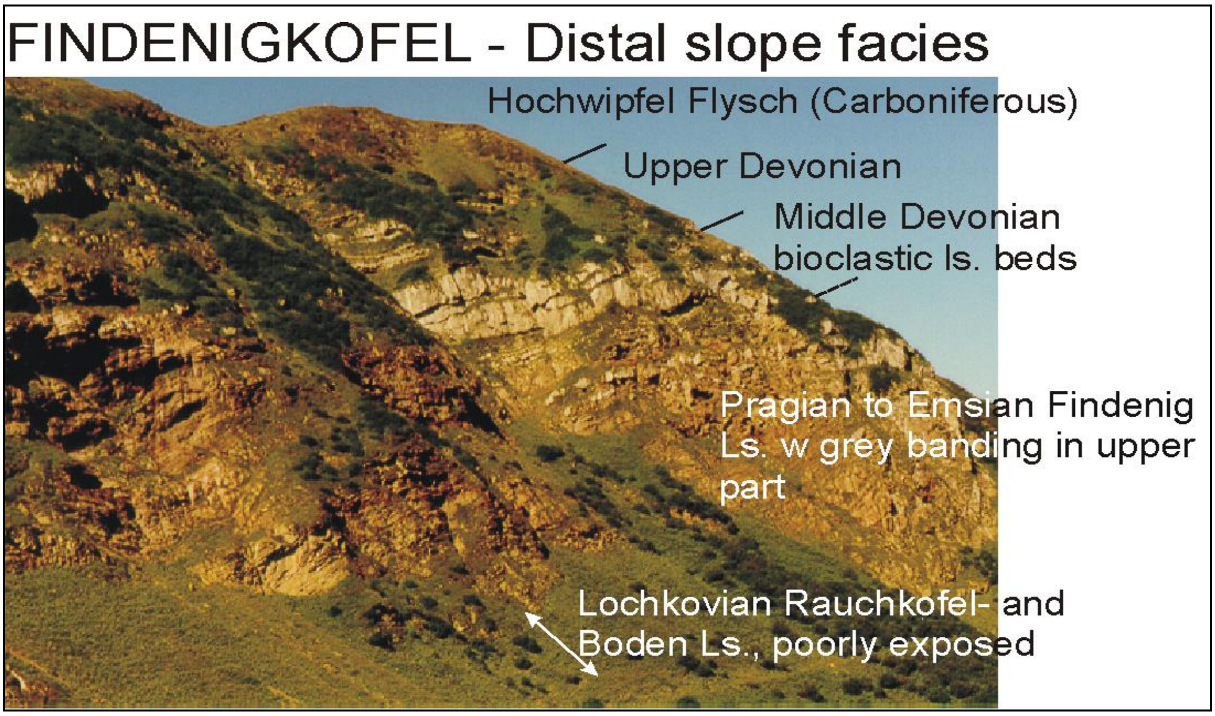

Fig. 16: View of distal slope sediments exposed at Findenigkofel from the Waidegger Alm.

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

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

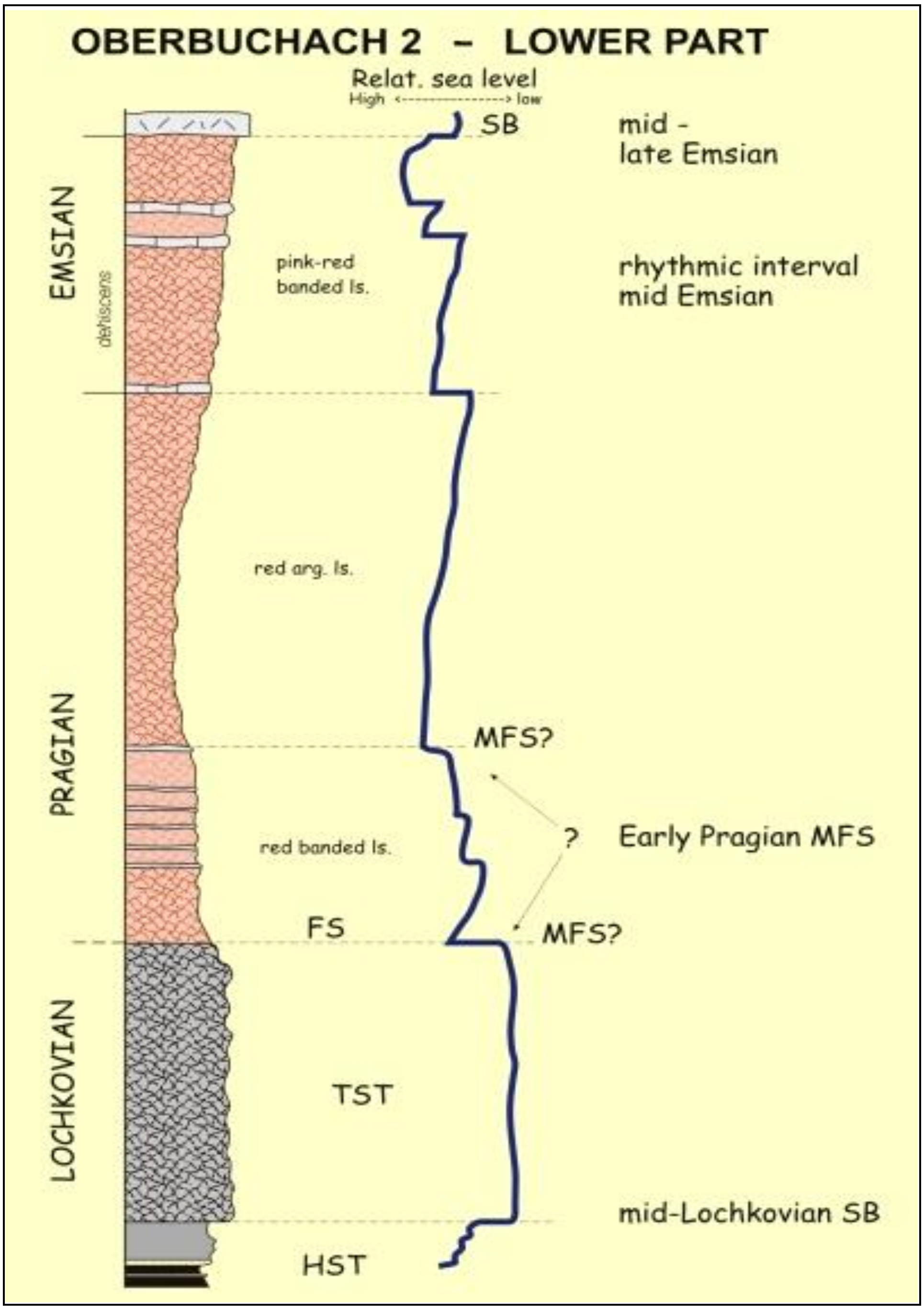

Fig. 17a: Section through the distal slope facies measured at Oberbuchach II, lower part. Adapted from SCHÖNLAUB, 1985. Sequence stratigraphic interpretation by C. BRETT.

Discussion

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

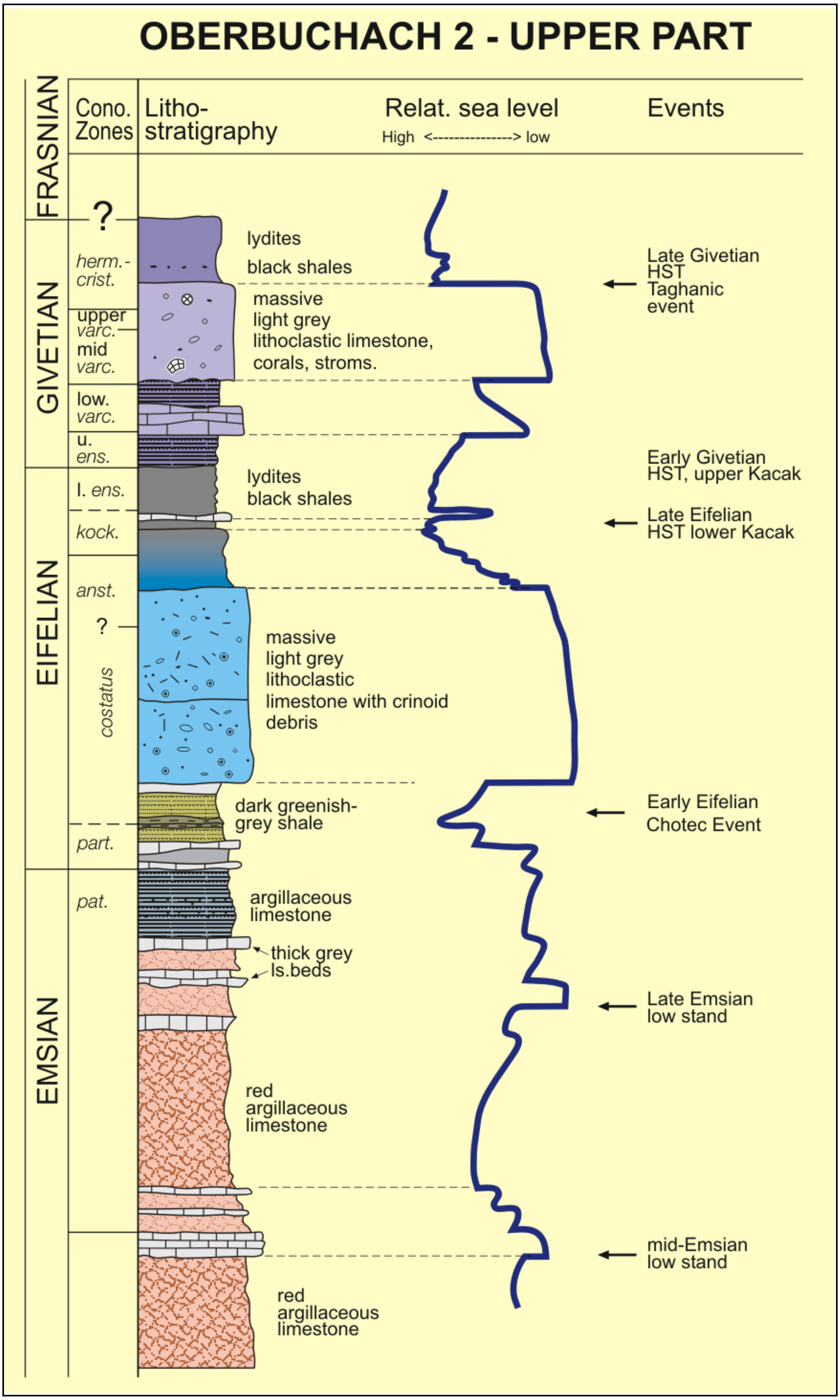

Fig. 17b: Section through the distal slope facies measured at Oberbuchach II, upper part. Adapted from SCHÖNLAUB, 1985. Sequence stratigraphic interpretation by C. BRETT.

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

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

Condensed Pelagic Limestone Facies (Rauchkofel Facies)

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

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

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

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

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

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

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Carboniferous

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

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

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

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

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

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

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

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

Permian

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

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