Taphonomy, Palaeoecology and Bathymetric Implications of the Nautiloid Fauna from the Silurian of the Cellon Section (Carnic Alps, Austria)

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18 Text-Figures

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Taphonomie, Paläoökologie und bathymetrische Verhältnisse der silurischen Nautiloiden-Fauna des Cellon-Profils (Karnische Alpen, Österreich)

Zusammenfassung

Eine taphonomische Studie der silurischen Nautiloideen-Fauna aus dem Cellon-Profil zeigte, dass aufgrund der Erhaltung der Fauna mehrere „Events" zu erkennen sind, die sich auf Änderungen im Sauerstoffgehalt und im hydrodynamischen System zurückführen lassen.

Die paläoökologischen und bathymetrischen Folgerungen aus dem morphologischen Aufbau der Nautiloideen wurden zusammen mit den taphonomischen Erscheinungen herangezogen, um auf das Milieu des Sedimentationsgebietes zu schließen. Danach handelt es sich bei der Karbonatabfolge des Silur der Plöcken-Fazies um Bildungen eines relativ seichten, von unterschiedlich starken Strömungen beeinflussten Ablagerungsraumes, in dem überwiegend reduzierte Sedimentationsbedingungen herrschten bzw. zeitweise keine Sedimentation stattfand.

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Abstract

A taphonomic study of the Silurian nautiloid fauna from the Cellon section has shown that various events may be identified from the preservation of the fauna with regard to the changing oxygen content and hydrodynamic regime of the relatively shallow water carbonate sequence of the Plöcken facies (shallow to moderately deep marine environment). The palaeoecological and bathymetric implications of the morphological structure of the nautiloids have been used together with the taphonomy to deduce environmental setting. The carbonate sequences of the Plöcken Facies were deposited in a relatively shallow environment, periodically effected by storm currents, with intervals of reduced deposition and non-sedimentation.

1. Introduction

The Cellon section, ranging from the upper Ordovician to lower Carboniferous, is exposed in a narrow avalanche gorge on the eastern side of Mount Cellon in the Central Carnic Alps (Text-Fig. 1) and represents the stratotype for the Silurian of the Eastern and Southern Alps. The pioneer work done by WALLISER (1964) on conodont biozonation from this section makes it an ideal location for studying the faunal changes in the Silurian sequence as there is a good stratigraphical constraint. The Silurian Plöcken facies (so named for the proximity of the classic locality to the Plöcken Pass on the border between Austria and Italy) is developed here as a moderately deep marine carbonate series (FLÜGEL et al., 1977). Lithological and microfacies studies indicate an overall transgressive sequence in the upper Llandovery/Wenlock part of the Kok Formation representing a moderately shallow environment with episodic deepening resulting in reduced sedimentation and condensed intervals. The alternating dark grey limestone and black shale beds of the Cardiola Formation (Ludlow) indicate a slightly deeper offshore environment with probable contemporary non-deposition taking place. A more stable pelagic environment is developed in the Alticola and Megaerella Limestones from the upper Ludlow continuing into the Pridoli (KREUTZER & SCHÖNLAUB, 1997). The published data on the fauna within the sequence were summarised by SCHÖNLAUB (1980), however, to date only a few groups have been studied in detail: graptolites (JAEGER, 1975), acritarchs (PRIEWALDER, 1987), chitinozoans (PRIEWALDER, 1997) and Cardiolid bivalves (KŘÍŽ, 1979.) The most recent work on the section has been compiled in SCHÖNLAUB (1997) and illustrates the past emphasis on micropaleontological studies for stratigraphy and the few studies of the abundant macrofauna.

The "Orthoceras" Limestone sequence of the Carnic Alps was noted from various localities by TIETZE (1870), STACHE (1879), FRECH (1887, 1894) and GEYER (1894, 1903) in stratigraphical studies of the Silurian of the Austrian Carnic Alps. Various Italian studies on the area by TARAMELLI (1870, 1881, 1895), GORTANI & VINASSA DE REGNY (1909), VINASSA DE REGNY & GORTANI (1910) and VINASSA DE REGNY (1908, 1913) also give details of these "Orthoceras" Limestones (GNOLI & HISTON, 1998). Four formations bearing cephalopods were described: the lower red "Orthoceras" Limestone or Kok Limestone, the Cardiola Niveau or Cardiola Formation, the Alticola Limestone and the Megaera or Megaerella Limestone. Few studies, however, of the nautiloid fauna from the Cellon section have been done. HERITSCH (1929) in his systematic study of Silurian fauna from the Eastern Alps described 44 nautiloid species and listed 54 species with their stratigraphical occurrence in his summary of the Silurian of the Carnic Alps (HERITSCH, 1943). However, only two species were from the Cellon section. GAERTNER (1931) noted eleven species of *Orthoceras* from the Silurian of the Cellon section and RISTEDT (1968) described four new species from this section in his study of the Orthoceratidae.

The peculiarly abundant occurrence of nautiloids at various stratigraphical levels in the Silurian of the Carnic Alps has not been looked at in detail to date. Several studies of this "Orthoceras" Limestone in Silurian sequences have been done in recent years (GNOLI et al., 1980; HOLLAND et al., 1994; FERRETTI & KŘÍŽ, 1995 and BOGOLEPOVA & HOLLAND, 1995) but each case appears to present particular environmental conditions and consistent similarities which may be used to determine the reason for the development of this facies are difficult to ascertain.

Comparative taphonomy has proved useful in recent years in facies analysis (BRETT & BAIRD, 1986; BRETT, 1995) as environmental setting may be indicated by the taphonomic properties of a fossil assemblage when considered together with the palaeoecological implications of the fauna. Seven taphofacies have been defined by SPEYER & BRETT (1991) based on taphonomic characters of fossil assemblages within various depth and lateral gradients in particular environmental settings. Significant palaeontological and taphonomic events may also be identified with regard to the rapid burial or time rich (slow sedimentation rate) accumulations of the fossil remains (KIDWELL, 1991; BRETT & SEILACHER, 1991; BRETT et al., 1997).

The data presented here form part of a more extensive multi-discipline study of the Silurian cephalopod limestone facies by an international working group with regard to the palaeogeographical setting of the Carnic Alps during the Silurian (SCHÖNLAUB, 1992). A detailed analysis of the palaeoecology and taphonomy of the nautiloid fauna is being carried out at two sections, Rauchkofelboden and Cellon, where the cephalopod limestone facies is well exposed and for which the stratigraphic levels are precisely known. The sections are located near the Italian-Austrian border (Text-Fig. 1).
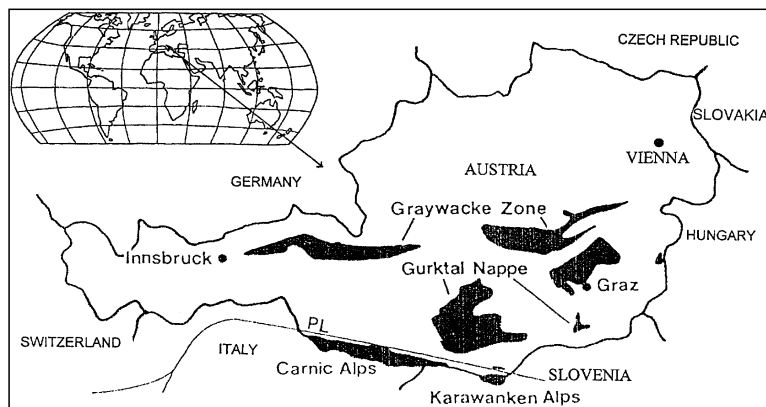
Text-Fig. 1.
Location map of the Carnic Alps.
PL = Periadriatic Line.

The observations given are based on detailed field studies at the Cellon section focusing on the particular preservation of the nautiloid fauna within the Kok Formation (upper Llandovery to lower Ludlow in age), Cardiola Formation (Ludlow in age), the Alticola Limestone (upper Ludlow to Pridoli) and Megaerella Limestone (Pridoli). These are correlated with the results of a similar study at the Rauchkofelboden section (FERRETTI & HISTON, 1997; HISTON, 1999). It is hoped by studying the small scale changes in the nautiloid taphonomy within the sequence to identify particular events or recurrent factors (KIDWELL, 1991) of the cephalopod limestone facies in the Silurian of the Carnic Alps. In comparing the results of the taphonomy and palaeoecology for the nautiloid fauna from the Silurian sections in the Carnic Alps, taking into consideration their bathymetric implications, it may be possible to identify various taphofacies as has been done for the Lower Palaeozoic sequences of North East America (SPEYER & BRETT, 1986; BRETT & BORDEAUX, 1990; O'BRIEN et al., 1994; TAYLOR & BRETT, 1996).

2. Taphonomic Parameters

In the determination of taphofacies various factors must be considered and their overall interaction noted with regard to palaeoenvironmental interpretation. The processes affecting fossil remains are mainly influenced by current energy, rate of burial and oxygen levels in the depositional environment (SPEYER & BRETT, 1991). The following parameters were used here in studying the nautiloid fauna: abundance, dimension, morphology, orientation to bedding, telescoping, fragmentation, geopetals and shell preservation.

Morphology has been used as an indicator of the particular bathymetric environment of the nautiloid fauna based on shell type; orthoconic, cyrtoconic etc. in some cases indicating more pelagic forms while some oncocerid forms may indicate a benthonic environment (BOSTON & MAPES, 1991; FURNISH & GLENISTER, 1964; HEWITT & WESTERMANN, 1996). The relative abundance of the nautiloids is used as an indication of rate of shell deposition (KIDWELL & BOSENCE, 1991), their dimension as to the presence of juvenile or adult assemblages. A ratio of septal spacing to shell diameter has been used to indicate approximately shallow or deep water fauna in that the greater the ratio the shallower the fauna (CRICK, pers. comm.; WESTERMANN, 1977; FREY, 1989). Orientation to bedding (perpendicular, high angle, parallel) may indicate the rate of descent of the nautiloid shell through the water column and its postdepositional history; whether the environment was tranquil enough and the nature of the depositional surface such for it to remain embedded in this original orientation or whether rapid or slow burial took place (RAUP, 1973; REYMENT, 1970; WEAVER & CHAMBERLAIN, 1976). Telescoping and fragmentation have been used as indicators of energy, geopetals for evidence of reworking (GNOLI et al., 1980; FERRETTI & KŘÍŽ, 1995). Other factors such as dissolution and iron coatings or infillings of the nautiloid shells have also been noted with regard to the changing oxygen levels of the depositional environment (CANFIELD & RAISWELL, 1991a,b; ALLISON et al., 1995; MAEDA & SEILACHER, 1996; TUCKER, 1990) and changing rate of sedimentation with respect to exposure time on the sedimentary surface (SPEYER & BRETT, 1991).

The general environmental and bathymetric implications of the associated fauna in each level will also be considered with the data observed for the nautiloids in order to give as complete an interpretation as possible of the environmental setting (FERRETTI & HISTON, in prep).

3. Kok Formation

In the Cellon section a hiatus is developed at the Ordovician/Silurian boundary, several conodont and graptolite biozones are missing from the base of the Silurian (SCHÖNLAUB, 1988). The Ordovician/Silurian boundary has been placed between beds 8 and 9 (numbers according to WALLISER, 1964) by SCHÖNLAUB (1985). The stratigraphic levels and significant taphonomic features of the Silurian of the Cellon section are given in Figure 2.

The 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 in the Wenlock–lower Ludlow. A variety of bed thickness occurs which in general decreases upwards and several sedimentation breaks have been noted within the sequence. Two deepening events are documented within the formation: at the transition between the Llandovery and Wenlock and between the Wenlock and Ludlow (SCHÖNLAUB, 1997). A preliminary bed by bed description of the taphonomy of this formation is given in HISTON (1997).

There are some particular taphonomic features within the formation that we would like to emphasis as they may have significant value in identifying minor changes in energy and oxygen levels within the sequence and may also contribute to the determination of the condensed intervals within this carbonate series (Text-Fig. 2).
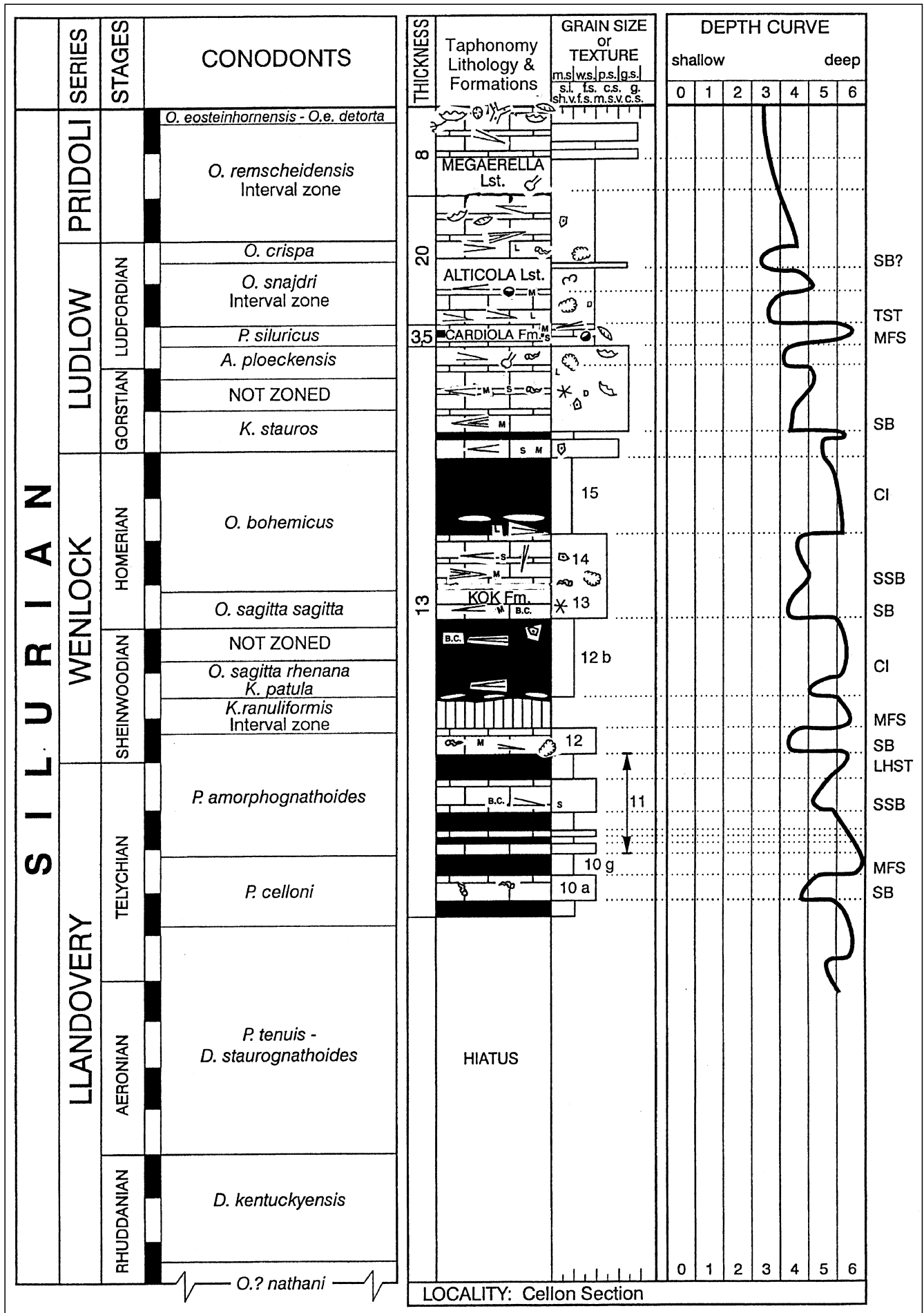
3.1. Llandovery

The lowermost sequences of the Llandovery are missing at this section and no nautiloids have been noted in the alternating levels of badly deteriorated grey micritic limestone and grey-black shale of the *P. celloni* conodont biozone (beds 9–10). Discontinous development of *thalassinoides* burrows is evident at the base of certain slightly reddish in colour carbonate levels (beds 10E & F). These possibly mark short term oxygenation events (SAVRDA & BOTTJER, 1989). The associated fauna and flora noted from this stratigraphic interval includes chitinozoans, acritarchs, foraminifers, trilobites, brachiopods and graptolites.

3.2. Wenlock

At present the precise level of the boundary between the Llandovery and Wenlock cannot be drawn but data from graptolites and conodonts indicate that it should be placed between beds 11 and 12 (SCHÖNLAUB, 1997). The transition sequence consists of alternating grey/black shales and dark grey-reddish micrite with a lenticular development, the carbonate lenses become thicker towards the top of the interval with the intermediate shales forming a crust around them. There is also a slight gradation within lenses and some recrystallisation is also evident towards the top of this interval.
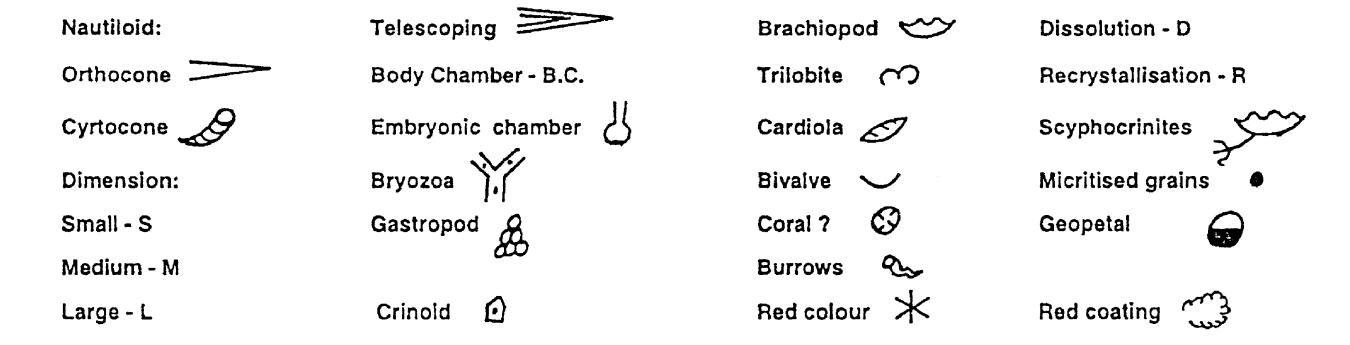
The first occurrence of a nautiloid fauna is in the *P. amorphognathoides* conodont biozone (base bed 11 – upper Llandovery) as badly deteriorated oxidised fragments of small orthocerids within grey/black shales. Higher in the biozone there are nautiloids both in the shales and lenticular micritic limestones with a more pronounced abundance in the shales. The fragmented shells occur as litho-

	SERIES	STAGES	CONODONTS	THICKNESS	Taphonomy Lithology & Formations	GRAIN SIZE or TEXTURE	DEPTH CURVE

GRAIN SIZE or TEXTURE
m.s|w.s.|p.s.|g.s.
s.l. f.s. c.s. g.
sh.v.f.s.m.s.v.c.s.

DEPTH CURVE
shallow   deep
0 1 2 3 4 5 6

S I L U R I A N						

PRIDOLI — O. eosteinhornensis – O.e. detorta

O. remscheidensis Interval zone

MEGAERELLA Lst. — 8

LUDLOW — LUDFORDIAN

O. crispa

O. snajdri Interval zone — ALTICOLA Lst. — 20

P. siluricus — 3,5 — CARDIOLA Fm.

A. ploeckensis

GORSTIAN

NOT ZONED

K. stauros

WENLOCK — HOMERIAN

O. bohemicus — 15

O. sagitta sagitta — KOK Fm. — 14, 13 — 13

SHEINWOODIAN

NOT ZONED

O. sagitta rhenana
K. patula

K.ranuliformis Interval zone — 12 b

12

LLANDOVERY — TELYCHIAN

P. amorphognathoides — 11, 10 g

P. celloni — 10 a

AERONIAN

P. tenuis – D. staurognathoides — HIATUS

RHUDDANIAN

D. kentuckyensis

O.? nathani

LOCALITY: Cellon Section

Depth curve labels (right side, top to bottom): SB?, TST, MFS, SB, CI, SSB, SB, CI, MFS, SB, LHST, SSB, MFS, SB

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Conodont stratigraphy, lithology, grain size, significant taphonomic features and depth curve of the Silurian of the Cellon section (Modified from SCHÖNLAUB, 1997, Text-Fig. 3).
CI = condensed interval; SB = sequence boundary; SSB = sub sequence boundary; LHST = late highstand (regressive) system tract; TST = transgressive system tract; MFS = maximum flooding surface.

Nautiloid:	**Telescoping**	**Brachiopod**	**Dissolution - D**
Orthocone	Body Chamber - B.C.	Trilobite	Recrystallisation - R
Cyrtocone	Embryonic chamber	Cardiola	Scyphocrinites
Dimension:	Bryozoa	Bivalve	Micritised grains
Small - S	Gastropod	Coral ?	Geopetal
Medium - M		Burrows	
Large - L	Crinoid	Red colour	Red coating

clasts within the shales (Text-Fig. 3) which show flow structures around the carbonate lenses. They lack both body chamber and apex and are generally not crushed. They probably sank to the seafloor after death from a relatively intermediate water depth of pelagic habitat and were transported along slope until rapid deposition took place within the shales (BOSTON & MAPES, 1991). Evidence of some reworking of nautiloids from lower carbonate levels is apparent higher in this zone as infill similar to micritic lenses below is seen. The shells within the carbonate lenses are in general larger in dimension and are also fragmented and oriented parallel to bedding but are not particularly abundant. They have a distinct pink coating of the shell which may be algal in origin. Deposition in a relatively shallow pelagic environment is envisaged with intermittent current reworking of the shells.
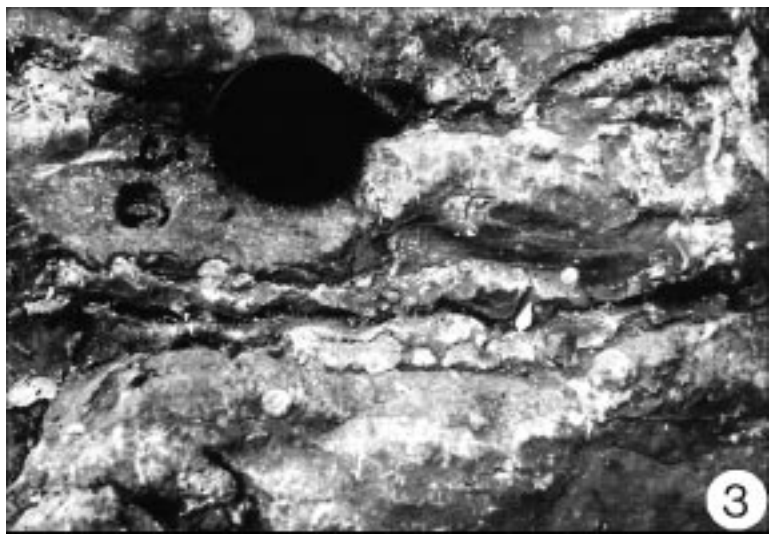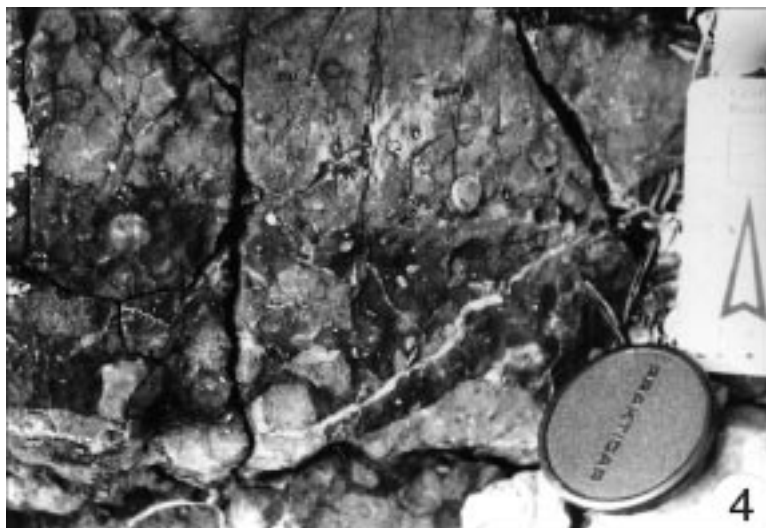

Text-Fig. 3.
Llandovery/Wenlock transition sequence: Preservation of nautiloids within shales and lenticular carbonates.

The lateral extension of these beds is difficult to follow as the lenses seem to fade out or unite along section. A *thalassinoides* level towards the top of the micritic lenses (approx. 0.6 m from base bed 11) is overlain by an horizon with a concentration of medium fragmented nautiloids parallel to bedding, then by dark grey shales with iron staining. The burrowed bed is quite distinctive and may be traced across the section. It may document an increase in the oxygen content. The overlying accumulation of medium-sized nautiloids may be due to winnowing by currents as they are oriented on this bedding plane and may indicate a return to a more ventilated situation (BRETT & BAIRD, 1993). There is a rich associated fauna throughout this stratigraphic interval, in particular within the shales,

of well preserved brachiopods (small dimension) and trilobite fragments (large dimension). Crinoid debris is abundant and pyrite development is common in the shales. Other groups noted within this biozone are acritarchs, foraminifers and graptolites. The *K. ranuliformis* conodont interval biozone is placed by SCHÖNLAUB (1997) at the base or within the badly deteriorated shales above the basal micritic horizons of bed 12A. Nautiloids were not observed within this stratigraphic interval.

At the base of the *O. sagitta rhenana-K. patula* conodont biozone (bed 12B – this horizon is precisely dated as *Cyrtograptus rigudus* biozone by JAEGER [1975]) a graded series of thin grey micritic carbonate levels occur within a relatively thick black shale sequence. An abundant small to medium sized nautiloid fauna is seen in one micrite layer, for the most part fragmented and oriented randomly to bedding, however juvenile fauna complete with embryonic chambers are also present in the same level. Adult bivalves are the dominant element of the fauna with abundant gastropods and brachiopods also noted in this accumulated horizon (KŘÍZ, 1979; KŘÍZ, in press), probably due to winnowing by relatively gentle currents. The presence of juvenile fauna may also indicate fluxes in the oxygen level. At the top of the Sheinwoodian (interval not zoned by conodonts) there is a distinct change to thick carbonate development with four distinct levels of again lenticular micritic grey limestone (beds 12C-E). An abundant orthocerid nautiloid fauna oriented parallel to bedding with body chambers and apexes preserved is developed in two of these layers while the others bear a rich crinoid debris and brachiopod/bivalve fauna. These beds also appear slighty recrystallised. The nautiloids are well-preserved indicating little transport and accumulation due to winnowing by gentle currents. A relief surface at the top of this biozone (bed 12E) and possible stylolitic level may indicate a break in sedimentation at this point of the sequence.

In the *O. sagitta sagitta* conodont biozone (bed 13) and the lower *O. bohemicus* conodont biozone (beds 14 ?–15) a series of brown ferruginous limestones occurs with for the first time an abundant nautiloid fauna, both in number and

Text-Fig. 4.
Base *O. sagitta* conodont biozone (Wenlock): Ferruginous limestones with terrigenous influxes giving "patchy" effect to limestone surface.
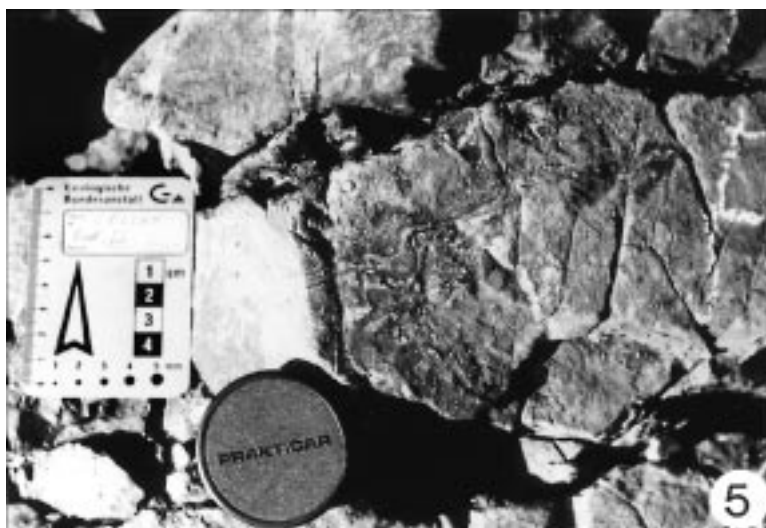
Text-Fig. 5.
O. bohemicus conodont biozone (Wenlock): Bioturbation effects.

Text-Fig. 6.
Kok Formation: red coating and infilling of nautiloids.

diversity (Text-Fig. 4). The source for the high iron content in these beds which gives them their distinctive colour is not known although terrigenous influx as mud is seen on some surfaces giving it a patchy effect (Text-Fig. 4). There is an overall development of a thick basal layer followed by a series of 5–6 thinly developed beds separated by stylolites in bed 13, a pattern which is repeated in bed 14. The numbering of the stratigraphic division by WALLISER (1964) for the most part follows this natural partition. Stylolites occurring between each cycle and more iron rich layers, which have an uneven lateral development, give the beds their distinctive appearance.

Bioturbation is evident and is prevalently concentrated in these iron rich areas (Text-Fig. 5) where there also seems to be a predominance of crinoid debris.

Within this overall sequence small scale cycles are developed of 2–3 cm in thickness showing varying taphonomic features of the nautiloid fauna (HISTON, 1997; Text-Fig. 3). The base of the cycle is marked by an accumulation of medium sized nautiloids parallel to bedding probably as a result of winnowing by gentle currents as the shells retain their body chambers. Telescoping within medium shells with parallel orientation to bedding is dominant in the mid cycle possibly indicating an increase in energy while the smaller shells within the same horizon show mainly a random orientation to bedding. This latter feature may indicate that the accumulation is time rich as varying preservations of the nautiloids are observed with contradictory hydrodynamic implications. The higher levels of the cycle are in general dominated by small dimension nautiloids sometimes oriented perpendicular to bedding with body chambers and apexes intact, showing a return to a more tranquil environment. These cycles are in most cases separated by stylolites which sometimes seem to cut off the medium nautiloids in the underlying bed. Dissolution of some medium shells is also evident. Both of the latter may imply a significant exposure time for these nautiloid bearing layers due to reduced sedimentation rates. Dominance of small juvenile nautiloid fauna in two of the upper levels of bed 14 may also suggest changes in oxygen content.

A distinctive outer red coating is a prevalent feature of the preservation throughout the lower beds of the *O. sagitta* biozone which appears to be dominantly on the nautiloid fauna and may be algal in origin (Text-Fig. 6). It is also seen internally in some shells towards the top of the *O. bohemicus* biozone infilling cameral chambers and lining the siphuncle. This coating seems to be quite rare on the associated fauna of bivalves, trilobites, brachiopods and gastropods. Geopetals are in some cases parallel to bedding but the internal sediment of some shells, particularly of small dimension, appears to be finer than the surrounding sediment indicating some degree of reworking. There is a concentration of large orthocerid nautiloids parallel to bedding

(base bed 15) some of which also seem to have been reworked. Their presence indicates a relatively deep pelagic nautiloid fauna.

Gradation towards the top of the *O. bohemicus* biozone occurs (bed 15A) and there is less iron content overall as we approach the Wenlock/Ludlow transition with stylolites not being evident.

The varying degrees of energy throughout the *O. sagitta* and *O. bohemicus* biozones may be well documented by comparing the strata with telescoped and reworked shells to those that appear quite intact retaining both body chambers and apexes. The structural diversity of orthocerid nautiloid fauna seen, when considered with the associated fauna and evidence of bioturbation in certain horizons, also indicates that they were deposited in a relatively shallow environment of intermittent sea-level changes. The complex mixture of taphonomic signatures with wide lateral extension, as seen here within the thinly developed cycles, and the frequency of stylolites has been interpreted by BRETT & BAIRD (1993) as indicative of condensed sequences. A similar example from the Devonian of Morocco has been well-documented by WENDT (1988).

3.3. Ludlow

Basal black shales overlain by grey slightly crystalline carbonate layers with a fauna of nautiloids, bivalves, abundant juvenile brachiopods and abundant crinoid debris occur towards the middle of the Kok Formation at the Wenlock/Ludlow transition (*K. stauros* conodont biozone: beds 15B–15D, formerly named *O. crassa* biozone sensu WALLISER 1964). This carbonate is here referred to as an encrinitic level in a broad sense. The nautiloids are small to medium in size with respectively random and parallel orientation to bedding. The medium nautiloids show mechanical damage, distortion and some disarticulation of cameral chambers. Body chambers appear to be absent but the shells are otherwise well preserved. This may be due to deposition in a shallow shelf slope environment where the shell has been damaged during post-mortem drift and suffered some dissolution of the shell wall due to extended exposure on the shelf-floor (HEWITT & WESTERMANN, 1996). A distinct level of small dimension brachiopods within these carbonates may be due to winnowing by currents. These levels are again overlain by black shales with an interbedded thin dark grey lenticular micrite horizon with rare fragmented medium nautiloids parallel to bedding showing telescoping and internal iron-rich lining of siphuncles. No other fauna was apparent. This obviously marks an increase in the hydrodynamics of the nautiloid habitat, the shells however, may have accumulated downslope in a deeper shelf environment.

The upper part of bed 15 and base bed 16 (not zoned by conodonts) show a return to more micritic grey carbonate beds which appear to fine upwards. They show alternating levels of small scale cycles rich in nautiloids, crinoid debris, brachiopods and trilobites with "iron" rich areas (these sometimes appear to be only a surface feature but sometimes also show internal sedimentary layering: indicating terrigenous influxes and possibly the presence of stromatolites or other microbial mats. Pockets of biodetritus are evident within these "iron" rich levels which are highly bioturbated, tiering of trace fossils is also evident with dimension increasing upwards within individual layers from *chondrites* to *thalassanoides*.

The nautiloid fauna is found as horizons of medium sized, fragmented shells oriented parallel to bedding showing dissolution and slight compression effects indicating winnowing by currents and extended exposure on the sea-floor. The cameral chambers are infilled in some cases by dark quartz suggesting that the chambers were fluid filled and intact on deposition and underwent some degree of diagenesis. Particular levels (within beds 15E, base 16) of a not very abundant small juvenile nautiloid fauna alternate with the "iron" rich layers possibly indicating fluxes in oxygen content due to the terrigenous influxes, if that is what the "iron" rich layers represent.

Both the *K. stauros* conodont biozone and the overlying unzoned interval seem to represent composite fossil beds which are significantly time-rich (BRETT & BAIRD, 1993) concluded from the variety of groups represented, the varying grades of skeletal preservation and single event horizons.

The *A. ploeckensis* conodont biozone (beds 16a-20) is marked by a return to the cyclic carbonate deposition seen in the *O. sagitta* and *O. bohemicus* biozone. An increased frequency of cycles and of faunal abundance occurs higher in the sequence in beds 17 and 18 with "iron" rich layers and stylolites developed together as sedimentary breaks or condensed intervals between the carbonate beds.

Medium sized nautiloids are sometimes "trapped" within these stylolites at the top of cycles. This feature may represent evidence of a more resisent nautiloid shell structure or the remains of internal primary shell deposits within the stylolitic layers. The red external coating and internal lining of chambers and siphuncle are again common, indicating algal activity.

There are also particular layers of an abundant juvenile nautiloid fauna which are quite distinctive and are easy to trace along section. Bioturbation also occurs in some horizons, again showing tiering. Both of the latter indicate fluxes in the oxygen content.

Towards the top of the Kok Formation there is a definite increase in the variety of nautiloid fauna both in species and number (a count per 0.5 m^2 indicates 139 specimens at the base of the *O. sagitta sagitta* biozone, 249 in the *A. ploeckensis* biozone). The structural limits of the nautiloids indicate a relatively deeper water fauna at the base of this biozone and a more varied shallow and deep water fauna at the top. This is consistent with accumulated levels of more pelagic fauna earlier in the *A. ploeckensis* biozone followed by a more in-situ varied fauna in the upper beds. Dissolution effects become evident indicating extended exposure times and dark quartz is developed in some cameral chambers implying some diagenetic effects.

The nautiloid fauna shows a wide variety of preservation with embryonic chambers being preserved (Text-Fig. 7) in those horizons showing low levels of energy indicating little or no transport. Gradation of the beds higher in this conodont biozone is evident, with coarsening upwards and a more lenticular development with interbedded shales. The pattern of cycles and the overall taphonomic features seen in the *O. sagitta* and *O. bohemicus* biozones seems to be repeated here. Therefore we may also indicate that this is a condensed sequence.

A distinct level of small brachiopods in dark grey micrite (base bed 20) marks a change in lithology and colour at the top of this stratigraphic interval to dark grey lenticular levels of micrite interbedded with black shales, a pattern which continues into the overlying Cardiola Formation. The brachiopod level may be due to winnowing by gentle currents.
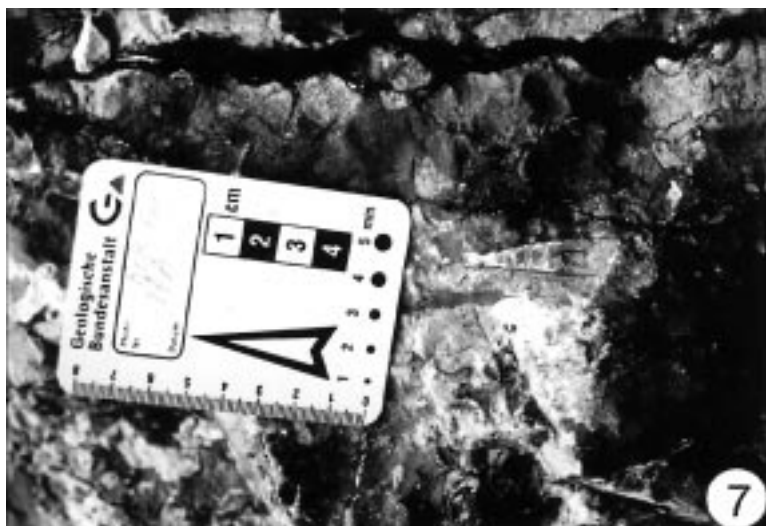
Text-Fig. 7.
A. ploeckensis conodont biozone: embryonic nautiloid chamber.

3.4. General Remarks on the Kok Formation

In general the Kok Formation is characterised by changing energy and oxygen levels and the presence of numerous condensed intervals as well as intermittent changes in sea level particularly towards the top of the sequence.

In the Llandovery two oxygenation events may be seen as evidenced by the *thalassinoides* levels while in the Llandovery / Wenlock transition zone (*P. amorphognathoides* conodont biozone) the first incursion of a nautiloid fauna can be observed mainly as accumulations within the shales. At the top of the *K. patula* biozone the first abundant nautiloid fauna appears which has undergone little or no transport indicating a more offshore environment. A relatively shallow environment with varying sea-level and reduced sedimentation is envisaged for the *O. sagitta* and *O. bohemicus* biozones whereas the *K. staurus* biozone and the overlying unzoned interval may represent a shallow shelf habitat with some notable single oxygenation events. In the *A. ploeckensis* biozone there are cycles of variation in sea-level and oxygen content, with reduced sedimentation in some levels. The nautiloid fauna shows a marked increase both in variety and numbers perhaps suggesting a more ventilated environment. The taphonomic features indicate composite fossil beds (BRETT & BAIRD, 1993) from the base of the Kok Formation up to the *O. sagitta* biozone where a condensed sequence is developed. A return to composite fossil beds in the *K. staurus* biozone and to a condensed sequence in the *A. ploeckensis* biozone can be observed.

The data for the structural limits of the nautiloids based on a ratio of conch diameter to septal spacing imply a mixed shallow and deep water fauna in the lower beds of the formation, becoming dominated by a stronger deeper water fauna in the middle part of the formation and by a dominantly weaker fauna in the upper levels which is in part consistent with the sea-level curve for the section (SCHÖNLAUB, 1997). The palaeoecological implications of the orthocerid nautiloid morphology in general indicate a relatively shallow water pelagic habitat.

The environmental implications of the data given here compare quite well with those of KREUTZER & SCHÖNLAUB (1997) which document a shallow to intertidal setting for the Llandovery to lower Wenlock and a transgressive sequence in the Wenlock and lower Ludlow. PRIEWALDER (1997) emphasizes the absence of chitinozoans from the base of the Wenlock to the lower Ludlow interval, which may be due to unfavourable conditions for their preservation (high energy in shallow sea; oxidation). This also compares well with the varying hydrodynamic regimes shown by the nautiloid taphonomy. WENZEL (1997, Text-Fig. 7) also illustrates several variations of the oxygen isotope ratio throughout the Kok Formation which match well with the data given here in particular at the transition of the Llandovery/Wenlock and Wenlock/Ludlow. Other comparisons with positive oxygen isotope excursions may be made where bioturbation levels are noted and where levels of nautiloids of large dimension occur, for example for the latter at the base of beds 15 (*O. bohemicus* biozone) and 17 (*A. ploeckensis* biozone).
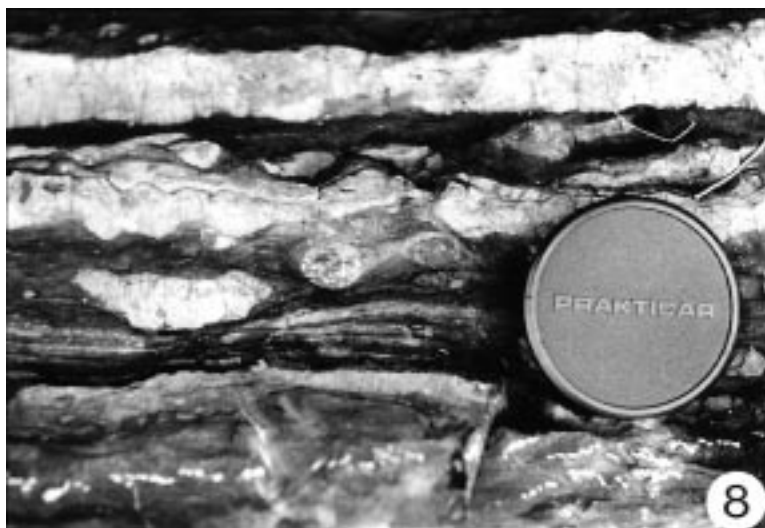
4. Cardiola Formation

4.1. Middle Ludlow

In the Cardiola Formation (middle Ludlow *P. siluricus* conodont biozone – beds 21–24) a distinct change may be seen not only in the lithology but also in the preservation of the nautiloids.

A relatively deeper water carbonate series is developed with evidence of reworking of particular beds and intermittent deepening of the environment marked by shale deposition. There is a definite cycle of deposition (bed 21 base) with a basal bed of light grey micritic limestone (dolomitised in appearance) composed almost entirely of fragmented medium to small sized nautiloids oriented parallel to bedding. An accumulation due to winnowing by relatively high energy currents is concluded with a prolonged exposure time before burial. This stratum is followed by a thick compact band of thinly laminated dark grey /black micrites which show gradation upwards. Small fragmented but uncrushed nautiloids occur within the laminations as lithoclasts with the laminated layers showing flow structures around them. Rapid deposition after short periods of transport is suggested for these shallow water occurrences.

These laminates are overlain by an interbedded series of black ferruginous shales and nodular grey micritic limestones with lenticular development which occur usually in groups of four or five in number (Text-Fig. 8). The limestone beds can be quite thin and contain abundant medium sized nautiloids oriented parallel to bedding the diameter of which sometimes actually forms the thickness of the bed itself. The upper surface of these horizons often only shows the relief of the nautiloids (Text-Fig. 9) and their perpendicular orientation to each other on the bedding surface. This preservation again marks winnowing by currents but with less energy than before as they are not as fragmented as in the basal beds of these cycles. They sometimes appear to be reworked due to the re-orientation of the geopetals and finer sediment infill. The shells also show dissolution effects suggesting extended exposure on the sea-bottom before burial. There is a small fragmented nautiloid fauna and also reworked medium nautiloids from the underlying nodular bed within the shales, again occurring as lithoclasts with the shales showing flow structures around them as before in the laminates. Rapid deposition is again envisaged for these layers.

Text-Fig. 8.
Cardiola Formation: Development of shales and micritic carbonate beds.

Text-Fig. 9.
Cardiola Formation: Nautiloids on bedding surface.

A thick ferruginous black shale band forms the top of this series indicating an overall deepening of the depositional environment. Distinct ferruginous bands of 1 cm or less in thickness, which sometimes also show pyritisation, may be traced laterally in the shales. These may represent single event fossil beds. However, recognisable fossil fragments have not been collected to date from these horizons. Beds 21A–24 of the formation show a repetition of this development with shales becoming more frequent towards the top of the stratigraphic biozone.

Nautiloids are the dominant fauna but levels of a concentrated small brachiopod-bivalve fauna also occur which may indicate a change to a more ventilated situation within the sequence (base bed 21, base bed 22A, base bed 22B, base bed 23 (only in pockets). A carbonate layer containing large orthoconic nautiloids within bed 22 is also significant as it may imply the presence of a more pelagic fauna. Some pyritic coating of nautiloids and dark quartz within the cameral chambers was observed in one of the upper nodular levels of bed 22 suggesting anoxic conditions and some degree of dolomitisation. Pockets of *chondrites* were noted, particularly in the laminated beds and also in the nodular layers of beds 23 and 24, indicating slight increases in the oxygen content. The associated fauna within this stratigraphic interval is quite varied with conodonts, chitinozoans, brachiopods, bivalves (KříZ, 1979), trilobites and graptolites (JAEGER, 1975). The development seen in the *P. siluricus* conodont biozone is reminiscent of the interbedded lenticular micrites and shales of the *K. patula* conodont biozone of the lower Wenlock and a similar offshore environmental setting may be inferred.

4.2. General Remarks on the Cardiola Formation

The Cardiola Formation is characterised by alternating rapid deposition of black shales and laminated micrites with more time rich light grey nodular micrites composed of a rich nautiloid fauna. Current activity of varying hydrodynamic regime is evidenced by these accumulations and periodic increases in oxygen content throughout the sequence may be implied from the concentrations of brachiopods /bivalves, pockets of *chondrites* and incursion of a large nautiloid fauna. Single fossil events may also be suggested by the ferruginous-pyritic horizons noted within the shale sequences. The palaeoecological implications of the orthocerid nautiloid fauna with both structurally adapted shallow and deep water species point to a shallow pelagic environment.

KREUTZER & SCHÖNLAUB (1997) infer an offshore environment with deposition of black shales and micrites with contemporary nondeposition taking place possibly due to currents. This interpretation is consistent with the environmental setting deduced here. PRIEWALDER (1997) cites an abundant chitinozoan fauna both in number and species diversity in some levels suggesting that environmental conditions were suitable for their preservation, i.e. low hydrodynamic setting. This is also in agreement with the nautiloid data for the shale and laminated micrite levels, however, the intermittent strata of current accumulated nautiloid fauna indicate a higher energy environment. WENZEL (1997) has shown an increase in the oxygen isotope ratio at the base of bed 22 which is in agreement with the more ventilated environment suggested by the incursion of a large nautiloid fauna, the concentrated brachiopod/bivalve horizons and the pockets of *chondrites*. RISTEDT (1969) cited a mass occurrence of juvenile *Hemicosmothoceras celloni* from the base of the Cardiola Formation (base bed 21) which is coincident with the concentrated stratum of brachiopod/bivalve fauna. This horizon of juvenile fauna may represent an increase in ventilated conditions at the base of this conodont biozone which however, was not continuous, only intermittent, throughout the *P. siluricus* interval. The environmental interpretation given by KříZ (1993, 1996) for the *Cardiola docens* community, dominated by epibyssate forms, which also occurs in the Cardiola Formation (KříZ, 1979) is also consistent with that given here.

5. Alticola Limestone

The Alticola Limestone (Ludlow–Pridoli in age) is distinctive in that it forms the base of the steep slope of the section. The erosive base of the grey dolomitised massive beds contrasts

sharply with the black shales of the underlying Cardiola Fm and pass upwards to an easily recognizable greyish to reddish limestone. It has an overall thickness of 20 m and represents a transgressive carbonate series within more stable pelagic conditions (SCHÖNLAUB, 1997). Grey to dark pink micritic limestones with a variety of bed thickness and frequent stylolites are common in the Ludlow with a dominant nautiloid fauna. The beds decrease in thickness in the Pridoli and alternate with interbedded laminated micrites with a dominant nautiloid and brachiopod fauna. Several deepening events marked by the development of black shales have been documented within the uppermost levels of the Pridoli. The taphonomic data outlined below show that frequent sealevel changes and possible variations in oxygen were also prevalent in the upper Ludlow and Pridoli sequences.

5.1. Ludlow

The base of bed 25 of the overlying Alticola Limestone (upper Ludlow *O. snajdri* interval conodont biozone, beds 25–29) is marked by an abundance of medium to large orthoconic nautiloids in a distinctive grey dolomitised limestone. In general their diameter is approximately 10 cm, body chambers are preserved and they are oriented parallel to bedding (Text-Fig. 10). They mark a change to a deeper water pelagic fauna and were probably deposited by gentle currents

Text-Fig. 10.
Alticola Limestone: Basal bed with concentration of medium sized nautiloids.
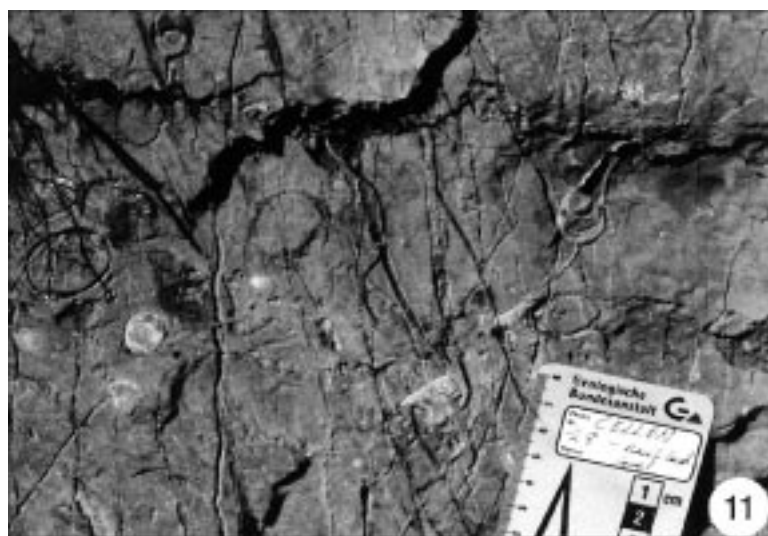
Text-Fig. 11.
Alticola Limestone: Nautiloid level in bed 28, *O. snajdri* conodont biozone.

as the shells are well preserved. Above this basal horizon the beds (25–27) have a similar dolomitised appearance with stylolites in the form of buff coloured "silt" layers. The nautiloid fauna is relatively sparse in comparison to the previous formations but seems to have undergone a high degree of dissolution. Internal features are rarely seen and the shells have a similar buff coloured coating as seen in the stylolites. This may be algal in origin. When cameral chambers are preserved they have a dark brown lining. This coloration may represent alteration of the sediment infill of the chambers and coating of the specimens due to dolomitisation. The nautiloids are oriented parallel to bedding and do not appear to be fragmented or concentrated in particular levels indicating slow deposition by gentle currents in a relatively tranquil environment. The only other fauna noted includes large trilobites. In beds 26–27 the nautiloid fauna becomes more abundant but is still relatively sparse, dissolution is again evident and there are also some telescoped specimens possibly indicating variations in the local hydrodynamic regime.

A change in lithology is evident in the upper part of the *O. snajdri* interval conodont biozone approximately 3 m above the base of the formation (beds 28–29), from grey to a dark purple-red limestone with frequent stylolites. The fauna is notably quite rich and varied with a particular abundance of nautiloids and large trilobites (Text-Fig. 11). The preservation of the nautiloids is also better with internal features observed and the shells being relatively intact, dimensions vary from small to medium sized shells. Some nautiloids show dissolution effects and are cut off by the stylolitic levels. Body chambers and apexes are present and orientation is dominantly parallel to bedding with concordant geopetals also seen. Winnowing by gentle currents is concluded for the mode of deposition. An outer red coating is seen on the shells, similar to that noted in the Kok Fm., which again may suggest algal activity. A distinctive level of small brachiopods occurs in bed 28 again suggesting more ventilated conditions. The horizons between stylolites appear to be similar in development without specific small scale depositional cycles as seen in the Kok Formation. The "stylolitic" levels almost appear to be thin brown-buff coloured silty intercalations between the carbonate horizons and sometimes show layering. This preservation may be dolomitic in origin.

Gradation is evident in bed 29 and the beds are greyer in colour. A striking stratum of dark pink coloured limestone (5 cm in thickness) occurs towards the top of bed 29 which has a concentration of medium nautiloids, oriented parallel to bedding with geopetals in place. The nautiloids are fragmented indicating accumulation due to winnowing by high energy currents and have an outer red coating suggesting algal activity.

A similar limestone development continues in the upper Ludlow *O. crispa* biozone (beds 30 –

Text-Fig. 12.
Alticola Limestone: Bioturbation level in bed 30, *O. crispa* conodont biozone.
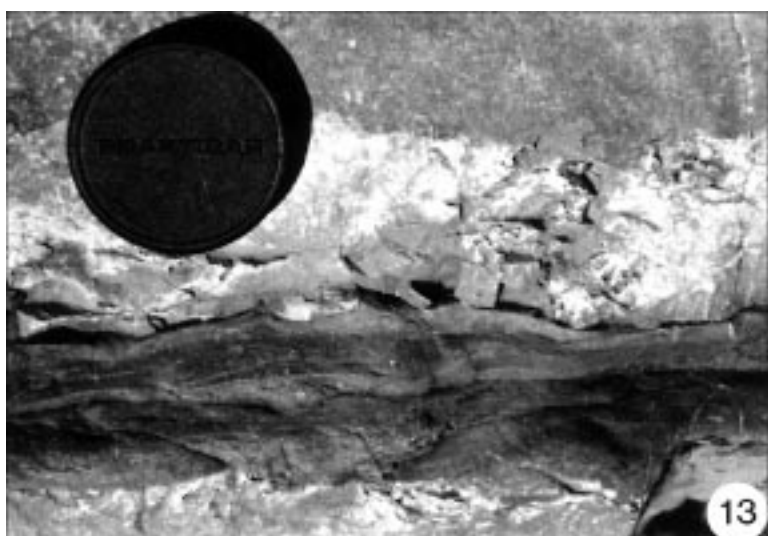
Text-Fig. 13.
Alticola Limestone: Laminated micritic intercalations, *O. remscheidensis* conodont biozone.

Text-Fig. 14.
Alticola Limestone: Brachiopod level, *O. remscheidensis* conodont biozone.

base 32) with frequent stylolites, the only apparent difference being that the limestone beds are less red in colour. The silty intercalations also appear as surface patches as was previously seen in bed 16 (Kok Fm. – Lower Ludlow) and bioturbation (*chondrites*) occurs in these areas also indicating more ventilated conditions (Text-Fig. 12). These areas appear to be more eroded superficially and have a marked pocked appearance. The nautiloids are again generally oriented parallel to bedding, are fragmented and have an outer red coating so winnowing by strong currents and the presence of algal activity is implied from their preservation. Large nautiloids were observed in bed 30 suggesting a more pelagic fauna and more ventilated conditions. Some telescoped specimens were also noted and these do not seem to be reworked as the internal sediment is similar to the matrix. The associated fauna consists dominantly of large trilobites and sparse brachiopods. At the base of bed 32 lenses and lithoclasts of the carbonate beds may be seen within these silty-micritic laminated intervals, the carbonate levels show dissolution features and variation of colour within the beds themselves.

5.2. Pridoli

The basal beds (bed 32A–34) of the *O. remscheidensis* conodont biozone (former *O. eosteinhornensis* conodont biozone of WALLISER [1964]) show a distinct colour change to light grey and display dissolution effects and gradation. Nautiloids are varied in dimension from small to medium with random orientation to bedding indicating slow accumulation in a tranquil environment. In beds 33–34 laminated micrites, which may be dolomitised with a silty surface appearance, are interbedded with thin grey-black shales and lenticular light grey carbonates in the form of more massive horizons (Text-Fig. 13), a sequence which is similar to that seen at the base of the Cardiola Fm (Ludlow). The micritic levels have lithoclasts and nautiloid fragments within the laminations which show flow structures around them indicating rapid deposition. Some bedding surfaces show imprints of a probable brachiopod fauna indicating more ventilated episodes (Text-Fig. 14). The more massive carbonate banks appear to have an abundant fauna of trilobites with biodebris visible towards the top of individual beds. The upper bedding surface is undulating and is infilled by the overlying laminates. Stylolitic levels are evident in bed 34 and have a laminated crust-like appearance in some cases.

Nautiloids are rare but when seen are medium in dimension and parallel to bedding with apex and body chamber present suggesting deposition by gentle currents. Some shells have finer internal sediment indicating that they have been reworked during higher energy episodes.

Beds 35–39 of the *O. remscheidensis* conodont biozone show a similar development with thin lenticular light grey carbonate horizons alter-

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nating with laminated micrites and ferruginous black shales. Imprints of a possible brachiopod fauna may be seen on the bedding surfaces of the laminites and round pyritic nodules (diameter 2 cm) also occur on some bedding surfaces of beds 36–37 both indicative of changing oxygen content. A trilobite fauna has also been noted in some levels. The surface of bed 36C shows a peculiar layered feature which may be stromatolitic or algal in origin. In the upper level of bed 37B a 5 cm thick horizon of crinoid stems, still articulated, are oriented parallel to the bedding plane and were possibly accumulated due to winnowing by gentle currents.

Nautiloids are rare and where preserved are parallel to bedding within the carbonates which seem to grade upwards with a high biodetritus content. The shells are perpendicular to each other on the bedding surface indicating orientation by currents. The whole sequence is similar to that seen in the Cardiola Fm. (Ludlow) but with more laminites than black shales developed. A silty brown surface coloration (dolomitic in origin?) of the laminates is again evident in beds 38–39 but bioturbation of these was not noted here (Text-Fig. 15). Fragmented nautiloids are sometimes seen within the laminated levels which tend to show flow structures around them again indicating rapid deposition.
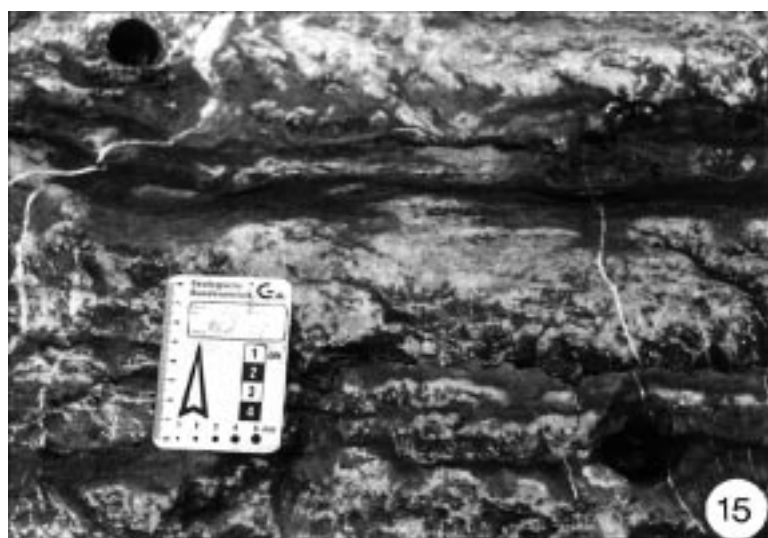
Text-Fig. 15.
Alticola Limestone: laminated carbonates with "silty" intercalations, *O. remscheidensis* conodont biozone.

5.3. General Remarks on the Alticola Limestone

An offshore setting frequently ventilated by currents of varying energy is envisaged from the nautiloid taphonomy for the upper Ludlow and Pridoli sequences of the Alticola Limestone. Dissolution effects are high in the lower beds of the *O. snajdri* conodont biozone which may be due to dolomitisation or may reflect extended exposure time on the sea-floor. The sequence represents time rich deposition. Two single event horizons were observed in the upper levels of this conodont biozone with a concentration of brachiopods indicating more ventilated conditions and a horizon of oriented concordant nautiloids representing an increase in the energy of the depositional environment. The distinctive colour changes within this interval possibly reflect fluxes in the oxygen levels and increased algal activity.

In the upper Ludlow *O. crispa* conodont biozone a similar development is seen but the varying hydrodynamics of the depositional environment become more evident and there are possible episodes of terrigenous influxes. Bioturbation of these areas indicates that there were also frequent changes in the oxygen levels.

In the Pridoli *O. remscheidensis* conodont biozone a sequence of interbedded graded micritic carbonate horizons with laminated micrites and shales is developed. The depositional environment represented by rapidly deposited shales and laminites alternating with more massive micritic strata which show internal grading, indicated that the hydrodynamic regime was constantly changing. Evidence of reworking of the nautiloid fauna in some cases also supports this interpretation. The intermittent brachiopod horizons indicate more ventilated episodes in this offshore setting. A graptolite fauna with occurrences of *M.* aff. *ultimus* in bed 32 and *M. transgrediens* in beds 35, 36 and 37, has been documented within this interval by JAEGER (1975).

The orthocerid nautiloid fauna, with a dominant number of specimens structurally adapted for a relatively deep water environment, imply a slightly deeper palaeoecological habitat than the underlying formations. A similar offshore pelagic environment is concluded by KREUTZER & SCHÖNLAUB (1997).

WENZEL (1997) shows a distinct increase in the oxygen isotope ratio at the base of the formation (bed 25) which may be associated with the abundance of medium-large nautiloids indicating a change to a more pelagic fauna. Other oxygen isotope excursions shown by WENZEL (1997) throughout this formation coincide with bioturbated levels and horizons with a dominant brachiopod fauna. PRIEWALDER (1997) indicates a rich chitinozoan fauna from some levels from the upper Ludlow–Pridoli interval therefore the depositional environment was of a low hydrodynamic regime that they could be preserved. This is supported in some cases by the nautiloid data where deposition was by gentle currents however, some horizons are indicative of high energy currents.

6. Megaerella 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. It has a thickness of 8 m and forms the steep step at the top of the section. The boundary between the Silurian and Devonian is drawn between horizons 47A and 47B based on conodonts with the first occurrence of *Icriodus woschmidti* (WALLISER, 1964). However, the first evidence from graptolites of Lochkovian age is found in bed 50 with the occurrence of *M. uniformis* (JAEGER, 1975).

6.1. Pridoli

In the upper horizon of bed 40A above a black shale interval a rich fauna of small to medium size nautiloids occurs in a dark grey-black micrite, embryonic chambers are preserved with an associated fauna of brachiopods. The larger nautiloids appear quite fragmented with a random orientation to bedding indicating deposition by a gentle current. Beds 40–45 of the *O. remscheidensis* conodont biozone (former *O. eosteinhornensis* conodont biozone of WALLISER [1964]) return to more massive graded grey car

Text-Fig. 16.
Megaerella Limestone: large nautiloid, bed 45, *O. remscheidensis* conodont biozone.

Text-Fig. 17.
Graded strata of Silurian/Devonian boundary in level where lens cover is placed.

Text-Fig. 18.
Interbedded black shales and laminites of the Rauchkofel Limestone (Lochkovian) above the Silurian/Devonian boundary, positioned in carbonate bank on the left of photo 1.

bonate banks rich in biodetritus, sometimes laminated towards the top of the horizon with interbedded silt-like laminated micrites which have a brown surface appearance. A nautiloid fauna of medium sized shells parallel to bedding is present in the massive strata but is not abundant. Towards the top of the *O. remscheidensis* conodont biozone (former *O. eosteinhornensis* conodont biozone of WALLISER [1964]) a level of large nautiloids is seen (Bed 45) which have been reworked as the internal sediment is of dark micrite which contrasts sharply with the grey carbonate of the surrounding matrix indicating an increase in environmental energy (Text-Fig. 16). This level also shows gradation with a high content of biodetritus, fining upwards to laminites at the top of the horizon. In bed 46 an abundance of crinoid debris and rare bivalves are seen in the graded carbonates which become laminated upwards. The sequence overall seems to represent rapid accumulations alternating with slow deposition time rich carbonate horizons in an offshore setting.

The transition to the *O. eosteinhornensis-O. e. detorta* conodont biozone is not defined at the Cellon section. The boundary between the Silurian and Devonian is drawn between 47A and 47B based on conodonts, however, the first evidence from graptolites of Lochkovian age is found in bed 50. Gradation is evident in bed 47 with many biodebris levels (Text-Fig. 17).

The lower levels of the Rauchkofel Limestone (Lochkovian in age, beds 47C–50) indicate a more varied hydrodynamic regime with frequent black shale intervals and biodebris rich lenticular graded carbonates (Text-Fig. 18). Particular taphonomic features of the *I. woschmidti* conodont interval are worth noting as they demonstrate a shallower, near shore environment alternating with offshore black shale deposition.

A well preserved bryozoa and bivalve fauna occurs on the upper bedding surface of 47B – the base of the Rauchkofel Limestone (Lochkovian). They may indicate a colonization of this surface within a relatively shallow high energy environment which was preserved due to the rapid deposition of the overlying shales.

Articulated crinoid stems and brachiopod imprints on bedding surfaces seem to indicate that the well-preserved state of this fauna of a more ventilated environment may also be due to rapid burial by the overlying shales and laminites. *Scyphocrinites* loboliths are preserved within the laminated carbonates which show flow structures around them and solitary corals in life position occur in thin carbonate horizons within the upper levels of bed 49 – base 50 indicating a shallower higher energy environment.

6.2. General Remarks on the Megaerella Limestone

The upper Pridoli sequences show a general alternation of sea level with deposition of graded laminated carbonates with abundant

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biodetritus and evidence of reworking from the nautiloid fauna. Bed 40A of this interval has an abundant nautiloid fauna (Ristedt, 1968) with both juvenile and fragmented shells indicating deposition by a gentle current. The nautiloid fauna are varied structurally with both deep and shallow water species present. In the overlying accumulated levels nautiloids are rare and where present seem to be reworked. 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 with the occurrence of a bryozoa fauna.

The taphonomic and nautiloid data broadly agree with that of Kreutzer & Schönlaub (1997) of an overall transgressive series with regressive pulses at the base and top within a pelagic setting. The data given here suggest a more hydrodynamically changing shallow water setting than the previous authors have indicated. The large oxygen isotope ratio excursion shown by Wenzel (1997) at the boundary may be supported by the more ventilated environment implied by the bryozoa fauna. Priewalder (1997) indicates a rich chitinozoan fauna from sone levels of the Pridoli–Lochkovian interval therefore the depositional environment was of a low hydrodynamic regime favorable for their preservation. This agrees in part with the data given here but not for those horizons where a fauna with more affinities to higher energy settings has been noted.

7. Correlation
with the Rauchkofelboden Section

When the taphonomic features of the nautiloid fauna of the Cellon section are compared with those of the Rauchkofelboden section where a similar taphonomic study has been done (Ferretti & Histon, 1997; Histon, 1999), distinct levels may be traced in both sections.

1) The iron rich coatings of the nautiloid fauna of the lower beds of the Kok Formation at the base of the *O. sagitta sagitta* conodont biozone (Wenlock) are comparable as are the abundance, orientation and dimension of the nautiloids.
   These red coatings may represent algal activity or a particular replacement of the nautiloid shell as in general they are only seen on the nautiloids.

2) The shells are usually quite fragmented with telescoping occurring at frequent corresponding intervals indicating a somewhat higher energy environment. The mechanism of telescoping is not known but it is hoped to study this phenomenon in detail both in the field and in thin section to see if any occurring pattern may be identified. In both the sections studied here it appears to be found at the base of small scale cycles showing energy changes within the beds the top of which is formed of parallel oriented medium shells, the actual order of occurrence of these minor cycles may be disrupted by stylolites.

3) The abundant nautiloid fauna above and below the encrinitic horizon of bed 323 at the Rauchkofel Boden section may be correlated with that of bed 15 at the Cellon section at the Wenlock-Ludlow transition. The distinctive level of large nautiloids prior to the encrinitic bed may also be traced at both sections indicating a deeper water fauna.

4) Beds 16 and 17 of the Cellon section (lower Ludlow) may be compared with iron-rich limestones with particular stylolitic levels above bed 324 at Rauchkofelboden. The preservation of nautiloids trapped between these stylolites is very distinctive.

5) Iron oolitic concentrations found at the Rauchkofel Boden section (Ferretti & Histon, 1997) which may mark the limit of depositional cycles have not yet been seen at Cellon but a definite gradation of beds occurs at the same level of the Lower Ludlow.

6) The thinly developed strata of a probable juvenile fauna of nautiloids and brachiopods are also comparable in position in both sections within the lower Ludlow and may indicate a change in oxygen content as the beds are also a particular red-pink colour.

7) The abundance and variety of fauna seen in the upper part of the Kok Formation with the thinner development of beds and more evidence of dissolution may also be traced in both sections.

8) The Cardiola Formation has an extremely thin development at the Rauchkofel Boden section but the thin lenticular beds showing parallel oriented nautiloids may be used as a marker horizon within the sequence.

9) The distinctive occurrence of large nautiloids at the base of the Alticola Limestone is also comparable in both sections. The dolomitised levels with high dissolution effects again followed by an abundant fauna with a distinctive stratum of parallel oriented medium nautiloids with geopetals is also traced in both the Cellon and Rauchkofel Boden sections in the upper Ludlow.

10) The occurrence of levels of large nautiloids and *Scyphocrinites* in the Pridoli and Silurian/Devonian boundary transition beds is also comparable in both sections.

8. Discussion

It is hoped by comparing the results of the taphonomy and bathymetric indications for the nautiloid fauna from both sections to identify various taphofacies within the Silurian sequence.

At present the data for the nautiloid fauna indicate a possible placement for the lower beds of the Kok Formation in taphofacies 4 (shallow to moderately deep environment) and the upper beds in taphofacies 2 (shallow environment; Speyer & Brett, 1991). Taphofacies 6 (relatively deep setting) may be indicated for parts of the Cardiola Formation while a return to taphofacies 4 is suggested for the lower part of the Alticola Limestone. Taphofacies 3 (shallow to moderately deep setting) may be indicated for some bioturbated levels in the Ludlow and taphofacies 2 for those levels that have been winnowed by gentle currents.

The frequency of stylolites and the overall complexity of the cycles developed makes determination of taphofacies for the overall sequence quite difficult. A more complete environmental interpretation will be possible when the present results are combined with Bivalvia palaeoecological data (Křiz, in press), the microfacies data and an overall study of the biosedimentology of the sections (Ferretti & Histon, in prep.).

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