Stop 1

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

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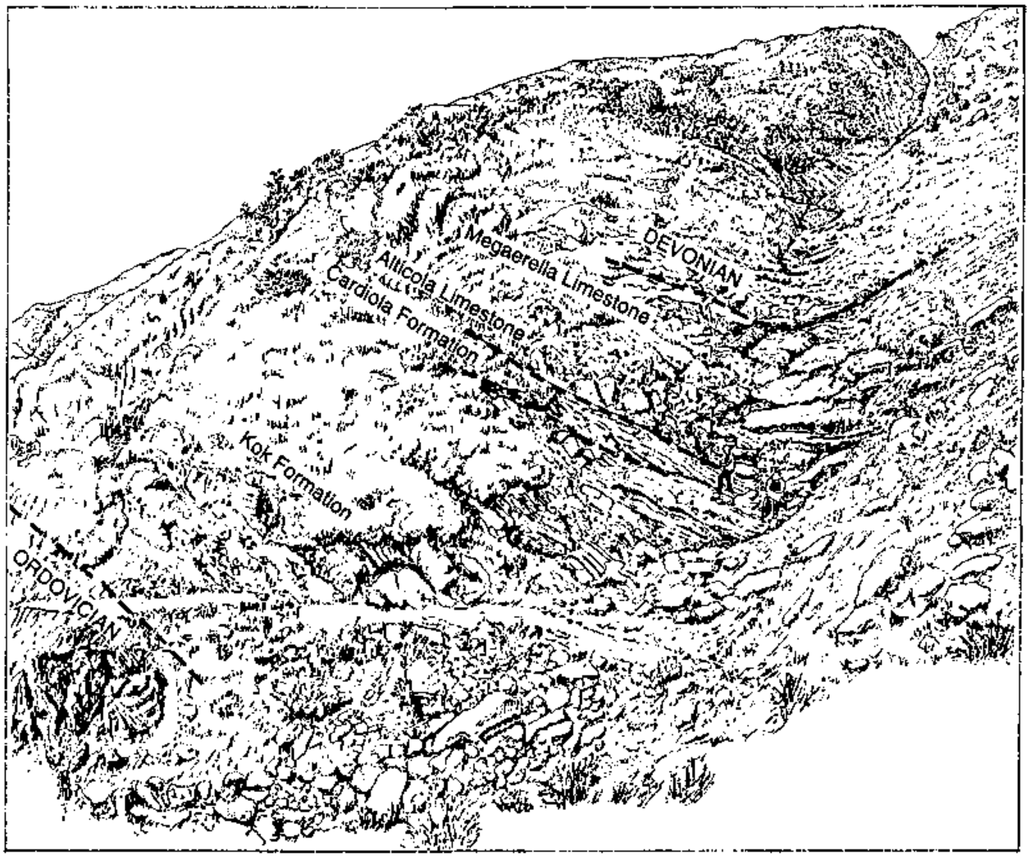

Fig. 2 - View of the Cellon section

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

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

Stratigraphy

The Cellon section represents the stratotype for the Silurian of the Eastern and Southern Alps. Nowhere else in the Alps has a comparably good section been found. It has been famous since 1894 when GEYER first described the rock sequence. In 1903 it was presented to the 9th IGC which was held in Vienna. According to GAERTNER (1931) who studied the fossils and rocks in great detail, the 60 m thick continuously exposed Upper Ordovician to Lower Devonian section could be subdivided into several formations. Since WALLISER's pioneering study on conodonts in 1964 it still serves as a standard for the worldwide applicable conodont zonation which, however, has been further detailed and partly revised in other areas during the last two decades. Although the conformable sequence, corresponding to the Plöcken facies (see SCHÖNLAUB & HISTON this volume for environmental setting), suggests continuity from the Ordovician to the Devonian, in recent years several small gaps in sedimentation have been recognized which reflect eustatic sea-level changes in an overall shallow-water environment. From top to base the following formations can be recognized (Fig. 3. and see PRIEWALDER, Fig. 1 this volume)):

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

According to SCHÖNLAUB (1985) the Ordovician/Silurian boundary is drawn between the Plöcken and the Kok Formations, i.e. between sample nos. 8 and 9. In the Plöcken Fm. index fossils of Hirnantian age clearly indicate a latest Ordovician age. These strata represent the culmination of the end-Ordovician regressive cycle known from many places in the world (SCHÖNLAUB 1988).

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

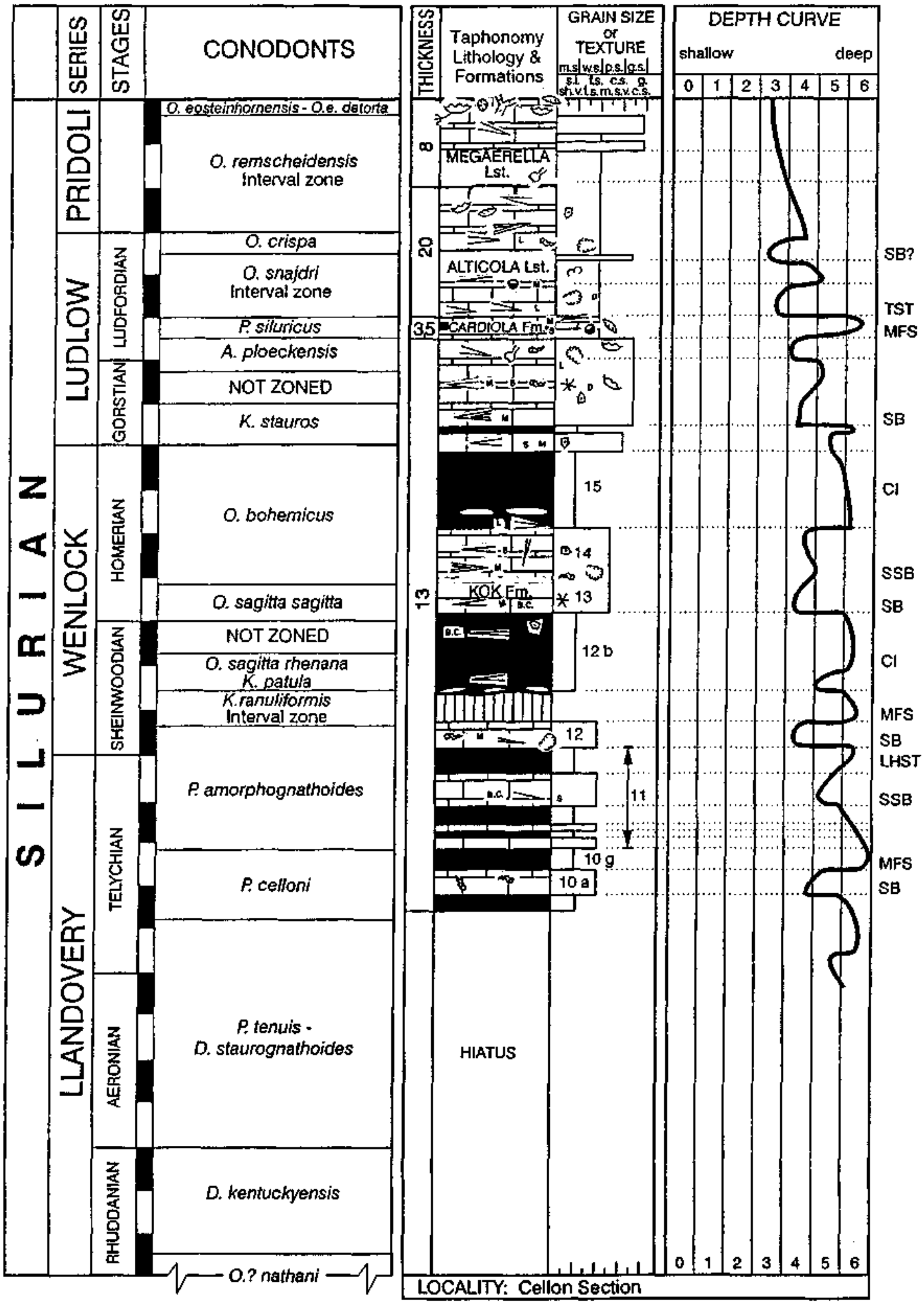

Fig. 3 - Conodont stratigraphy, lithology, grain size, significant taphonomic features and depth curve of the Silurian of the Cellon section (Modified from SCHÖNLAUB 1997)

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

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

By correlation with Bohemian sequences and the occurrence of index graptolites for the base of the Pridoli, the Ludlow/Pridoli boundary is drawn a few cm above sample no. 32 (SCHÖNLAUB in KRIZ et al. 1986). This horizon lies some 8 m above the base of the Alticola Lst.. The corresponding sediments of the Ludlow have thus a thickness of 16.45 m.

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

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

Lithology and Microbiofacies

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

Kok Formation (Beds 9 – 20):

Thin beds of ferruginous limestone, sometimes bioturbated, are intercalated at the base of the formation in dark shales locally rich in small brachiopods. At the top of bed 12, a thin and lenticular calcareous horizon (12b) in shales has provided an important cardiolid fauna (KRIZ, 1999). This is a cephalopod wackestone the matrix of which bears many ostracodes, echinoderms, rare small bivalves and gastropods. Many muellerisphaerida are present in darker bituminous micritic areas.
Starting from bed 13, the limestone becomes thicker and more massive. The reddish colour and the intensive bioturbation (Fig. 4) are the most typical features of the upper part of the Kok Formation up to level 17. This cephalopod wackestone is locally rich in brachiopods, echinoderm debris, trilobites, gastropods and ostracodes. Some organisms, mostly cephalopods, reveal peculiar iron-banded coatings (see Stop 2, Fig. 9). Dolomitization is frequent. Around level 15 B1 a singular grainstone of well sorted equidimensional bioclasts occurs which strongly resembles the coeval horizon of the Rauchofel Boden Section. Abundant small thin-shelled bivalves, preserving the two valves still connected, gastropods, trilobites and isolated echinoderm ossicles have iron-stained shells. Shell in shell structures are there common. Starting from around bed 18 the limestone becomes greyer. Pyrite aggregates in the matrix may be occasionally found.

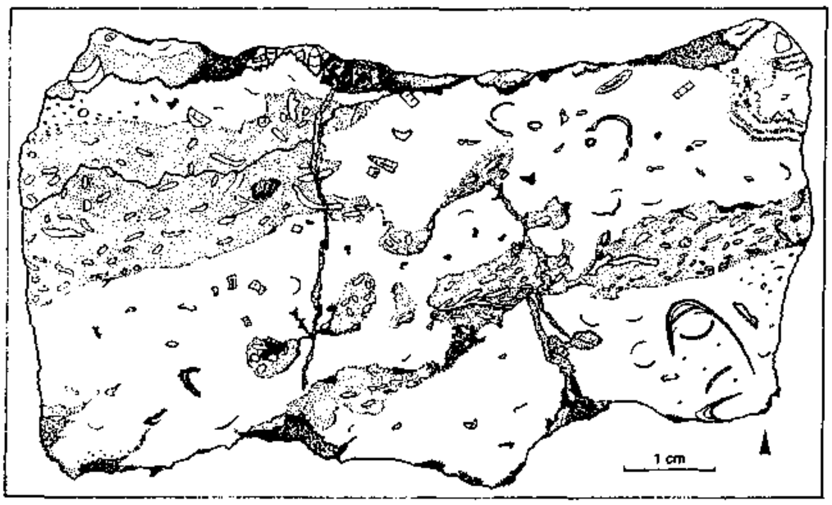

Fig. 4 - Intensive bioturbation in the Kok Formation (bed 16) redrawn from a thin section.

Cardiola Formation (Beds 21 – 24):

It is represented by a few centimeter thick bioclastic shelly layers (wackestone-packstone) with a sharp base interbedded with dark shales. At the base of the Cardiola Formation (level 21) bioclastic wackestones rich in cephalopods, trilobites, crinoids and ostracodes are intercalated in soft micritic sediments. Scouring traces at the top of the soft sediments, debris grainstone at the base of the overlying horizon with enrichment in iron and manganese oxides would exhibit, according to KREUTZER (1992b), the existence of a Fe-Mn hard-ground.

Millimetric pavements of small brachiopods are present in bed 22. When seen in thin-section, they reveal a cephalopod-ostracode bioclastic packstone with abundant brachiopods, but also associated with graptolites, thin-shelled bivalves and micritized grains. Shelter porosity, common orientation of geopetal structures and telescoping of cephalopods have been observed. Sorting is moderate. These shelly laminae decrease in thickness towards the top of the formation and alternate with thin dark bands rich in organic matter and muellerisphaerida, possible ostracodes and recrystallized cephalopods.

Alticola Limestone (Beds 25 – 39):

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

Megaerella Limestone (Beds 40-47 A):

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

Nautiloid Fauna

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

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

Apart from the species described by RISTEDT (1968), citations by GARTNER (1931) and a faunal list by BOGOLEPOVA (1998) a detailed systematic study of the nautiloid fauna has not yet been published for the Cellon section.

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

In 1943 HERITSCH proposed the following zonation:

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

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

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

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

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

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

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

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

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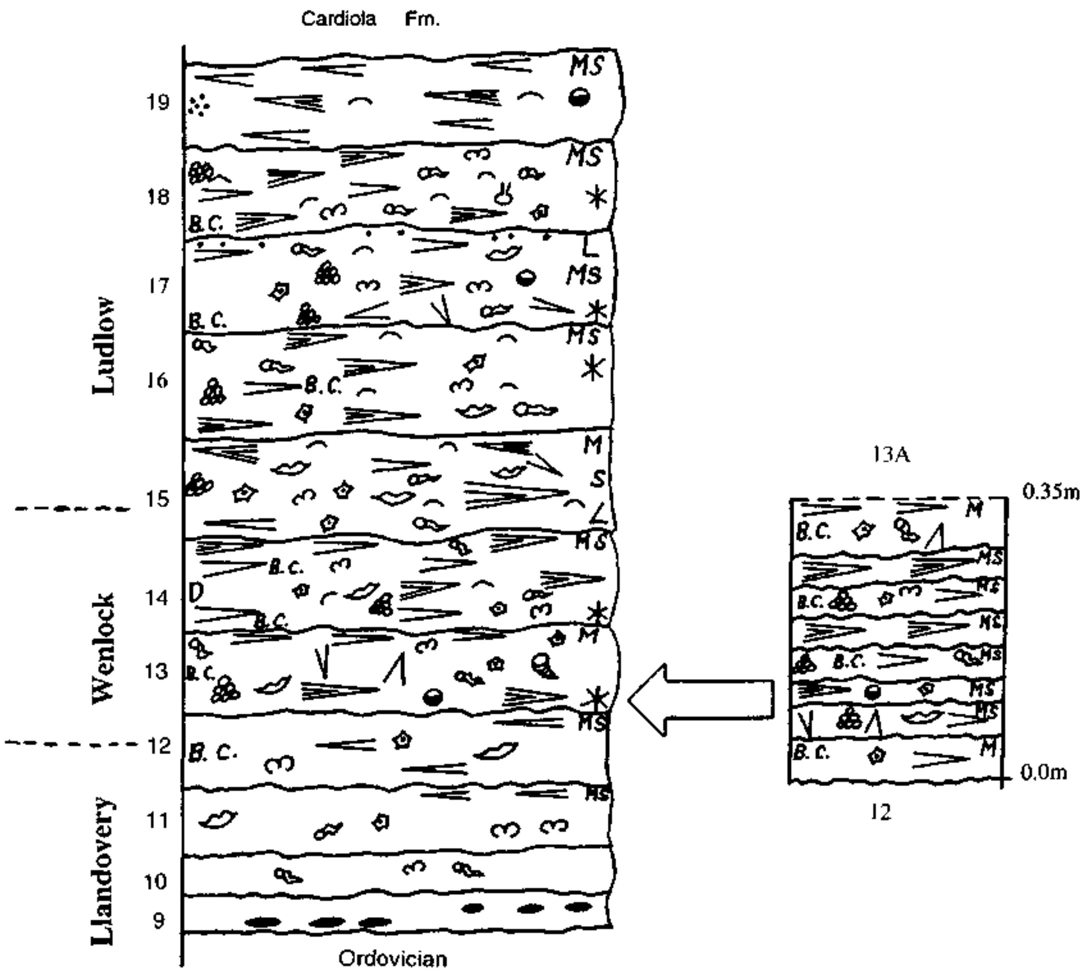

Fig. 5 - Taphonomy of the Kok Formation. Note detail of small scale cyclic repetition of beds indicating changes in the hydrodynamic regime.