

Conodont biostratigraphy of the Silurian-Devonian boundary stratotype at Klonk, Czechoslovakia

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with 2 Text-figures and 1 Table

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Two new late Pridoli conodont zones are defined, the *Ozarkodina steinhornensis eosteinhornensis* s. str. Zone and the *Ligonodina elegans detorta* Zone. The former correlates with part of the *Monograptus transgrediens* graptolite Interzone and the latter with a post *M. transgrediens* interregnum. Both conodont zones are identified in the condensed latest Silurian strata exposed at Klonk, the type locality for the base of the Devonian System. The known range of *Icriodus woschmidti* starts below or possibly just above the base of the *L. elegans detorta* Zone casting serious doubt on its value for identifying the base of the Devonian. The well-known conodont fauna from Unterrüden may be late Silurian in age.

Es werden zwei neue Conodonten-Zonen des späten Pridolium neu definiert: die Zone der *Ozarkodina steinhornensis eosteinhornensis* s. str. und die Zone der *Ligonodina elegans detorta*. Die erste Zone läßt sich mit Teilen der *Monograptus transgrediens*-Interzone parallelisieren, die letztere mit einem auf die *M. transgrediens*-Zone folgenden Interregnum. Beide Zonen können in der kondensierten spätestilurischen Schichtfolge von Klonk, der Typlokalität für die Basis des Devon-Systems, erkannt werden. Die bekannte Reichweite des *Icriodus woschmidti* beginnt unter oder möglicherweise gerade über der Basis der *L. elegans detorta*-Zone, was ernsthafte Zweifel an seinem Wert als Fossil, das die Basis des Devons markiert, wach werden läßt. Die bekannte Conodonten-Fauna von Unterrüden (Remscheider Sattel) könnte spätes Silur-Alter haben.

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Introduction

Klonk was approved as the official stratotype for the Silurian/Devonian boundary by the International Stratigraphic Commission during the 24th International Geological Congress in Montreal in 1972. Conodonts have been reported to be rather scarce there (MCLAREN 1972; CHLUPÁČ 1980), although BARNETT (1977:259) mentioned a large collection from the Devonian Bed 21, and no specimens have been illustrated or bed log published.

The rapid evolution of *Ligonodina elegans elegans* via *L. elegans detorta* to *L. elegans elegans* n. ssp. took place in the interval around the Silurian-Devonian boundary (JEPPSSON 1972, 1975, 1981, 1986), and so it seemed worth-while to look for *L. elegans* at Klonk. Thus, in 1980 I collected six samples from the then exposed beds (Bed 15, a lens 0.05–0.10 m above Bed 16, Bed 17, Bed 19, lower part of Bed 20 and upper part of Bed 20) together with three from Karlstejn and two from U topolů for comparison purposes. Unexpectedly the lens above Bed 16 produced a large conodont fauna. Since that fauna included *L. e. detorta*, it was of interest to study older beds too to see if the level of its appearance could be identified. Dr. Chlupáč (Ustřední ústav geologický, Praha) therefore arranged that 5 samples from Beds 10, 11, 12, 13 and 14 were collected and sent to me.

The stratigraphic results from all the conodont samples are given herein whereas the taxonomic results have been accepted for publication in next volume of *Geologica et Palaeontologica*.

Samples, methods and conodont faunas

The first six samples from Klonk and all those from other localities were dissolved using the 10% acetic acid method. The additional samples from Klonk were dissolved using the improved method of JEPPSSON, FREDHOLM & MATTIASSON (1985). The samples broke down slowly and left a lot of residue. Various methods were used on one or more of the residues to reduce them – ultrasonic, bromoform, Na-hypochlorite, magnetic separation, and petroleum-ether. Information regarding the screen used is given for each sample below.

All conodont elements recovered, both from Klonk and the other two Bohemian localities, are small, none as large as 1 mm. However, many of them are mature in all characters which reveal the ontogenetic age of an individual. They are, however, not dwarfs but pygmies. The preservation varies. In most samples most of the elements are badly fractured, and I have not considered it meaningful to try to count the number

of elements per species and sample. Due to the state of preservation, many elements do not permit a definitive identification. The most trustworthy identifications are based on the presence of several different kinds of elements of a species, or on those elements which are unique for a species, e. g., the pl and ke elements of *O. excavata* and the detortiform element of *L. elegans* which cannot easily be confused with any element of any other taxon known from this time interval. Therefore, I have in some cases noted the important elements identified. The distribution of conodont elements in the samples is given in Tab. 1, and in more detail below. The names of the Bohemian localities and the bed numbers follow CHLUPÁČ, JAEGER & ZIKMUNDOVA (1972).

Klonk, Bed 10: 1599.9 g, above 63 µm. Hundreds of elements and fragments. *O. steinhornensis* dominates; at least 10 sp elements belong to *O. s. eosteinhornensis* s. str. The remainder lack the ridge on the basal cavity lip, but otherwise they agree with that taxon. *O. excavata* (including 6 pl and ke elements), *Belodella mira* (over 50 elements), *B. sp. S*, *Pseudooneotodus beckmanni*.

Klonk, Bed 11: 1371.7 g, above 63 µm. Many hundreds of conodont elements. The *O. steinhornensis* group dominates strongly; about 14 of the sp elements can be assigned to *O. s. eosteinhornensis* s. str., a similar number to *O. remscheidensis*, and the remainder probably belong to either of

these two. *O. excavata* (sp, ne, hi, ke, pl, tr; about 13 ke and pl elements), *O. confluens* (one sp, one pl, possibly also oz and ne), *Ligonodina* sp. (1 hi), *Belodella mira* (about 190 elements), *B. sp. S* (13 elements), *Pseudooneotodus beckmanni* (2 elements), *Panderodus* (one element).

Klonk, Bed 12: 1374.5 g, above 63 µm. Over 1000 conodont elements and fragments. The *O. steinhornensis* group dominates strongly, with over 100 sp elements. About 50 of these are well enough preserved to be identified as *O. remscheidensis*; all of the remainder lack any character that would exclude them from that taxon. *O. excavata* (including 22 pl and ke elements), *Belodella mira*, *B. sp. S*, (about 60 elements of *Belodella*, *B. mira* dominates), *P. beckmanni* (5 elements).

Klonk, Bed 13: 1556.9 g, above 90 µm. Over 200 elements and fragments. Fauna as in Bed 12 but fewer specimens of all elements, one specimen of *Panderodus*.

Klonk, Bed 14: 1660.0 g, above 63 µm. Over 300 elements and fragments. *Belodella mira*, *B. sp. S* (over 150 specimens of *Belodella*, *B. mira* dominates), *O. steinhornensis* (about 20 sp elements), *O. excavata* (including about 15 pl and ke elements), *Panderodus unicostatus* (one denticulated element), a small element which may be an ne element of *L. elegans*.

Klonk, Bed 15: Sample Tj80-6LJ, 557.59 g, above 90 µm. A single unidentified fragment of a simple cone.

Klonk, Interbed 16/17: Sample Tj80-7LJ, from a lens 0.05–0.10 m above Bed 16, 510.8 g, above 90 µm. Over 200 elements

Tab. 1: Conodont distribution in the described Bohemian samples. For collection large enough for an evaluation of the relative frequencies, these have been ranked in three groups. Taxa that dominate the collection are marked with a large dot, an intermediate dot marks taxa that are so frequent that their presence in a new collection of similar size is expected, and a small dot marks taxa represented by only a single or a few specimens – thus, their absence in other samples does not prove any change in frequency. Question-marks indicate uncertainty in the lowest level of identification – thus, when a subspecies is indicated, then there is no question regarding the species level identification.

Localities and Beds		<i>O. s. eostein. s. str.</i>	<i>Ps. beckmanni</i>	<i>O. confluens</i>	<i>Belodella sp. S</i>	<i>B. mira</i>	<i>O. excavata</i>	<i>O. s. remscheidensis</i>	<i>Panderodus</i>	<i>Ligonodina sp.</i>	<i>L. elegans</i>	<i>L. e. detorta</i>	<i>B. anomalis</i>
Klonk	20u.					•	•?	•?					
	20l.					•?	•?						
	19				•	●		•			•		•
	17		•	•?		•		•					
	16/17			●	•		●?				●		
	15			●		●	●						
	14			●	●	●	●	•		•?			
	13		•	●	●	●	●	•					
	12		•	•		●	●	●					
	11	●	•	●	●	●	●	•	•				
10	●	•	●	●	●	●							
Karlstejn	41					•	•?			•			
	39/40						•?		•				
	38			•	•		•?	•					
U topolů	10			•?		●	•?						
	3			●	●	●	•?				•		

and fragments. *Belodella* sp.S is most abundant (over 60 elements), *B. mira* (one specimen), *O. steinhornensis* (at least 10 sp elements, too juvenile or too poorly preserved for subspecific identification; nothing excludes them from *O. remscheidensis*), *L. e. detorta* (over 20 elements).

Klonk, Bed 17: Sample Tj80-8LJ, 504 g, above 90 µm. 14 elements and fragments, one element probably belongs to *O. excavata*, one fragment of *O. confluens*, *Belodella* sp.S?, *Panderodus*.

Klonk, Bed 19: Sample Tj80-9LJ, 504 g, above 90 µm. Over 60 elements and fragments, so dirty that they are very difficult to identify. *O. excavata*, *Belodella* sp. indet., *Panderodus* (1 element).

698 g, above 90 µm, 36 elements and fragments. *O. excavata* dominates, *L. e. detorta* (1 element), *Belodella anomalis* (2 or 3 specimens), *B. mira* (one doc element, larger than any one from Bed 11), *Panderodus* (1 element).

Klonk, Bed 20, lower part: Sample Tj80-11LJ, 865.5 g, above 90 µm. About 20 dirty elements and fragments. *O. excavata* and *O. steinhornensis* can be identified with some certainty.

Klonk, Bed 20, upper part: Sample Tj80-12LJ, 500 g, above 90 µm. About 75 dirty elements and fragments. *O. excavata*, *L. elegans*? (one fragmentary hi element, with one small denticle between the innermost two – the only ones preserved – normal sized; two other elements may also belong here), *Panderodus*? (1 element).

Karlstejn, Bed 38, upper part: Sample Tj80-4LJ, 724 g, above 90 µm. About 40 elements and fragments. *O. steinhornensis*, *Belodella mira*, *B. sp.S*, *Panderodus*.

Karlstejn, the middle limestone bed of the three limestone beds in Interbed 39/40: Sample Tj80-3LJ, 731.5 g, above 90 µm. 8 elements and fragments. *O. steinhornensis*, *Ligonodina* sp., one unidentified coniform element.

Karlstejn, upper part of Bed 41: Sample Tj80-5LJ, 505.5 g, above 90 µm. About 50 elements and fragments. *O. excavata*, *O. steinhornensis*, *L. elegans* (3 elements).

U topolů, Bed 3: Sample Tj80-1LJ, 730.5 g, above 90 µm. A few hundred elements. *Belodella mira* dominates, *B. sp.S* (a few specimens only), *O. excavata*, *O. steinhornensis*, *L. e. detorta* (one well preserved detortiform element; plus one hi element and one ne element neither of which could be identified at the subspecies level if alone).

U tupolů, Bed 10: Sample Tj80-2LJ, 548 g, above 90 µm. 11 elements and fragments. *O. steinhornensis*, *Belodella* sp.S? (1 specimen), four coniform elements resembling those of *Decoriconus*.

In addition, one sample from the Rheinische Schiefergebirge will be discussed below.

Untenruden. A sample from the level of sample e of ZIEGLER 1960, 1962. *O. s. remscheidensis* (dominates strongly), *L. excavata*, *I. woschmidti* (about 10 elements, including some ramiform elements, of the kind described by SERPAGLI 1983).

The significance of the conodont faunal changes at Klonk

During the selection of a Silurian-Devonian boundary section, no continuous sedimentary record with zonal graptolites throughout was found anywhere. Thus, at Klonk there is an 1.60–1.70 m thick interregnum (including Bed 14 – main part of Bed 20; see Text-Fig.2) lacking diagnostic graptolites (CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972). Other graptolites do occur in this interval – CHLUPÁČ & KUKAL (1977) reported *Linograptus p. posthumus* and »*Monograptus nanus*«. In the most recent description of the Pridolian graptolite sequence (JAEGER in KRÍZ et al. 1986) the youngest unit is the *M. transgrediens* Interzone. Here I will restrict that subdivision to the interval below the extinction of *M. transgrediens* and refer to

the rest of the Silurian as the post-*M. transgrediens* Interregnum, in order to be able to discuss the finest details in the stratigraphy. PARIS, LAUFELD & CHLUPÁČ (1981) found profound changes in the chitinozoan faunas from Klonk both where *M. transgrediens* ends and at the base of the Devonian where *M. uniformis* appears. Similarly the changes in the conodont faunas (described below and Tab.1) are amazing. None of these faunal changes can be ascribed to an obvious lithological change. Instead the lithological uniformity of the succession has been noted repeatedly (e.g. HORNÝ 1955; CHLUPÁČ 1953, 1957; CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972; CHLUPÁČ, HLADIL & LUKES 1986; PARIS, LAUFELD & CHLUPÁČ 1981). The largest lithological differences are those between the limestone and the interbedded shales. However, PARIS, LAUFELD & CHLUPÁČ (1981) who could study both lithologies hardly found any significant faunal differences in chitinozoan assemblages between any limestone bed and the succeeding shale; that is a further evidence that the faunal changes found were not an effect of the known lithologic differences.

The conodont faunal changes can be correlated with similar changes elsewhere (see below). With respect to older Silurian conodonts I have identified world-wide faunal changes and concluded that they reflect changes in the composition of the sea water (JEPSSON 1984, 1985, 1987). Contrary to earlier opinions the composition of the sea water has not been stable or only slowly evolving with time; instead, many rapid changes have been identified (e.g. HOLSER 1984; WRIGHT, MILLER & HOLSER 1987). Conodonts were very sensitive to such changes (JEPSSON 1985, 1987) and can be used to monitor them. Planktic graptolites are unlikely to have been less sensitive and the gap in the graptolite zonation may not reflect varying local preservational conditions, but widespread, inhospitable environments for these graptolites. Thus the post *M. transgrediens* Interregnum in the latest Silurian may be stratigraphically important, although often difficult to delimit exactly. It did not reflect simply an excursion in the sea water composition in the sense that it afterwards returned to its immediately preceding state. Instead, there is good faunal evidence that the earliest Devonian was subject to a very different regime. Regarding graptolites, JAEGER (1978) noted that the majority of the *Monograptus* species that are found at the base of the Lochkov appear »out of the blue«.

A large number of the taxa studied by CHLUPÁČ, JAEGER & ZIKMUNDOVÁ (1972) – chiefly macrofossils – show similar changes. Sometimes the faunas can be compared bed by bed at different localities. Thus, the post *M. transgrediens* Interregnum (= *L. e. detorta* Zone) is characterized by a distinct faunal assemblage in Bohemia.

Late Silurian conodont zones

The youngest Silurian conodont zone introduced by WALLISER (1964) was the *eosteinhornensis* Zone. The zone includes not only the whole of the Pridoli, but it also ranges back into the latest Ludlow (WALLISER 1966, SCHÖNLAUB in KRÍZ et al. 1986). Thus, it is of little use in detailed stratigraphy. However, conodonts permit a much more refined stratigraphy. WALLISER noted and illustrated the large variation in *O. s. eosteinhornensis* (WALLISER 1964: 86, Pls. 20, 26 etc), and JEPSSON (1975:38) restricted the circumscription of the subspecies to those populations which are closely similar to that from which the holotype was selected. At Cellon, these are only found in a short interval (see below).

I have previously noted that the Pridolian Beyrichienkalk of the Baltic area includes four distinct conodont faunas (JEPSSON 1981). The youngest of these was characterized by *Ligonodina elegans detorta*, a direct descendent of *L. e. ele-*

gans which occurred in the three older faunas. More details about the evolution of that lineage can be found in the Cellon section, where *L. e. elegans* occurs in WALLISER's Beds 42A-44A, *L. e. detorta* in Beds 45-46A and a third subspecies in Bed 48, about 1.5 m above Bed 44A. The Silurian-Devonian boundary has been drawn between Beds 47A and 47B (WALLISER 1964). *L. e. detorta* is now known to be widespread in strata of this age (see below). This wide distribution and its easy identification makes it very useful in stratigraphy, and I use it herein to form the basis of a new latest Silurian conodont biozone. *O. s. eosteinhornensis* s. str. is presently not identified from such a wide area, but it is widespread enough to justify using it in the establishment of another zone.

Where *O. s. eosteinhornensis* sensu lato is still found to be useful in stratigraphy it may be more appropriate to call the stratigraphic unit in question a superzone since its duration is several times longer than that of a typical zone.

In his list of the Cellon conodonts WALLISER (1964, Tab. 2) recorded the presence of each element separately. Thus it is possible to judge the relative frequency of each species. In 1972 Dr. Walliser kindly showed me all his collections, and I have used my notes to confirm and supplement such conclusions.

The *Ozarkodina steinhornensis eosteinhornensis* s. str. Zone

The lower boundary is defined by the appearance of the *O. s. eosteinhornensis* s. str. (as restricted in JEPPSSON 1975). At present there is an interval between the last specimens of *O. s. eosteinhornensis* s. str. and succeeding *L. e. detorta* Zone

which cannot be included in either of the two zones (for details, see below; see also Text-Fig. 1). The *O. s. eosteinhornensis* s. str. Zone is best known from the Cellon section in Austria (WALLISER 1964). Here it starts in Bed 39A and ranges about 2.5 m up into Bed 41 (Text-Fig. 2). It is also known from Beds 10 and 11 at Klonek (herein; see Text-Fig. 2) and Hvizdalka (WALLISER 1964, sample 7, Pl. 20, Fig. 9-11) in Bohemia, the »Orthocerenkalk« at Schübelberg in Germany (WALLISER 1957, samples W61) and from Santa Creu in Spain (WALLISER 1964, samples 26, 27). Further, DRYGANT (1986: Pl. 13, Fig. 9) illustrated an sp element from the Dzwiniogorod Beds in Podolia, about 3.5 m below a level with *M. uniformis angustidens* (DRYGANT 1986: Fig. 30). *I. woschmidti* starts about 1.5 m above *M. u. angustidens* (DRYGANT 1986: Tab. 13). However, NIKIFOROVA & PREDTECHENSKIJ (1968: Fig. 23) reported a few specimens from strata well below the *M. u. angustidens* of their outcrop 64, which is close to (or the same as) DRYGANT's locality. NIKIFOROVA (1977) reported that the range of *I. woschmidti* starts 2 m below that of *M. uniformis*. The Dzwiniogorod Beds contain *Scyphocrinites* (NIKIFOROVA & PREDTECHENSKIJ 1968:23).

Graptolites are rare at Cellon, and none is known from the *D. megaerella* Beds. Thus the Cellon distribution only permits a conclusion that the Zone is within or above the *M. transgrediens* Interzone (graptolite data from JAEGER 1975; see Text-Fig. 2 herein). Both at Hvizdalka (WALLISER 1964) and at Klonek the *O. s. eosteinhornensis* s. str. Zone is found in the *M. transgrediens* Interzone. Since the *M. transgrediens* Interzone ranges up into Interbed 13/14 at Klonek, whereas Bed 11 is the youngest referable to the *O. s. eosteinhornensis* s. str.

	Graptolite Zones etc	Conodont Zones etc	Selected conodont ranges				Selected localities		
			Klonek	Cellon	Other localities				
DEVONIAN	(lower) <i>M. uniformis</i> Zone	<i>L. e. n. ssp.</i>	<i>L. e. n. ssp.</i>	<i>L. e. n. ssp.</i>	?				
	post <i>M. transgrediens</i> Interregnum	<i>L. e. detorta</i> Zone	<i>L. e. detorta</i>	<i>I. woschmidti</i>	<i>O. s. remscheidensis</i>	K. 20 K. 19	C 48 C 46A		
SILURIAN	<i>M. transgrediens</i>	" <i>O. confluens</i> ssp."	<i>L. e. elegans</i>	<i>O. confluens</i> ssp.	<i>O. confluens</i>	K. 16/17 lens K. 14	C 45 C 44A	U topolu 3	
		<i>L. e. elegans</i>				K. 13		Untenruden	
	Interzone	<i>O. s. eosteinhornensis</i> s. str. Zone	<i>O. s. eostein. s. str.</i>			K. 11 K. 10	C 41 C 40		
							C 39A		

Fig. 1: Correlation between graptolite- and conodont-based stratigraphies, selected conodont ranges and correlations between important samples (Cellon data from WALLISER 1964).

Zone it can be concluded that the latter corresponds to the upper but not the uppermost part of the *M. transgrediens* Interzone (see Text-Fig. 1).

The pre-*Ligonodina elegans detorta* Interregnum

Professor Walliser showed me a collection from Bed 43B in Cellon, containing a fragment which probably belongs to *O. s. eosteinhornensis* s. str. If the presence of *O. s. eosteinhornensis* s. str. at that level can be established, then it would mean that the taxon ranges higher than now recognized. The frequency of the taxon in the interval currently included in the zone is high, whereas any occurrence in younger strata would have to be in lower frequency. Even if *O. s. eosteinhornensis* s. str. turns out to range into Bed 43B, there would still remain an unzoned interval below the *L. e. detorta* Zone. Conventionally that would be included in the *O. s. eosteinhornensis* s. str. Zone. However, the general conodont faunal aspects of the interval above Bed 41 in Cellon differ strongly from that of the *O. s. eosteinhornensis* s. str. Zone.

In Beds 39A–41 (= the *O. s. eosteinhornensis* s. str. Zone), the *O. steinhornensis* group is important and sometimes even dominates whereas that group is rare or unknown from most of Beds 41A–44B, in which *O. excavata* dominates. A strange form (WALLISER 1964: 80, Text-Fig. 8 m, n, Pl. 22, Figs. 20–25), referred by WALLISER to *O. confluens* occurs in most samples from these beds. Typical *O. confluens* occurs in low frequency in older strata and reappears in the *L. e. detorta* Zone and is abundant in several samples (WALLISER 1964). In Wenlock and Ludlow strata *O. confluens* is nearly ubiquitous, and most faunas are strongly dominated by *O. confluens* and *O. excavata*, but in the Pridoli *O. confluens* has a much more limited presence.

Because of these differences the interval under discussion is not included in the *O. s. eosteinhornensis* s. str. Zone but referred to a pre-*L. e. detorta* Interregnum. The strange form of *O. confluens* illustrated by WALLISER (1964) has also been found in Nevada, in the same stratigraphic position (KLAPPER & MURPHY 1975:32, MURPHY 1977). Both in Cellon (WALLISER 1964: Pl. 22) and in Nevada (MURPHY 1977: Text-Fig. 2) the form evolves rapidly. Thus, it may perhaps be appropriate to use it for zonation of the interval.

The *Ligonodina elegans detorta* Zone

The lower boundary is defined by the evolution of *L. e. detorta* from *L. e. elegans*. The upper boundary may coincide with the base of the *I. woschmidti* Zone as presently identified in Cellon. As is discussed below, that zone is rather vague. Thus, the upper boundary probably should be drawn at the evolution of the next *L. elegans* ssp.

The *L. e. detorta* Zone is at present best known from the Cellon section (WALLISER 1964; see also Text-Fig. 2 herein). Here it starts in Bed 45, whereas the predecessor of *L. e. detorta* is found in Bed 44A; thus the thin Bed 44B might also belong to this zone. The last *L. e. detorta* is at present identified from Bed 46A, and the succeeding subspecies occurs in Bed 48, whereas *I. woschmidti* appears in Bed 47B. Thus there is a small interval which now cannot be referred to any unit.

The *L. e. detorta* Zone is now known from the Beyrichienkalk erratics, the Chełm core from eastern Poland, Klonek and three other Bohemia localities (see below), the Cellon section in Austria, and the former »Spanish Sahara« (for details see JEPSSON 1975, 1981).

The relationship to the graptolite zonation is known from most of these places (see Text-Fig. 2). Thus, at Chełm, Klonek and Cellon the *L. e. detorta* Zone is only identified between the *M. transgrediens* and *M. uniformis* ranges. At the former two localities the graptolite ranges are well known; thus this zone can be correlated with the post *M. transgrediens* Interregnum. At Klonek I have not studied the conodont faunas of Bed 16; only a single specimen was found in the sample from Bed 15; and Bed 14 probably contains *L. elegans*, but a larger collection is needed to identify the subspecies. Similarly the faunas from Beds 12 and 13 are too small to even indicate if *L. elegans* was present or not. Thus, it cannot be excluded that the lower boundary here coincides with or is found slightly below the beginning of the post *M. transgrediens* Interregnum.

However, at U topolu *L. e. detorta* has been found in Bed 3. This is below the highest find of *M. transgrediens* – in the thin limestone bed between Beds 4 and 5 (CHLUPÁČ, JAEGER & ZIKMUNDOVA 1972:126). My specimen of *L. e. detorta* is a very well preserved detortiform element. Such elements are very fragile, and it is highly unlikely that it is a laboratory contaminant. *M. transgrediens* was found in the following beds and interbeds: 2, 2/3, 3 and 4/5 (Dr. Člupáč in letter 1986.04.22), thus this find shows that the base of the *L. e. detorta* Zone is slightly below the top of the *M. transgrediens* Interzone (0.5 m at this locality, see CHLUPÁČ, JAEGER & ZIKMUNDOVA 1972).

The *L. e. detorta* Zone correlates with MARTINSSON's (1965) *Nodibeyrichia gedanensis* and *Kloedenia wilkensisiana* ostracode fauna in the Beyrichienkalk (JEPSSON 1981) and the *N. gedanensis* Zone in the Stobno 2 core from northern Poland as described by ŽBIKOWSKA (1974).

The latest Pridolian conodont faunal sequence in Bohemia

The samples from Beds 10 and 11 at Klonek contain the zone fossil of the *O. s. eosteinhornensis* s. str. Zone (Tab. 1). The faunas from Beds 12 and 13 are large enough to indicate that that zone does not range higher here. No samples from Beds 1–9 have been available, but since the strata at Klonek generally seem to be thinner than those from Cellon, it may be guessed that the *O. s. eosteinhornensis* s. str. Zone is not much thicker than 1 m at Klonek. The co-occurrence of *O. s. eosteinhornensis* and *O. s. remscheidensis* in the collection from Bed 11 may either indicate that these two taxa co-existed towards the end of the *O. s. eosteinhornensis* s. str. Zone or, considering the condensed sequence, it is possible that the boundary is found within Bed 11 or that the mixing is post-mortem. The rich faunas of Beds 10 and 11 are dominated by the *O. s. eosteinhornensis* group. *Belodella mira* dominates among species with coniform elements. *B. sp. S*, *O. excavata* and *Pseudooneotodus beckmanni* are present in low frequency in Bed 10. In Bed 11 *O. confluens*, *Ligonodina* sp. and *Panderodus* are also found, but in such a low frequency that it cannot be excluded that the absence of them from the collection from Bed 10 is a matter of chance.

The faunas from Beds 12 and 13 at Klonek are similar to those from Beds 10 and 11 except that *O. s. eosteinhornensis* s. str. has not been identified (Tab. 1). However, in Bed 14, the basal bed of the post *M. transgrediens* Interregnum, *O. excavata* is of about equal importance to the *O. steinhornensis* group.

The conodont collection from U topolu Bed 3 is closely similar to that from Bed 14 at Klonek in that the *O. steinhornensis* group has decreased in frequency to become slightly less frequent than *O. excavata*. As a consequence, the taxon that earlier was number two – *Belodella* – dominates in the fauna. In addition, Bed 3 contains *L. e. detorta*. Bed 14 is just above the *M. transgrediens* range whereas Bed 3 is about 0.5 m below it

– it ends in an un-numbered limestone bed in Interbed 4/5. Graptolites are unknown from many of the beds, even within the range of *M. transgrediens*, but in spite of that a correlation of the recorded extinction of that taxon would be in very good agreement with conodont evidence. That is, Bed 3 to the un-numbered limestone in Interbed 4/5 at U topolů would be correlated with only Interbed 13/14 and possibly Bed 14 at Klonek. That would agree well with ostracode-based correlations of the un-numbered limestone bed at U topolů with Beds 13 and 14 at Klonek (CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972:126). There is a change in the chitinozoan fauna too between Interbed 12/13 and Bed 14 (Bed 13 and Interbed 13/14 were not studied) (PARIS, LAUFELD & CHLUPÁČ 1981: Fig. 4). Thus chitinozoan, conodont, graptolite and ostracode faunas all change in the interval represented by Interbed 13/14. Since the thickness of the involved strata is lower than the likely smearing of ranges through bioturbation etc. (see e.g. SIGNOR & LIPPS 1982) the relative order – or contemporaneity – of faunal changes cannot be resolved at Klonek. Most of these changes are appearance or disappearance/extinction events, but that of *L. e. detorta* is an evolutionary event. Thus the overlap of at least 0.5 m at U topolů between *L. e. detorta* and *M. transgrediens* should not be used in conclusions regarding the temporal relationships of the other events, but it may be used to conclude that the base of the *L. e. detorta* Zone is within Interbed 13/14 and that the pre-*L. e. detorta* Interregnum includes Beds 12 to 13.

The low conodont frequency in most of the succeeding samples may be real or a result of the treatment of these samples. Two good collections did come out using the unbuffered acetic acid method, from U topolů Bed 3 and from a lens from Interbed 16/17 at Klonek. However, the former collection derived from the only sample older than this interval. Similarly, the second collection derived from one of the interbeds. Thus, it may not represent the same environment as the numbered beds. Thus, the fact that Bed 15 at Klonek has produced but a single conodont element may or may not be significant. Bed 21 produces large collections (BARNETT 1977:259); thus, if the low frequency is real, then the harsh conditions ended about the same time as zonal graptolites returned.

The samples from Interbed 16/17 and Bed 19 at Klonek can be referred to the *L. e. detorta* Zone. In addition to the U topolů record noted above, R. J. Aldridge has informed me that the *L. elegans* reported from samples BW 1A and 3A of WALMSLEY, ALDRIDGE & AUSTIN (1974) is the subspecies *L. e. detorta*. Both samples represent the pure limestone facies, whereas Klonek and U topolů represent the facies with shale rich platy limestone (CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972).

The condensed sequence at Klonek thus serves well as a standard for latest Silurian correlation at the present level of resolution. However, considering the fact that together the three zonal intervals here discussed only are represented by 11 beds and 10 interbeds, it is evident that correlations of a resolution beyond that provided at the zonal level, will require a standard that permits higher precision. Such studies have already begun in the late Cambrian and the Ordovician (SHAW 1964, SWEET 1984). Below, I discuss the length of these three zonal intervals and conclude that they are of a similar length as other good zones. Thus it may be calculated that the rate of sedimentation (compacted sediments) was in the order of a few to some m/Ma (mm/1000 years, = 10^{-6} m/a). Calculations of the kind done by SADLER (1981), SCHINDEL (1982), DINGUS (1984), and PLOTNICK (1986) may seem somewhat pessimistic for the kind of carefully selected section that Klonek represents, but they are a reminder that the section may be incomplete even at or slightly below the zonal level. The probable lack of strata from the *M. transgrediens* – *L. e. detorta* overlap may be an example of this.

Ecology

In one of the first discussions on conodont ecology, WALLISER (1964:26) noted that non-coniform taxa are rare in dolomite samples whereas coniform taxa are rare in dolomite free limestones. A marked difference in the relative frequency of these two groups is also evident in the collections discussed here. Thus, no true coniform taxa were described by ZIEGLER (1960) from Untenruden – the few cones found derive from *Icriodus* – and none are found in my topotype sample. In the Beyrichienkalk samples coniform taxa constitute less than 1%, probably only about 0.1%. The Klonek faunas are rather balanced, both coniform and non-coniform taxa are abundant. The dolomite content of these beds is about 5% (CHLUPÁČ & KUKAL 1977). In pre-Pridoli Silurian strata from Gotland there is also a range in the proportions of coniform and non-coniform taxa, from faunas in which coniform elements constitute less than 1% to those in which they form the bulk of the preserved elements. However, no correlation with the dolomite content has been noted.

Dolomite may be primary or secondary, but that is not important, since the fact that only some of the beds discussed by WALLISER (1964) are dolomitic indicates a primary difference in the sediment. This primary difference reflects the environmental fluctuations that caused the faunal difference. Dolomite production requires the right combination of several variables, whereas the faunal changes may have been caused by the variation in a single one of these. Thus, a possible explanation is as follows. The other variables remained more or less favorable in the areas studied by WALLISER, whereas one or more of them were unfavorable on Gotland. Local variations in that one, which was crucial for these faunal changes, were thus recorded both in fauna and in lithology in WALLISER's study but only in the faunal changes in the sequence of Gotland. The rather low dolomite content and the balanced faunas in the strata at Klonek exclude that this factor reached the more extreme values there, although the change between Beds 13 and 14 might have caused by a change in this factor.

Both Cellon (MÜLLER 1960, and topotype collections) and Klonek represent the biofacies where *Belodella* is important, whereas that genus is absent from both the Beyrichienkalk and the Ockerkalk at Untenruden. The biofacies with *Belodella* was the most offshore one identified by ALDRIDGE & JEPSSON (1984).

The *Icriodus woschmidti* range

The presence of *Icriodus woschmidti* has often been taken as proof of Devonian age (e.g. ZIEGLER 1960, 1962, 1971, 1979, WALLISER 1962, 1964, 1971) but more detailed studies have led to the conclusion that the range of *I. woschmidti* starts slightly before the range of *M. uniformis* (CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972, MURPHY 1977, MURPHY & EDWARDS 1977, CHLUPÁČ et al. 1985). In spite of this, the widely identified *I. woschmidti* Zone has usually been taken as the basal Devonian conodont zone (ZIEGLER 1971, 1979, KLAPPER & ZIEGLER 1979).

In Cellon, *I. woschmidti* appears 2.2 m below the level of *M. uniformis* but graptolite finds are scattered in that section, and no conclusion can be drawn. However, the appearance is near the top of the *L. e. detorta* Zone; thus it is close to the base of the Devonian.

CHLUPÁČ, JAEGER & ZIKMUNDOVÁ (1972) reported *I. woschmidti* from Bed 8 at Čertovy schody well below the last *M. transgrediens*, which was found in Interbed 10/11. *M. transgrediens* has also been found in Interbeds 1/2, 2/3, 6/7, 8/9 and in Bed 10 (Dr. Člupáč in letter 1986.04.22). Thus

it is evident that Bed 8 belongs in the *M. transgrediens* Interzone, and tectonic repetition of the strata can be excluded as an explanation. Thus, this find of *I. woschmidti* is at least one full zone (the *L. e. detorta* Zone) below the base of the *M. uniformis* Zone. However, these specimens have not been illustrated and it has not been possible to compare them with the oldest *I. woschmidti* populations found elsewhere. If the record is substantiated, then it would indicate that the first *I. woschmidti* occurs not only slightly below the base of the Devonian but below the base of the *L. e. detorta* Zone, or possibly just above its lower boundary.

At Srbsko *I. woschmidti* occurs in the upper range of *Warburgella minuta* (ZIKMUNDOVÁ in CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972, as *Prantlia minuta*). Since the range of *W. minuta* approximately corresponds to the *L. e. detorta* Zone, this find is also below the base of the Devonian.

I. woschmidti is reported from several other localities in the Barrandium too, but in most cases only in one bed from each section (WALLISER 1964; KLAPPER 1969; CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972; WALMSLEY, ALDRIDGE & AUSTIN 1974; MEHRTENS & BARNETT 1976; CHLUPÁČ, KRÍŽ & SCHÖNLAUB 1980). Thus it was only briefly present at each place (compare WALLISER 1962). Present correlations place two of these finds in the Silurian and the rest in the Devonian. If the taxon had such a long range, then it is reasonable to expect that it should have been found at more localities and in more samples, unless local conditions had a decisive influence on its presence. Alternatively the distribution of the taxon is intermittent in time; if so, it may have been present in the Barrandian during very brief episodes, each so short that it is a matter of chance if specimens have been found. The distribution of *I. woschmidti* in the Appalachians is similarly irregular and has been interpreted to be facies-controlled (BARNETT 1971, 1977).

Icriodus woschmidti was described by ZIEGLER (1960, 1962) from strata referred to as the »Horizont der Ockrigen Kalke« at the base of the Hüinghäuser Schichten from Untenruden in the Rheinische Schiefergebirge. The middle part of the studied sequence was described as rich in crinoids. The Hüinghäuser Schichten had been dated with trilobites as early Gedinnian in age, except that no diagnostic fossils were found in the »Ockrige Kalk« (E. & R. RICHTER 1954:43, see ZIEGLER 1960:171, 173). Since then, trilobites have been found (ALBERTI 1962) including *Warburgella rugulosa rhenana*. ALBERTI (1975) noted the possibility that this subspecies may be an ancestor to *W. r. rugosa*. In Bohemia the latter subspecies appears one or two beds above the first *M. uniformis* (see CHLUPÁČ, JAEGER & ZIKMUNDOVÁ 1972). Subspecies of *W. rugulosa* have been widely used as one of the most important indicators of the basal Devonian. *W. r. rhenana* has been reported as preceding *W. r. rugulosa* in Poland (PAJCHLOWA, TOMCZYKOWA & TOMCZYK 1970; TOMCZYK, PAJCHLOWA & TOMCZYKOWA 1977), although the report of *M. angustidens* deeper down the core is confusing. *W. r. rugulosa* co-occurs with *W. r. rugosa* in Bohemia (SNAJDR 1980). TIMM (1981a) added other trilobite evidence and concluded that it suggests a Silurian age for the Hüinghäuser Ockrige Kalke.

To my knowledge, the lithological sequence at Untenruden has not been used for correlation (see DEGENS, TIMM & WONG 1981). JAEGER (1962), describing Silurian-Devonian successions in Barrandium, Thüringen, and the Rheinische Schiefergebirge recorded an »Ockerkalk Gruppe« between »Unteren« and »Oberen Graptolithenschiefer«. The »Scyphocrinites-Horizonte« comprises the upper metre (up to 5 m) of the Ockerkalk and the basal metre (to 3 m) of the Oberen Graptolithenschiefer. The Ockerkalk Gruppe has turned out to be a stratigraphically very useful unit, found as far away as SW Sardinia and Thüringen in exactly the same stratigraphic position (JAEGER 1976, 1977). The succeeding graptolite shale

contains *M. transgrediens* in the basal beds and/or *M. uniformis* slightly higher up (JAEGER 1962:110, 1976). The sequence in the northern Rheinische Schiefergebirge differs from those described by JAEGER (e.g. 1962) in many aspects, e.g. graptolites have not been found, parts of it contain a varied shelly fauna, and the shales interbedded in the Ockerkalk dominate over the carbonate beds (comp. TIMM 1981 b). It agrees in that the Hüinghäuser Ockrige Kalke is the principal carbonate unit in the Silurian and earliest Devonian sequence of dark shales (e.g. WONG & DEGENS 1981; TIMM 1981 b) and in that the shales were deposited in an partly anoxic environment.

Now when a type locality for the base of the Devonian exists, ZIEGLER's (1960, 1962) suggestion that the incoming of *Icriodus* should be defined as the base of Devonian is no longer tenable. Further *I. woschmidti* does span the boundary elsewhere (see above). Therefore, the correlation has to be based on the trilobites and the lithological sequence.

Thus trilobite evidence places the type level of *I. woschmidti* and *O. s. remscheidensis* in the Silurian, and the lithological evidence places it somewhere below the top of the *M. transgrediens* Zone. The lack of *O. s. eosteinhornensis* s. str. indicates that the most likely correlation of the level is just above that zone (see Text-Fig. 1).

ZIEGLER (1960) reported 31 conodont taxa, but after revisions, only the following three or four taxa remain: *I. woschmidti*, *O. s. remscheidensis*, *Ligonodina excavata* and possibly *O. confluens* (the tr element in ZIEGLER 1960: Pl. 15, Fig. 1 may belong here). *L. excavata* is important in Wenlock and Ludlow strata but rare in immediately younger strata.

This redating affects the correlation of a closely similar conodont fauna from another basal Gedinnian sequence in its broad type area, that is the French part of the Ardennes (BORREMANS & BULTYNCK 1986). Thus, it seems that part of the Gedinnian – earlier the oldest Devonian stage – falls below the Silurian – Devonian boundary as now defined at Klonek.

Time

The *L. e. detorta* Zone is very thin both at Klonek and at Cellon – about 0.9 m (at the most 1.8 m) and 0.5 m (at the most 1.1 m), respectively. Thus, it might perhaps be concluded that the zone represents a very short time interval. However, in the Pozary section in Bohemia the older six graptolite based stratigraphical units distinguished by JAEGER (in KRÍŽ et al. 1986) are together represented by only about 7 m. Other Bohemian localities give both lower and somewhat higher averages. Several of the graptolite zones and subzones are in the order of some metres thick (or less) where thickest in Bohemia (JAEGER in KRÍŽ et al. 1986), that is, somewhat thicker than the *L. e. detorta* Zone at Klonek. However, one reason why Klonek was selected as the type locality was that the post *M. transgrediens* Interregnum was thinnest here, thus it is to be expected that the *L. e. detorta* Zone should be thinner here than elsewhere and thinner here than the maximum thickness of strata from intervals of similar duration.

Similarly, in Cellon the older seven Pridoli graptolite units of Jaeger are represented by about 5 metres of strata (compare WALLISER 1964; JAEGER 1975 and JAEGER in KRÍŽ et al. 1986), thus here too the thickness of the *L. e. detorta* Zone is comparable to that of the average of these graptolite units.

Since both the *M. beatus* Band and the *M. perneri* Zone are thin (JAEGER in KRÍŽ et al. 1986) it is evident that it is the *M. transgrediens* Interzone which is anomalously thick here – it forms about 14 m of Pridoli strata in Cellon and probably at least a similar proportion of the 39 m in the Pozary section.

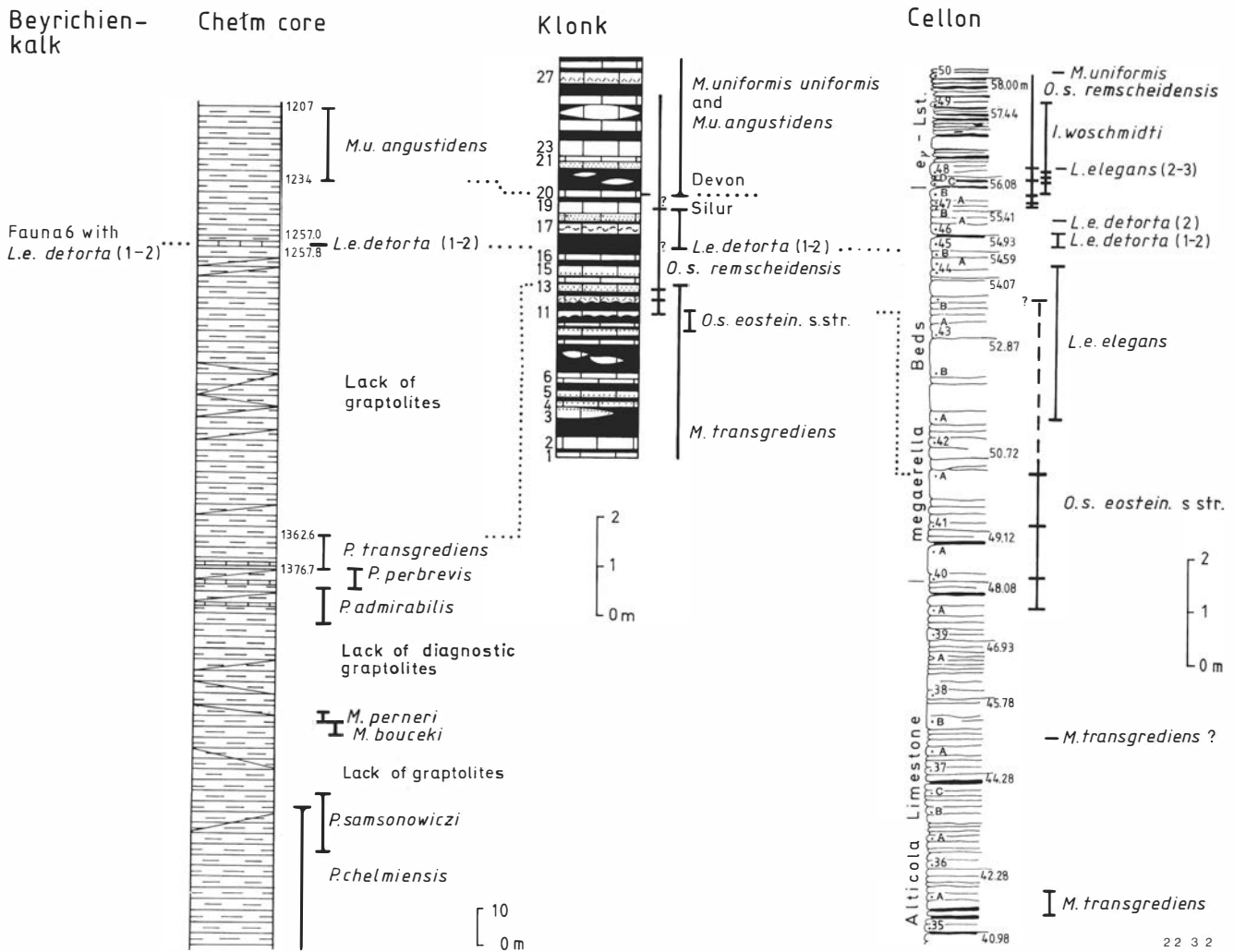


Fig. 2: Correlation between the latest Pridoli parts of the Beyrichienkalk, the Chełm core, and the sections at Klonek and Cellon. The Chełm core is redrawn from TELLER (1964), the Klonek section from CHLUPAČ & KUKAL (1977) and the Cellon section from WALLISER (1964) with graptolite occurrences from JAEGER (1975). Identification of *O. s. eosteinhornensis* s. str. and subspecies of *L. elegans* and *O. s. remscheidensis* at Klonek are based on my own studies, other ranges are from the above publications. The base of the *L. e. detorta* Zone is used as datum. The graptolite names used by TELLER have been included, but JAEGER (1977:338) has included *P. chelmiensis*, *P. samsonowiczi*, *P. admirabilis* and *P. perbrevis* in *M. transgrediens*.

In the Chełm core from Poland the *M. transgrediens* Interregnum with its 128.2 m constitutes about a third of the total Pridoli thickness (TELLER 1964), whereas the *M. transgrediens* Interzone is only 68.3 m after taxonomic revisions by JAEGER (1977:338), and the older Pridoli zones in that core are together 180.8 m or more, after taxonomic revisions by JAEGER (in KRÍŽ et al. 1986).

In the Stobno 2 core the *N. gedanensis* Zone is 120 m thick, whereas the two preceding Pridoli zones are 134 and 95 m thick, respectively (ŽBIKOWSKA 1974).

To sum up, strata correlated with the *L. e. detorta* Zone have a similar thickness as the average of most Pridolian graptolite units in Bohemia and Cellon, and as the average of the two preceding ostracode zones in the Stobno 2 core, but are much thicker in the Chełm core. Similarly, the *M. transgrediens* Interzone is many times thicker than the average zone in Bohemia and in Cellon and perhaps twice as thick in the Chełm core. The lack of fossils is of course not especially reliable for a single section, thus it cannot be excluded that part of the sequence lacking *M. transgrediens* in the Chełm core was depos-

ited prior to the extinction of *M. transgrediens*. Thus, then the relative thickness of the Pridoli below the *M. transgrediens* Interzone, that Interzone and the *L. e. detorta* Zone could well be still closer to that found in Bohemia and in Cellon.

The anomalous thickness of the *M. transgrediens* Interzone may indicate that it represents a much longer time interval, or an interval of strongly increased rate of sedimentation, or perhaps a combination of these factors. The interzone corresponds to at least three distinct conodont faunas whereas other parts of the Silurian graptolite zonation remain unsurpassed. Thus, there is some support for a conclusion that the *M. transgrediens* Interzone represents an interval of time that is several times as long as that of an average Pridoli zone. If difference in the length of time was the sole cause of the difference in thickness, then the *M. transgrediens* Interzone would represent more than half of the Pridoli Epoch, based on both Cellon and Bohemian data.

Available data indicate that the *L. e. detorta* Zone had about the same length as an average zone. The time represented by the *O. s. eosteinhornensis* s. str. and the pre-*L. e. detorta* Interregnum was probably of a similar duration.

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