Early Famennian conodont biostratigraphy of the stratotype area
(Montagne Noire, Southern France)

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ABSTRACT – The early Famennian deposits of three important sections (Abandoned quarry Coumiac, Causes et Veyran, and La Serre trench C) from the Montagne Noire are stratigraphically analysed. In contrast to former studies, the regional conodont successions reveal extensive differences compared to the global one. Several index fossils used for the identification of Late Devonian conodont zones are lacking or appear delayed in the fossil record. Consequently, a regional conodont stratigraphic scheme extending from the Frasnian/Famennian boundary to zona as young as Middle crepida- age is proposed and correlated with the Late Devonian standard conodont zonation. Furthermore, conodont faunal composition is estimated to be triggered by sea-level changes of the 3rd and 4th order. Implications, especially for the duration of conodont zones in the early Famennian are discussed.

RIASSUNTO – [Biostratigrafia a conodonti del Famenniano inferiore nell’area tipo (Montagna Nera, Francia meridionale)] – Sono stati analizzati da un punto di vista stratigrafico i depositi del Famenniano inferiore di tre importanti sezioni della Montagne Noire (Cava abbandonata di Coumiac, località Causes et Veyran e La Serre trincea C). In contrasto con gli studi precedenti la successione a conodonti presentata, a livello regionale, mostra differenze rispetto a quella globale. Nella fauna studiata alcuni fossili significativi per l’identificazione delle zone a conodonti del Devoniano Superiore mancano, oppure appaiono in ritardo. Di conseguenza, viene proposta, e correlata con la zonatura “standard” del Devoniano Superiore, una schema stratigrafico regionale a conodonti che si estende dal limite Frasniano/Famenniano fino alla Biozona Middle crepida. Inoltre si suppone che la composizione delle faune a conodonti sia stata influenzata da variazioni del livello marino di terzo e quarto ordine. Infine sono state discusse in particolare conseguenze riguardanti la durata delle zone a conodonti nel Famenniano inferiore.

INTRODUCTION

The stratigraphy of Devonian strata of the Montagne Noire area has been studied for more than a century. First studies concerning Late Devonian faunas of this region were published in the mid to late nineteenth century (e.g.: Fournet 1850, Koenen 1883a,b, Frech 1887, de Rouville 1887) mainly dealing with ammonoids. In this century, several authors refined the above stratigraphic approaches successively (e.g.: Böhm 1935, Schulz 1967). The first Late Devonian conodont descriptions were published by Lys & Serre (1957) and Ziegler (1959). The conodont faunas studied in the above investigations were rather small sized and were scattered throughout the Frasnian and Famennian record. Focusing on Devonian and Carboniferous litho- and biostratigraphy, Boyer et al. (1968) were the first to methodically study the conodonts from the Montagne Noire area. After their early work, investigations on the Late Devonian of this region intensified within the early 1980’s. On the occasion of an SDS (International Subcommission on Devonian Stratigraphy) field meeting in Montpellier in 1983, several artificial trenches matching Middle and Late Devonian stage boundaries and the Devonian/Carboniferous boundary respectively were dug by R. Feist (University of Montpellier), for example at La Serre (locality 3 of this study). Since then, the Late Devonian conodont succession of the Montagne Noire has been extensively analysed (e.g. Klapper 1985, 1989; Klapper & Foster 1986, 1993; Sandberg et al. 1988a; Girard 1994b, 1995; Girard & Feist 1997; Schülke 1995, 1996, 1997a, in press) especially regarding the Frasnian/Famennian boundary interval. Eventually, among other causations a considerable increase in knowledge about the Montagne Noire stratigraphy led the SDS to designate the boundary stratotype (GSSP) of the Frasnian/Famennian stage boundary at the famous abandoned Coumiac quarry (Klapper et al., 1993; locality 1 of this study).

Despite the fact that the conodont record of the Montagne Noire sections appeared to have been extensively elaborated, the conodont succession revealed several considerable differences compared with the global one (standard conodont zonation of e.g. Ziegler 1962; Ziegler & Sandberg 1990) when I carried out further detailed work (Schülke, 1995, 1997a). The Frasnian conodont succession has been studied by Klapper (1989). Mainly because of differences in taxonomic concepts of species of the standard Frasnian conodont zonation, he established a separate thirteenth-fold Montagne Noire conodont zonation. Klapper’s zonation has been successfully applied to several Devonian outcrops throughout the world (Klapper & Foster 1993). In contrast, the early Famennian conodont succession was claimed to resemble the global zonation (e.g. Klapper et al., 1993). This assumption was based on about half a dozen samples (Klapper et
al., 1993) ranging in age from the Frasnian/ Fammennian boundary well into strata as young as “Late crepida” age.

Detailed study of three sections from the Montagne Noire (loc. 1: abandoned Coumiac quarry; loc. 2: Causses et Veyran new trench; loc. 3: La Serre trench; Text-fig. 1) has led to a refinement and this new description of the early Fammennian conodont succession. Distinctive differences in conodont first appearances and composition of faunas have been observed which induce me to propose a new regional conodont zonation (see later). This new zonation is based on the successive appearance of index species of the genus *Palmatolepis* much like the global standard zonation (Ziegler & Sandberg, 1990). Hence, it differs from the Frasnian Montagne Noire zonation of Klapper (1989) which uses species of other genera besides *Palmatolepis*. Since applicability of the new zones to other sections mainly in the Rheinishe Schiefergebirge was considered in choosing the index species, there is a high degree of correlation between the new scheme and the concept of Ziegler & Sandberg (1990). In addition, several early Fammennian conodont species first described by Schülke (1995), and consequently not considered in the global standard zonation of Ziegler & Sandberg (1990), are very useful in stratigraphic analysis of the sections published herein and have yet to be correlated to the pre-existing zonation.

Text-fig. 1 - Geographic position of localities investigated in the Montagne Noire, southern France (1: abandoned quarry Coumiac, 2: Causses et Veyran trench; 3: La Serre trench C).
of the Cabrières area an equivalent sedimentary gap is not developed.

**Locality 1: Abandoned Coumiac Quarry (boundary stratotype of the Frasnian/Famennian stage boundary)**

**Geographic position** – The abandoned Coumiac quarry is situated in the southeastern Montagne Noire, Département Hérault, about 1.5 km NE of Cessenon village and 0.175 km WSW of the Les Granges farmhouse near the road D 136 between Cessenon and Causses et Veyran (topographic mapsheet 1:25000 Murviel lès Béziers) (Text-fig.1).

The Frasnian part of the boundary stratotype section is exposed in the upper quarry (the northernmost of a series of three abandoned marble quarries) followed by the Frasnian/Famennian boundary above its eastern wall. The Famennian part of the section extends on the slope in a NE direction where it is exposed in natural outcrops.

**Tectonics and Lithology** - Probably known to, but not reported by former workers (e.g. Klapper et al., 1993), the most recent measuring of the section during a field campaign late in 1997 revealed a small wrench fault which crosses the Famennian part of the section in a northward direction. The displacement amounts to about 0.80 m.

The early Famennian part of the section which is allocated in the Coumiac Formation is composed mainly of reddish, marly, nodular cephalopod limestones with intercalated marls. Bed character changes subsequently from the basal Famennian with evenly bedded, reddish strata to yellowish red strata with knobby bedding planes. In the middle Famennian, the Coumiac Formation is overlain by the transgressive, red and partly yellow nodular limestones of the Griotte Formation.

**Facies** – The depositional environment of the cephalopod limestones exposed in the Mont Peyroux area is estimated to belong to a quiet outer carbonate ramp regime (e.g. Feist, 1990). In the Upper Coumiac Formation 4th order sedimentary cycles are developed that mark sea level changes in the context of the Nehdenian transgression (Schülke, 1997b).

**References** – The Coumiac section has been known since De Rouville (1887) as a locality for Frasnian goniatites. The importance of this section for trilobite, goniatite and other faunal groups has been emphasised for example by House et al. (1985), Becker et al. (1989), Klapper (1989), Schindler (1990), Feist (1990, 1991), Lethiers & Feist (1991), Becker (1993), Klapper et al. (1993), Feist & Schindler (1994), Girard (1994a, 1994b, 1995), Girard & Feist (1997) and Schülke (1995, 1996, 1997a). Chemostratigraphic investigations on these sections have been carried out by e.g. Joachimski & Buggisch (1993), Grandjean et al. (1993) and Girard (1994b).

**Locality 2: Causses et Veyran New Trench**

**Geographic position** – The “Causses et Veyran new trench” section is positioned in the southeastern Montagne Noire, Département Hérault, about 450 m NW of Causses et Veyran village in an abandoned vineyard near a country lane branching off uphill from the D 19 at the western edge of Causses et Veyran toward Mont Peyroux (topographic mapsheet 1:25000 Murviel lès Béziers) (Text-fig. 1).

While uppermost Frasnian strata are frequently exposed on the southern slope of the Mont Peyroux by natural outcrops, less competent early Famennian deposits are mostly covered by up to 80 cm of soil in the “outcrop” area. Therefore, a small artificial trench was dug during a field campaign late in 1995 about 20 m away from the section “Causses et Veyran-South” of Feist (1990).

**Lithology** – The sedimentary succession of this section resembles that of the Coumiac section (loc. 1) to a very high degree. Exceptions are for example, the light grey Upper Kellwasser Horizon (beds 3, 4a) which is typically dark grey to almost black in Coumiac, and the almost bluish red colours of basal Famennian strata belonging to the Middle Coumiac Formation (up to bed 12 in fig. 3). Additionally, in the Upper Coumiac Formation a smaller number of marly clay horizons are intercalated between the limestones (up to bed 38 in Text-fig. 3).

**Facies** – The depositional regime of the early Famennian succession at Causses et Veyran is presumed to resemble that of the Coumiac section except for a slightly reduced clastic influx especially in the Upper
Coumiac Formation.

References – The Causses et Veyran section has only been roughly analysed for its faunal content (Feist, 1990) being understood only as a subsidiary section to that of Coumiac quarry which was proposed as the Frasnian/Famennian boundary stratotype. Recently, studies commenced on early Famennian *Nephranops incisus* layers situated in beds 6 and 7 in fig. 3, 4 (personal communication from R. Feist, Montpellier). The early Famennian conodont succession is presented for the first time in this study.

Locality 3: La Serre trench C

Geographic position – Trench C at La Serre hill is situated in the southeastern Montagne Noire, Département Hérault, about 2.5 km S of Cabrières village and 450 m E of the farmhouse “La Rouquette” on the southern slope of the hill (Topographic mapsheet 1:25000 Pezenas).

Middle Devonian to Carboniferous rocks on the southern slope of La Serre hill are scarcely covered by soil and are frequently exposed in small natural outcrops. The section of La Serre trench C was dug.
Text-fig. 4 - Basal Famennian part of the Causses et Veyran section (Loc. 2). On the right, development of conodont generic abundances. For symbols used in the lithological column, refer to Text-fig. 2.
under the direction of R. Feist (Montpellier) in the the late 1970s and early 1980s. It extends from upper Frasnian to strata as young as Early Carboniferous with well developed Frasnian/Famennian and Devonian/Carboniferous boundary intervals.

Lithology - The deposits of this section consist of well-bedded grey limestone, dark grey shales, marls, nodular limestones, and partly black laminated limestone beds which belong to the La Serre Formation (Text-fig. 3). The lithology differs strikingly from the localities described above both in its higher amount of intercalated shales and marls and the typically light to medium grey colours of calcilutite beds. The black Kellwasser facies (black laminated limestones) passes over the Frasnian/Famennian boundary (Kellwasser horizon: beds 14d, 14e in text-fig. 3) and extends to middle Famennian strata. In addition, large parts of these rocks are microsparitically recrystallized. When compared to the above sections, significantly more benthic faunal elements can be recognized at La Serre (e.g. Feist & Schindler, 1994).

Facies – The depositional environment of the deposits exposed at La Serre trench C is presumed to have been shallower than that of Courmiac (Loc. 1) and Causses et Veyran (Loc. 2) (e.g. Schindler 1990, Feist & Schindler 1994) because of its higher content of benthic faunal elements. This assumption is sustained by the generally higher content of *Icriodus*, a shallow water conodont taxon, although differences are not distinctive. Schindler (1990) proposed a middle to deep carbonate ramp depositional regime possibly situated in a slight depression.

References – This section has been analysed several times for its goniatite content beginning late in the nineteenth century (v. Koenen, 1883a,b; Frech, 1887;

![Text-fig. 5](image_url)

EARLY FAMENNIAN CONODONT BIOSTRATIGRAPHY OF THE MONTAGNE NOIRE

BERGERON, 1889; SCHINDEWOLF, 1921; BÖHM, 1935; V. GAERTNER, 1937. Detailed investigations of the goniatite succession from this locality were published e.g., in HOUSE ET AL. (1985), and BECKER (1990, 1993). As is the case with the abandoned quarry Coumiac (loc. 1), detailed studies of conodont faunas from this locality began in 1980s (KLAPPER, 1989; FEIST, 1990; KLAPPER & FOSTER, 1993; GIRARD, 1994, 1995; SCHÜLKE, 1996, 1997a). Mega- and microfaunal content has been described e.g. by Flajs & Feist (1988), SCHINDLER (1990), FEIST & SCHINDLER (1994), and DERYCKE ET AL. (1995).

EARLY FAMENNIAN MONTAGNE NOIRE
CONODONT ZONATION (Text-fig. 5)

FRASNIAN/FAMENNIAN BOUNDARY: THE TRIANGULARIS "PROBLEM"

The base of the Famennian has been positioned at the beginning of the Early triangularis Zone of the Late Devonian standard conodont zonation as defined by e.g. Ziegler (1962), and Ziegler & Sandberg (1990). The lower limit of this conodont zone was situated by these authors on the first appearance of *Palmatolepis triangularis*. In general, this conception appeared to be stable for about 25 years until the end of the 1980s. During investigations concerning the Frasnian/Famennian boundary, large scale conodont sampling of the Upper Kellwasser strata at several locations throughout the world had a detrimental effect on this stratigraphic usage. From these samples conodont specimens are present which resemble the early Famennian *Pal. triangularis* to a very high degree except for the downbent posterior platform tip of the Pa element, which is strongly upbent in typical *Pal. triangularis* Pa elements. This morphological difference induced SANDBERG ET AL. (1988b) to establish a new species named *Pal. praetriangularis*. They interpreted this species as an evolutionary forerunner to Famennian palmatolepids. Recently, the validity of *Pal. praetriangularis* has been discussed by KLAPPER ET AL. (1993) and SCHÜLKE (1995). KLAPPER ET AL. (1993) have found rare specimens of typical *Pal. triangularis* morphology within the Upper Kellwasser Horizon in the abandoned quarry Coumiac (loc. 1). Consequently, they synonymized *Pal. praetriangularis* Sandberg, Ziegler & Dreesen, 1988 with *Pal. triangularis*.

Text-fig. 6 - Regional conodont stratigraphic scheme of the basal Famennian of the Montagne Noire and correlation with the Late Devonian standard conodont zonation of e. g. Ziegler & Sandberg (1990), Schülke (1995) and with 4th order cycles (comp. Text-fig. 7).
Sannemann, 1955, because the specimens of both formerly separated species constituted a complete morphological continuum even at the earliest part of their existence. An additional reason was given to place the two species in synonymy by Schülke (1995). Throughout the existence of both morphological types, they constituted a morphological continuum within a single unbranched evolutionary lineage. Since no branching off of any of these types can be observed, Schülke (1995) placed both species in synonymy on the basis of his concept of the species. However, this new specific concept of *Palmatolepis triangularis* has not so far induced a discussion about its stratigraphic significance.

Herein, the first typical specimens of *Palmatolepis triangularis* (the "maintype" as defined by Schülke (1995)) are figured (Pl. 1). Specimens of this species make up a small, but considerable part of the fauna even within the lowest bed of Upper Kellwasser Horizon (loc. 2; Causses et Veyran) which is definitely Frasnian in age. Consequently, the base of the Early *triangularis* Zone would have to be placed at the base of the Upper Kellwasser Horizon at least at this locality, and would therefore not conform to the base of the Famennian defined by the "golden spike" (GSSP) at Coumiac (loc. 1). Treating the stratigraphic results at this section and others such as the section at "Grube Christiane" near Adorf in the Rheinishe Schiefergebirge, which also display the appearance of typical *Palmatolepis triangularis* specimens within the Upper Kellwasser Horizon (Findings of Schindler, *vidi*), implies severe consequences for the stratigraphic usage of the stage boundary itself.

In the following, a resolution of this problem is emphasized which is evidently traceable within the Montagne Noire sections (pers. comm. G. Klapper) and all sections published throughout the world.

**Zonal concept**

The zonal conception resembles that of the Late Devonian standard conodont zonation of e.g. Sandberg & Ziegler (1973), Ziegler & Sandberg (1990, pp. 12-13, 1994), Sandberg *et al.* (1989) to a very high degree. In their definition, the limits of standard conodont zones are defined by the first appearance of a diagnostic taxon. If that diagnostic taxon is absent, associated conodont taxa have to be used in recognizing the zone.

Schülke (1995) altered this conception by the use of morphotypes, mainly maintypes of diagnostic species following his definition, in defining zonal limits. Additionally, he subdivided the conodont zones in the early Famennian into two to three intervals which are defined by the first appearance of maintypes of additional taxa of this zone. This allowed the resolution of very short stratigraphic intervals in the early Famennian that are presumed to have lasted about 150 to 200 ky (Schülke, 1995).

The use of morphotypes instead of species in defining zonal limits is caused by the difference in first appearance of these morphotypes and the beginning of the species’ existence which may only be defined by the complete morphologic separation of its field of variation from an ancestral species (for further consideration see Schülke, 1995, 1996). Generally, the first specimens of morphotypes, that form the center of a specific field of variation of a descendant species, appear distinctively before the speciation as marginal varieties in the range of variation of the ancestral species. This position contrasts with the statement of Weddige & Ziegler (1979) who stressed that the transition between two members of a conodont phyletic succession occurred very quickly and that the relevant zonal boundary is therefore very precise.

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**EXPLANATION OF PLATE 1**

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Specimen Details</th>
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<tbody>
<tr>
<td>Fig. 1</td>
<td><em>Palmatolepis vinchelli</em> (Stauffer, 1938), Pa element; <em>linguiformis</em> Zone, Causses et Veyran (Loc. 2), bed 3; x90; Orig. no.: GPH 1998 IX 1/5.</td>
</tr>
<tr>
<td>Fig. 2</td>
<td><em>Palmatolepis bogartensis</em> (Stauffer, 1938), Pa element; <em>linguiformis</em> Zone, Causses et Veyran (Loc. 2), bed 1; x75; Orig. no.: GPH 1998 IX 1/1.</td>
</tr>
<tr>
<td>Fig. 3</td>
<td><em>Palmatolepis clarkei</em> (Stauffer, 1938), Pa element; <em>linguiformis</em> Zone, Causses et Veyran (Loc. 2), bed 8; x85; Orig. no.: GPH 1998 IX 1/8.</td>
</tr>
<tr>
<td>Fig. 4</td>
<td><em>Palmatolepis quadratolimbata proterita</em> Schülke, 1995, Pa element, <em>Middle triangularis</em> Zone, Causses et Veyran (Loc. 2), bed 5; x60; Orig. no.: GPH 1998 IX 1/11.</td>
</tr>
<tr>
<td>Figs. 5-6</td>
<td><em>Palmatolepis robusta</em> Schülke, 1995, Pa element, <em>Early crepida</em> Zone, Causses et Veyran (Loc. 2), bed 10; x90; Orig. no.: GPH 1998 IX 1/20 (fig. 5), GPH 1998 IX 1/21 (fig. 6).</td>
</tr>
<tr>
<td>Fig. 7</td>
<td><em>Palmatolepis triangularis</em> Sannemann, 1955, Pa element, <em>linguiformis</em> Zone, Causses et Veyran (Loc. 2), bed 3; x85; Orig. no.: GPH 1998 IX 1/77.</td>
</tr>
<tr>
<td>Figs. 8-12</td>
<td><em>Palmatolepis triangularis</em> Sannemann, 1955, Pa element, <em>Early triangularis</em> Zone, Causses et Veyran (Loc. 2), bed 4b; fig. 8; x95, fig. 12; x80; Orig. no.: GPH 1998 IX 1/9 (fig. 8), GPH 1998 IX 1/10 (fig. 12).</td>
</tr>
<tr>
<td>Fig. 9</td>
<td><em>Palmatolepis arcuata</em> Schülke, 1995, Pa element; <em>Late triangularis</em> Zone, Causses et Veyran (Loc. 2), bed 8; x75; Orig. no.: GPH 1998 IX 1/18.</td>
</tr>
<tr>
<td>Fig. 10</td>
<td><em>Palmatolepis prothomboides</em> Sandberg &amp; Ziegler, 1973, Pa element; <em>Middle triangularis</em> Zone, Causses et Veyran (Loc. 2), bed 5; x130; Orig. no.: GPH 1998 IX 1/13.</td>
</tr>
<tr>
<td>Fig. 11</td>
<td><em>Palmatolepis rhena</em> Bischoff, 1956, Pa element; <em>linguiformis</em> Zone, Causses et Veyran (Loc. 2), bed 2; x60; Orig. no.: GPH 1998 IX 1/3.</td>
</tr>
</tbody>
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MONTAGNE NOIRE CONODONT ZONES OF THE EARLY FAMENIAN

Early triangularis Zone MN

Lower limit – Mass appearance (dominating part of the palamtelepid fauna) of Palamtelepis triangularis (Sannemann, 1955 maintype of Pa element (as defined by Schülke (1995)). The lower limit of this zone corresponds to that of the Late Devonian standard conodont zonation (Ziegler & Sandberg 1990), but is redefined.

Upper limit – First appearance of Palamtelepis protorhomboides Sandberg & Ziegler, 1973 maintype of Pa element (as defined by Schülke (1995)). The upper limit of this zone is positioned in the middle of the Middle triangularis Zone of Ziegler & Sandberg (1990) and corresponds to the base of “interval 2” within this zone according to Schülke (1995, fig. 16).

Associated conodonts – Starting from the base of this zone Palamtelepis delicatula, Pal. subperlobata, and Pal. quadrantisnakosabata praeterita are associated with Pal. triangularis. Also, Polygnathus webbii, Pol. brevilaminus, Pol. angustidiscus, Icriodus alternatus, Prioniodina cf. recta, “Ozarkodina” sp. and Ancyrognathus cryptus are present. Within this zone rare specimens appear which represent transitional types between Pal. triangularis and Pal. clarki (Integrading Morphs following Schülke (1995)).

Middle triangularis Zone MN

Lower limit – First appearance of Palamtelepis protorhomboides Sandberg & Ziegler, 1973 maintype of Pa element (as defined by Schülke, 1995).

Upper limit – First appearance of Palamtelepis robusta Schülke, 1995 maintype of Pa element (as defined by Schülke, 1995). The upper limit of this zone is situated in the middle of the Late triangularis Zone of Ziegler & Sandberg (1990) and corresponds to the base of interval 2 of this zone as described by Schülke (1995).

Associated conodonts – From the start of this zone Pal. clarki clarki occurs in small quantities. It has not been designated as index fossil for the lower limit of this zone, since it can be missing in the basal part (e.g. loc. 2: Causses et Veyran). Furthermore, the earliest specimens of Pal. clarki clarki maintype are reported to occur late within the Early triangularis-Zone (in the limits of Ziegler & Sandberg, 1990, Schülke, 1995) e.g., at sections in the Rheinische Schieferegebirge (Schülke, 1995), but it has not been found in samples from the Montagne Noire representing this stratigraphic interval. Palamtelepis triangularis is present in this zone, but makes up only an accessory part of the fauna and vanishes late within this zone except for single occurrences. Palamtelepis quadrantisnakosabata praeterita and Pal. subperlobata are common, the latter giving rise to Pal. arcuata late in this zone. Also, Polygnathus webbii, Pol. brevilaminus, Icriodus alternatus, Prioniodina cf. recta, “Ozarkodina” sp. and Ancyrognathus cryptus are present in small to large quantities. Pol. angustidiscus vanishes from the fossil record in the Montagne Noire sections late in this zone, but is known to range at least into the Late triangularis Zone elsewhere. In the upper part of this zone the first specimens transitional between Ancyrognathus cryptus and Ag. sinelaminus appear.

EXPLANATION OF PLATE 2

Fig. 1 - Palamtelepis quadrantisnakosabata sandbergi Ji & Ziegler, 1993, Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2), bed 20; x60; Orig. no.: GPH 1998 IX 1/30.
Fig. 2 - Palamtelepis quadrantisnakosabata Sandberg & Ziegler, 1973 maintype of Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2), bed 20; x60; Orig. no.: GPH 1998 IX 1/22.
Fig. 3 - Palamtelepis quadrantisnakosabata quadrantisnakosabata Sannemann, 1955, Pa element; Middle crepida Zone MN, Causses et Veyran (Loc. 2), bed 44; x62; Orig. no.: GPH 1998 IX 1/39.
Fig. 4 - Palamtelepis quadrantisnakosabata Sannemann, 1955, Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2), bed 31; x55; Orig. no.: GPH 1998 IX 1/33.
Fig. 5 - Palamtelepis quadrantisnakosabata Ulrich & Bassler, 1926, Pa element; Early crepida Zone, Causses et Veyran (Loc. 2), bed 11; x48; Orig. no.: GPH 1998 IX 1/24.
Fig. 6 - Palamtelepis quadrantisnakosabata Cooper, 1931, Pa element; Middle crepida Zone MN, Causses et Veyran (Loc. 2), bed 35; x60; Orig. no.: GPH 1998 IX 1/35.
Fig. 7 - Palamtelepis quadrantisnakosabata Sannemann, 1955, Pa element; Middle crepida Zone MN, Causses et Veyran (Loc. 2), bed 38; x100; Orig. no.: GPH 1998 IX 1/38.
Fig. 8 - Palamtelepis quadrantisnakosabata Sannemann, 1955, Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2) bed 18; x85; Orig. no.: GPH 1998 IX 1/26.
Fig. 9 - Palamtelepis quadrantisnakosabata Sannemann, 1955, Pa element; Middle crepida Zone MN, Causses et Veyran (Loc. 2), bed 44; x85; Orig. no.: GPH 1998 IX 1/42.
Fig. 10 - Palamtelepis quadrantisnakosabata Sannemann, 1955, Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2), bed 28; x75; Orig. no.: GPH 1998 IX 1/31.
Fig. 11 - Palamtelepis quadrantisnakosabata Sandberg & Ziegler, 1973 maintype of Pa element; Early crepida Zone MN, Causses et Veyran (Loc. 2), bed 19; x105; Orig. no.: GPH 1998 IX 1/28.
Late triangularis Zone MN

**Lower limit** – First appearance of *Palmatelepis robusta* Schulzke, 1995 maintype of *Pa* element as defined by Schulzke (1995).

**Upper limit** – First appearance of *Palmatelepis quadratrinodososalobata sandbergi* Ji & Ziegler, 1993 maintype of *Pa* element as defined by Schulzke (1995). The upper limit of this zone correlates with the upper limit of the Late triangularis Zone of the Late Devonian standard conodont zonation of Ziegler & Sandberg (1990), but had to be re-defined since the index conodont *Palmatelepis crepida* marking the beginning of the following zone, e.g. in the Rheinische Schiefergebirge (Early crepida Zone) appears delayed. Partly, *Pal. crepida* first occurs as late as *Pal. termini* (Coumiac, loc. 1, La Serre trench C, loc. 3) which itself indicates the subsequent Middle crepida Zone. In the Causses et Veyran section the first few and untypical specimens of *Pal. crepida* appear early in this zone, but are lacking throughout a considerable part of this zone. In contrast, the associated fauna vastly resembles the typical conodont succession of this time throughout the world. Therefore, *Pal. quadr. sandbergi* which usually co-appears with *Pal. crepida* has been chosen to indicate the upper limit of this zone.

**Associated conodonts** – Typical palmaotelepid conodonts present in the zonal interval are *Pal. arcuata*, *Pal. clarki gablei*, *Pal. quadratrinodososalobata praeterita*, *Pal. protorhomboida*, and *Pal. perlobata* (rare specimens). In the middle of this zone *Pal. lobicornis*, *Pal. spathula*, and *Pal. wolskae* (justified emendation following Metzger 1994) have their first appearance. In contrast, *Pal. subperlobata* is no longer present from the middle of the Late triangularis Zone. *Icriodus alternatus* is very abundant during the complete zone reaching abundance ratios of up to 50%. Other commonly associated conodonts are *Pal. brevilaminus*, *Pal. procerus*, *Anycrognathus sinelaminus*, *Promiodina* cf. *Pr. recta*, *Ozarkodina* sp., while e.g., *Anycrognathus cryptus* abruptly disappears right after the start of this zone. Also, rare specimens of *Icriodus cornutus* and *Pelekygnathus planus* have been observed.

Early crepida Zone MN

**Lower limit** – First appearance of *Palmatelepis quadratrinodososalobata sandbergi* Ji & Ziegler, 1993 maintype of *Pa* element as defined by Schulzke (1995).

**Upper limit** – First appearance of *Palmatelepis termini* Sannemann, 1955 maintype of *Pa* element as defined by Schulzke (1995).

**Associated conodonts** – The most important palmaotelepids are *Pal. quadratrinodososalobata quadratrinodososalobata*, *Pal. glabra renupunctata*, and *Pal. minuta* during most of this zone. Early within this zone *Pal. crepida*, nominal species for the “global” Early crepida Zone, first appears in some of the sections studied (Coumiac, La Serre trench C) and successively increases in faunal ratio. *Pal. wolskae* and *Pal. regularis* are also present in small numbers, but successively disappear until the middle of this zone. Coincidently, *Pal. minuta* gives rise to *Pal. sp. aff. Pal. gracilis*, a taxon morphologically not completely corresponding to *Pal. gracilis gracilis*, but displaying morphologic features, that indicate a close relationship, if not direct ancestor-ship. Also, rare specimens of *Pal. perlobata* may be present. Again, *Icriodus alternatus* reaches faunal portions of up to 35% at the base of this zone, and successively decreases in abundance until the end of this zone when it constitutes only minor parts of the fauna. *Pal. brevilaminus* disappears during this zone. In the following, *Pal. eoglaber* and rare specimens of *Pal. procerus* are the only representatives of the genus *Palmatelepis*. Also, *Anycrognathus sinelaminus* and *Pelekygnathus planus* occur in varying faunal ratios.

Late crepida Zone

**Lower limit** – First appearance of *Palmatelepis glabra prima* Ziegler & Huddle, 1969 maintype of the *Pa*
element as defined by Schülke (1995).


Remarks – This zone correlates well to the global Late Devonian standard conodont zone as defined by e.g. Ziegler & Sandberg (1990), and consequently does not need to be revised for use in the Montagne Noire herein.

SEQUENCE STRATIGRAPHY OF THE BASAL
FAMENNIAN DEPOSITS: A PRELIMINARY APPROACH

3rd ORDER CYCLES

The third order cycles (Vail et al., 1977) whether globally or regionally developed are presumed to be triggered by several regional or continent-wide tectonic mechanisms which are by far too numerous to list in this study. However, they have been observed on numerous occasions (e.g. Haq et al., 1987, 1988, Hallam 1975) throughout the stratigraphic record. This type of cyclicity may also be extracted from the Late Devonian sea-level curve published by Johnson et al. (1985) and Johnson & Sandberg (1989). This sea-level curve displays 7 (½) TR cycles of this order grouped together into two larger scaled cycles (Ie, II) oriented with the general eustatic trend. Together with the assumption of Sandberg & Ziegler (1996) and Ziegler & Sandberg (1998) based on radiometric dating of Claoué-Long et al. (1992) of the Famennian lasting about 10 my, these 3rd order cycles are assumed to have an average duration of about 1.5 my. Two of the Famennian 3rd order cycles are recorded in the sections studied here. The first one equals the time interval represented by the Early triangularis Zone to the upper part of the Early crepida Zone (Text-fig. 6). The second 3rd order cycle starts within the upper part of the Early crepida Zone with its upper limit exceeding the stratigraphical interval investigated. The sequence boundaries and the interpretation of high- and lowstand sediments conform to the results of Matyja & Narkevicz (1992), Matyja (1993), and Racki (1997) for both cycles developed in Polish sections. Sedimentological and stratigraphic data as presented e.g. by Schindler et al. (1998) for the Rheinische Schiffragebirge, Johnson & Sandberg (1989) for the Western United States, and Schülke 1997b for the Montagne Noire allow similar correlations. The respective data from the Urals published by Kuzmin & Yatskov (1997), and Veimann et al. (1997) provide a high degree of uncertainty in stratigraphic correlations, and can only be presumed to further strengthen the observations made elsewhere. Otherwise, analysis of eustatic sea-level changes of the Pripyat depression (Russian platform) resulted in a similar development of the sea-level as presented here (Pushkin, 1997).

The reconstruction of the sea-level curve for Northwest Australia as e.g. presented by Becker & House (1997) also correlates with my data especially concerning the lowstand in the Early and Middle crepida Zone which is represented by the 15 cm-thick "Fruituxites Bed".

Within the sections investigated the respective lowstands can be clearly observed in the conodont generic faunal composition. They are indicated by extensive fluctuations in the Icriodus abundance, a genus generally interpreted as preferring shallow water conditions (Sedison & Sweet, 1971; Sandberg & Dreesen, 1984 among many others) showing increased values in the Middle triangularis Zone and the upper part of the Early crepida Zone (loc. 1, loc. 2, Text-fig. 4). Additional faunal data sustaining the results given here are gained by Riemann (1998) for microvertebrate remains from abandoned quarry Coumiac (loc. 1) and Causses et Veyran (loc. 2), and by Levy (in prep.) in a macrofaunistic analysis of the La Serre section (loc. 3). Furthermore, within the lowstand sediments as indicated here, an increased trilobite content has been observed (pers. comm. R. Feist: "Nephranops beds"). Sedimentological investigations on the lower Famennian part of the Coumiac section are in progress (Spiehl, in prep.).

4th ORDER CYCLES

The analysis of conodont faunal composition at the specific level (Text-fig. 5) supported the results of the respective analysis at the generic level. Distinctive peaks in Icriodus alternatus (no. 28 in Text-fig. 5) abundance are developed in the Middle and Late triangularis Zones and the uppermost part of the Early crepida Zone, separated by an interval of almost constant abundance (about 12 %) and followed by a phase of very low abundance (varying around 4 %). Following the "depth stratification" model of Seddon & Sweet (1971), the Icriodus alternatus abundance development is released and directly reflects the water depth of this environment. Considering the palmatolepid fauna composition, which is highly diverse compared to the icriodid fauna, it shows its most extensive compositional changes in the same stratigraphical intervals where Icriodus alternatus is most frequent. In contrast, within the intervals Icr. alternatus shows no or only slight changes in abundance, palmatolepid specific composition is subjected to compositional variations of a minor degree. This led me to conclude that the faunal composition of palmatolepids is also triggered by sea-level changes of probably minor effect, but higher frequency. For the subsequent sequence-analysis, frequency changes of single palmatolepid species have been calibrated where possible by the Icr. alternatus abundance and then transferred to intervals in which such calibration was impossible. The results of this analysis are illustrated in Text-fig. 7. Since the first preliminary approach is based only on the conodont
Text-fig. 7 - Exemplary correlation of a regional sea-level curve (which corresponds well with the global sea-level curve after Johnson et al. (1985), 3rd and 4th order cycles with the basal Famennian deposits and conodont stratigraphy of the Causses et Veyran section (loc. 2). For symbols used in the lithological column, refer to Text-fig. 2.
fauna, a variety of attempts were made to validate these results: (1) Analysis of the rich and diverse foraminifer faunas (study in prep.) from the localities 1 and 2 of this study seems to sustain the conodont data on a semiquantitative level. (2) Carbonate content analysis (Spiehl, in prep.) resulted in data correlating with the conodonts.

In contrast, microfacies analysis showed no significant results, since facies variations released by the sea-level changes of the 4th order cyclicity seem to be too weak to produce distinctive differences in this open marine environment (Spiehl, in prep.). Several different methodologic approaches, however, are in progress to sustain or refute the preliminary results presented here.

**Conodont zones and time**

Estimations presented here on the time elapsed in the stratigraphic interval of concern are, of course, highly interpretative and possibly controversial, but seem to be much better supported by the data than the pure assumption made by e.g., Sandberg et al. (1988b), Ziegler & Sandberg (1990), Sandberg & Ziegler (1996), and Ziegler & Sandberg (1998) that conodont zones represent almost equal time intervals in the Late Devonian. Following the estimations made in previous pages of the average duration of 3rd order cycles in the Famennian, the time elapsed in the stratigraphic interval investigated amounts to about 3 my. This is much the same value that would result from a calculation based on conodont zones lasting about 0.5 my (6 zones) stated by Sandberg & Ziegler (1996). The interval of 3 my is subdivided in 5 1/2 cycles of higher frequency (comp. Text-figs. 6, 7). Consequently, the high frequency cycles show best fit with a 400 ky cycle, which does not exclude that they can also be partly overprinted by cycles of higher frequency. If this calculation proves correct, however, the time elapsed in the interval represented by the Early to Late **triangularis** Zone amounts to about 600 ky while the Early **crepida** Zone is presumed to have lasted more than 2 my (Text-figs. 6, 7). Results of Bai et al. (1994) and Bai (1995) based on element abundance and carbon isotope values differ from those presented here, but also support the strong necessity for further investigations concerning the Late Devonian time scale.

The points raised above strongly influence the discussions on e.g., rates of faunal recovery after the Frasnian/Famennian mass extinction, the timing of the Kellwasser event in total, and furthermore strengthen the hypothesis of “punctuated equilibria” playing an important role in the evolutionary processes of diversification.

**Conclusions**

From the bio- and sequence stratigraphic analysis of the early Famennian deposits of the Montagne Noire area presented here the following conclusions can be drawn:

1. Though conodonts in general provide a useful database for global biostratigraphic correlations, the differences in regional facies and ecologic conditions may produce regional stratigraphic schemes such as that presented here which still have to be correlated with the global zonation.

2. A consensus about the time duration of conodont zone, whether they are of subequal size or differ greatly, remains elusive, but analysis herein tends to support a strongly fluctuating zonal length.

3. Only further sequence stratigraphic testing may produce new ideas about geologic and evolutionary processes connected with the Kellwasser mass extinction event.

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