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The mid-Famennian ammonoid succession in the Rhenish Mountains: the "*annulata* Event" reconsidered

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The mid-Late Devonian pelagic sedimentary successions of the Rhenish Mountains and other regions show a double black shale horizon called the *annulata* Black Shale. It marks, at the species level, a prominent faunal turnover of ammonoids from the *Prolobites delphinus* Zone into the *Platyclymenia annulata* Zone. An analysis of ammonoid genera distribution, phylogenetic relationships, and morphospace occupation demonstrates that the "*annulata* Event" does not correspond to a crisis of the group and does not fulfill the criteria of a major biotic event.

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INTRODUCTION

A dark shale horizon with limestone nodules rich in conchs of the ammonoid *Platyclymenia annulata* (Münster, 1832) and other species was previously noticed by the field geologist Denckmann (1900), when mapping the Palaeozoic rocks at the northern margin of the Rhenish Mountains. The horizon is conspicuous because it occurs within a succession of nodular limestones and red or grey claystones. Denckmann (1900) called this unit "Zone der *Clymenia annulata*" (Fig. 1), referring to the abundance of the nominal species.

Soon after its discovery, the horizon was exploited by Wedekind (1910, 1913, 1914), who had already recorded 17 species from the locality at the Beul summit (Beuel of other authors, Beil on the topographic map 1:25 000 map sheet Balve). Lange (1929) published a list of 27 taxa from this locality. However, some of the species must be regarded as synonyms (for prionoceratids, see Korn, 1994; for platyclymeniids, see Korn, 2002*a*), such that the total diversity was reduced to approximately 15 species.

From other regions outside the Rhenish Mountains, black shales or black *Platyclymenia annulata*-bearing limestones were reported from various places, e.g., South Portugal (Fantinet *et al*., 1976), the Cantabrian Mountains (Sanz-López *et al*., 1999), Thuringia (Bartzsch *et al*., 1999) the Holy Cross Mountains (Czarnocki, 1989; Bond and Zatoń, 2003), Moravia (Rzehak, 1910), the Anti-Atlas of Morocco (Korn, 1999), the Saoura Valley of Algeria (Fig. 3), *etc*. This means that black sediments of this age are widely distributed.

The term "*annulata* Event" was coined by Walliser (1984). House (1985) called it the "Annulate Event" to describe "one (or a few) thin argilite unit(s) usually in pelagic carbonate sequences, where many costate platyclymenids are seen. This level marks the last appearance of true *Platyclymenia* and *Trigonoclymenia*." In his later paper on ammonoid extinction events, House (1989) did not list this event. However, it was shown that *Platyclymenia annulata* can also be collected from beds above the black shale (Korn and Luppold, 1987; Becker, 1992). Nevertheless, the term "*annulata* Event" was frequently used by authors, in the expectation that the black shale horizon really marks a mid-Famennian biotic event (e.g. Walliser, 1985, 1996; House, 2002).

THE *ANNULATA* BLACK SHALE

The full succession of the *annulata* Black Shale is known from a number of outcrop localities in the Rhenish Mountains (Figs. 2 and 3). A transition from claystone-dominated to lime-

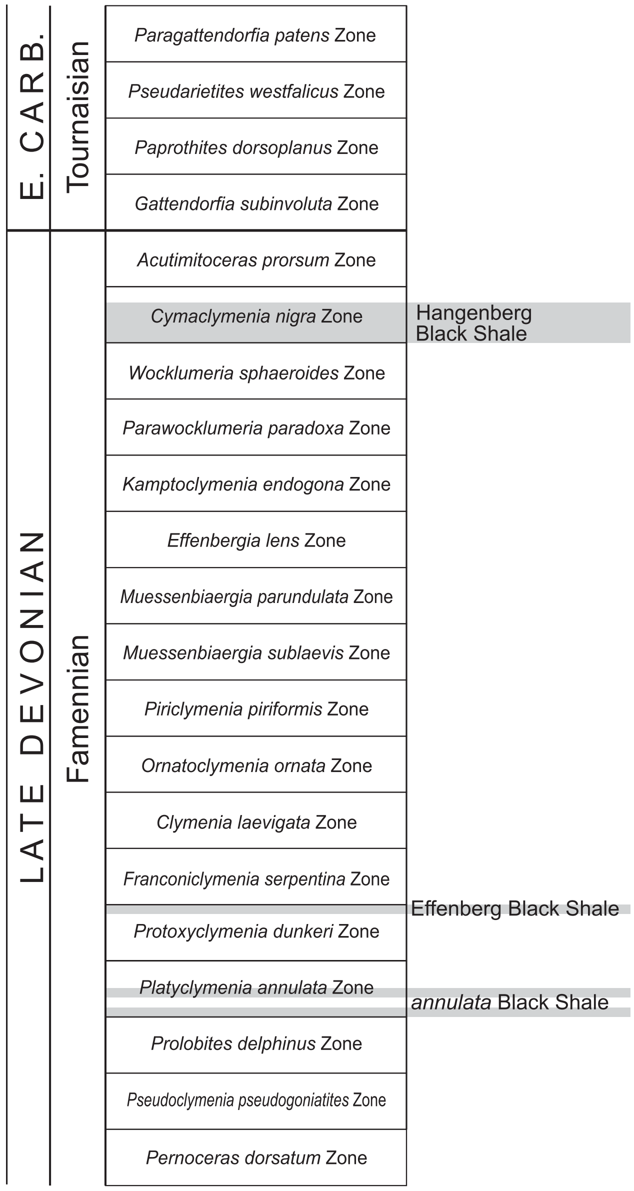

Fig. 1. Ammonoid stratigraphy of the mid and late Famennian and the early Tournaisian and the position of the black shale horizons, after Korn (2002*b*)

stone-dominated sections of the *Platyclymenia annulata* Zone can be observed in an easterly direction on the northern flank of the Remscheid-Altena Anticline.

From the Reitenberg north of Letmathe (map sheet 4611 Hagen-Hohenlimburg), Becker (1992) described a claystone succession of middle Famennian age with irregularly distributed limestone nodules, in which two black shale horizons, approximately 30 and 15 cm in thickness, are intercalated. Below, between and above the black shales, grey claystone horizons (Becker's beds 21, 23b, a), each of two metres thickness, were shown (Becker, 1992, p. 8). Becker recorded faunas with *Platyclymenia annulata* in a succession ten metres above the upper *annulata* Black Shale. He interpreted the event facies as being "hypoxic (dysaerobic-exaerobic), eutrophic, semi-vital-pantostrate".

In the Oese road-cutting (map sheet 4512 Menden), which was previously studied by Ziegler (1962), the claystones show a reduced thickness and beds of nodular limestones occur more frequently. The two black shales have thicknesses of 19 and 42 cm respectively, and span a total interval of 98 cm. In the lowest portion of the grey claystones between the black shales, one horizon of small limestone nodules with many bivalves can be seen. Above the upper black shale, 1.35 m of greenish-grey claystones follow, which are overlain by a nodular limestone bed of 6 cm thickness (Ziegler's sample 36). Above another 122 cm of grey claystones with a few small limestone nodules, the second nodular limestone (Ziegler's sample 35) follows.

Further to the east, the railway cutting of Ober-Rödinghausen (map sheet 4613 Balve) shows a more carbonate-rich section around the *annulata* Black Shale. It closely resembles the road cutting section that was also studied by Ziegler (1962). In comparison to Oese, the succession below the *annulata* Black Shale in particular differs markedly by its much higher carbonate content and by thinner claystone interbeds. The two horizons of the *annulata* Black Shale have thicknesses of 18 and 35 cm, respectively, and are separated by 42 cm of grey claystones. Near the base and in the middle of these claystones, two horizons of small limestone nodules are rich in bivalves. 48 cm of grey shales lie above the upper *annulata* Black Shale, followed by two beds of nodular limestone, these in turn are overlain by a claystone succession with interbedded nodular limestones.

Sections in which the *annulata* Black Shale complex is most fossiliferous were trenched on the Beul summit (map sheet 4613 Balve). Above light grey, locally reddish nodular limestones (*Prolobites* limestone), a lower strongly weathered black shale horizon of 6 to 8 cm thickness represents a sharp sedimentary break. The black shale is followed by 19 to 24 cm of grey or reddish shales with two or three extremely fossil-rich limestone nodule horizons. Overlying this is the upper *annulata* Black Shale of 6 to 8 cm in thickness. Toward the top, the section continues with grey nodular limestones. The total thickness of the observed *annulata* Black Shale complex was 34 to 48 cm.

In the large Effenberg quarry (map sheet 4613 Balve) the *annulata* Black Shale is best exposed and shows the following succession: above light grey nodular limestones that form beds of 10 to 20 cm thickness, a lower black shale horizon 13 cm thick characterises an abrupt sedimentary change. The top of the black shale shows a similarly sharp contact to the succeeding brittle grey claystones of 12 cm thickness. At the bottom and the top of this unit, two horizons of grey limestone nodules are present. A second black shale, 43 cm thick in total, follows; its top contains a thin (3 cm) thick bituminous limestone bed. Separated by a thin black shale horizon, a platy bed of bituminous limestone, 8 cm in thickness is also interbedded in the topmost black shales. Above these, grey shales with mica flakes and grey nodular limestones follow. In total, the *annulata* Black Shale succession has a thickness of 67 cm.

A section on the axis of the Remscheid-Altena Anticline was trenched by Schäfer (1978) on the Dasberg summit (map sheet 4613 Balve). The section resembles that of the Beul, with a total thickness of the *annulata* Black Shale complex of only 33 cm, a lower black shale of 11 cm, an upper black shale of 10 cm, and between them, grey shales with two horizons of nodular limestone.

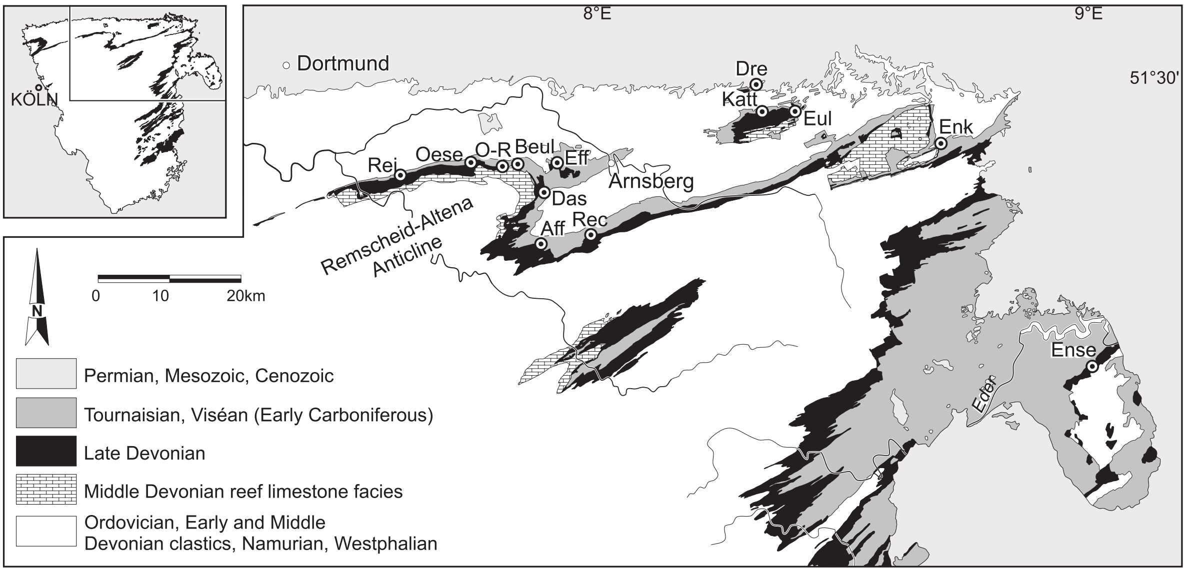

Fig. 2. The northern margin of the Rhenish Mountains with the position of the localities mentioned in the text

Rei — Reitenberg, O-R — Ober-Rödinghausen, Eff — Effenberg, Das — Dasberg, Aff — Affeler Hammer, Rec — Recklinghausen, Dre — Drewer, Katt — Kattensiepen, Eul — Eulenspiegel, Enk — Enkenberg

On the southern flank of the Remscheid-Altena Anticline, a reduced-thickness section of the *annulata* Black Shale (map sheet 4613 Balve) is exposed in a small quarry 1 km south-west of Hövel. It was described by Lange (1929) and Ziegler (1962) and shows only one black shale 5 cm thick, followed by two horizons with small limestone nodules, and then by a monotonous succession of nodular limestone beds 4 to 6 cm in thickness with thin claystone interbeds.

On the southern flank of the Lüdenscheid Syncline, localities in which a double black shale is developed are Affeler Hammer (map sheet 4713 Plettenberg; Ziegler, 1970), and Recklinghausen (map sheet 4614 Arnsberg; Koch, 1965).

A very similar succession as on the Effenberg can be studied in the large Kattensiepen quarry north of Suttrop (map sheet 4516 Warstein). Above the highest *Prolobites* limestones which show an alternation of grey nodular limestone beds with grey claystone intercalations each 5 to 8 cm thick, the lower *annulata* Black Shale of 14 cm thickness follows with a sharp contact. A claystone package of 13 cm can be seen between the lower and the upper black shale horizon, and as in the Effenberg section, it contains two horizons of grey limestone nodules. The total thickness of the upper black shale is 57 cm, and in the upper half of this package, a platy bivalve-rich bituminous limestone bed of 9 cm thickness, and a horizon with dark grey, bituminous limestone nodules up to 8 cm in thickness are interbedded. These limestone nodules contain an ammonoid fauna in excellent preservation (Staschen, 1968; Korn, 2002*a*). The rock succession above the *annulata* Black Shale is very similar to the succession below it. It should be noticed that the thickness of the *annulata* Black Shale succession varies laterally, as can be seen in the face of the large quarry. At the northern flank of the exposed anticline, there occurs a thickness reduction and the unit tends to wedge out, with only a single black shale horizon preserved.

In the trench on the Enkenberg (map sheet 4519 Madfeld), the succession is less clear because of intensive weathering and partial dolomitization (Korn and Ziegler, 2002). The section is almost entirely made up of nodular limestones, and there are three thin (up to 4 cm) shaly horizons below, between, and above the beds containing *Platyclymenia annulata*. The lower and upper of these are probably representatives of the *annulata* Black Shale.

The locality above the Beringhauser Tunnel (Clausen *et al.*, 1991) as well as at Ense (Schindewolf, 1934) near Bad Wildungen shows no clear indication of a black shale horizon, but yielded faunas with *Platyclymenia annulata*. Sections with only a single *annulata* Black Shale can be seen in the abandoned Drewer and Eulenspiegel quarries.

AMMONOID FAUNAS AROUND THE *ANNULATA* BLACK SHALE

BELOW THE BLACK SHALE

Many outcrops of nodular limestones below the *annulata* Black Shale yielded ammonoids, but a rich assemblage from these *Prolobites* limestones is only known from the Enkenberg (Wedekind, 1908; Lange, 1929; Paeckelmann and Kühne, 1936), where a new section was trenched in 1992 (Korn and Ziegler, 2002). The section is condensed (Fig. 4); the *Prolobites delphinus* Zone has a thickness of only 0.60 metres, and is highly fossiliferous. All the seven limestone beds yielded ammonoid faunas, which are particularly diverse in the middle portion of the unit. The fauna is composed of at least 16 genera: *Gundolficeras*, *Planitornoceras*, *Sporadoceras*, *Araneites*, *Erfoudites*, *Prolobites*, *Cyrtoclymenia*, *Protactoclymenia*, *Pricella*, *Hexaclymenia*, *Rectoclymenia*, *Genuclymenia*, *Pleuroclymenia*, *Platyclymenia*, *Stenoclymenia*, and *Sulcoclymenia*. A total of approximately 800 specimens were available for study.

The distribution of the ammonoid conch morphologies within the *Prolobites delphinus* Zone and *Platyclymenia*

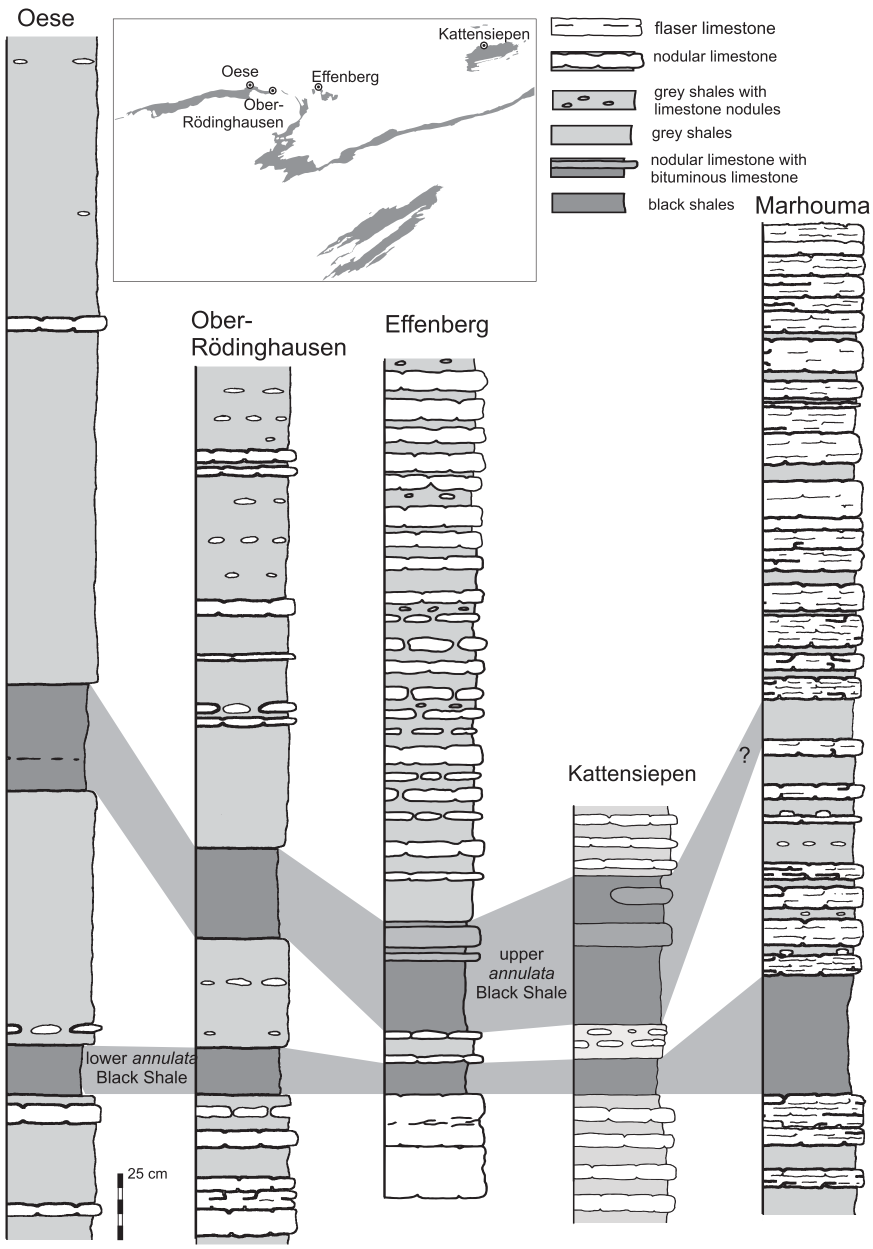

Fig. 3. Lithological logs of the *Platyclymenia annulata* Zone at the northern margin of the Rhenish Mountains and comparison with the exposure at Marhouma near Béni Abbès, Algeria

annulata Zone in the Enkenberg trench section shows a remarkable pattern. Three principal conch morphologies are represented:

— the goniatitic morph, represented by thickly lenticular to globular forms with a narrow or closed umbilicus and low to moderately high aperture,

— the cyrtoclymeniid morph, represented by lenticular to pachyconic forms with a moderate umbilicus and moderately high aperture,

— the platyclymeniid morph, represented by serpenticonic forms with a low to moderately high aperture.

Distribution of these morphs within the *Prolobites delphinus* Zone shows some fluctuations (Fig. 5), with respect to the total number of specimens and species diversity. In all seven beds, the goniatitic morph is predominant with 63 to 80% of the individuals in the samples. There is no distinct pattern in this ratio. In the distribution of the clymeniid morphs, on the other hand, a double-wedge pattern can be recognised. Within the first two beds, all clymeniids belong to the cyrtoclymeniid morph. In the three following beds, the proportion cyrtoclymeniid morph:platyclymeniid morph is 6:1 to 9:1. This ratio is reduced to 2:1 and almost 1:1 in the upper two beds of the *Prolobites delphinus* Zone (in the *Platyclymenia annulata* Zone of this locality, only the platyclymeniid morph is present, indicating that the situation at the basal *Prolobites delphinus* Zone is completely different).

In the basal bed of the *Prolobites delphinus* Zone, the two clymeniid genera *Cyrtoclymenia* and *Pricella* are represented by three species, all characterised by very simple suture lines. In the third bed, the serpenticonic and simple-lobed genera

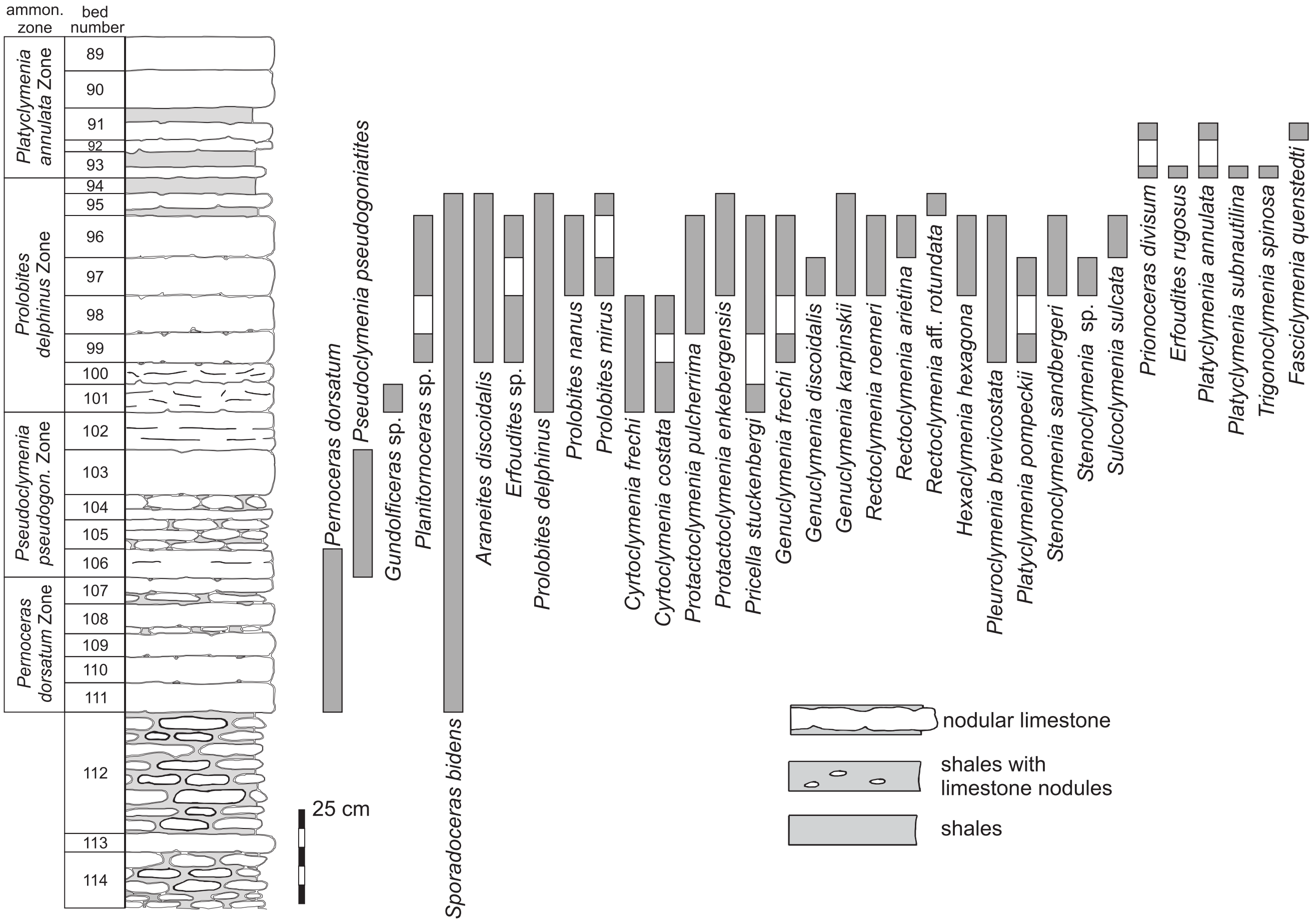

Fig. 4. Lithological log of the cephalopod limestones at Enkenberg, Rhenish Mountains, with the ammonoid species distribution of the *Prolobites delphinus* and *Platyclymenia annulata* zones

Bed numbers according to Korn and Ziegler (2002); for other explanation see Figure 3

Pleuroclymenia and *Stenoclymenia* appear, and in the same bed, *Genuclymenia* with an asymmetric lateral lobe occurs for the first time. In beds 97 and 96, the clymeniids show the highest diversity with 10 and 12 species respectively, of which only four could be recorded in the highest fossiliferous bed (bed 95) of the *Prolobites delphinus* Zone. This diversity pattern is not related to different sample sizes.

WITHIN THE BLACK SHALE

Rich assemblages of well-preserved ammonoids from the *Platyclymenia annulata* Zone are known from three Rhenish localities in particular: Beul (Wedekind, 1914; Lange, 1929, and new collections by the author), Kattensiepen (Korn, 2002*a*), and Ense (Schindewolf, 1934 and new collections). Of these, the first and third are composed of very similar species, but the second differs remarkably in its composition.

The occurrences at Beul and Ense yielded the genera *Posttornoceras*, *Prionoceras*, *Erfoudites*, *Prolobites*, *Protactoclymenia*, *Platyclymenia*, *Pleuroclymenia*, *Trigonoclymenia*, *Fasciclymenia*, and *Carinoclymenia*, whereas the Kattensiepen yielded *Gundolficeras*, *Erfoudites*, *Roinghites*, *Xenosporadoceras*, *Prolobites*, *Platyclymenia*, and *Pleuroclymenia*. This means that 13 genera are present in the nodules embedded in the double black shale horizon.

Of these 13 genera, 7 are already present in the underlying *Prolobites delphinus* Zone, i.e., *Gundolficeras*, *Posttornoceras*, *Erfoudites*, *Prolobites*, *Protactoclymenia*, *Platyclymenia*, and *Pleuroclymenia*. This is also possible for *Prionoceras* (Wedekind, 1908; Lange, 1929). Only five genera, i.e., *Xenosporadoceras*, *Roinghites*, *Trigonoclymenia*, *Fasciclymenia*, and *Carinoclymenia*, appear for the first time in the *Platyclymenia annulata* Zone. Of the 13 genera, *Gundolficeras*, *Posttornoceras*, *Prionoceras*, *Erfoudites*, *Platyclymenia*, and *Fasciclymenia* are also known from beds above the black shales.

The three localities analysed at Beul, Kattensiepen, and Ense show different distributions of the three ammonoid morphs. From the nodules between the *annulata* Black Shales at the Beul locality, 460 ammonoid specimens were recorded. The platyclymeniid morph is represented by 54%, the cyrtoclymeniid morph by 3% (almost exclusively specimens of *Carinoclymenia*), and the goniatitic morph by 43%. In the Ense sample of 238 specimens which were collected from one single large limestone nodule, the ratio platyclymeniid/goniatitic morph is 43:57, and in the Kattensiepen sample of 1280 specimens (Korn, 2002*a*), it is 33:67. The cyrtoclymeniid morph is absent in these two samples (Fig. 5).

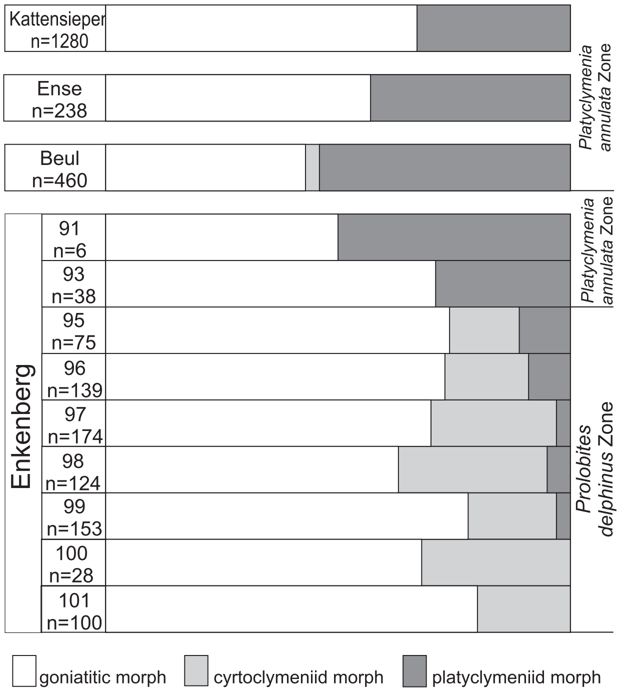

Fig. 5. Frequency of the three distinct ammonoid morphs within distinct beds of the *Prolobites delphinus* and *Platyclymenia annulata* zones in the Enkenberg section and in the *Platyclymenia annulata* Zone of the localities at Beul, Ense and Kattensiepen

Bed numbers in the Enkenberg section according to Korn and Ziegler (2002)

ABOVE THE BLACK SHALE

Collections of ammonoids from immediately above the *annulata* Black Shale are known from the Reitenberg (Becker, 1992) and from Beul. At the first locality, all specimens are crushed in shale and hence difficult to interpret, but at the second, they are well-preserved. This assemblage contains the genera *Prionoceras*, *Erfoudites*, *Platyclymenia*, and *Fasciclymenia*, i.e., genera of the spectrum known from the nodules between the two black shale horizons.

The next faunal complex is best represented at the section above the Beringhausen tunnel, where an assemblage of the genera *Sporadoceras*, *Nodosoclymenia*, and *Protoxyclymenia* occurs one metre above the limestone bed with *Platyclymenia annulata*. This assemblage can already be regarded as belonging to a younger *Protoxyclymenia dunkeri* Zone.

THE FAUNAL TURNOVER

According to present data, there is no single known ammonoid species in the Rhenish Mountains that has a stratigraphic range extending from the *Prolobites* limestones into the *Platyclymenia annulata* Zone. Of the 16 genera within the *Prolobites delphinus* Zone, only five are present in the limestone nodules within the *annulata* Black Shale. These data suggest a major extinction event, but one has to keep in mind that some of the genera, e.g. *Sporadoceras* and *Cyrtoclymenia*, reappear above the *Platyclymenia annulata* Zone, and that others, e.g. *Rectoclymenia*, *Genuclymenia*, *Stenoclymenia*, and *Sulcoclymenia*, have probable descendants in horizons younger than the *Platyclymenia annulata* Zone. If these data are taken into account, only a few of the genera became extinct without descendants near the top of the *Prolobites delphinus* Zone, e.g. *Araneites*, *Hexaclymenia* and *Pricella*. Of these, *Pricella* and *Hexaclymenia* have not even been recorded from the topmost bed of the *Prolobites delphinus* Zone. Such an extinction rate, approximately 20% of the genera within one zone, is not an unusual pattern in the succession of the Late Devonian ammonoid zones. This means that, if at all, there is only a very small-scale extinction event (House, 2002).

The faunal turnover near the boundary between the *Prolobites delphinus* Zone and the *Platyclymenia annulata* Zone, however, cannot be regarded as a local phenomenon that is restricted to the Rhenish Mountains. Very similar patterns are known from the Southern Urals (Bogoslovsky, 1969, 1971, 1981), though not fully investigated, and from the eastern Anti-Atlas of Morocco (Korn, 1999; Becker *et al*., 2002). In the Southern Urals, *Sporadoceras*-, *Prolobites*- and *Cyrtoclymenia*-dominated assemblages are replaced by faunas dominated by *Prionoceras* and *Platyclymenia*, just as in the Rhenish Mountains. *Sporadoceras* and *Prolobites* are much less common in the Anti-Atlas, and hence the faunal turnover is less sharp in that region.

The biometric analysis of the ammonoid species of the *Prolobites delphinus* Zone and *Platyclymenia annulata* Zone leads to the conclusion that the general pattern of morphospace occupation of both time intervals is quite similar. A principal components analysis was carried out, including the conch parameters: whorl expansion rate, umbilical width index, conch

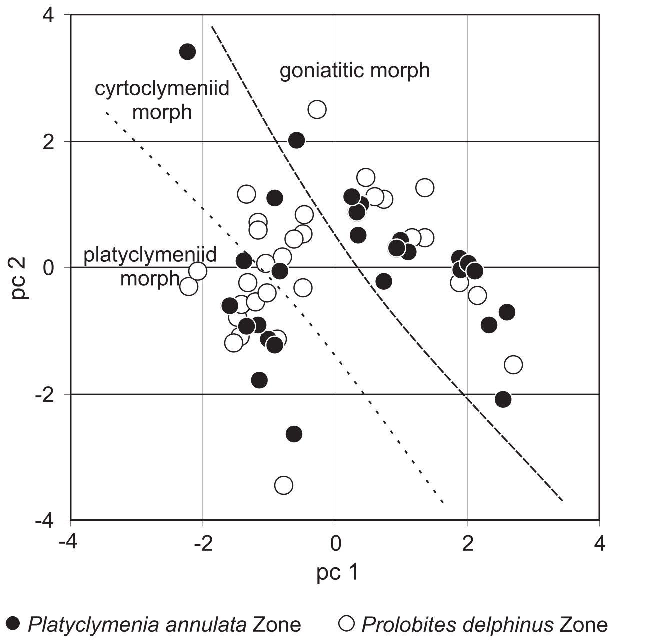

Fig. 6. Bivariate plot of the principal component analysis of the ammonoid taxa occurring in the *Prolobites delphinus* and *Platyclymenia annulata* zones of the Rhenish Mountains

Note close similarities in the distribution patterns of both ones; pc 1 and pc 2 refer to principal components 1 and 2, respectively width index, and imprint zone rate. The first two axes of the principal components analysis are composite independent characters (Fig. 6) and show very similar distributions for both time intervals, with only one exception, *Carinoclymenia beuelensis*, which represents a remote morphology present in the fauna of the *Platyclymenia annulata* Zone. Figures 5 and 6 demonstrate that the ammonoids do not show a blooming of specialized taxa, as presumed by Walliser (1996, p. 239).

Of the three ammonoid morphs occurring in the *Prolobites delphinus* Zone, only one, the cyrtoclymeniid morph, suffered at the *annulata* Black Shale. The goniatitic morph as well as the platyclymeniid morph were not affected, although an almost complete "overturn" of the genera spectrum took place. The very common sporadoceratids are almost absent in the Rhenish assemblages of the *Platyclymenia annulata* Zone, and *Prolobites* is also rare, except for the locality at Kattensiepen. Of the platyclymeniid morph, *Stenoclymenia* and *Sulcoclymenia* appear to be missing in the *Platyclymenia annulata* Zone, but *Platyclymenia* and *Pleuroclymenia* were not harmed at all.

CONCLUSIONS

The ammonoid diversity pattern at the *annulata* Black Shale shows, in superficial overview, some similarities with the Hangenberg Black Shale near the close of the Devonian (e.g. Walliser, 1996). However, the main difference between the two is that the rate of extinction is much higher in the latter, and that there are only a few surviving lineages that eventually reappear. The Hangenberg Event is one of the major crises in the evolution of the ammonoids and caused an almost-complete extinction of the entire clade (e.g., Korn, 1993). Only two groups of ammonoids are known from both sides of the Hangenberg Black Shale, the prionoceratids and the cymaclymeniids, of which the latter became extinct without descendants soon after the Hangenberg Event. The occupation of morphospace shows a deep impact, and complete recovery did not take place until at least four zones after the event (Korn, 2000). This means that, in contrast to the "*annulata* Event", the Hangenberg Event is recognisable in diversity as well as morphological disparity. The same is true for the Upper Kellwasser Event (Frasnian-Famennian Boundary), where eleven ammonoid genera became extinct without Famennian descendants (House, 2002). To conclude, the "*annulata* Event" can only, as pointed out by Walliser (1996, p. 239) and House (2002, p. 18), be regarded as a discrete sedimentary dysoxic perturbation, but not as an evolutionary event, with regard to the ammonoid record.

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