Palynomorphs (miospores, acritarchs, prasinophytes) before and during the Hangenberg crisis

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Above the richly documented palynomorphs (Becker *et al*., 1974) characterizing the lower part of the uppermost Famennian ("Strunian"), one can subdivide the Hangenberg crisis in 3 parts: "a lower crisis interval which started as a prelude with a minor eustatic sea-level fall, followed rather abruptly by pan tropically widespread black shale deposition"; "a middle crisis interval which is characterized by a gradual but major sea-level fall of glacio-eustatic origin"; "an upper crisis which is characterized by post-glacial transgression" (Kaiser *et al*., in press).

The base of the "Strunian", in the reference section of Chanxhe, falls within the higher LL (*lepidophyta–literatus*) Zone, more or less at the morphometric change in *Retispora lepidophyta,* ranging from a majority of large specimens (shale 112 and below) to a majority of small specimens (shale 116 and above) (Maziane *et al*., 2002). The foraminifer *Quasiendothyra kob. kobeitusana* first occurs in limestone 115; the conodont *Bispathodus ultimus* (Upper *expansa* Zone) first occurs in limestone 111. Indeed, a correlation with the Refrath borehole (western Germany, *ca.* 100 km east of Chanxhe) using the morphometric changes in *R. lepidophyta*, shows that the middle *expansa* conodont Zone (and *hemisphaerica–dichotoma* ostracod Zone) corresponds to shales 101 to 112 at Chanxhe (Streel & Hartkopf-Fröder, 2005). The morphometric change of *R. lepidophyta* allows correlations between several sections (outcrops and boreholes) in eastern Belgium (Streel, 1966; Maziane *et al*., 2002). Acritarchs and prasinophytes are particularly abundant in the "Strunian" at Chanxhe. The acritarchs belong to *Micrhystridium, Solisphaeridium, Stellinium* and *Verhyhachium* (Maziane, 1999; Maziane *et al*., 2007). A small percentage of *Maranhites* suggests locally a high sea-level. Higher in the section, acritarchs decrease in abundance and diversity, while miospores abundance is increasing, suggesting a closer shoreline. A lowering of the sea-level is corroborated by the occurrence above bed 123 of shallow water ostracods species belonging to the genera *Platycopina* and *Paraparchiticopina* (Casier *et al*., 2005). Prasinophytes (small *Leiosphaeridia*, small and large *Gorgonisphaeridium*, *Synspheridium, Cymatiosphaera, Pterospermella*) become more and more abundant, suggesting a shift to a lagoonal facies. The first occurrence of the large prasinophyte *Gorgonisphaeridium winslowiae,* above the first level of *Quasiendothyra kobeitusana* (Maziane & Vanguestaine, 1997; Maziane *et al*., 2002) is also a good characteristic of this timespan.

The lower crisis interval starts with the first occurrence of *Indotriradites explanatus* marking the base of the LE (*lepidophyta–explanatus*) Zone. At Chanxhe (shale 146), it corresponds to a major drop in the acritarch diversity and a complete dominance of small *Gorgonisphaeridium* and small *Leiosphaeridia*. These prasinophytes have affinities with cold water and dysoxic-anoxic facies (Tyson, 1995: 301). They are dominant, if not exclusive, until the top of the section (limestone 162) where a fault interrupts the sequence. Intensive work on intercalated shales (bed 156, for instance) showed the presence of *R. lepidophyta* and *I. explanatus* but did not provide other diagnostic miospores. Therefore, several attempts to complete the data until the base of the Hastière Limestone were made with the Royseux section in the Hoyoux valley (Austin *et al*., 1970; Maziane *et al*., 2002), and with the Rivage Pont de Scay section in the Ourthe valley (Sautois, 2007; Prestianni *et al*., in prep.). The LE Zone is confirmed everywhere. The Rivage Pont de Scay section was obviously used by Kumpan *et al.* (2014), although this was not clearly specified. A short positive carbon excursion is showed by these authors in that section and is tentatively correlated with a comparable carbon excursion in the Carnic Alps. It can be correlated with the lower part of the LE Zone in Chanxhe. In the Rhenish Massif, the LE zone is known from the highest part of the early *praesulcata* conodont Zone, in the upper part of the Wocklum Limestone at the Hasselbachtal section (Higgs & Streel, 1984). Ostracod transition between the *hemisphaerica–dichotoma* Zone and the *hemisphaerica–latior* is also firmly correlated with the LE Zone in Hasselbachtal section (Bless & Groos-Uffenorde, 1984). In more offshore localities, the Drewer sandstone, known within the LE Zone between the Wocklum Limestone and the HBS, is in the same stratigraphic position as the short positive carbon excursion in Rivage Pont de Scay and might correspond to a first short-termed glacial advance. The LE zone is followed by the LN (*lepidophyta–nitidus*) Zone which starts with the Hangenberg Black Shales (HBS), on top of the Wocklum limestone (Higgs & Streel, 1994).

The middle crisis interval starts in the Rhenish Massif, above the HBS in the Hangenberg shales (HS) and peaks in the Hangenberg Sandstone (HSS) immediately below the Stockum Limestone. The LN zone in the Rhenish Massif is based on rather poor assemblages with a small number of miospores of limited species diversity. However, in several localities, *Verrucosisporites nitidus* is accompanied by *Vallatisporites vallatus* (Higgs & Streel, 1984). This is consistent with the LVa (*lepidophyta–vallatus*) Zone defined in the Amazon Basin in Brazil by Melo & Loboziak (2003) where LE–LN assemblages have been recognized and renamed Rle–LVa. Diamictites and glacio-marine strata are common in these intervals. However, the Rle is considered possibly representing an impoverished variant (ecofacies?) of the LVa in places where *Verrucosisporites nitidus* and *Vallatisporites vallatus* are absent. Therefore, it is difficult (Streel *et al*., 2013) to accept the conclusion made by Wicander *et al*. (2011) that the diamictite sequence of the Itacua Fm they have studied in Bolivia was a composite representing several deglaciation events starting in the LL through the LE and LN Zones. However, on the evidence provided above in eastern Belgium and western Germany, a glaciation starting in the LE Zone and culminating in the LN Zone, interrupted by the transgressive HBS is well possible. In the Stockum trench II (Higgs *et al*., 1993; Streel, 1999), the more sandy part (HSS), corresponding to the maximum of the regression, contains an atypical LN assemblage of miospores, very rich in *Retusotriletes* ssp. and where *R. lepidophyta* is rare (about 1% but a consistent element). This atypical LN Zone has also been found from the top of the Old Head of Kinsale Fm, in southern Ireland, at the base of the regional Courceyan Stage (Higgs *et al*., 1988) as well as in the Kowala Fm of the Holy Cross Mountains in Poland (Marynowski & Filipiak, 2007). The LE-LN Zones or equivalents are well represented around the world. In north America, for instance, they allowed to date for the first time (Sandberg *et al*., 1972) not only the Bedford Shales in Ohio (see also Molyneux *et al*., 1984), but also the Sappington Shales in Montana (see also Warren *et al*., 2014). Also for the first time, using miospores, the lower part of the continental Pocono Fm in western Pennsylvania was dated as uppermost Famennian (Streel & Traverse, 1978). Laminites intercalated within diamictites (Brezinski *et al*., 2010) in the Spechty Kopf Fm of eastern Pennsylvania carry also well preserved LN assemblages (Richardson *et al.*, 2006, Streel *et al*., in prep). Correlation of the LE–LN Zones with equivalent in New York State and Pennsylvania Catskill Fm is still under study (Avkhimovitch *et al*., in prep.), emphasizing the range of changes through time of several new species of *Vallatisporites.* Correlation between Western Europe and the Russian Platform was given by Byvsheva *et al.* (1984), with Poland and Belarus, by Avkhimovitch *et al.* (1993).

The upper crisis interval starts in the Rhenish Massif above the atypical LN Zone where a transgression reflects a post-glacial eustatic rise. The next miospore zone, the VI (*Vallatisporites verrucosus–Retusotriletes incohatus*) Zone is poorly defined, above all by the disappearance of several taxa. Not only *R. lepidophyta* but also *Rugospora flexuosa, Diducites versabilis* and *D. plicabilis. V. verrucosus* is not diagnostic as it first occurs in the LE Zone. The VI Zone is dominated by simple laevigate or microapiculate forms such as *Retusotriletes incohatus* or *Apiculiretusispora coniferus,* known from older zones, but which may comprise here more than 50% of the total spore assemblage. The base of the VI Zone is well displayed, a few cm or dm. below the still official D–C Boundary, in trenches or borehole like the Hasselbachtal borehole (Higgs *et al*., 1993), the Seiler trench (Ziegler & Sandberg, 1984) and the Stockum trench (Alberti *et al*., 1974; Higgs *et al*., 1993). In the last-one, it coincides approximately with the Stockum limestone where the *Protognathodus kockeli* conodont zone is often present.

This limit is consistent with a major change in the terrestrial flora underlined by their deep change in miospores production all around the world.

A new D–C limit. The advocacy of Walliser (1984) for a natural D–C limit at the base of the HBS level is difficult to support from a palynological point of view. For instance in North America, it would return the Bedford and Sappington Shales in the Mississippian. It would also place the Gondwanan glaciation straddling the D–C limit. The contact between the top of the miospore atypical LN Zone (or the LN–VI limit) and the conodont *P. kockeli* is the most suitable candidate to characterise a "near event" limit and then replace the "*sulcata* limit". Renewed trenches like Stockum II might display this contact accurately. By the way, trench protected by a permanent roof is used to protect the stratotype of the Eifelian Stage in Germany. Such new limit would not disturb too much the existing correlation of the D–C Boundary around the world.

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