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LATE CRETACEOUS (SANTONIAN-MAASTRICHTIAN) SEDIMENTATION RATES IN THE MAASTRICHT (NL), LIÈGE/CAMPINE (B) AND AACHEN (D) AREA

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ABSTRACT. Analyses of samples recovered from boreholes and quarries have allowed a more detailed insight into the thickness and composition of Upper Cretaceous sediments in the study area. From a survey of sedimentological and chronostratigraphical data, it is concluded that these data are still too limited for calculations of real sedimentation rates. The values presented herein for these rates have been determined by combining maximum thickness of the deposits and minimum and maximum duration of the time units distinguished. It is obvious that the results obtained should be used with extreme caution.

KEYWORDS: Sedimentation, Late Cretaceous, Santonian, Campanian, Maastrichtian, The Netherlands, Belgium, Germany.

RESUME. Des analyses d'échantillons provenant de carottes de sondages et de carrières ont permis une meilleure compréhension de l'épaisseur et de la composition des sédiments du Crétacé Supérieur de la région étudiée. D'après une étude de données sédimentologiques et chronostratigraphiques, on conclut que ces données sont toujours trop limitées pour servir de base de calcul d'un réel taux de sédimentation. Les valeurs présentées ici pour ces taux ont été déterminées par combinaison de l'épaisseur maximale des dépôts et des durées maximales et minimales des périodes distinguées. Il est évident que les résultats obtenus doivent être utilisés avec une extrême précaution.

MOTS-CLES: Sédimentation, Crétacé Supérieur, Santonien, Campanien, Maastrichtien, Pays-Bas, Belgique, Allemagne.

1. INTRODUCTION

Over recent years, samples from more than a hundred boreholes drilled on Belgian as well as Dutch territory, which penetrated the entire Cretaceous sequence have been analysed for lithological features, foraminiferal assemblages and bioclast contents (P. J. Felder *et al.*, 1985; P.J. Felder, 1994). Comparable studies have been carried out on samples collected in quarries and also from residual deposits of Late Cretaceous age, found on the Ardennes plateau (Bless *et al.*, 1991). In addition, many macrofossils (Belemnites and Ammonites in particular) which allow a detailed biozonation and correlation of the Cretaceous strata in the area, have been collected. As a result of this, a more detailed insight has been gained into the geological setting of the area surrounding the type locality of the Maastrichtian Stage (Fig. 1).

The Upper Cretaceous strata in the area have in part been deposited in cyclothemes (W.M. Felder, 1976), which fit within the scheme of the sequence stratigraphy of, for instance, RGD en NOGEPA 1993, (Fig. 2). Sediment alterations in the area, such as sand-clay (Albers, 1976), chalk-flint, coarse-grained/fine-grained, indurated/non-indurated layers (Albers *et al.* 1978; Albers & Felder, 1979) are of note. Certain types of fossil, e.g. foraminifera, bryozoans, oysters, belemnites and crinoids (P.J. Felder 1981; P.J.Felder *et al.* 1985) also show regular cycles. In part, these alterations are regular to such extent that they have been described to astronomical cyclicity (P.J. Felder, 1981; Zijlstra, 1994). Zijlstra notes that,

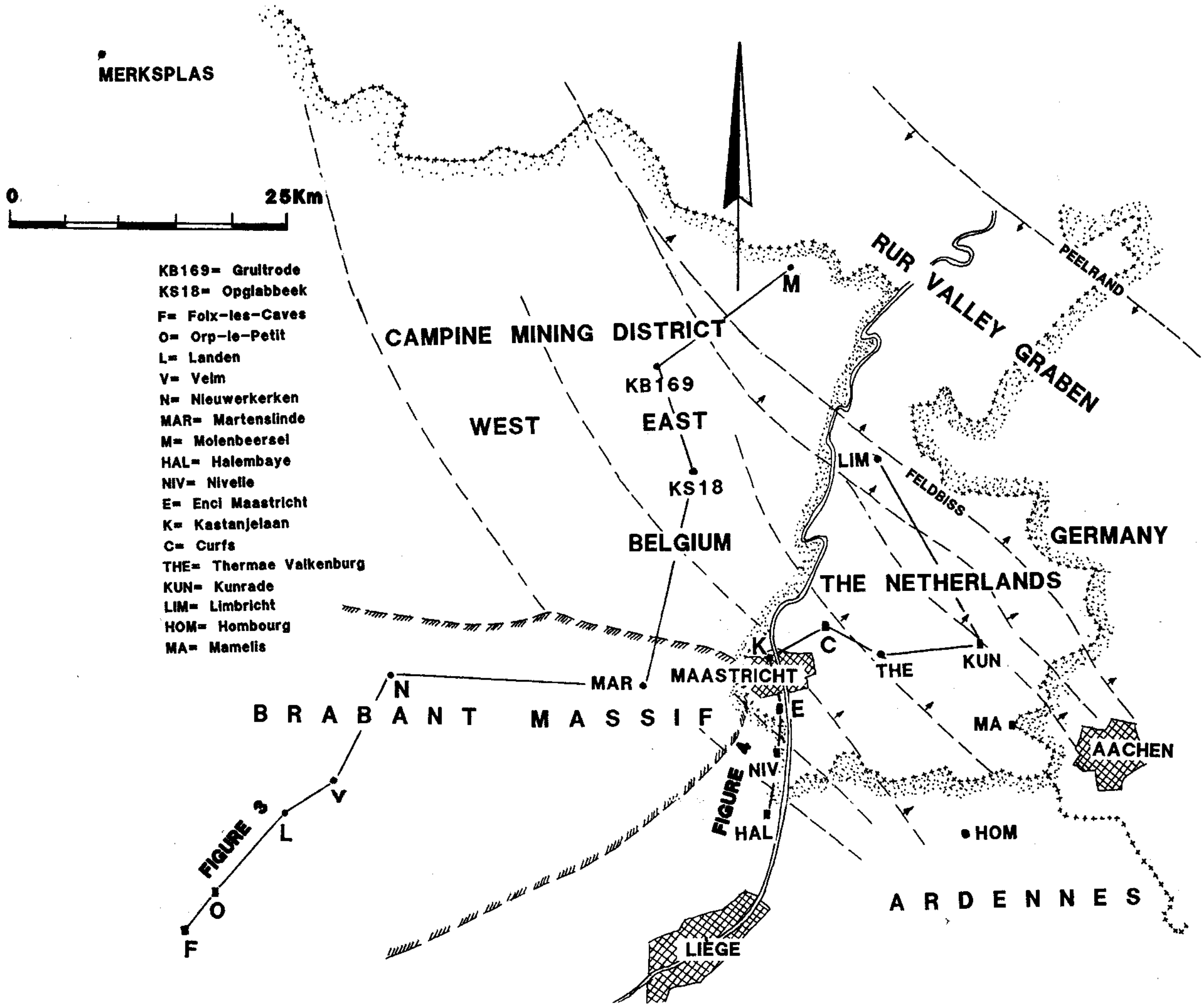

Figure 1. Locality map of Limburg and Belgian Campine area showing location of exposures and boreholes referred to in the text.

'It is concluded that the (Tuffaceous) chalk was deposited at rates of cm-dm per 1000 years and that the regular bedding reflects the influence of cyclic variation of storm intensity, as a result of periodic variations in the Earth's orbital elements'.

The sampling of these Upper Cretaceous deposits becomes increasingly more detailed. Sample series have been taken in distances of 5 and 10 cm, and these have already been analysed. Such sample series reveal cycles not recognised previously. The question as to the time frame within which these cycles formed becomes more prominent.

Up to now, no attempt was made to calculate the sedimentation rates in the study area, on account of a lack of sedimentological data and sufficient chronostratigraphical datum points. Now that a more detailed insight has been gained into the thickness of the lithological units and their biostratgraphical placement a first attempt at calculating sedimentation rates may be made.

2. SEDIMENTOLOGICAL DATA

Late Cretaceous sedimentation in the area has been shown to be tectonically influenced to a large extent (Bless *et al.*, 1987; Rossa, 1987). Lithofacies differences could thus in part be explained. Variations in thickness of the various deposits were also ascribed to the impact of synsedimentary tectonic movements. Of particular importance was the fact that for the first time it was realised that resting on hiatuses or condensed sequences were (much) thicker strata deposited during subsequent periods. The total thickness of the strata thus remained more or less equal.

Only recently have arguments been put forward in favour of an interpretation of the Late Cretaceous strata as shallow-water deposits laid down at water depths of possibly well below 100 m (Bless, 1991). Previously depths of up to 300 m (even up to 650 m) had been postulated (Hancock & Kauffman, 1979).

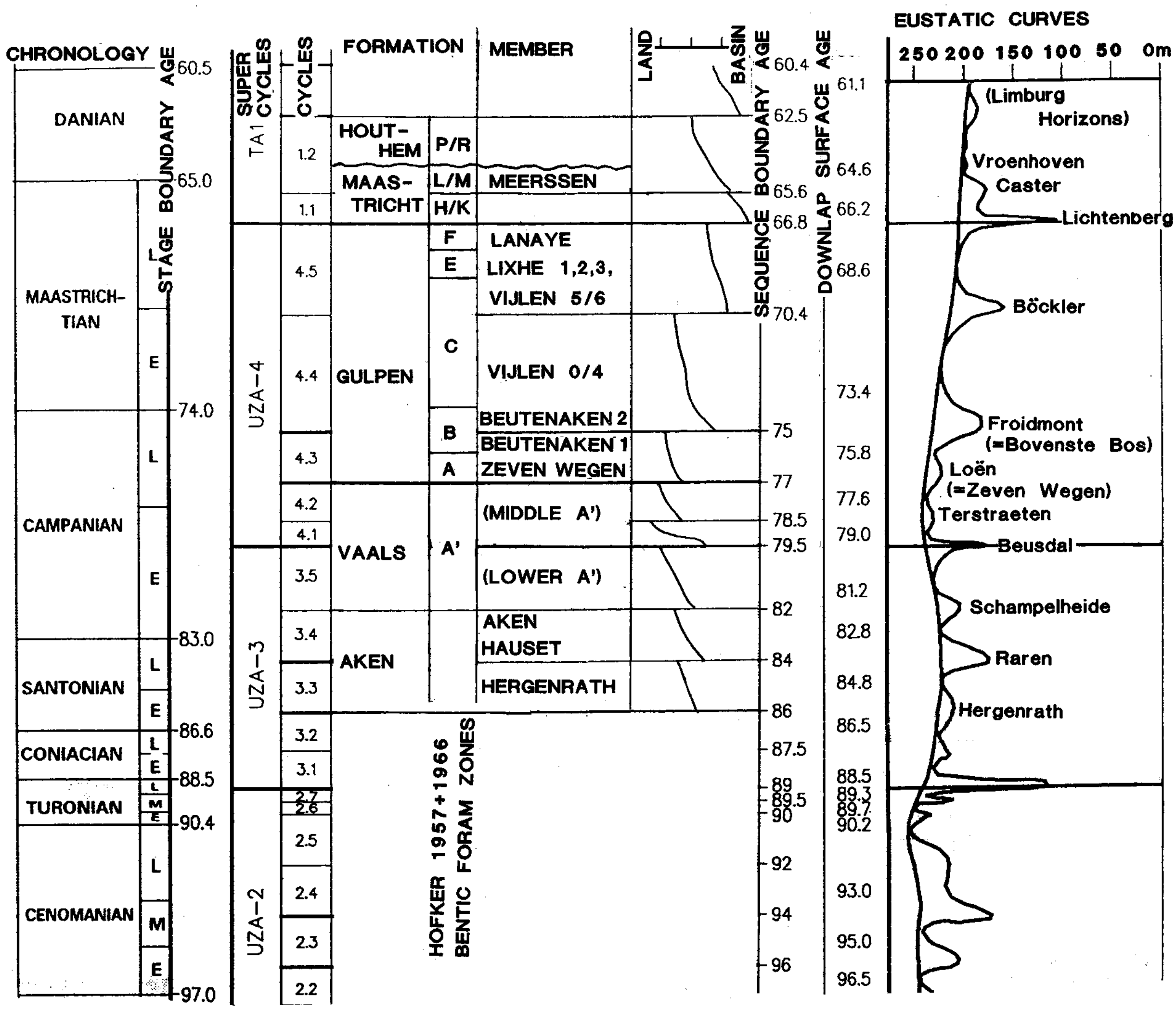

Figure 2. Comparison between the regional lithostratigraphic successsion in the Maastricht-Liège-Aachen area and the eustatic sequence stratigraphy of RGD & NOGEPA 1993.
Bentic foram zones in Vaals and Gulpen Formation after Hofker 1957 and 1966. (Hofker's subzone Upper A', is according to Felder & Bless 1989, the equivalent of his zone A.

Already at an early stage the Late Cretaceous strata in the area were subdivided into a sandy/clayey facies (Aken and Vaals Formation) and a fine- to coarse-grained chalk/calcarenite facies (Gulpen and Maastricht Formation) (Table 1), but only recently has it been realised that these units in fact represent two different transgressions. The transgressional sandy/clayey deposits originated in the Northeast during a period which saw the uplift of the Rur Valley Graben through inversion and subsidence of the Ardennes and the Limburg/Campine area (Bless & Fernández-Narvaiza 1994). During this transgression the strongest subsidence occurred in the Southeast along the uplifted Rur Valley Graben (Kunrade-Aachen). The chalky deposits were laid down during a transgressional pulse from the Southwest. At first fine-grained chalks (Gulpen Formation) were deposited. The strongest subsidence of the area then occurred in the Northwest (Merksplas, Belgium). The coarse-grained chalks of the Maastricht Formation originated as 'shoals of calcareous sand', and now rest upon older fine-grained strata and upon older sandy deposits in the Northeast.

Despite these new data, sedimentoligical data in the study area are still very limited.

3. CHRONOSTRATIGRAPHIC DATA

The number of available K-Ar datings of glauconite (Priem *et al.*, 1975) are at present rather limited, all invariably ranging between 66.7- and 76.5 Ma ± 2-2.5 Ma.

Jagt & Kennedy (1994) have recently proposed an age slightly younger than 69.42 ± 0.37 Ma for the Lower/Upper Maastrichtian boundary, on the basis of the occurrence of the ammonite *Jeletzkytes dorfi*.

Table 1. Litho- and chronostratigraphy of the Late Cretaceous of Southern Limburg (The Netherlands).

Uhlenbroek 1912	Hofker 1966	Felder W.M. 1975 MEMBER	FORMATION	AGE
Md	P N	GEULHEM	HOUTHEM	DANO/MONTIAN
	M L	MEERSSEN	MAASTRICHT	late LATE MAASTRICHTIAN
Mc	K	NEKUM		
Mb	I O J	EMAEL SCHIEPERSBERG		
Ma	H G	GRONSVELD VALKENBURG		
Cr4	F	LANAYE	GULPEN	early LATE MAASTRICHTIAN
Cr3c Cr3y	E	LIXHE 1,2,3		
Cr3b	C D	VIJLEN		EARLY MAASTRICHTIAN
	B	BEUTENAKEN		LATE CAMPANIAN
Cr3a	A	ZEVEN WEGEN		
Cr2	A'		VAALS	EARLY CAMPANIAN
Cr1		AKEN HAUSET HERGENRATH	AKEN	SANTONIAN

Table 2. Numerical age of Late Cretaceous stages (in Ma) according to various authors.

	Obradovich & Cobban 1975	van Hinte 1976	Ernst et al 1979	Thierstein 1976	Odin 1984	Kent & Gradstein 1985	Bayer 1987	Harland et al 1990 in RGD & NOGEPA 1993	Duration Min.	Max.	
TERTIARY	65	65	65	65	65	66.5	64.8	65			
MAASTRICHTIAN	70.5	70	71	70.5	72	74.5	71.5	74	5	9	Ma
CAMPANIAN	82	78	82	82	83	84	81.1	83	8	11.5	Ma
SANTONIAN	86	82	86	84.8	86	87.5	85.4	86.6	2.8	4.5	Ma

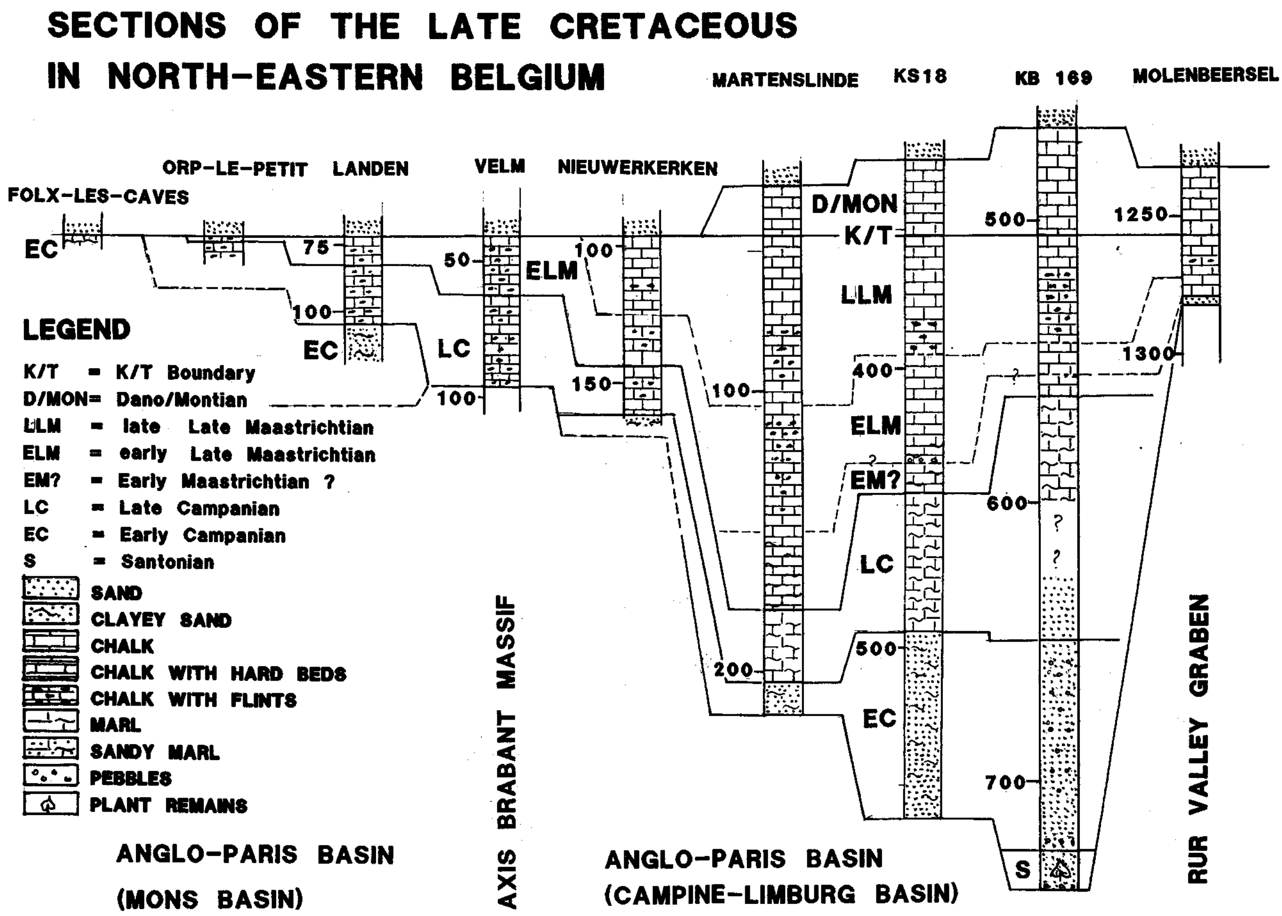

Figure 3. Section through the Campine-Limburg basin in Northeast Belgium.

Incidentally, the above figures correspond fairly well with those obtained from the literature on the Late Cretaceous (Tab. 2). It is evident that the limited number of data currently available (which are also difficult to tie in exactly with the scheme used at present) are insufficient to calculate sedimentation rates from. Consequently the data given in Table 2 here are used.

4. SEDIMENT THICKNESS

A section through the Campine-Limburg basin (Fig. 3) clearly illustrates the considerable differences in thickness of the various strata. The greatest thicknesses have been encountered in those boreholes that were drilled on tectonic blocks parallel to the Rur Graben (boreholes KS 18 and KB 169). The thinnest sequences are found on the Brabant Massif and in the Rur Graben.

A section through a number of boreholes and exposures in the Province of Liège (Belgium) and the Province of Limburg (The Netherlands) (Fig. 4) illustrates that the Cretaceous strata vary considerably in thickness. Figure 4 also shows that the thickness of Campanian strata is greatest where the overlying Maastrichtian deposits are thin and that the latter reach a much greater thickness than usual where the Campanian is thin or absent altogether.

However, the differences illustrated in these sections are in fact not the maximum differences, which may be even greater. In some places Late Cretaceous strata are missing altogether (Northeast of Aachen) and elsewhere very thin (borehole Limbricht 22 m).

Separate units may also differ strongly in thickness, for instance, Santonian strata are missing in the Merksplas borehole, but in the Hombourg borehole they reach some 25 m. In the Aachen-Hergenrath area the maximum thickness of the Santonian is estimated to be 60 m (W.M. Felder, 1975).

Furthermore we must keep in mind that we indeed know something about the thickness but less about sedimentation and hiatuses.

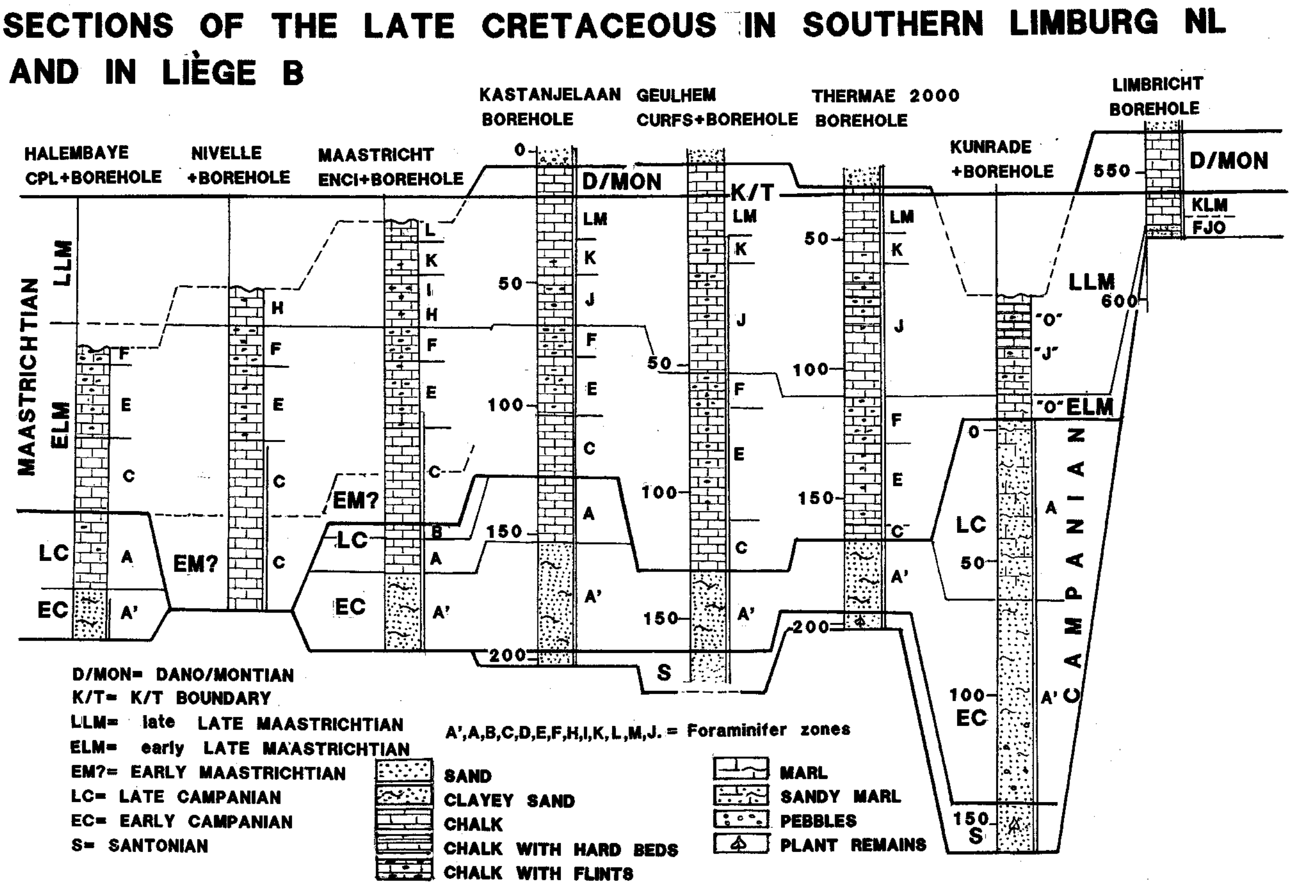

Figure 4. Section through the Northern part of Liège Province (Belgium) and Southern Limburg (The Netherlands).

SANTON	CAMPANIAN		MAASTRICHTIAN			AGE
	EARLY	LATE	EARLY	LATE ELM	LATE LLM	
4.5Ma	5.75Ma	5.75Ma	4.5Ma	2.25 Ma	2.25 Ma	Max. duration
2.8Ma	4Ma	4Ma	2.5Ma	1.25 Ma	1.25 Ma	Min. duration
60m	70m	128m	60m	56.5m	80.5m	Max. thickness

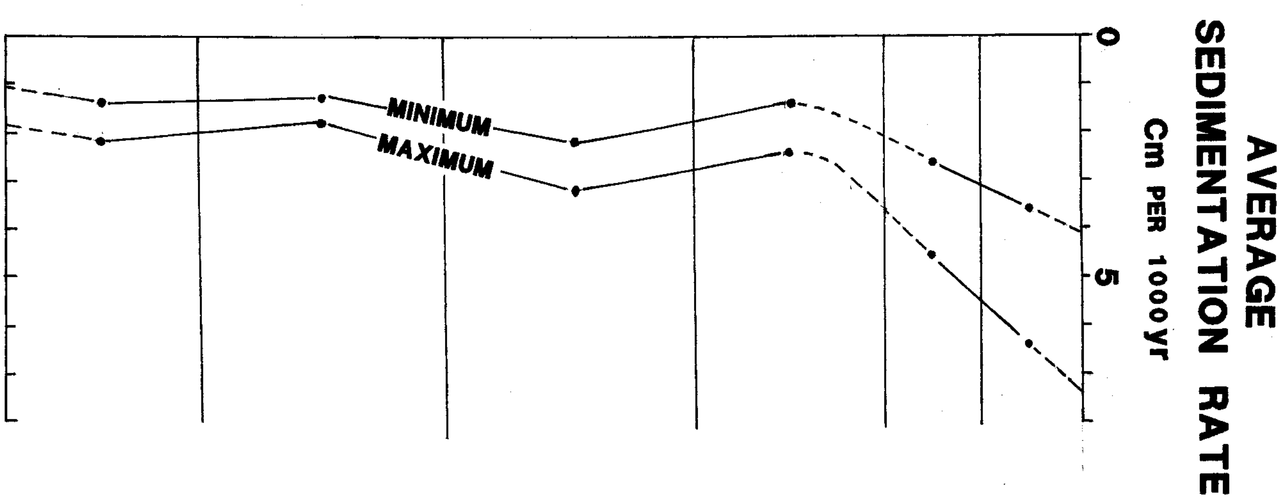

Figure 5. Graphic representation of sedimentation rates during the Late Cretaceous in Southern Limburg.

5. CALCULATING SEDIMENTATION RATES

Obviously, calculating sedimentation rates for those areas where virtually no sediments or none at all were laid down is pointless. It is much more important to try and obtain data on those areas where sediments reach their greatest known thickness. Figures thus obtained represent averages of the maximum sedimentation within a certain time interval (Fig. 5).

The localities of the greatest thickness (Fig. 5) are mentioned further on.

Below we shall try to obtain the sedimentation rates, mainly for lithostratigraphical units as recognised in the described area (Table 1), based on the minimum and maximum duration for the chronological stages as given in Figure 5.

5.1. SANTONIAN

Aken Formation

Assuming a maximum thickness for this Formation of 60 m in the Aachen area, average sedimentation rates during the Santonian would have been: maximum 2.14 cm/1000 yr and minimum 1.33 cm/1000 yr.

5.2.CAMPANIAN

Vaals Formation and lower part of Gulpen Formation

The Campanian in the study area is lithologicaly divided into a sandy part (Vaals Formation) and a chalky part (lower part of the Gulpen Formation). Based on Belemnites andAmmonites the larger part of the Vaals Formation is of Early Campanian age. The chalky part belongs, also based on Belemnites, Ammonites and other macrofossil evidence, to the Late Campanian. To calculate the different lithologies, here we divide the Campanian therefor in an Early- and Late Campanian equal in time.

5.2.1. Early Campanian

Part of Vaals Formation

It is now known that but a part of the Vaals Formation is of Early Campanian age (P.J. Felder & Bless, 1989). However, in some places it is impossible to determine exactly the position of the Early/Late Campanian boundary within this unit. Near Kunrade where the Vaals Formation reaches a thickness of up to 150 m, only 70 m is of Early Campanian date (P.J. Felder & Bless, 1989).

Average sedimentation rates during the Early Campanian would have been: maximum 1.75 cm/1000 yr and minimum 1.22 cm/1000 yr.

5.2.2. Late Campanian

Upper part of Vaals Formation, Zeven Wegen Member and Beutenaken Marl and Chalk of the Gulpen Formation

The greatest thickness of the Late Campanian was found in the borehole Merksplas and amounted to 128 m.
Average sedimentation rates during the Late Campanian would have been: maximum 3.2 cm/1000 yr and minimum 2.23 cm/1000 yr.

5.3. MAASTRICHTIAN

Upper part of Gulpen Formation and entire Maastricht Formation

Like the Campanian, the Maastrichtian may be divided into an Early and a Late substage. Macrofossils collected during recent field work demonstrate that Early Maastrichtian strata occur in Limburg as well (Keutgen & van der Tuuk 1990). However, it has so far proved impossible to subdivide these strata, which explains why the Early Maastrichtian cannot be discussed but very briefly here.

We have no data about the exact duration of Early and Late Maastrichtian. Early and Late Maastrichtian are here assumed to have had the same duration.

In calculating sedimentation rates during the Early and Late Maastrichtian the dating supplied by the scaphitid ammonite species *Jeletzkytes dorfi* of slightly younger than 69.42 ± 0.37 Ma (Jagt & Kennedy, 1994) cannot be used. This dating cannot be recalculated so as to determine minimum and maximum ages as used throughout in this paper.

5.3.1. Early Maastrichtian

Upper part of the Gulpen Formation (lower part of the Vijlen Member)

The greatest thickness of Early Maastrichtian strata was found at Mamelis, Vijlen (Felder & Bless, 1994) and amounted to c. 60 m. Average sedimentation rates during the Early Maastrichtian would have been: maximum 2.4 cm/1000 yr and minimum 1.33 cm/1000 yr.

5.3.2. Late Maastrichtian

The Late Maastrichtian is represented by the uppermost part of the Gulpen Formation and the entire Maastricht Formation.

The greatest thickness of the entire Late Maastrichtian appears to be represented in the Thermae borehole at Valkenburg (Krings *et al.,* 1987) and amounted to 137 m. Average sedimentation rates during the Late Maastrichtian would thus have been: maximum 5.48 cm/1000 yr and minimum 3.04 cm/1000 yr.

The Upper Maastrichtian strata can easily be subdivided into two lithological units, one of early- (uppermost part of Gulpen Formation) and one of late Late Maastrichtian (Maastricht Formation) age. This twofold division is based mainly on differences in grain size and the occurrence of regularly deposited flint bands in the lower part. This division is also apparent in bioclast contents and foraminiferal assemblages (Hofker 1966). For the remainder of the paper the duration of the early Late Maastrichtian is assumed to have been equal to that of the late Late Maastrichtian.

5.3.3. Early Late Maastrichtian

Uppermost part of Gulpen Formation

The greatest thickness of the early Late Maastrichtian has been found at the Thermae 2000 borehole at Valkenburg: 56.5 m. Average sedimentation rates during the early Late Maastrichtian would have been: maximum 4.52 cm/1000 yr, and minimum 2.51 cm/1000 yr.

5.3.4. Late Late Maastrichtian

Maastricht Formation

The late Late Maastrichtian in the Thermae 2000 borehole reaches a total thickness of 80.5 m. Average sedimentation rates during this interval would have been: maximum 6.44 cm/1000 yr and minimum 3.58 cm/1000 yr.

6. SUMMARY

From all available data for the Late Cretaceous in the study area it is apparent that periods of no or little sedimentation alternated with periods of (high) sedimentation. For instance, in places where the Campanian is missing the overlying Maastrichtian compensates for this in extra thickness, and where the Campanian reaches a comparatively great thickness, the Maastrichtian is relatively thin. This explains why only the maximum thickness of units was used to calculate sedimentation rates.

On the basis of maximum sediment thicknesses and the longest and shortest duration of the various stages deduced from litarature data, average sedimentation rates for the Late Cretaceous of Limburg, Liège, Campine and Aachen areas have been calculated. These rates clearly differ from the Santonian to the Maastrichtian (Fig. 5).

However, 'real' sedimentation rates must have differed from one locality to the next, in view of large differences seen in sediment thickness. Figures calculated herein should therefore be used with extreme caution.

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