

LITHOFACIES AND PALEO GEOGRAPHIC DISTRIBUTION OF THE LATEST CRETACEOUS DEPOSITS EXPOSED IN THE HINNISDAEL UNDERGROUND QUARRIES IN VECHMAAL (COMMUNE HEERS, BELGIAN LIMBOURG)

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(4 figures , 1 table)

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Introduction

The Maastricht Formation, of late Maastrichtian to earliest Danian age, consists of cream to yellow porous calcarenites, or weakly cemented bioclastic grainstones, with some flint nodules and silicified levels. During the time of deposition of the Maastricht Formation the Roer Valley Graben was flooded for the first time since the beginning of the Cretaceous transgression over the Campine basin and adjacent Brabant Massif, hence no detrital sediments were sourced from this area. High bioproductivity in the well-aerated shallow marine setting with warm bottom conditions, led to rapid accumulation of bioclasts. Sedimentation rates of the bioclastic grainstones attained 10 cm/ka (Vonhof & Smit, 1996).

Hardgrounds and coarse-grained fossil hash beds form the basis of the lithostratigraphic succession in 6 members (W.M. Felder, 1975; cf. Robaszynski et al., 2002).

The upper Meerssen and Nekum Members (formerly denominated as 'Md' and 'Mc' respectively, Robaszynski, 2006) are commonly grouped in the informal 'upper Maastricht Formation'. They are overlying fine grained flint-bearing bioclastic grainstones of the 'lower Maastricht Formation' (Valkenburg to Emael Members). In the subcrop zone they are overlain either by fine to coarse grained bioclastic grainstones of the Houthem Formation of Paleocene (Danian) age or by younger unconformable Cenozoic strata.

The occurrence and facies characteristics of the Meerssen and Nekum Members are well documented by Felder & Bosch (2001) for the outcrop zone in the Mergelland of Dutch South Limburg. Outside this area, and despite some limited biostratigraphic controls, the lithological distinction of the Maastricht and Houthem Formations, a fortiori of their constituting members, has been at most tentative.

Felder (1981) developed a method for semi-quantitative analysis of bioclasts which resulted in a sequence of ecozones based on bioclast assemblages. This method proved reliable for the detailed subdivision of the Campanian to Danian carbonate-dominated sequences in both outcrop and subcrop areas (Felder, 1994, 2001). Ecozones reflect the biota with calcareous skeletons present in the cosystem and thus depend on ecological factors such as water depth and temperature gradient, turbidity, water currents, density of the sediment and rate of sediment accumulation. The ecozone stratigraphy can be used as a proxy for lithostratigraphy, allowing recognition of the presence or absence of the different members of the Maastricht Formation (Felder et al., 1985).

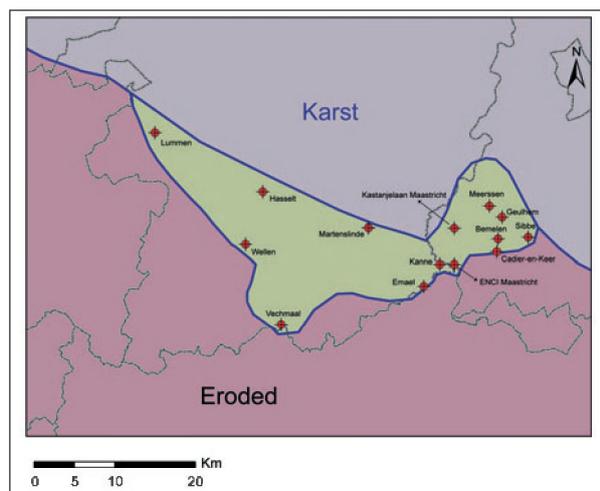


Figure 1: Geographic occurrence of the upper Maastricht Formation in the type area, in between the terminal Cretaceous inversion zone of Roer Valley Graben and Campine Basin to the North, and the Cenozoic uplift and erosion zone on the Brabant Massif to the South.

Lithostratigraphy and lithofacies of the calcarenite in the Hinnisdael underground quarries

The Hinnisdael underground quarries form the westernmost - thus farthest from the type location - still

accessible extraction site of Maastricht limestone in the 'Mergelland' of southern Limbourg (Fig. 1). They were exploited for building stone and soil conditioner by room and pillar mining. The underground quarries allowed detailed lithofacies descriptions in combination with ecozone stratigraphy (Dusar et al., 2005). Two members of the Maastricht Formation are exposed and consist of slightly different rock types, hence leading to different exploitation methods and cave morphologies (Fig. 2).

The older Nekum Limestone is exposed over 8 m and consists of cream-yellow coloured, fine-grained calcarenites with frequent fossil debris beds, organised in wavy bedding. Macrofossils are mostly composed of echinoids, serpulids and oysters. The Kanne Horizon constitutes a persistent fossil bed, rich in serpulids, near the top of the unit. Two levels with complete large echinoids (Hemipneustes beds) occur above and below the Kanne Horizon. Flint and tauw (silicified fossil beds) also occur in two distinct horizons towards the base of the Nekum Member and around the Kanne Horizon respectively. Total thickness of the Nekum Member will be in the order of 10 m, based on the observation that its coarser-grained basal sequence has not been reached in the underground quarries and taking into account the rather reduced total thickness for the Maastricht Formation in the region, which is in the order of 30 m.

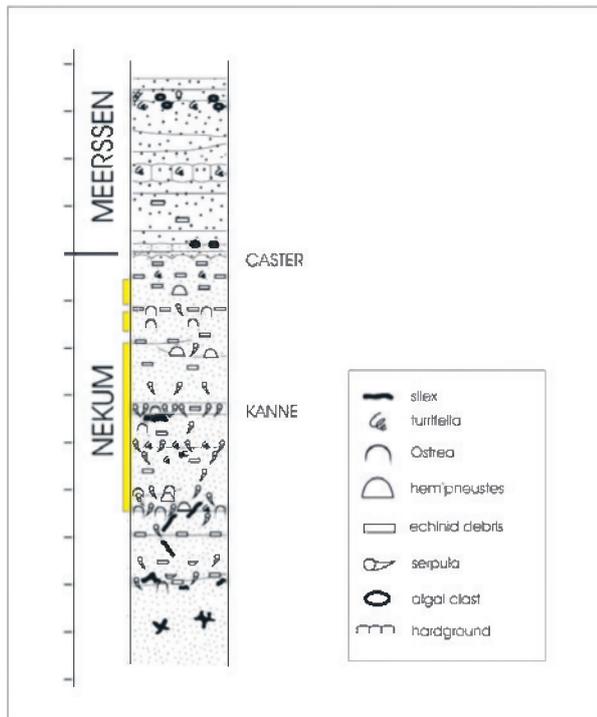


Figure 2: Composite lithologic section of the Hinnisdael caves, showing position of the Caster Horizon at the limit between the Meerssen and Nekum Members, and the Kanne Horizon in the upper part of the Nekum Member. Yellow-lined border indicates the intervals exploited as building stone (metric scale).

The younger Meerssen Limestone is exposed over 4 m and consists of orange-yellow coloured, coarser-grained calcarenites and several, strongly disturbed hardgrounds, indicative for shallowing irregular sea-bottom and frequent erosion and reworking of hardground elements. The intensely bored Caster Hardground forms the boundary between the Nekum and Caster Members and the sediment overlying this hardground is enriched in foraminifers, bryozoans and algal clasts.

Integrating stratigraphic information from piezometric well 106E0765 located 750 m towards the north-east of Hinnisdael and assuming that all hardground units alternating with coarse-grained calcarenites occurring in this well can be associated with the hardground sequence of the Meerssen Member, maximum preserved thickness of the Meerssen Member would reach 9,5 m (Gulinck, 1974).

Exploitation of the Hinnisdael underground quarries

Only the upper part of the Nekum Limestone was suitable for quarrying the regionally important 'mergelsteen' or 'Maastrichtersteen' building stone (Dreesen et al., 2002). Galleries in this stratigraphic level show sawed walls and rectangular sections, becoming parabolic where lithostatic pressure approximated the mechanical strength of the roof, i.e. where the thickness of Cretaceous calcarenites overlying the excavation is reduced to metric scale or even less. The base of the Caster Hardground, occasionally the

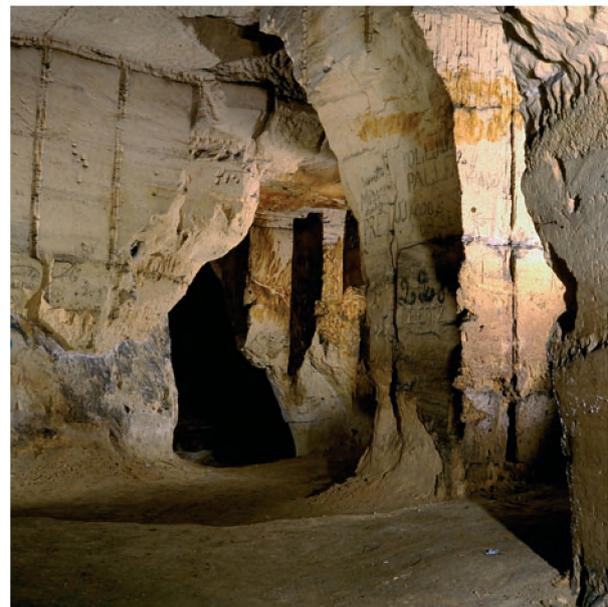


Figure 3: Underground quarry in Nekum calcarenitic limestone, extracted for 'maastrichtsteen' building stone, resulting in rectangular sections. Grote Kuil, Vechmaal (photo B. Odeur).



Figure 4: Underground quarry in Meerssen calcarenitic limestone, extracted as soil conditioner, resulting in arched sections. Waterkuil, Vechmaal (photo R. Dreesen).

Kanne Horizon, form the sufficiently solid roof for the excavations (Fig. 3). The building stone was dispatched to the southern part of the County of Borgloon (coinciding with the central-southern part of the actual province of Belgian Limbourg), as could be derived from the occurrences of the typical tauw facies among the building stones recorded in monuments. From this same origin, but corroborated by historical documents, most quarrying for building stone must have taken place in the late 13th to 16th centuries. The coarser-grained and irregularly lithified Meerssen Limestone and the lower, flint-bearing part of the Nekum Limestone served as soil conditioner and fertiliser. Galleries carved out in these levels present an arched section (Fig. 4).

The stratigraphic level (or rock quality) thus determines the type of exploitation. The location of the artificial

caves is controlled by the necessity to have access to a minimum thickness of 7 m for the Cretaceous strata, between the groundwater table and the overburden, consisting of low-permeable Oligocene clayey sands and loam. Tectonics decide where which stratigraphic level occurs within this narrow interval. The Cretaceous strata slightly dip to the northeast but are cut by one normal fault with a throw of 4 m. The fracture network responded to the stresses created by the bending termination of the Brabant Massif, not to the opening of the Roer Valley Graben. Weathering and paleokarst (both exokarst with dolines and solution pipes and endokarst with cylindrical natural caves and dissolution pockets made up of alveoli) occurred at different periods of uplift and erosion during the Cenozoic and have strongly affected the extent and colouration of the remaining carbonates. Current hazards to the preservation of the artificial caves are more related, however, to mudflows from collapse sinkholes and to potential roof collapse in zones with weakened pillars (Dusar et al., 2005).

Regional distribution of the Meerssen and Nekum Members (upper Maastricht Formation)

Geographic distribution of the 'upper Maastricht Formation' is restricted to the Maastricht region, extending in Belgium over the northeastern Hesbaye plateau and the Demer valley in central Limbourg province (Fig. 1, Table 1).

In the outcrop area around the Maastricht type section the occurrence of the Meerssen and Nekum Members is restricted to the area between Maastricht, Valkenburg and Margraten and to the St.-Pietersberg and Jeker

Geodoc	Location	Thickness	Zone	Cover	Reference
76E0303	Lummen- Schulensbroek	2 m	Vc	Danian	Felder 2001
92E0502	Hasselt - Trekschuren	11 m	Vc	Thanetian	Felder 2001
92W0387	Wellen	2 m	Vc	Thanetian	Felder 2001
106E0816	Hinnisdael quarries	min. 12 m	Vc+Vd	Quat./Oligocene	Dusar et al 2005
106E0765	Vechmaal	min. 10 m	Mc+Md	Quaternary	Gulinck 1974
93W0560	Martenslinde	21 m	Mc+Md	Danian	Dusar & Langenaeker 1992
107E0244	Emael, Marnebel quarry	min. 4 m	Mc, Vc	Quaternary	Felder & Felder, in prep.
107E0285	Kanne, Albert Canal cut	19 m	Mc+Md	Oligocene	Geodoc

Table 1: Belgian boreholes and outcrops with proven intersection of the Meerssen and Nekum Members of the Maastricht Formation. Stratigraphic information is derived from semi-quantitative bioclast analysis or ecozonation (codes Vc and Vd as proxies for Nekum and Meerssen Members respectively) or by lithostratigraphic interpretation (codes Mc for Nekum and Md for Meerssen Members). Geodoc refers to Geological Survey of Belgium file numbers. Thickness refers to currently preserved thickness under unconformable cover: Danian: Houthem Formation. Thanetian: Heers Formation. Oligocene: St.-Huibrechts-Hern Formation. Quaternary: upper Meuse river gravel (Hoogterras) or loam.

valley south and southwest of Maastricht (Felder & Bosch, 2001). In the western and southern Hesbaye, these youngest Cretaceous strata have been removed by post-Cretaceous erosion. Towards the north and east, in direction of the Roer Valley Graben boundary faults, the equivalent of the upper Maastricht Formation is represented by a stratigraphic gap, overlying a diagenetic alternation of loose and lithified calcarenitic beds, displaying the Kunrade facies. Further west in the Campine basin, at increasing distance from the Roer Valley Graben boundary faults, the Kunrade facies is again replaced by 'normal' Maastricht calcarenite facies.

Taking identification of Felder's ecozones Vc and Vd as proxies for the presence of respectively the Nekum and Meerssen Members in sampled boreholes and outcrops west of the Meuse valley (Felder, 1994, 2001; Felder et al., 1985), the geographic distribution of these members is limited to a roughly triangular area between Maastricht, Lummen and Heers (Fig. 1). The northern boundary of this zone west of Maastricht follows an east-west trace along the Bilzen fault (to stay south of the Diepenbeek borehole but north of the Martenslinde borehole), then runs NW-SE, parallel to the subcrop trends in the underlying Carboniferous of the Campine basin (to include the Hasselt and Lummen wells). The southern boundary is more irregular, following post-Cretaceous erosion surfaces and partly offset by faults. Towards the margins of the subrop area, preserved thickness of the Nekum and Meerssen Members is greatly reduced by uplift and erosion either during the K/T boundary inversion (along the northern margin) or during subsequent Cenozoic erosion phases (along the western and southern margin) (Table 1).

North of this occurrence area, in the Campine coal basin and Roer Valley Graben, the upper part of the Maastricht Formation is replaced by a hiatus between the lower Maastricht Formation (corresponding to the Valkenburg to Emael Members, represented by Felder's Va and Vb ecozones) and the Houthem Formation (represented by Felder's VI ecozone). The contact between the lower Maastricht and the Houthem Formations, thus spanning the time gap corresponding to the Vc-Vd ecozone hiatus, is affected by uplift and karstification (Bless et al., 1993; Felder et al., 1985; Swennen & Dusaar, 1997).

Discussion and conclusions

As can be derived from investigation of the Hinnisdael underground quarries, the facies characteristics and the thickness distribution of the upper Maastricht Formation remains similar to the type area all over outcrop and subcrop zones on both east and west side of the river Meuse and definitely indicate deposition in the same depositional basin. The erosive top of the Meerssen Member in Hinnisdael can be correlated to *cyclis* IVf-6 (Felder & Bosch, 2001), just below the Berg-en-Terblijt Horizont,

corresponding to the K/T boundary in the area east of Maastricht (Brinkhuis & Smit, 1996). The uppermost part of the Meerssen Member (with estimated thickness of 3 m) and the entire Houthem Formation (estimated thickness 30 m) probably have been deposited in the Hinnisdael area but were eroded prior to deposition of the lower Thanetian Gelinden Marl. This can be deduced from the tectonic deformation style, with tensional fractures and flexuring requiring a sediment load, whose development was coeval with the early diagenetic silicification (tauw and flint lithification), completed before the erosion phase marking the transition to the deposition of the 'clastic Tertiary' sequence (Dusaar et al., 2005). The Upper Maastrichtian to Danian succession thus could have remained fairly complete all over the depositional area of the upper Maastricht Formation. Each member of the Maastricht Formation would approximatively correspond to one long eccentricity cycle (Zijlstra, 1994), resulting in rapid sedimentation rates and shallowing of the sea (Dusaar et al., 2005).

Based on Schiøler et al. (1997), Vandenberghe et al. (2004) suggest that the Romontbos Horizon (base of the Emael Member) and the Kanne Horizon (fossil hash layer near the top of the Nekum Member) can be interpreted as sequence boundaries. However, the lenticular fossil hash layers and serpulid beds, such as the Kanne Horizon, are more characteristic for storm deposits than as omission surfaces or precession cycle markers (Zijlstra, 1994). Moreover, the Kanne Horizont cannot be used as a time-line but is merely the most prominent among fossil hash layers that concentrate in the upper part of the Nekum Member. The Caster Hardground and overlying fossil bed, selected as the boundary between the Nekum and Meerssen Members (Felder, 1975) and located ca 3 metres above the Kanne Horizon, marks the onset of a presumed shallower sequence. In view of the absence of noticeable time gaps, the appearance of an irregular hardground succession at the base of the Meerssen Member could merely indicate a shallowing threshold, providing less accommodation space in a more energetic environment, due to sediment build-up rather than relative sea level fall.

Seismic sections covering the Maastricht and Houthem formations interval in the Campine coal basin and Roer Valley Graben comprise continuous high-amplitude reflectors indicative for shallow-marine carbonates deposited under fluctuating sea level (Demyttenaere & Laga, 1998; Gras & Geluk, 1999; Vandenberghe et al., 1998). The boundary between both formations is unusually sharp, despite similar lithologies. From geophysical well logs from numerous coal exploration boreholes and from the Molenbeersel borehole in the Roer Valley Graben, it is obvious that during the time of deposition of the Maastricht and Houthem formations, the graben boundary faults were inactive. However, this period of relative tectonic relaxation was interrupted by an inversion during the latest Maastrichtian (corresponding to

the time of deposition of Meerssen and Nekum members, estimated at approx. 0,25 Ma). This final Maastrichtian inversion was not recognised before (Rossa, 1987) or the different stratigraphic attribution of the top Maastrichtian strata was considered of erratic nature (Vandenberghé et al., 1998). Based on seismic backstripping along faults, Rossa (1987) assumed continuous sedimentation during the time of deposition of the Maastricht Formation but could not know that the upper part of the Maastricht Formation was uniformly absent in both the Campine coal basin and adjacent Roer Valley Graben.

The geographical extension of this latest Maastrichtian (subhercynian) inversion pulse and hiatus thus covered the Roer Valley Graben and most, if not all of the Campine basin. As a result, the uppermost units of the Maastricht Formation have been preserved in a through, compensating for the uplift of the Campine basin and Roer Valley Graben, at the eastern termination of the Brabant Massif and in a narrow transition zone between the Campine basin and the Brabant Massif. Elsewhere in the Campine basin, Cretaceous sedimentation was interrupted well before the K/T boundary (Fig. 1).

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