CRETACEOUS FLOODING OF THE BRABANT MASSIF AND THE LITHOSTRATIGRAPHIC CHARACTERISTICS OF ITS CHALK COVER IN NORTHERN BELGIUM

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(6 figures, 1 table)

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ABSTRACT. Chalk is the most characteristic facies type of the Upper Cretaceous in Belgium and the only Cretaceous rock type found on the central and northern parts of the Brabant Massif. Marine Cretaceous deposits gradually encroached the Brabant Massif from the south during transgressive pulses starting in the Cenomanian – Turonian, displaying chalk facies from the Coniacian onwards. The chalk cover on the northern part of the Brabant Massif and in the Campine basin was not installed until the late Santonian and Campanian, while inversion of the Rur Valley Graben prevented any sedimentation. The base of the chalk deposit is diachronic and may be laterally equivalent to more detrital, continental-marine facies. Flooding was gentle, covering a peneplanated landscape, while partly preserving the saprolitic paleosol and thus not influencing the chalky nature of the sediment. Peneplanation did not erase all irregularities in paleotopography, leading to differences in timing of the onset of marine sedimentation, in accommodation space and sediment thickness across the axis of the Brabant Massif. Subsequent uplift of the Brabant Massif relative to the Campine Basin led to progressive disappearance of the Maastrichtian and erosion cutting into the chalk in a southern direction. South of the axis of culmination of the Brabant Massif, in the southern half of West-Flanders, the chalk forms the latest Cretaceous formation, partially preserved. North of the axis of culmination, in the northern part of West- and East-Flanders and the westernmost part of the province of Antwerp, the chalk forms the earliest Cretaceous formation, equivalent to the more detritic sediments of the Campine basin which were supplied by the inverted Roer Valley Graben. In contrast to the Mons sedimentary-tectonic basin to the south, where the standard lithostratigraphical scale of the Belgian Cretaceous has been established, the Coniacian to Campanian chalk deposits on the Brabant Massif cannot be differentiated lithologically. A formal lithostratigraphic unit, the Nevele Formation, is introduced comprising all chalk deposits on the Brabant Massif.

KEYWORDS: boreholes, geophysical well logs, Campanian, Santonian, Campine basin, Nevele Formation.

1. Introduction

With the exception of paleotopographical highs along the WNW-ESE-running axial spur of the Brabant Massif, Cretaceous deposits everywhere occur in northern Belgium but are mostly covered by a northwards thickening Cenozoic sequence (Legrand, 1968) (Fig. 1). Outcrops are limited to the Lower Meuse valley between Maastricht and Visé and surroundings (South Limburg, Pays de Herve and eastern Hesbaye; W.M. Felder, 1975; Felder & Felder, 1981; Felder & Bosch, 2000), the borders of the Haine trough around the city of Mons (Marlière, 1970), some small erosion windows on the Hesbaye-Hainaut loess plateau between these areas (Rutot & Van den Broeck, 1888; Calembert, 1957; Bless *et al.*, 1991b) or around the city of Tournai, and to the silicified residue on the faulted paleosurfaces of the Hautes Fagnes (Bless *et al.*, 1991a). Elsewhere access to the Cretaceous is by boreholes and reflection seismics, the latter being limited to the Campine basin and a section on the Scheldt river south of Antwerp. It can be regretted that reflection seismic profiles, aimed at deeper strata, have hardly been used for subsurface mapping of the Cretaceous (Demyttenaere, 1989) or did not contribute to its better understanding (De Batist & Versteeg, 1999). However, seismic exploration assisted to identify the fault pattern associated with the Roer Valley Graben (Demyttenaere & Laga, 1988; Geluk *et al.*, 1994) or to deciphering inversion tectonics (Rossa, 1986). Subsurface lithologic mapping of the Cretaceous is therefore essentially based on descriptions of borehole cores and cuttings, geophysical well logs and, with more limited availability, some ecostratigraphic (Felder *et al.*, 1985; Felder, 1994ab, 2001) and biostratigraphic controls (Louwye, 1993, 1995; Slimani, 1994, 2000). The Cretaceous has rarely been a target for drilling, except for the fractured Gulpen chalk (Zeven Wegen Member) on the eastern Hesbaye plateau (Dassargues & Monjoie, 1993) and the Maastrichtian aquifer in northern Hesbaye and southern Campine, in which case boreholes just reach the top part (Gulinck, 1974; De Smedt *et al.*, 1981). On the northern and western parts of the Brabant Massif, where the chalk thickness is of over 25 m, the chalk is tight (Halet, 1939). Drilling trough the Cretaceous is generally difficult because of the extreme difference in rock mechanical properties of flint nodules or silicified beds versus soft porous chalks and calcarenites. Hence,

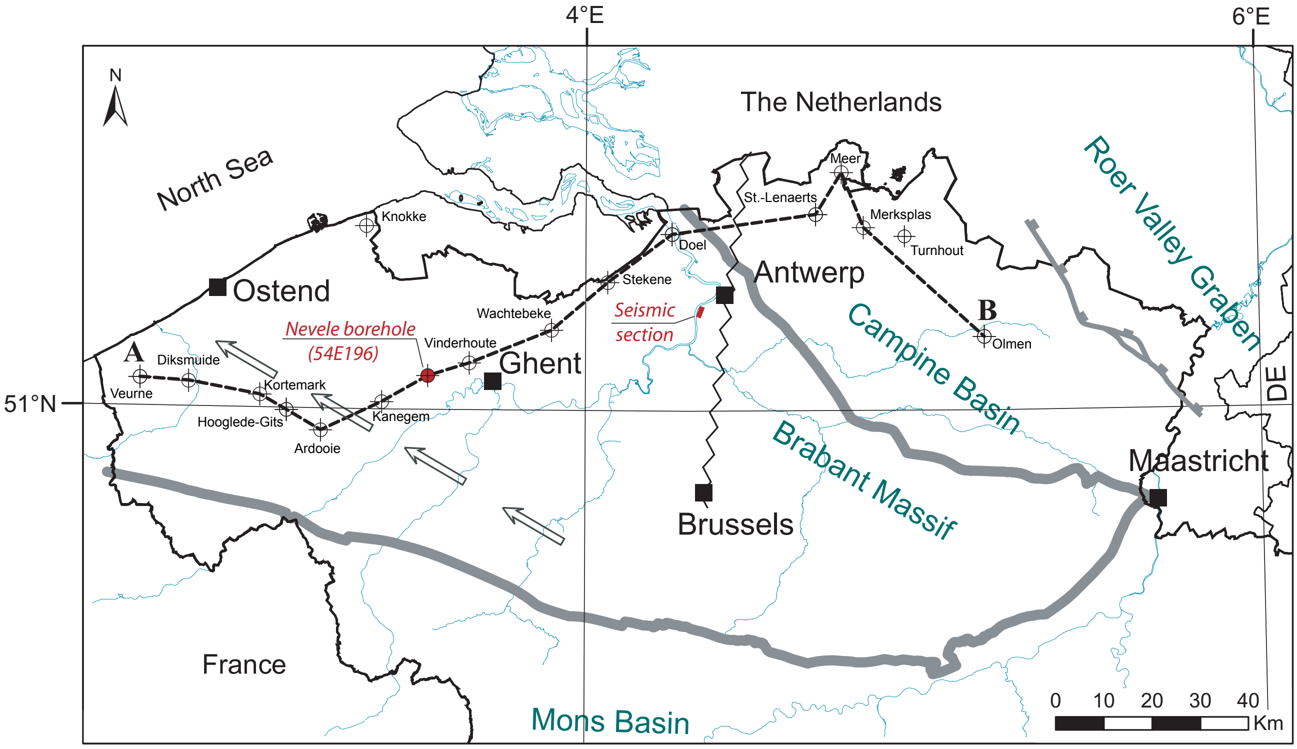

Figure 1: Simplified structural sketch map of northern Belgium showing the boundaries of the Brabant Massif, with the position of Nevele borehole (GeoDoc 54E196) and of a seismic section south of Antwerp. The crooked line indicates a zone of lateral transition of the Nevele Formation to the Vaals Formation and Zeven Wegen Member of the Gulpen Formation. The white arrows show the dip direction of the axis of the Brabant Massif. Updip, Cretaceous deposits wedge out.

cuttings are often of dubious quality and good core recovery is generally restricted to the flint-poor, lower part of the Cretaceous deposits. The stratigraphic succession has been studied in the main outcrop areas, Maastricht-Visé as the eastern reference, the Haine trough (or Mons basin) as the western reference by many authors starting with André Dumont (1849). An overview of the stratigraphic subdivision in use on the old geological map of Belgium is provided by the Conseil Géologique de Belgique (1929). Formalised lithostratigraphic scales of the outcrop areas were introduced by W. Felder (1975) for the Maastricht type region and by Marlière & Robaszynski (1975) or Robaszynski *et al.* (2001) for Belgian territory, with emphasis on the Mons Basin or Haine trough (with alternative subdivision used for the new geological map of Wallonia, cf. Hennebert & Doremus, 1997) (Fig. 2).

In the much larger subsurface area, stratigraphic interpretation remained in a rudimentary state, whereby regional geologists indifferently used and mixed litho- and biostratigraphic scales of both reference regions, and detailed correlations were practically impossible. It should be noted that the Cretaceous lithostratigraphic framework includes the lowermost Paleocene, Dano(-Montian) carbonates (Marlière *et al.*, 1977; Moorkens, 1982). Both previous and current practice in description and interpretation of borehole cuttings shows that in wells without cores, geophysical well logs or biostratigraphic datation, these Danian carbonates, assigned to the Houthem Formation, are indistinguishable from the underlying Maastrichtian strata, assigned to the Maastricht Formation, and, that, consequently, they have always been mapped together (e.g. Legrand, 1968).

Meanwhile (since the 1980's), a fair number of geological reconnaissance boreholes have been drilled for groundwater or energy resources in the underlying rocks (the fractured aquifer in the top of the basement, consisting of the Lower Paleozoic rocks of the Brabant Massif, or the Upper Carboniferous coal measures and Lower Carboniferous saline aquifer in the Campine basin; Felder *et al.*, 1985). These boreholes possess geophysical well logs and occasionally a cored contact between the base Cretaceous and the underlying strata. This allowed to establish lithostratigraphic correlations across the Brabant Massif and to link both outcrop areas where different lithostratigraphic scales have been defined. This poses the problem of the transition between the standard successions of the Maastricht type area and the Mons Basin in the Haine through

2. Geological framework

Cretaceous strata overlay folded low-grade metamorphic and volcanic Cambrian to Silurian strata, belonging to the Brabant Massif (Legrand, 1968; De Vos *et al.*, 1993). Before the Cretaceous onlap, a long phase of subtropical weathering, inducing kaolinitisation, has affected this bedrock to depths reaching a preserved maximum of 80 m. Although the higher parts of the weathering zone including the vegetated paleosols have not been preserved under the Cretaceous transgression, however gentle this has been, saprolites are widely preserved, with strongly varying thickness, even at a local scale (Mees & Stoops,

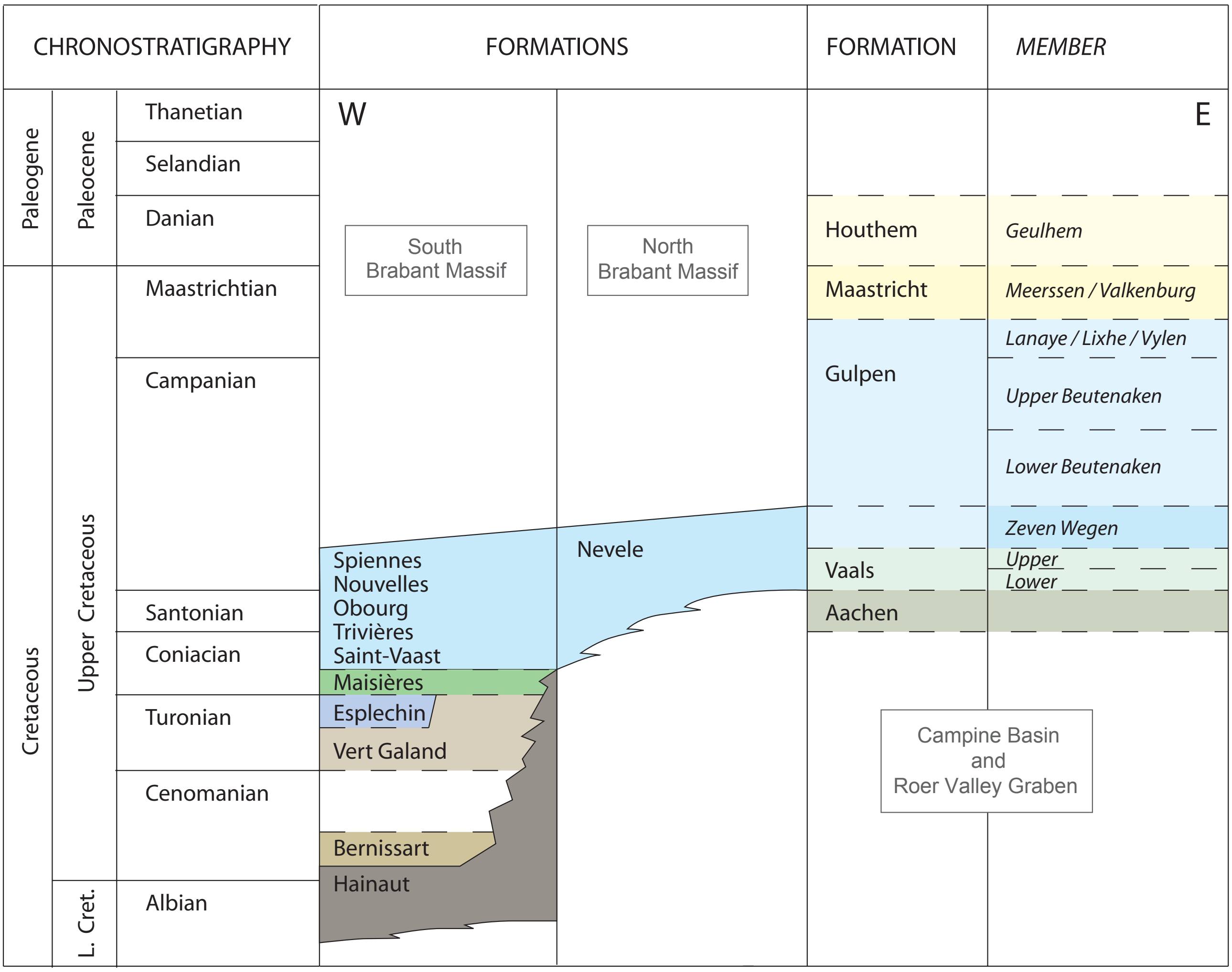

Figure 2: Lithostratigraphical correlation scheme of the Cretaceous south and north of the Brabant Massif and in the Campine Basin and Roer Valley Graben.

1999). Rubefied saprolites are occurring especially on the Cambrian core of the Brabant Massif (Legrand, 1968). This weathering phase developed after the Mid-Jurassic uplift and subsequent erosion phase, which was largely achieved during the lower Cretaceous (Vercoutere & Van den haute, 1993). No significant additional erosion of the Paleozoic bedrock has occurred ever since. The paleoweathering and pedogenesis on the Brabant Massif, starting during the lower Cretaceous, has continued to the Cenomanian along its southern margin, to the Santonian along its northern margin, or even later, depending on the timing of local flooding. The longest continental time span was reached on the axial culmination of the Brabant Massif. Pedogenesis, kaolinitisation and silicification are also observed on the Cretaceous peneplanation surfaces in the Ardennes, south of the Brabant Massif (Alexandre, 1976; Dupuis *et al.*, 1996; Thiry *et al.*, 2006) and dated lower Cretaceous (Yans, 2003), or on the Dinantian carbonates of the Visé-Puth structure east of the Brabant Massif, reaching depths of 100-200 m below the Cretaceous cover (Gökdag, 1982; Dusar & Hogenhuis, 1998). Similarly, "ghost rock" weathering of Carboniferous limestones on the Upper Paleozoic platform to the southwest of the Brabant Massif (Tournai – Soignies area) by selective dissolution of the carbonate fraction resulting in a high porosity saprolite with preserved sedimentary features, chert bands and fossil structures postdates late Jurassic to early Cretaceous Wealden karst deposits and predates Cenomanian – Turonian transgressive marine sediments (Quinif *et al.*, 1997; Vergari, 1998; Quinif *et al.*, 2006).

The sedimentary succession of the Upper Cretaceous to Paleocene deposits in northern Belgium is thus controlled by both stepwise marine transgressions to final flooding, accompanying the Upper Cretaceous sea level rise (Robaszynski *et al.*, 1998), and by tectonic relaxation pulses of the Brabant Massif and inverted Roer Valley Graben (Rossa, 1986; Felder, 1994c) (Fig. 3, Table 1). Cenomanian – Turonian transgressions advanced from the English Channel or Paris Basin and gradually covered the southern reaches of the Brabant massif with detrital sediments of reduced thickness. These clastic-carbonatic sedimentary successions remained south of the axis of culmination of the Brabant Massif, south of the line Ostend-Oudenaarde, and can be correlated to the Mons Basin (or Haine trough), which has remained under marine influence since the Albian due to localised subsidence over dissolving Upper Paleozoic evaporites (Marlière,

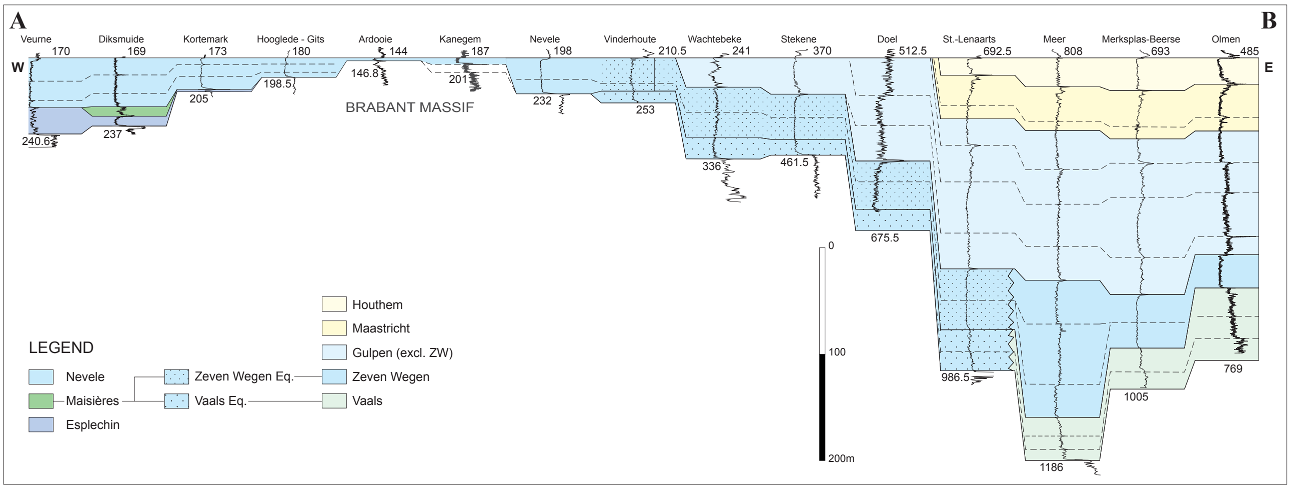

Figure 3: East-West cross section through northern Belgium over the axis of the Brabant Massif (see fig. 1 for location of points A – B). Correlation based on natural gamma-ray logs.

1970; Delmer, 1972). At the same time, advance of the Cretaceous transgressions from the north (North Sea and Hannover-Münster basins) were blocked by the inversion of the Roer Valley Graben and the uplifted Campine – Brabant block (Ziegler, 1990). Due to tectonic relaxation of the Campine – Brabant block the Santonian-Campanian transgression finally passed over the paleotopographic ridge of the Brabant Massif and linked the Mons basin to the Campine Basin (Marlière, 1954; Louwye, 1993). Late Santonian sediments comprise glauconite-bearing chalk on the west-central Brabant Massif, glauconitic sands (Lonzée sand) on the eastern Brabant Massif, coastal to estuarine sands and clays with lignite (Aachen Formation) when approaching the Roer Valley Graben, suggesting that sedimentation was occurring in different pulses strongly dependent on local accommodation and sediment budget (Jagt *et al.*, 1995; Jagt, 1999; Robaszynski *et al.*, 2001; Vandenberghe *et al.*, 2004). The Lower Campanian resulted in widespread chalk deposits on the western and northern Brabant Massif and continued with green sands and clays on the Campine basin or eastern Brabant Massif. Maximal flooding occurred during the Upper Campanian transgressive phase, despite continued inversion of the Roer Valley Graben, with the generalised deposition of white chalks incorporated in the Nouvelles Formation of the Haine trough and the Zeven Wegen Member of the Gulpen Formation in the Maastricht type area (Bless *et al.*, 1987b). An important sea level fall and incision phase terminated the Campanian chalk deposit (Calembert & Meijer, 1955; Felder, 1996). Late early and early late Maastrichtian carbonates must have covered the northern reaches of the Brabant Massif but were removed by the

BGD no.	Location	KB no.	Year	Depth	X	Y	Z	Top Cret.	Base Cret.
046E0279	Olmen	KB188	1986	1545	207160	203283	36	485	769
017W0265	Merksplas	KB165	1983	1761	181938	225856	30	693	1005
007E0205	Meer	KB149	1981	2513	177378	237304	13	808	1186
007E0223	St.-Lenaarts	KB203	1990	1390	172063	228544	24	692.5	986.5
014E0240	Doel		1998	688	142240	224444	8	512.5	675,5
026E0111	Stekene		1999	506	128880	214425	3	370	461.5
041W0179	Wachtebeke		1999	383	117170	204550	5	241	336
055W1090	Vinderhoute		1999	266	100115	197715	5	210.5	253
054E0196	Nevele		1989	273	91440	195165	10	198	232
053E0058	Kanegem		1994	267	81840	189700	29	187	193
068W0534	Ardooie		1988	285	69210	183872	21	144	146,8
067E0178	Hooglede-Gits		1985	377	62023	188126	30	180	198.5
052W0154	Kortemark		1968	238	56535	191340	7	173	205
051W0144	Diskmuide		1985	250	41855	194180	4	169	237
050E0235	Veurne		1999	252	31682	194938	5	170	240.6
017E0225	Turnhout	KB120	1952	2706	190573	223829	29	704	1002
011E0138	Knokke		1980	444	78776	226370	5	311	432

Table 1: List of boreholes. Depth, top and base Cretaceous are in mbs (meter below surface). X, Y and Z coordinates are in Belge Lambert 72 system.

Artois tectonic uplift affecting also the central and western Brabant Massif. However, the chalk facies was already replaced by calcarenitic facies, indicative for more energetic shallow water deposition (Bless *et al.*, 1986, 1991b; Felder, 1996; Vandenberghe *et al.*, 2004).

Except for this maximal flooding event, spatial – temporal facies distribution shows differences between Maastricht type area and Campine basin to the North and East of the Brabant Massif and the Haine basin to the Southwest of the Brabant Massif, preventing easy cross-correlations. In fact, lateral facies changes due to inversion of the Roer Valley Graben, diachronous onlap on the Brabant Massif coming either from the Paris or North Sea basins, or differential post-sedimentary erosion related to the Artois uplift all could lead to mismatch of the chalk deposits across the axis of the Brabant Massif. However, towards the axis of the Brabant Massif, where tectonic subsidence is most restricted and overlying strata are thinnest, pure chalks are the dominant, often exclusive Cretaceous lithology. Therefore, these all-chalk deposits along the northwestern spur of the Brabant Massif and their problematic connection to the more complete and diverse successions in the northeast and southwest makes it necessary to study this transition in more detail and introduce a new formation.

3. Formal description of the Nevele Formation, grouping the chalk deposits on the western and central parts of the Brabant Massif

Name: derived from Nevele commune (province of East-Flanders, 13 km west of Ghent)

Stratotype: Nevele borehole in borough Hansbeke, GeoDoc 54E 196. Lambert coordinates: x = 91440, y = 195165, z (ground level) = 10 m; depth interval 198.0 – 232.4 m (corresponding to the entire Cretaceous marine section at this site).

Well, drilled 1989 for the piezometric network of Flemish Administration for Environment, Nature and Land Management (AMINAL), deepened and cored by Flemish Administration for Natural Resources and Energy (ANRE). Borehole description in DOV <www.dov.vlaanderen.be> and GeoDoc files of the Geological Survey of Belgium. Continuous wireline core from 211 m till final depth of 273,20 m. Cores are cut lengthwise and preserved in the core repository of the Geological Survey of Belgium (Fig. 4).

Description: Pale gray (2,5 Y 8/1) fine grained chalk (biomicritic wackestone), becoming more white-coloured downward (N 9/0), with darker wavy, non-parallel laminae and bioturbations (2,5 Y 7/1). Few macrofossils (rhynchonellids and mollusc shell debris, pyritised silicic sponge remains). Rarely silex (flint) bearing. The bottom bed (229,55-232,40 m) consists of glauconitic, strongly bioturbated chalk, with phosphatic grains and frequent, often green-coated pebbles derived from the regolith (Fig. 5).

Underlying strata: rubefied regolith (7,5-10R, 2,5-10 YR), of earlier Cretaceous age, reaching a depth of 40 m, developed on fractured and steeply inclined greenish-grey (10 GY) phyllites (Stoops, 1992; Mees & Stoops, 1996) of the Cambrian Oisquercq Group (Piessens *et al.*, 2005).

Overlying strata: On the north flank of the Brabant Massif, the Nevele chalk is the only Cretaceous formation present,

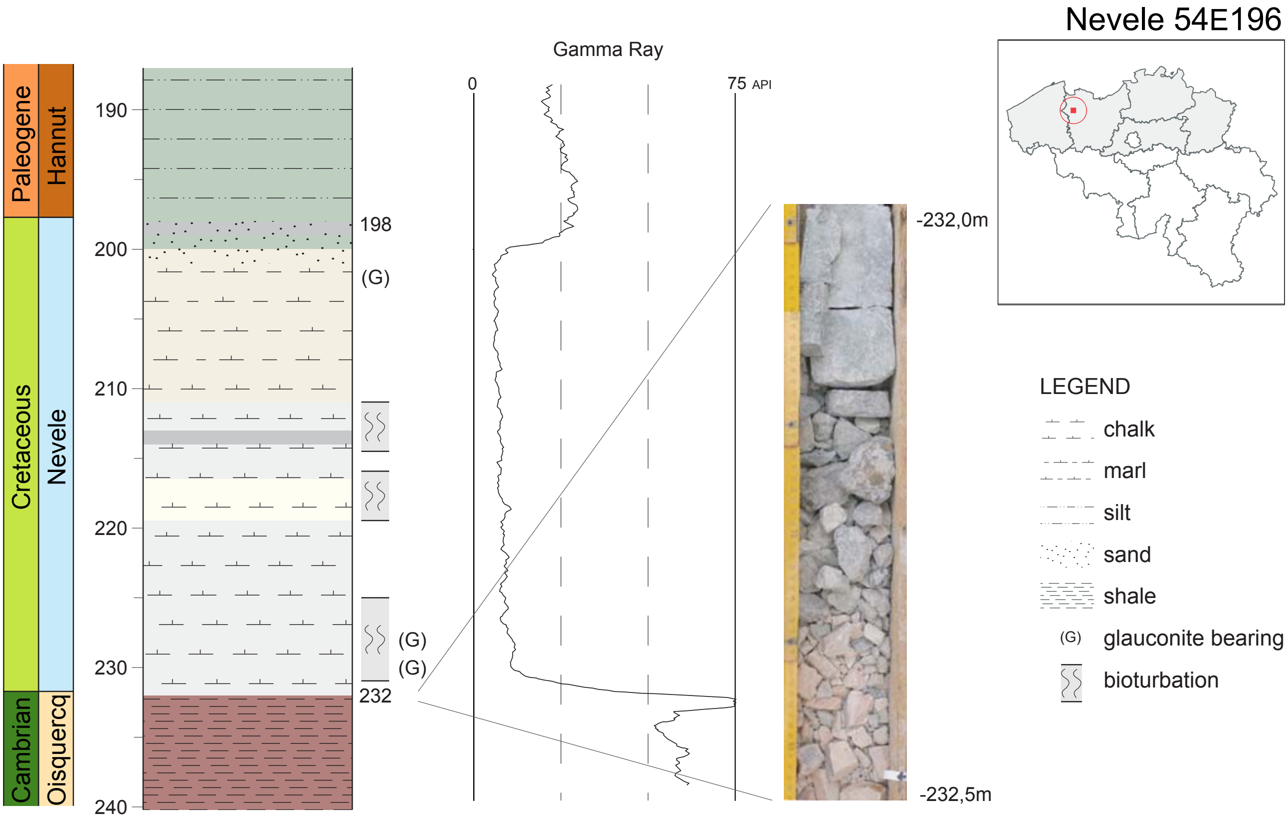

Figure 4: Lithostratigraphy, lithological log and geophysical well log of Nevele borehole (GeoDoc 54E196) with photo of core section at the contact between the Cretaceous Nevele Formation and the underlying Cretaceous paleosol, developed on Cambrian formations.

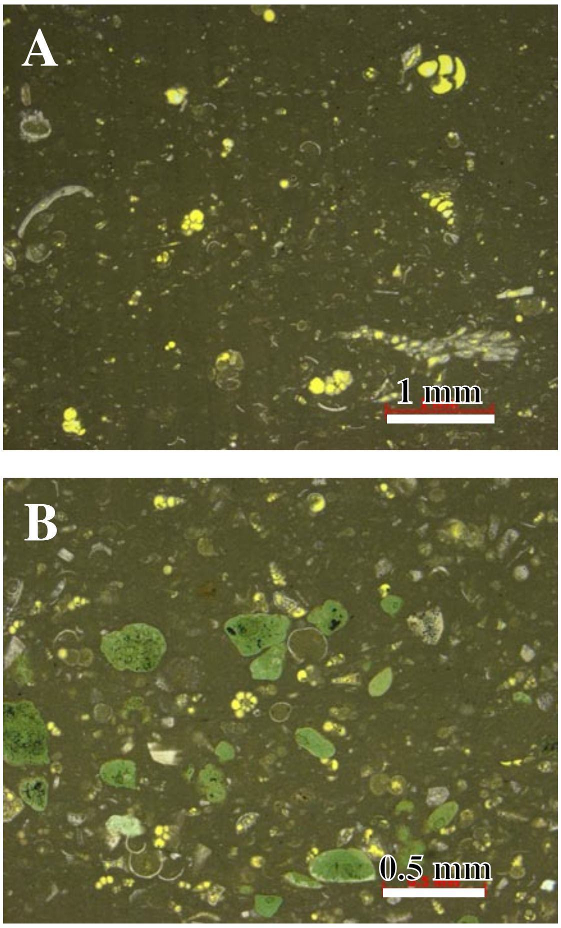

Figure 5: Thin sections from the basal Cretaceous in Nevele borehole (GeoDoc 54E196):
A. depth 220 m - Bioclastic foraminifer-rich wackestone (benthic and planktonic small forams) with transported (?) shallow water biota (a.o. bryozoa and ostracodes). (B) bryozoa; (F) foraminifera.
B. depth 231,15m - Glauconite rich bioclastic foraminifer wackestone. (G) glauconite.

covered by grey sandy clays and glauconite-bearing clayey sands of the Hannut Formation, Landen Group, Thanetian (Jacobs *et al.*, 1999; Vandenberghe *et al.*, 1990).

Area: NW Belgium, on the Brabant Massif west of the line Antwerp-Brussels and along the western rim of the Campine basin; only known as subsurface occurrence. Eroded towards the southern margin of the Brabant Massif.

Towards the Campine basin, the chalks assigned to the Nevele Formation laterally grade into more diverse sedimentary units, which make up the lower part of the Gulpen Formation, namely the Zeven Wegen Member, and the Vaals Formation. Typical Campine facies are still developed in the Turnhout – Beerse-Merksplas area, whereas Nevele-type chalks appear in the Loenhout gas storage zone, close to the western rim of the Campine basin, still overlain by younger Gulpen members displaying Campine facies (Fig. 3). The latter disappear on the Brabant Massif, partly because of stratigraphical offlap, mainly because of tectonic uplift (cf. Fig. 6).

In the more strongly subsiding Mons basin, the homogeneous chalks assigned tot the Nevele Formation are equivalent to 5 different chalk units, successively the Saint-Vaast, Trivières, Obourg, Nouvelles and Spiennes Formations.

Thickness: 34.4 m in the Nevele borehole (54E196) stratotype. Increasing in thickness towards the northwest and northeast, reaching 121 m in the Knokke well (11E138).

On the Brabant Massif, the top of the Nevele Formation is eroded and covered by much younger, Thanetian strata assigned to the Landen Group. The erosion gaps tends to widen in stratigraphic range from north to south. However, the thickness reduction towards the axial culmination of the Brabant Massif is at least partly due to existing paleotopography at the time of flooding, so that there was

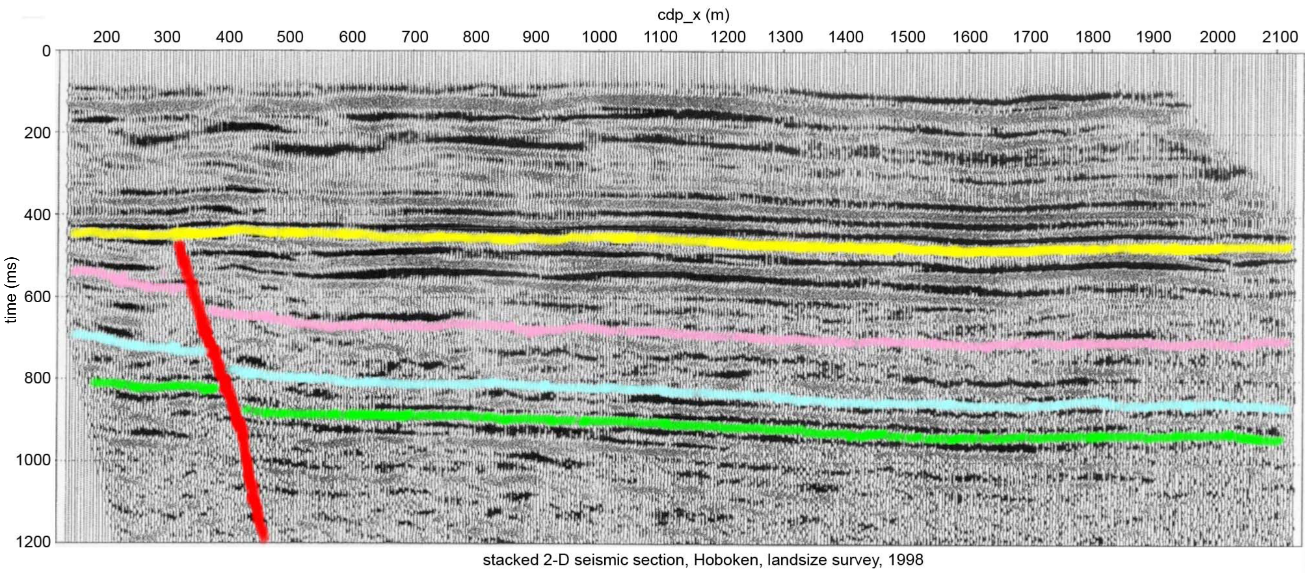

Figure 6: Seismic section along the Scheldt river between Cockerill-Yards in Hoboken (South) and southern petroleum harbour of Antwerp (North) made by students of TU Delft in 1998 (supervision and processing G. Drijkoningen) with tentative seismostratigraphic interpretation based on indirect borehole control. CDP units in meters, depth two-way travel time in milliseconds. Colour legend: yellow base Tertiary, lila base Maastrichtian (top Nevele Formation or Zeven Wegen equivalent), blue base Zeven Wegen - top Vaals equivalent, green base Cretaceous (base Nevele Formation), red Nijlen - Hoboken fault.

less accommodation space. This is suggested by the fact that there is no facies change associated with the thinning of the sediments assigned to this formation. On the other hand, steep ridges developed as inselbergs on vertical quartzites of the Cambrian Tubize Formation (formerly known as Devillian). The height of these ridges above the peneplain could exceed the maximal thickness of the Cretaceous in the surroundings of Brussels (Matthijs *et al.*, 2005). The same holds for Ashgillian (Ordovician) volcanics in the region of Ardooie, which could form elevated blocks raising about 50 m above the peneplain and only covered by Tertiary (Thanetian) sediments. Even larger inselbergs, resulting from differential early Cretaceous weathering, were described in the area surrounding the Paris Basin (Thiry *et al.*, 2006).

Age: There is no biostratigraphical datation applied directly to the Cretaceous of the Nevele borehole. However, typical bioclast assemblages indicate biofacies control of the sediment and depend on the paleoecological evolution, allowing regional correlations. Felder (1994a) elucidated a succession of bioclast assemblage zones or ecozones of regional extent, based on semi-quantitative analysis of bioclasts obtained from the fraction 1-2,4 mm. The same interval could be dated Santonian by benthic foraminifera (comm. F. Robaszynski) and by dinoflagellate cysts (Louwye, 1993). According to this information, the Nevele Formation at the type locality, including the upper non-cored part, is deposited during the Santonian to Campanian (correlation to Ecozones 4, Santonian, and 5, probably Campanian, of Felder, 1994a).

Historical background:

In borehole descriptions filed in the GeoDoc archive of the Geological Survey of Belgium and in the associated literature, this formation is designated as “white chalk, Cretaceous chalk or Senonian chalk”. More precise lithostratigraphical information nor correlations to the stratigraphical schemes of the outcrop areas have ever been provided.

4. Lithological characterisation

Boreholes traversing the northern flank of the Brabant Massif all display the Nevele Formation in its most typical form, as homogeneous chalk, irrespective of thickness. On geophysical well logs, the chalk appears as a blocky unit, with steep transitions to underlying and overlying units (Fig. 4). Flint concretions are rare, composed of black to dark grey translucent flint. They are not always observed and limited to few horizons or sometimes reworked in the basal gravel. Glauconite loading of the basal beds is weak and does not force the colour, which remains white except for the basal layer. This may locally appear as a chalky greensand with decimeters thickness at most. The basal gravel consists of unweathered pebbles derived from the underlying regolith, quartz grains, phosphatic nodules and dark splinters of silicified concretions, which all may be green-stained. The quartz grains are bimodal, with translucent angular quartz granule (typically 1-3 mm in size) and stained rounded quartz grains (<1 mm). Macroscopically, the quartz inclusions are almost invisible.

Translucent to white quartz sand grains and pebbles, known as ‘diamonds of Fleurus’ because of their purity and shock resistance, and derived from Lower Cambrian strata, are more frequently found in continental Wealden sediments, now assigned to the Hainaut Formation (Hennebert & Doremus, 1997; Groessens, 1998). As is also the case for the base of the Brussels sand Formation in the area of Fleurus, occurrences at or near the base of the Nevele Formation are probably reworked from such Wealden deposits, because they bear no relationship to the local bedrock, which is also represented in the basal gravel.

In some boreholes, the Nevele chalk is interrupted midway, or about 5 to 10 m above the base, by a boundary bed enriched in quartz and some glauconite, quite similar to the basal layer (but without pebbles of basement rock). This horizon has no influence on the overall lithological composition and apparently does not seem to represent a sequential boundary. It must testify of a local event, with slowdown of subsidence and influx of weathering products from the nearby onshore.

5. Biostratigraphic characterisation

Geophysical well log correlation strongly suggests that the Nevele Formation is at least laterally equivalent to the Vaals Formation and the Zeven Wegen, locally also the lower Beutenaken Members of the Gulpen Formation of the Campine Basin (Fig. 3). The Campanian age of these lithological units has been amply demonstrated by different paleontological methods in the Maastricht type region and the classical Meuse section (see Felder & Felder, 1981; Bless *et al.*, 1987a; Robaszynski *et al.*, 1985).

Dinoflagellate cyst stratigraphy is of most practical applicability to the concealed chalks. A reference section has been established by Slimani (1994, 1996, 2000) in the Turnhout borehole (KB120, 17E 225) in the Campine Basin. The dinoflagellate cyst biozonation has been tied to the lithological description of this borehole by Gulinck (1954) and correlated to the classical reference sections in Hallembaye (Meuse valley) and Beutenaken (South Limburg). In the lower part of the Turnhout well, these correlations are unequivocal, and prove that the upper part of the Vaals Formation (interval 972-986 m, sensu Felder *et al.*, 1985) and the lower Gulpen Formation, composed of the Zeven Wegen Member (interval 932-972 m, covered by hardground) and the Beutenaken Marl Member (interval 888-932 m, covered by double hardground) are of Upper Campanian age.

Outside the Nevele type locality, the stratigraphic range can vary and span the entire Santonian and most of the Campanian or include only parts of these stages. South of the axis of the Brabant Massif, in the Schore borehole (‘BH6’, 36E137), the Nevele chalk contains the following benthic foraminifera: *Gavelinella arnagerensis* (= “*rhombensis*” auct.), *Stensioenina granulate, S. exsculpta gracilis, S. polonica*. The latter is a European marker for the Lower Santonian and frequently accompanies inoceramid shell accumulation at the basis of such chalk units. No markers for the Upper Santonian were found (interval 182-214 m). The underlying greenish sandy marls of the Maisières Formation are characterised by small *Reussella* and *Lingulogavelinella*, typical for the Upper Coniacian (F. Robaszynski, personal communication).

North of the axis of the Brabant Massif, in the Knokke borehole (11E138), the basal beds with glauconite and gravel (interval 428-432 m) can be assigned to the late Santonian, the more strongly lithified chalk (interval 348-428 m) to the early Campanian equivalent of the Vaals Formation, the upper chalk (interval 317-348 m) to the late Campanian equivalent of the Zeven Wegen Member of the Gulpen formation. This datation is based on calcareous nannoplankton and dinoflagellates. The upper beds of the Knokke borehole (interval 311-317 m) already may attain an early early Maastrichtian age, equivalent to the Vijlen Member of the Gulpen formation, but this datation is only based on calcareous nannoplankton and not confirmed by dinoflagellates (Vandenberghe *et al.*, 1990; Bal & Verbeek, 1990; Louwye, 1990, 1993). It should be noted that boundaries may slightly shift depending on the biozonation used, but these changes do not modify the overall age distribution of the sediment, which remains in the Santonian to Campanian time span but tends to become younger when traversing from southwest to northeast the axis of the Brabant Massif.

Towards the Campine basin, it becomes more difficult to ascertain if Santonian-aged sediments are still incorporated in the chalk formation, as information from different fossil groups is somewhat conflicting. Although a Lower Campanian age for the Vaals formation is accepted, Jagt *et al.* (1995) described possibly late Santonian ammonites in the lower Vaals Formation of the Campine mining district. Evidently, the Santonian - Campanian transition is not punctuated by important events causing change in sedimentation or important faunal breaks.

6. Geographical correlations

The Nevele Formation biostratigraphically correlates with:

- the Aachen and Vaals Formation and the Zeven Wegen Member of the Gulpen Formation in the Campine basin and Hesbaye plateau on the eastern Brabant Massif, and possibly also the lower Beutenaken marl member in the Antwerp Campine (however, the age of the Beutenaken Member of the Gulpen Formation is ill-constrained because of more pronounced tectonic activity and sediment and fossil reworking during the time of deposition of this unit, close to the Campanian – Maastrichtian boundary, personal communication Sj. Felder);
- the restricted Lonzée greensand and the Folx-les-Caves arenaceous chalk members of the southern Hesbaye plateau on the east-central Brabant Massif (Rutot & van den Broeck, 1888) ,
- the Saint-Vaast, Trivières, Obourg, Nouvelles and Spiennes Formations of the Mons basin. By lithological comparison, it provides most affinities with the Zeven Wegen Member and the Obourg-Nouvelles Formations but cannot be fully identified by the stratigraphic definition in use for these existing lithostratigraphic units.

The Nevele Chalk Formation corresponds to the Ommelanden Formation, as redefined in van Adrichem Bogaert & Kouwe (1993) for the northern Netherlands and the Dutch offshore, of Turonian to Maastrichtian age, similar to the other North Sea bordering countries. The Ommelanden Formation comprises white to light-grey fine grained coccolitic limestones of chalky nature, becoming denser by compaction at greater depth, attaining hundreds of meters of thickness in the North Sea depocentres. Several unconformities could occur within this succession but no attempts to further subdivisise this very thick and monotonous formation have been realised (van Adrichem & Kouwe, 1993). The coarser grained bioclastic limestones and intercalated marly and sandy beds of South Limburg are separated from this formation, but all Upper Cretaceous carbonate-dominated sedimentary sequences are incorporated in a Chalk Group.

Similar observations can be made in France (Boulonnais) and the UK, but further lithostratigraphical subdivision of the French and British Chalk groups are largely based on the identification of fossil markers. The main distinction to be made is that the chalk deposits on the Brabant Massif result from flooding of a basement high, whereas thicker sequences in surrounding areas represent a facies response to deepening of the water column and reduction of continental influence in existing marine basins. However, Maastrichtian sediments are absent and the sedimentary record is probably less complete than on the Brabant Massif. The only area where the extent of the Nevele formation cannot be properly delimitated is under the Belgian offshore of the North Sea or French Flanders, because of lack of data.

7. Boundary conditions

The Cretaceous of the Brabant Massif and the Campine basin clearly differ in the succession of sedimentary sequences and their thickness distribution, with the exception of the highstand deposit corresponding to the white chalk facies of the Zeven Wegen Member, and also to the Nouvelles Formation in the Mons basin. The underlying Vaals Formation of the Antwerp Campine shows transitional facies with a change from greensand to marl to light grey chalk. However, this Vaals equivalent chalk can still be distinguished from the Gulpen chalk on geophysical wireline logs (Fig. 3).

There is no particular facies change in the Cretaceous sediments, associated with the boundary between Campine basin and Brabant Massif in the Antwerp area, but the stratigraphic gap at the K/T boundary widens towards the west. Maastrichtian-aged sediments quickly wedge out west of the Scheldt river and the thickness of Cretaceous strata reduces accordingly. The relative uplift position of the Brabant Massif even more strongly reduces Cretaceous thickness and increases the stratigraphic gap at the K/T boundary also from north to south. These processes are enhanced by flexures and synsedimentary faults, demonstrated by the Nijlen-Hoboken fault. High-resolution seismic surveying in the river Scheldt (at pick 218 of the Scheldt profile, RCMG 1989), 2-D reflection seismics in Hoboken (Fig. 6) and along the southern and western margin of the Campine basin in the vicinity of Lier ('Nijlen' hinge line, Limestone Subcrop seismic reconnaissance by the Geological Survey of Belgium in 1989, unpublished; Langenaeker, 2000) revealed the presence of a faulted hinge-line, contemporaneous with Cretaceous sedimentation, active at least during the Santonian-Campanian. Tensional flexure with onlap of younger, Maastrichtian, strata increase the thickness of the Cretaceous strata in the Campine basin by 40 m compared to the Brabant Massif. However, an inversion is exhibited for the Santonian-Campanian strata in the lower part of the Cretaceous section, contributing to the more widespread presence of Santonian-aged chalk and to the uniformity of the chalk facies on the Brabant Massif. This Hoboken fault follows a deep-seated WNW-ESE oriented Caledonian lineament, and thus appears associated post-Caledonian deformation of the Brabant Massif.

The Nevele Formation thus characterises the Cretaceous in the province of East-Flanders, whereas the area immediately east of the line Antwerp – Mechelen – Brussels and west of Hoogstraten – Lier – Mechelen forms an intermediate zone to the Campine basin stratigraphy.

South of the axis of the Brabant massif, the K/T stratigraphic gap continues to widen, but older Cretaceous strata are onlapping the Brabant Massif and the subsidence rates again increase southwards in direction of the Paris and Mons basins during the time of deposition of the Cretaceous formations. Near the Belgian–French or Flemish-Walloon borders, in the southern part of the province of West-Flanders, the stratigraphic succession becomes more complete, allowing a return to the stratigraphical scale of the Mons Basin.

8. Conclusions

The Brabant massif has a different tectono-sedimentary history compared to the basins surrounding it, with much less tectonic interruptions or terrestrial input. Basically, there is one transgression depositing chalk, the timing of which may vary gradually: flooding of the Brabant Massif came from the southwest, flooding of the Campine basin (which much longer remained under the effect of tectonic inversion) came from the northeast. It was only at the time of maximum sea level highstand that a uniform facies, characterised by white chalk, was spread over all depositional areas and beyond, over a large part of Europe.

The Nevele formation most exactly corresponds to that highstand period and shows indications for slow and gradual flooding of a terrestrial landmass, with partial preservation of its soil cover, different from the erosive basal contacts in the surrounding basins.

The Nevele formation is laterally equivalent to the Zeven Wegen Member of the Gulpen Formation and to the underlying Vaals and Aachen Formations of the Campine basin, which have a different origin and nature; it is also time equivalent to the St Vaast, Trivières, Obourg, Nouvelles and Spiennes formations of the Mons basin which possess more similar characteristics but is yet impossible to correlate the Nevele Formation or parts thereof precisely to the chalk formations of the Mons basin, deposited in a very different subsidence regime, reacting to dissolution and compaction of underlying karst and evaporites (cf. Delmer, 1972).

The geographical boundary between the subcrop area of the Nevele formation and the Campine basin stratigraphy is in the zone where the different Cretaceous stratigraphical units of the Campine basin lose their lithological characteristics and turn into a homogeneous chalk unit. This boundary cannot be resolved as a sharp line but is sufficiently precise and located over the Loenhout dome. The boundary with the Mons basin stratigraphy is less clear but this is mostly due to the effect of erosion, separating the chalk deposits on top of the Brabant massif from those of the Mons basin by the subcrop of older Cretaceous units extending as far north as the WNW-ESE axis of culmination of the Brabant Massif.

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