

Lithostratigraphic Information Sheets (LIS)

Proposal for discussion

(this version is replacing Vandenberghe & Wouters, 2011 presently at the NCS website)

RUPEL GROUP

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1 Rupel Group

Hierarchical unit name : not existing

Type: Group

Code: RU

Authors of the LIS: Noël Vandenberghe & Laurent Wouters

Alternative names: The present LIS is a further elaboration of the previous NCS website version of the Rupel Group by the same authors. Note however that in contrast to earlier versions of the stratigraphic inventory, the Voort Sand is no longer included in the present definition of the Rupel Group. This follows from the integration of the mainly Chattian sand and clay units, such as the Voort Sand, into the Veldhoven Formation of Chattian to Aquitanian age (De Nil & Verhaegen, 2022) occurring dominantly in the RVG; hence further including these units in the Rupel Group would expand this group too far outside its core area of occurrence.

Origin of the name: Following the tradition of the Subcommission Paleogene-Neogene Stratigraphy formations have been grouped under the name of rivers or of a geographic area in the region of the main occurrence of the formations (Maréchal, 1993).

The Rupel river area is the iconic outcrop area of the Boom Clay which is at the same time the main lithostratigraphic unit of the Group and the unit stratotype of the 'Rupélien' introduced by Dumont (1849) for the middle part of a threefold subdivision of the Oligocene time. Therefore, although the term Rupelian is the international chronostratigraphic stage name for the lower part of a twofold Oligocene subdivision (ICS International Chronostratigraphic time scale and discussed in Van Simaey & Vandenberghe (2006)), the name of the river Rupel is also given to the lithostratigraphic group in which the Boom Clay occurs.

Formal

Date LIS: edited May 2023

Cite as: **NCS-addition**

1.1 Characterizing Description (Figs. 4 & 5)

The term Rupel group is referring to the Boom Clay Formation, the main clay unit in the group, and to the other fine-grained sandy or clayey deposits which are sedimentologically, paleogeographically and geometrically related to the Boom Clay. These comprise on the one hand the superjacent much sandier Eigenbilzen Sand Formation displaying in some outcrops the typical rhythmicity of the Boom Clay and considered as a geometrical and mainly lateral equivalent of part of the Boom Clay. On the other hand in East-Limburg a sandy unit, the Kerniel Sand, splits up the main clay unit in two parts: the overlying clay designated as Boom Clay and the thinner underlying clay unit as the Kleine-Spouwen Clay (Van den Broeck, 1883a,b). Also included in the Rupel Group is the coastal Berg Sand, underlying the Kleine-Spouwen Clay; in some areas the Berg Sand also occurs below the Boom Clay where it is a paleogeographical lateral evolution of the lower part of the Boom Clay. The Kerniel Sand, Kleine-Spouwen Clay and Berg Sand are grouped as members into the Bilzen Formation.

Lithologically and from a sedimentary sequence genetic perspective the lagoonal to shallow marine Ruisbroek Sand unit underlying the Boom Clay in the northwestern part of the occurrence area of the Rupel Group could be included into the Rupel Group (Vandenberghe et al., 2002), but as it occurs in the top of an alternation of lithostratigraphic clay and sand units, originally abbreviated a (argile) and s (sable) and grouped as the 'Complexe argilo-sableux de Kallo' by Gulinck (1969), it has been grouped as a member in the Zelzate Formation of the Tongeren Group (see NCS website). An analogous remark could be made about the Borgloon Formation of the Tongeren Group underlying the Rupel Group in its southern and eastern occurrence area as these deposits make up the initial sediments of the important transgression that will later deposit the Rupel Group sediments (Vandenberghe et al., 2003).

1.2 Type section, type locality, type borehole, type geophysical borehole.

The Rupel Group is slightly dipping to the north-northeast (Figure 1b). It reaches the surface at the south-southwestern rim of its occurrence area, except in the northern Hageland, where channel erosion and channel infill has removed the Rupel Group sediments and replaced it by the Neogene Diest Formation. As a consequence, two main outcrop areas can be considered: a western area comprising the Land van Waas, the Rupel area and the Nete-Dijle interfluvium, and an eastern area comprising the southern Hageland and the Demer area in Limburg (Figure 1a).

As reference sections for the Rupel Group in the Antwerp Campine, the cored and geophysically logged boreholes at Weelde (SCK 98) and Mol (SCK-15), together with ON-Mol-1 and ON-Dessel-1, are chosen as representative for the Eigenbilzen and Boom Formations (Figure 2). In the Limburg area the geophysically logged Koewijde-KS2 borehole and the temporary outcrop along the Albert Canal near Eigenbilzen are chosen showing the Bilzen, Boom and Eigenbilzen Formations (Figure 3) (Vandenberghe et al., 2001).

1.3 Description of upper boundary

Generally in the Antwerp province the Rupel Group has been eroded and its top is now situated in the Boom Clay Formation, or in the north of the province the Eigenbilzen Formation (Figure 1b). The upper boundary is easily recognized as this clay is overlain by glauconitic sands of commonly Neogene age or locally of Chattian age. However towards the east and in the Limburg province the Chattian Voort Sand overlies the Eigenbilzen Sand of the Rupel Group, making the recognition of the Rupel Group top in some cases more tedious, in particular in non-cored rotary drilled boreholes. Indeed the Voort Member covers the Eigenbilzen Formation without noticeable gravels or reworked deposits at its base. The boundary however can be recognised by a colour transition from grey Eigenbilzen Sand to green glauconite-enriched Voort Sand, by a slightly lower clay content and coarser grain-size in the Voort Sand, and especially by the common occurrence of shell fragments in the Voort Sand.

Geophysical well log characteristics are not very helpful to locate the boundary between the Eigenbilzen Fm and the Voort Sand. On regional reflection seismic profiles a slight unconformity is observed between the Eigenbilzen Formation and the Voort Member, the logical extension of the observed important erosional top of the Rupel Group in the west (Dusar & Vandenberghe, 2020).

1.4 Description of the lower boundary

In the area where the Boom Clay Formation of the Rupel Group directly overlies the Ruisbroek Sand of the Zelzate Formation (Tongeren Group), the base of the Rupel Group is relatively easily picked where the fine sand of the Ruisbroek Sand is relayed by the silt dominated lower part of the Boom Clay

Formation. This change is also particularly well expressed on the Res geophysical log (Figure 2). In the Waasland outcrop zone (SVK pit) a phosphatic bed occurs at the boundary (Vandenberghe et al., 2002).

In the area where the base of the Rupel Group consists of the Bilzen Formation (Figure 3) the basal member systematically consists of the coastal marine Berg Sand. In outcrop sections the sand is easily distinguished from a variety of underlying coastal plain deposits belonging to the Borgloon Formation of the Tongeren Group (NCS website). A typical gravel of black flat cm-size flint generally occurs at the base of the Berg Sand.

1.5 Thickness

The maximal thickness in North Belgium is about 140 m (Weelde SCK 98 borehole) and about 120 m in the Mol-Dessel area (Figure 2). Compared to the North Belgium area the Rupel Group was eroded by about 80 m towards the Antwerp area (De Man et al., 2010). In the outcrop zone along the Rupel river the thickness is even further reduced to about 40 m (Reet borehole). In the Land van Waas area only the lower part of the Rupel Group is preserved, about 12 m clay is exposed in the former clay pit at Sint-Niklaas (SVK pit). Along the Albert Canal in Southeast Limburg the Rupel Group thickness is about 45 m (Figure 3).

1.6 Occurrence

The deposits of the Rupel Group occur north of the rivers Durme, Rupel, Dijle, and of the line Leuven-Tongeren. Along the southern rim of this area, the Rupel Group crops out. The deposits dip to the north and are therefore present in the subsurface of the Antwerp Campine and Limburg Campine areas (Figure 1b).

1.7 Regional correlations

Vandenberghe et al. (2001) have presented a correlation scheme, based mainly on geophysical well signatures and cored boreholes, between the clay-enriched, sand-enriched and silty to sandy clay units across North-Belgium, the Lower-Rhine area in Germany and South Limburg and the Achterhoek in the Netherlands. An actualized version for Belgium is presented in Figure 4.

1.8 Age

The chronostratigraphic scheme presented in Figure 5 is based on the Geological Times Scale 2020 (Speijer et al., 2020). Note that the age for the GSSP Chattian is slightly different (27,82 Ma) in the ICS chart (2023/4). Chronostratigraphic anchoring is based on magnetostratigraphy (Lagrou et al., 2004) and on nannoplankton and dinoflagellate biostratigraphy. The identification of *D. biffi* in Van Simaey et al. (2005) has not been withheld (for arguments see 5.1 in Munsterman and Deckers, 2020). The hiatus between Rupelian and Chattian is mainly situated in Rupelian time (see also Coccioni et al., 2018). In addition age intervals within the Rupel Group are based on the obliquity cycles in the ON-Mol-2D borehole (Vandenberghe et al., 2022) starting with the base of Rupel Group at 32 Ma (NP22/NP23 boundary). A silicified foraminifera event is considered the start of the tectonic tilting with uplift and erosion in the west (De Man et al., 2010). The boundary between the Rupel Group and the overlying Veldhoven Formation (line 4) is a low angle unconformity (Dusar and Vandenberghe, 2020 3.2) and in northeast Belgium at this level the RVG graben fault activity resumes depositing much thicker Chattian deposits in the graben. The hiatus between the top of the Rupel Group and the base of the Chattian Voort Sand is dated following De Man et al. (2010) and Coccioni et al. (2018). The age of the basal Voort Sand is put at the start of the *Svalbardella* interval including the *Asterigerina* horizon almost at the

NP24/NP25 boundary (Coccioni et al., 2018 table 1; Speijer et al., 2020 fig.28.11). Assuming the latter boundary only slightly deviates from the North Sea NP24*/NP25* proxy (De Man et al., 2010), the Voort Sand outlier in the Antwerp area is correlated to this nannoplankton boundary (Vandenberghe et al., 2004).

2 Bilzen Formation

Unit Name: Bilzen Formation

Hierarchical unit: Rupel Group

Type: Formation

Code: Bi

Authors of the LIS: Vandenberghe Noël & Wouters Laurent

Alternative names: The formation has been coded as Bi on the 1:50 000 geological maps. Its components are coded with R (from Rupelian) on the former 1:40 000 map and in the Stratigraphic register (Anonymous, 1929 & 1932).

Origin of the name: The name Bilzen for the formation was first introduced by Marechal (1993) based on the Nationale Commissie voor Stratigrafie: Tertiair (1988). Bilzen is a village in South East Limburg. The village lends its name to the first detailed geological map sheet in the area (1:20 000) on which the different components of what is today known as the Bilzen Formation are mapped (Van den Broeck, 1883a; Van den Broeck & Rutot, 1883).

Formal

Date: May 2023

Cite as: **NCS-addition**

2.1 Characterizing description

The formation consists essentially of fine-sized and quartz-dominated sandy sediments (the Kerniel Member and the Berg Member) and a mollusc-rich (*Nucula compta* Goldfuss, 1837) calcareous clayey intercalation (the Kleine-Spouwen Member) between both. The formation rests on the Tongeren Group below and underlies the Boom Formation.

2.2 Type section, type locality, type borehole, type CPT and/or geophysical borehole.

A complete succession of the formation is seldom accessible in outcrop. In a detailed description of a profile between Tongeren and Waltwilder, Cadée et al. (1976) represent only the Berg Sand and the Kleine-Spouwen or Nucula Clay. Halet (1932) presents a complete profile along the Albert Canal west of Maastricht close to the profile in Vandenberghe et al. (2001, fig.10) drafted during the enlargement of the Canal section in the area of Gellik-Eigenbilzen (Sturbaut et al., 1999; Baut & Génault, 1999).

Therefore the area bordering the Albert Canal northeast of the village of Bilzen is indicated as type area for the Bilzen Formation (Figure 3). A characteristic geophysical log signature of the Bilzen Formation is

recorded in the borehole Koewijde-KS2 (Figures 3, 9) located north of the reference Canal area (Figure 1a).

2.3 Description upper boundary

The Bilzen Formation is always capped by the Boom Clay Formation. The contact is a clear lithological contrast if the top of the Bilzen Formation consists of the Kerniel Sand or the Berg Sand. However towards the west and northwest the Kerniel Sand disappears and the Kleine-Spouwen Clay is in direct contact with the Boom Clay. Although in the subsurface Gulinck (1975) still could follow the Kleine Spouwen Clay Member as an individual layer in the base of the massive Boom Clay as far westwards as the Winterslag colliery shaft, such distinction is tedious and therefore the entire clay section is considered as the Boom Clay Formation. This means that the upper boundary of the Bilzen Formation in this situation equals the upper boundary of its Berg Sand Member. In such situation, geophysical logs in the overlying Boom Clay show a marked change in signature from sand to clay, marked by a black arrow 1, correlating laterally with the base of the Kleine Spouwen Clay (examples in Figures 6, 8a,b,c,d and Vandenberghe et al. (2001 figs. 5 to 9)); this correlation is confirmed by paleontology as far as in the Waasland and Brabant areas (Steurbaut et al., 1999; Vandenberghe et al., 2001 p 71).

2.4 Description lower boundary

The transgressive Berg Sand is always present at the base of the Bilzen Formation and in the western part of the formation's occurrence area it is even the sole unit of the formation (see in 3.). Its base overlies a variety of coastal plain deposits of the Formation of Borgloon (Tongeren Group) displaying a very different sediment type from the Berg Sand and hence the base of the Bilzen Formation is generally easily recognised. If geophysical logs show the presence of a similar sand type below the Berg Sand, the boundary is tentatively put at the base of the upper broad gamma ray or resistivity lobe and thereby respecting the general thickness of the Berg Sand (e.g. Donderslagse Heide KS29 (Figure 6), Opglabbeek Industrie KS19 (Figure 8a)).

2.5 Thickness

Depending on the presence of all 3 composing members of the Bilzen Formation its thickness varies between 5 and 25 m.

2.6 Occurrence

The formation crops out in the south of the Hageland and in Limburg (Figure 1a). Further north, the formation occurs in the deeper parts of the subsurface of the eastern Campine while in the western part it is laterally relayed by the lower part of the Boom Clay Formation (Figures 8a,8b,8c,8d). Three areas can be distinguished (Figure 7): a zone southeast of the line Maaseik, Genk, Hasselt where the three members of the formation occur, a central zone around Aarschot-Leopoldsburg with only the Berg Member present and the northwest zone including Mol-Dessel, the Antwerp Campine and the Boom Formation type area, where the Bilzen Formation is laterally entirely replaced by the Belsele-Waas and Terhagen Members of the Boom Clay Formation. Note that the quality of presently available data in the boundary areas between the 3 zones makes the exact interpretation of the stratigraphic unit present remaining debatable (for example compare the Kerkhoven borehole in Figure 8a and in Vandenberghe et al. 2001 fig. 5).

2.7 Regional correlations

Geophysical borehole logs allow to correlate the different members of the Bilzen Formation in Belgium and also into the neighboring areas in the Netherlands and Germany (Vandenberghe et al., 2001). In Germany, the Berg Sand is known as the Walsumer Sand and the Kleine-Spouwen Clay as the Ratinger Ton. In Belgium to the west, as discussed above (3. & 6. and Figures 8a,b,c,d), the Kleine-Spouwen Member is relayed by the lower part of the Terhagen Member of the Boom Clay Formation, the Kerniel Sand by the main part of the Terhagen Member and the Berg Sand Member is relayed by the Belsele-Waas Member of the Boom Clay Formation (Steurbaut et al., 1999; Vandenberghe et al., 2001). Note that Figures 8c & 8d suggest that it is possible that the upper finest grained part of the Berg Sand already correlates to the lowermost part of the Terhagen Member.

2.8 Age

The base of the Berg Sand, the lower member of the Bilzen Formation, occurs at the start of the nannoplankton biozone NP23 (Steurbaut et al., 1999) estimated at 32 Ma. Therefore the Bilzen Formation can be situated in the lower part of this biozone as figured in Vandenberghe (2017, fig.4) (Figure 5).

3 Berg Sand Member (Bilzen Formation)

Unit : Berg Member

Hierarchical unit name: Bilzen Formation, Rupel Group

Type: Member

Code: BiBe

Authors of the LIS: Vandenberghe Noël and Wouters Laurent

Alternative names: No other names have been used. However it should be noted that the Ruisbroek Sand unit occurring below the Belsele-Waas Member of the Boom Clay Formation has sometimes been mistaken for the Berg Sand, simply because geometrically both sand units occur under the clay.

On the geological maps 1:40 000, the Berg Sand Member has been labelled R1b and its basal gravel has been separately labelled R1a (Anonymous 1892, 1896, 1900, 1909) while in the Stratigraphic register (Anonymous 1929,1932) the Berg Sand was labelled R1. On the recent 1: 50 000 map, the Berg Sand Member is coded as BiBe.

Origin of the name: The name was introduced by Van den Broeck (1883b) in an explanatory note of the 1/20.000 geological map Bilzen. Berg is a hamlet northeast of Tongeren, and is a dependent municipality of the city of Tongeren (Limburg province).

Formal

Date: May 2023

Cite as: NCS-addition

3.1 Characterizing description

The base of the Berg Sand Member is a regionally occurring transgressive surface characterized by black and flat flint pebbles generally about 2 to 3 cm in diameter. In the exposure area Leuven-Tienen-Tongeren, the Berg Member consists of yellowish to pale grey, slightly glauconitic, medium-grained quartz sand. It is expected that under the water table the sand may turn more greyish. In the about 6 m thick outcrop section the lower part is clearly horizontally bedded with a 150-175 µm grain-size modal value but the upper part is more homogeneous and cohesive with a modal size of 100-125 µm and clay fraction approaching 10% at the top (Gullentops, 1988 p. 242-243). Probably the twofold nature of the geophysical signal of the Berg Sand Member in some borehole logs reflects the same lithological subdivision as observed in outcrops (Figures 8c,8d,10). At particular levels (Figure 10) occur sparse molluscs, a.o. *Astarte trigonella* (Nyst, 1845), *Glycymeris obovata* (Lamarck,1819) and *Arctica islandica rotundata* (Agassiz, 1845) (Glibert & de Heinzelin, 1954; Glibert, 1955 & 1957 and for nomenclature see also Marquet et al., 2012).

3.2 Type section, type area, type borehole, type geophysical borehole

Van den Broeck (1883b) refers to the “gîte classique de Berg”, an outcrop along a road on the southern slope of the small hill on which the hamlet Berg (north of Kleine Spouwen, southeast of Bilzen) is

located. For the ancient references to this historical stratotype see Glibert & de Heinzelin (1954 p. 301, point 200 and map fig.4) (Coordinates: X = 233.040; Y = 171.340; Z = + 105 m). In the archives of the Geological Survey of Belgium more recent information on investigations at this site can be found (Archives Geological Survey 93W0243).

A long standing outcrop of the Berg Sand Member is the Roelants extraction pit at Lubbeek near Leuven (Figure 10). In the subsurface, the geophysical signature of the Berg Sand Member is well expressed on resistivity and gamma-ray logs (Figures 8a, 8b, 9 and figs. 8, 9 in Vandenberghe et al., 2001).

3.3 Upper boundary description

The Berg Sand Member is overlain by a grey clay deposit, either the Kleine Spouwen Member or the Boom Clay Formation and therefore the upper boundary contact is always sharp (Figure 10).

3.4 Lower boundary description

The Berg Sand Member is overlying a variety of coastal plain facies of the Borgloon Formation of the Tongeren Group. The contact is always fairly easily recognizable as an extensive subhorizontal transgressive surface with characteristic small flattened black pebbles occurring at its base; even if the underlying Borgloon Formation facies also consists of sand, differences in colour and in sedimentary structures allow an easy recognition of the base of the Berg Member. However if in the subsurface geophysical logs show the presence of a similar sand type below the Berg Sand unit itself, the boundary is tentatively put at the base of the upper broad gamma ray or resistivity lobe respecting the general thickness of the Berg Sand as is shown in the Donderslagse Heide KS29 log (Figure 6) and the Oplabbeek Industrie KS19 log (Figure 8a).

3.5 Thickness

The thickness of the Berg Sand Member is between about 5 and 10 m.

3.6 Occurrence

The Berg Member occurs in outcrops and in the shallow subsurface in the Leuven-Tienen-Tongeren area, and slightly north of this area. Towards the northwest the Berg Sand Member continues in the subsurface but will be relayed by the Belsele-Waas Member of the Boom Clay Formation northwest from the area Mechelen Geel Mol onwards (Vandenberghe et al., 2002; Vandenberghe et al., 2001 figs. 4,5) (Figure 7).

3.7 Regional correlations

For paleogeographical reasons the Berg Sand Member transits to the northwest into the Belsele-Waas Member of the Boom Clay Formation. The Berg Sand corresponds to the Walsumer Sand in Germany.

3.8 Age

The Berg Sand Member contains nannoplankton biozone NP23. The transition from the NP22 to NP23 biozone occurs precisely at the base of the member which is exactly the same biostratigraphic position of the base of the Belsele-Waas Member of the Boom Clay Formation overlying the Ruisbroek Member of the Zelzate Formatie. The age estimate for this biostratigraphic boundary is 32 Ma (Speijer et al., 2020).

4 Kleine Spouwen Clay Member (Bilzen Formation)

Unit: Kleine Spouwen Member

Hierarchical unit name: Bilzen Formation, Rupel Group

Type: Member

Code: BiKs

Authors LIS: Vandenberghe Noël and Wouters Laurent

Alternative names: A short historical review of the stratigraphic classification of the clay unit called nowadays the Kleine Spouwen Member is given in Glibert & de Heinzelin (1954 p 283-284 and Tableau I). Based on his mapping of the Bilzen 1:20 000 sheet, Van den Broeck (1883a,b) individualized the now-named Kleine Spouwen clay unit and separated it from underlying units. This clay unit was labelled as R1c on the geological maps 1:40 000 (Anonymous, 1892,1896, 1900, 1909). However the name used to refer to the clay unit, already as long ago as Bosquet (1851), was 'the clay with *Nucula compta* (or *compta*)' as this shell is commonly present in the clay. In the Legend of the geological map 1:40 000 the clay is described as 'argile en masse lenticulaire à *Nucula compta*' (Anonymous 1909), as 'clays with Nucules' in the Stratigraphic register (Anonymous, 1929,1932) where it is labeled R2a and as 'Argile sableuse à nucules' in Glibert & de Heinzelin (1954). Gulinck (1954) reports on 'l'argile à *Nucula compta*, dite aussi argile de Klein-Spauwen'. 'Argile sableuse à *Nucula compta*' is also reported by de Heinzelin & Glibert in the Lexique Stratigraphique International (Denizot, 1957 p 142). At the occasion of their study in the Sint-Truiden area Bor et al. (1980) have also presented a detailed historical nomenclature review used for the clay unit and concluded with the proposition to use the name *Nucula Clay Lyell, 1852*, emend. However in the logic of naming lithostratigraphic units with reference to a locus typicus, the Nationale Stratigrafische Commissie (1988) decided to further use the term Kleine Spouwen Member. On the recent 1:50 000 geological maps the Kleine Spouwen Clay Member is coded BiKs. Note that several spelling variants have been used in literature used (Kleine-Spauwen, Klein-Spauwen, Kleyn-Spauwen,...).

Origin of the name: The clay unit was individualized as a separate stratigraphic unit by Van den Broeck (1883b) in an explanatory note of the geological map Bilzen (scale 1/20.000). However it was originally named the 'argiles à Nucules' (see Alternative names) and the term 'Klein-Spauwen Clay' was only introduced later (Gulinck, 1954). Kleine Spouwen is a village in South East Limburg, today a dependent municipality of Bilzen.

Formal

Date: May 2023

Cite as: NCS-addition

4.1 Characterizing description

The member consists of greenish to yellowish grey clay, turning brownish when oxidized. The member is frequently calcareous, rich in foraminifera and with numerous *Nucula compta* accompanied by some more rare shells. Calcareous concretions have been described by Gulinck (1954). The fossils indicate a

fully marine depositional environment (see also Janssen, 1979). The presence of sand has been described by several authors and Gulinck (1954) even reports that it may grade into the underlying sand of the Berg Member accompanied with a thickness reduction.

4.2 Type section, type area, type borehole, type geophysical log

The type area undoubtedly is the Kleine and Grote Spouwen area between Bilzen and Tongeren. Glibert & de Heinzelin (1954) refer to the 'gisement classique de l'argile à nucules' in the outcrop points 205-206 in Kleine Spouwen (op.cit. p 301 and map fig.4) and present a section through the Kleine Spouwen hill (op.cit. p 306 fig. 12) that was also referred to by Van den Broeck (1883b). This section through the hill has coordinates between X = 233.180, Y = 170.420, Z = + 117 m and X = 232.860, Y = 170.250, Z = + 122 m. This is also the type locality reported in the Lexique Stratigraphique International (Denizot, 1957). In the subsurface, the geophysical signature of the Kleine Spouwen Clay Member is well expressed on resistivity and gamma-ray logs (Figure 9; Vandenberghe et al., 2001 figs. 8 ,9).

4.3 Upper boundary description

When the Kleine Spouwen Clay Member is overlain by the Kerniel Sand Member, generally the lithological contrast is easily picked, although Matthijs (1999 p. 41) also reports that the transition can be gradual. Westwards from its type area (map Figure 7) the Kerniel Sand wedges out and the geophysical logs lose the individual signatures of the Kerniel and Kleine Spouwen Members (Figure 8a and Vandenberghe et al., 2001 fig. 9). There the Kleine Spouwen Clay becomes overlain directly by the Boom Clay and the entire clay unit is described as part of the Terhagen Member of the Boom Clay and it directly overlies the Berg Sand Member of the Bilzen Formation. Gulinck (1975) could still identify the Kleine Spouwen Clay Member as an individual layer directly under the Boom Clay, till the Winterslag colliery shaft, slightly more westwards than where the geophysical borehole logs lose the individual Kleine-Spouwen and Kerniel Member signals (Figure 8a). On geophysical logs, where the Berg Sand is directly overlain by the Boom Clay, a characteristic sharp increase in clay content is observed just above the Berg Sand Member and labelled with a black arrow 1 (Figures 6, 8a). This arrow 1 signal can be observed westwards above the Berg Sand and even further westwards above the Belsele-Waas Member in the Rupel area (Figures 8d, 11). Remarkably the clay section between this arrow 1 above the Belsele-Waas Member in the Waasland area and the base of the Boom Clay Formation above the Berg Sand in Brabant has the same biostratigraphic content as the Kleine Spouwen Clay Member in its type area in the east (Vandenberghe et al., 2001 p 71). Steurbaut et al. (1999) have correlated the biostratigraphic content of the type Kleine Spouwen Clay with the interval between the top of the Belsele-Waas Member (from bed IV/5 in Figure 12) and the septaria level S 10 in the Boom Clay Formation area (see Figures 8d, 12).

4.4 Lower boundary description

The Kleine Spouwen Clay Member always overlies the Berg Sand Member and therefore the lithology contrast gives a clear lower boundary of the Kleine Spouwen Member. Gulinck (1954) reports that in some places the clay unit seems to be replaced at its base by the underlying sand (see 1.).

4.5 Thickness

The member has a reported maximum thickness of 10 m (Claes et al. , 2001). Gulinck (1954) notes that the development of the clay unit is very irregular.

4.6 Occurrence

The Kleine Spouwen Clay Member occurs in the shallow subsurface of the Sint-Truiden–Tongeren area in South Limburg (Claes et al., 2001; Claes & Gullentops, 2001), and is known northwards as far as Genk, Waterschei, Winterslag, Maasmechelen–Eisden (map Figure 7) (see also 3.). On the Hasselt geological map sheet, Matthijs (1999) reports thickness between 6 and 9 m and notes that variations in thickness suggest tectonic activity in the area.

4.7 Regional correlation

As discussed in section 3, a carbonate rich signature of the Kleine Spouwen Member can be traced far to the west where it is no longer recognized as the individual Kleine Spouwen Member but forms the lower part of the Terhagen Clay Member of the Boom Clay Formation, up to and including the septaria S10 level. The Kleine Spouwen Member can be traced into the Netherlands and also in the Lower Rhine area where it is named Ratingen Ton or Tonmergel and contains a septaria horizon correlated with septaria horizon S10 (Vandenberghé et al., 2001 fig. 15).

4.8 Age

Paleontological data show that the Kleine Spouwen Clay Member falls within the same biozonation as the interval between the top of the Belsele-Waas Member and the Terhagen Member clay around septaria level S10 (Sturbaut et al., 1999; Vandenberghé et al., 2001 p71).

5 Kerniel Sand Member (Bilzen Formation)

Unit: Kerniel Member

Hierarchical unit: Bilzen Formation, Rupel Group

Type: Member

Code: BiKe

Authors LIS: Vandenberghe Noël and Wouters Laurent

Alternative name: The labelling of the Kerniel Sand on the 1:40 000 geological map (Anonymous 1909) consists of 3 codes: R1d, R2a and R2b. The reason is that within the Rupelian stage (R), two 'assises' were distinguished (R1 & R2); within each of these marine cycles or 'assises' a theoretical sedimentary cycle was assumed with successive facies 'a' (gravel), 'b' (transgressive sand), 'c' (deeper marine clay) and 'd' (regressive sand) (Rutot, 1883). As the Kerniel Sand at Kerniel near Borgloon (Looz) interpreted by Van den Broeck (1893 p. 270) as a stratigraphically independent sand unit between two deeper marine clay units, the argile à *Nucula compta* (Kleine Spouwen Member) and the argile à *Leda Deshayesiana* (Boom Formation), this intermediate Kerniel Sand unit needs to be composed of a succession of regressive sand, a base gravel and an overlying transgressive sand, labelled respectively as R1d, R2a and R2b.

In the Stratigraphic Register (Anonymous, 1929,1932) the sand unit corresponding to the Kerniel Sand is not listed. On the recent 1: 50 000 geological maps the coding for the Kerniel Sand is BiKe.

Origin of the name: The sand unit has been recognized as an individual stratigraphic subdivision in an explanatory note of the geological map Bilzen 1/20.000 by Van den Broeck (1883a, 1883b). Van den Broeck (1893 p 270) refers to the Kerniel section near Looz (Borgloon) as an example of the sand unit between the Kleine Spouwen Clay Member and the Boom Clay Formation. The village of Kerniel lies north of Borgloon and is now a dependent municipality of Borgloon (Limburg province). The term Sand of Kerniel has been used by Glibert and de Heinzelin (1954) and Gulinck (1954).

Formal

Date: May 2023

Cite as: NCS-addition

5.1 Characterizing description

The Kerniel Sand Member consists of medium-grained, white to yellowish quartz sand with only rare mica and glauconite grains. The sand has been described as clayey at the base and fining towards the top. Occasional layers of *Glycymeris obovata* (Lamarck, 1819) shells and marine shell imprints have been described in the upper part. Other characteristic species are *Arctica islandica rotundata* (Agassiz, 1845), *Pycnodonte queteleti* (Nyst, 1853), *Hilberia hoeninghausi* (Defrance, 1825) (Vervoenen, 1995; Baut & Génault, 1999). Except for some reworked foraminifera, no microfauna has been observed. Small lignite fragments are occasionally present. In Limburg the gravel in the middle of the sand unit is reported to be

well developed and consists of rounded quartz and flint pebbles (from Van den Broeck 1893 p 285, 280; Gulinck, 1954; Batjes, 1958; Kruissink et al., 1978; Claes et al., 2001; Claes & Gullentops, 2001).

As the Kerniel Sand Member is seldom exposed, the Gellik-Eigenbilzen Albert Canal section in the early 90's of the previous century is an exceptional outcrop worth mentioning. The section was studied for fossils by Vervoenen (1995) and Baut & Génault (1999). Remarkably in the middle of the 9-10 m thick sand section the last authors describe a dm thick shell grit layer (op.cit. fig.4) with a wavy eroding base (op.cit. fig.3) containing fish and other vertebrate remains and also small white quartz pebbles, undoubtedly the same level described by Steurbaut et al. (1999) with channels, gravel and oblique lamination. This observation seems to fit the subdivision in three units labelled R1d, R2a, R2b by Van den Broeck (1893) as discussed above.

5.2 Type section, type area, type borehole, type CPT and/or geophysical log

Van den Broeck (1883) refers to the railroad Looz (Borgloon)-Kerniel, at Kerniel, a section in which he originally had erroneously taken the Kerniel Sand for 'boldérien sableux' (Van den Broeck, 1893 p 270) (an interpretation still held for possible by Gullentops, oral com.). This railroad section is point 163 in Glibert & de Heinzelin (1954, p 299 and map fig.4). In the close vicinity Glibert & de Heinzelin (op. cit.) report an open sand pit in the Kerniel Sand at their point 164 and a few other outcrops.

In the subsurface the sand lithology of the Kerniel Member between the clays of the Kleine Spouwen Member and the Boom Formation is easily recognized on geophysical logs (examples Figures 3, 8b, 9 and Vandenberghe et al., 2001 fig. 9).

5.3 Upper boundary description

Unless erosion has left Quaternary deposits directly above the Kerniel Sand, the member is overlain by the Boom Clay Formation, and therefore the top of the Kerniel Member is a clear lithological boundary.

5.4 Lower boundary description

Although the base of the Kerniel Sand Member is reported to contain some clay (Kruissink et al., 1978 fig.2 ; Claes et al., 2001; Claes & Gullentops, 2001) the contact with the underlying Kleine-Spouwen Clay Member is generally beyond difficulty. This is in line with the clear distinction observed on resistivity and gamma-ray logs (examples Figures 3, 8b, 9 and Vandenberghe et al., 2001 fig. 9).

5.5 Thickness

Thickness of the Kerniel Sand Member varies from 5-7 m on average to maximal 10 m (Claes et al., 2001; Claes & Gullentops, 2001).

5.6 Occurrence

The Kerniel Member occurs in South Limburg: northeast and east on the geological map sheet Sint-Truiden and north on the map sheet Tongeren (Claes et al., 2001; Claes & Gullentops, 2001) (Figure 7). Further northwards in the subsurface, the member can be identified on geophysical logs as far north as the boreholes Koewijde-KS2 (Figure 3, 9), Dornerheide-KS6 (Figure 8a), and Ruwmortelsheide-KS22 (063E0222 and Vandenberghe et al. 2001 fig. 9), whilst west of these boreholes the Kerniel Member, as well as the Kleine-Spouwen Member are absent in the Opplabbeek-KS19 borehole (Figure 8a and Vandenberghe et al. 2001 fig. 9).

5.7 Regional Correlations

The Kerniel Sand Member is relayed westwards by the Terhagen Clay Member of the Boom Clay Formation (Figures 4, 8a, 8b). Steurbaut et al. (1999) demonstrated that the paleontological content of the basal part of the Kerniel Sand section along the Albert Canal correlates with the clay layer above septaria S10 in the Boom Clay type area and its middle part with the layers 12-18 (Figure 12 numbering III). It is possible that the higher sandy or silty intervals in the Terhagen Clay Member above the interpreted Kerniel Sand Member interval in the boreholes Koewijde KS2 (numbers 1-5 in the Terhagen Member in Figure 9) and Driepaalhoeve KS3 (Vandenberghé et al., 2001 fig.9) are indicative of the lateral transition between Terhagen Clay and the thickening Kerniel Sand towards the east; in the Lower Rhine area the thicker Kerniel Sand replaces a large part of the Terhagen Member below the level with septaria S40 (Vandenberghé et al. 2001 fig. 15).

5.8 Age

The chronostratigraphic position of the Kerniel Sand Member is in the lower part of nannoplankton zone NP23 and is geometrically equivalent to part of the Terhagen Member of the Boom Clay Formation (Figure 4).

6 Boom Clay Formation

Unit name: Boom Formation

Hierarchical unit name: Rupel Group

Type: Formation

Code: Bm

Authors LIS: Noël Vandenberghe & Laurent Wouters

Alternative names: informally this unit has also been referred to as Rupelian clay or Rupel clay. In the description of the area around Bilzen, Van den Broeck (1883b) used the term “glaise schistoïde du Limbourg”. Coding on the geological maps and the stratigraphic legends has differed through time: R2c on the 1:40 000 map (Anonymous 1892,1896,1900,1909), R2b in the stratigraphic registers (Anonymous 1929,1932) and Bm on the most recent 1:50 000 geological maps in use today (<https://www.vlaanderen.be/publicaties/lithostratigrafische-tabel-van-het-neogeen-en-paleogeen-tertiair-lithostratigrafic-of-the-paleogene-and-the-neogene-in-flanders>).

Origin of the name: The reference to Boom has been made for the first time in literature by De Koninck (1837) describing ‘l’argile de Basele, Boom, Schelle etc.’. Boom is the main town along the Rupel river where the clays have been extensively exploited for structural clay products like bricks, floor and roof tiles.

Formal

Date: May 2023

Cite as: **NCS-addition**

6.1 Characterizing description

6.1.1 General lithological properties of the Boom Clay Formation

An extensive synthesis on the Boom Clay geology is given in Vandenberghe et al. (2014). The Boom Clay is a grey silty clay or clayey silt with fairly constant chemical and mineralogical properties. Macroscopic fossil content is limited and mostly single shells of the mollusc *Portlandia deshayesiana* (in the literature also reported as *Nuculana* and *Leda*) are observed.. The ecological analysis of all observed fauna and flora in the clay proves the marine character of the clay deposit. The Boom Clay has been deposited in an open shelf sea under warm climatic conditions as a life-supporting mud at an approximate depth of about 100 m for the most clay-enriched parts, although the water depth fluctuated with several tens of meters due to eustatic variations during the full history of the clay sedimentation. The most silty horizons contain glauconite pellets. The clay contains a few percent of very early diagenetic, mm to cm and even dm scale concretionary pyrite that formed clearly associated with the presence of organic matter in the clay. Black staining of the clay is due to the presence of an increased amount of fine particles of land-derived plant remains. Small quantities of marine organic matter adsorbed on the clay minerals are always present. Marl horizons occur and typically large septaria concretions have developed in the most calcareous horizons. The septaria are an iconic property of the Boom Clay

Formation (Septarienton in Germany). Detailed clay mineralogy of the Boom Clay can be found in Zeelmaekers et al. (2015).

6.1.2 The micro-lithostratigraphy of the Boom Clay

The clay is typically banded with layers of about 20 to 50 cm thickness, expressed by rhythmic variations in silt content producing shades of grey, black layers with increased amounts of land-derived plant remains and paler clay enriched in carbonates. Some originally marl horizons are now almost completely converted into septaria horizons.

Importantly, all these thin layers can be correlated in outcrops or by geophysical log signatures in the subsurface and hence they define a constant vertical succession for the entire Boom Clay (Vandenberghe, 1978; Vandenberghe et al., 2001). Therefore the layers can be used as a microstratigraphic instrument. Eastwards in the Limburg Campine area however the upper part of the clay becomes more sandy and grades into the Eigenbilzen Formation (Figure 4).

The succession of the layers in the outcrop area have been established and numbered by Vandenberghe (1978, p.39) and a more complete numbering scheme has been further developed by Mertens & Wouters (2003) based on the detailed analysis of cores and geophysical borehole logs in several boreholes related to the NIRAS/ONDRAF SCK/CEN research project for the deep storage of nuclear waste in the Mol-Dessel area (Figure 12).

As numbering has been developed over the years some authors have used numbering systems slightly deviating from the original and all explained in Figure 12 under the roman-figure headings (I,II,III, IV, V). Especially in the lower thick silt layers of the Boom Clay a consistent numbering between areas remains difficult as the thickness of this basal part of the clay increases to the northeast as illustrated with the boreholes Reet (Rupel cuesta) and ON-Dessel-1 (Campine) correlated in Vandenberghe et al. (2001, fig.7) (Figure 11).

It is not excluded that the number of microstratigraphic layers detected will still increase if in the future more of the detailed signals on the geophysical logs could become consistently identified between boreholes. An example is the layer 39 sensu Abels et al. (2007) (heading II in Figure 12). This layer is recognisable on resistivity logs but not individually numbered as it is less well outspoken in field logging (see Vandenberghe, 1980 fig. 139) although the original grain-size data (Vandenberghe 1978) already suggested the presence of an additional silt horizon, later confirmed by detailed analyses by Van Boven (1998). Another example of an additional silt horizon identified on geophysical logs compared to the field log is marked 68? on the Mol-Dessel reference section between septaria levels S70 and S80 (Figure 12), or septaria level S75 in De Craen (1998 fig.V-4).

6.1.3 Bed status for key layers.

In the microstratigraphic succession, not all individual layers have prominent properties that allow their easy identification in a section. However in the outcrop area some layers do and have been the key for correlating between clay pits. Therefore such layers can be considered as key-horizons and could eventually be given an official 'bed 'status. At present they are considered as informal beds. These key layers in the Boom Clay Formation outcrop area are (indicated by the number under heading III in Figure 12):

- the slightly pink to brownish horizon R (nr 21) with a thin white horizon at its base (Figure 14);

- the boundary surface between grey and black clay (between layers nr 31 and 32) , also very well expressed in the natural gamma ray logs (Figures 13,18);
- the very silty to fine sandy double layer labelled db or DB (nr 39-41) (Figures 14,17,18);
- septaria layer S20 characterised by large and numerous septaria (in layer nr 14);
- septaria layer S50 characterized by large platy septaria containing multicoloured pyrite crystals precipitated in the septae (nr 49);
- septaria layer S60 , containing siderite, rusty coloured, with visible bioturbation tracks (nr 56).

These layers are figured in Vandenberghe (1978, photographs 3, 4, 5 and 6) and in Vandenberghe et al. (2014 figs 10, 36 and 42). Other layers in the subsurface could also be singled out for their particular correlation potential such as the numbered high-resistivity signals in the Boeretang Member (heading I in Figure 12, see LIS Boeretang Member). Another particular horizon proposed for a 'bed' status is the phosphoritic fragment bed at the base of the Belsele-Waas Member in the Waasland area (see LIS Belsele-Waas Member 4.).

6.1.4 Subdivision of the formation into members.

The boundaries of the 4 members in the Boom Clay Formation are indicated in Figure 12. At the base occurs the Belsele-Waas Member with characteristically thick silty clay layers, thereby limiting the Belsele-Waas Member to the truly silty base of the Boom Formation as shown in Figure 12; in previous studies the top of the Belsele-Waas Member was put just below the clay bed containing S10 and labelled 'original boundary' in Vandenberghe et al. (2014 fig. 12) in which study the present top was labelled as 'proposed boundary'. The Terhagen Member above the silty clay is a grey coloured and typically banded clay containing the S20 septaria horizon and the pinkish-brownish R bed (key layers). The overlying Putte Member is a black stained typically banded clay containing the silty DB bed and the characteristic S50 and S60 septaria beds. The black staining of the clay is caused by the systematic occurrence of black layers, of comparable thickness as the silty-clayey layers, characterized by increased amounts of land-derived plants. The Boeretang Member at the top is characterised by a coarsening upwards trend with relatively thick very silty layers alternating with clayey layers; this member is typically well expressed on geophysical well logs (Figure 2). From geometric and lithological considerations, the distinction in Limburg by Halet (1936) between light grey clays labelled R2c below sandy clay with 'schistoid' (s) black or brown plastic clay horizons labelled R2cs, could well fit the distinction Putte Member and Terhagen Member as defined in the present LIS (see Vandenberghe 1978 fig. 1.3).

6.2 Type section, type area , type borehole, type CPT and/or geophysical log

The area in which the Boom Clay Formation traditionally has been and still is exploited for brick making or other structural clay products, along the Rupel river between Rumst and Boom (Rupel Cuesta) and along the Scheldt between Temse and Antwerpen, is designated as the type area of the Boom Clay (Figure 1a). Instead of the former numerous brick yards with their own clay extraction pits, nowadays only two actively exploited large pits are active: the Wienerberger clay pit at Rumst and the Argex clay pit at Kruibeke-Burcht. Both clay pits are therefore the practical type sections at present. Many sections of former clay pits in the type area are documented in Vandenberghe (1978) and the cored and geophysical borehole at Reet (water tower) documents the Rupel cuesta section (Van Echelpoel, 1991 fig. 4.5; Vandenberghe et al., 2001 fig. 3).

As the upper part of the Boom Clay Formation is considerably eroded in the designated type area (Figures 4 and 5), a group of additional boreholes around Mol-Dessel in the Antwerp Campine (Mol SCK 15, ON-Mol-1 and ON-Dessel-1), is selected as reference boreholes to demonstrate the complete Boom Clay Formation section (Figures 2 and 12). The geophysical well logs of the three boreholes presented in Figure 2 are interpreted in terms of the 4 members of the Boom Clay Formation and a few key horizons. The link of the geophysical logs to the lithology section of the boreholes is easy as the same interpretation terms are figured on the lithology section of the same Mol-Dessel area in Figure 12 which is representing the most complete information extracted from cores and geophysical logging including core imaging. A correlation between the Reet borehole section in the outcrop area and the equivalent part in the Mol-Dessel area is shown in Figure 11.

6.3 Description upper boundary.

Where eroded, the Boom Clay section is overlain by late Oligocene or Neogene glauconitic sands. This lithological contrast is easy to pick in outcrop and on geophysical logs. If overlain by the Eigenbilzen Formation, the distinction is where the silt-and-clay-fraction- dominated Boom Clay Formation is replaced by the very-fine-sand dominated Eigenbilzen Formation. In geophysical well logging the transition is marked by a sudden change in the resistivity and gamma ray signal (Matthijs, 1999, figs. 10 & 11). In the geophysical well log collection of Vandenberghe et al. (2001), the lower part of the Eigenbilzen Fm is coded A (see Figures 3,4,6,9). Also on geophysical well logs the banded signal so typical for the Boom Clay Formation is replaced by broader lobes in the Eigenbilzen Formation (see Figure 2). In the legend accompanying the 1:50 000 map sheet 25 Hasselt, Matthijs (1999) could show that there is a gradual transition of the Eigenbilzen Formation west and northwards to the clay-enriched Boom Clay Formation (see e.g. Matthijs, 1999, fig. 12 and Figures 4 and 5).

6.4 Description lower boundary

The lower boundary of the Boom Clay Formation overlying the Ruisbroek Sand of the Zelzate Formation (Tongeren group), the Berg Sand or the Kerniel Sand of the Bilzen Formation (Rupel Group) is easily picked by the sharp lithological contrast between clay and sand.

6.5 Thickness

In the Campine subsurface, the maximal thickness of the Boom Clay Formation is about 100 to 120 m, but the formation thickness is reduced where its top is either eroded or where it is replaced by the Eigenbilzen Formation and/or the Bilzen Formation pro parte (Figure 5): e.g. a few meter thickness in the southern part of the Waasland area, 40 m in Rupel area, 40 m in the Hasselt area, 80 m in the Antwerp area and about 10 m in the Albert-Canal section near Eigenbilzen.

6.6 Occurrence

The Boom Clay Formation outcrops in the Waasland area, north of the Rupel river, between the Grote Nete and the Dijle-Demer rivers, and in southern Limburg (Figure 1a). North of this outcrop area the clay occurs in the subsurface, except for some locations in the Hageland where the erosion surface underlying the late Miocene Diest Formation has locally completely removed the Boom Clay Formation.

6.7 Regional correlations

Using geophysical logs and cored boreholes, the internal subdivisions in the Boom Clay Formation at layer scale and at member level can be straightforwardly correlated within Belgium and into the

neighboring countries the Netherlands and Germany (Vandenberghe et al., 2001; Vandenberghe et al., 2014, fig. 14).

6.8 Age

Based on available chronostratigraphic data (Figure 5) the Boom Clay Formation is older than about 29.3 Ma and younger than 32 Ma.

7 Belsele-Waas Silt Member (Boom Formation)

Unit: Belsele-Waas Member

Hierarchical unit: Boom Clay Formation, Rupel Group

Type: Member

Code: BmBw

Authors of LIS: Noël Vandenberghe and Laurent Wouters

Alternative names: In a now obsolete two-fold subdivision of the Boom Clay, Vandenberghe (1974, fig. 8.1. and p. 186; Vandenberghe, 1978) distinguished a lower grey clay and an upper black clay, respectively named Waasland clay and Putte clay. The Waasland clay included the present Belsele-Waas and Terhagen Members. The silty base of the Boom Clay Formation to which the Belsele-Waas Member refers has been long recognized and although no formal name was given to this silty base in the type area of the Boom Clay Formation it has been indicated by the special symbol 'R2b' by Halet (1936) and Gulinck (1965) (discussion in Vandenberghe, 1974, p. 186). The silty base of the Boom Clay Formation is included pro parte in the unit labelled R2c on the geological map 1:40 000 (Anonymous, 1892,1896,1900,1909) and pro parte in the unit labelled R2b in the Stratigraphic Register (Anonymous, 1929, 1932). On the recent 1: 50 000 geological maps, the Belsele-Waas Member is coded BmBw.

Origin of the name: The name Belsele-Waas Member refers to the several clay pits close to each other exploited by Scheerders-Van Kerchove, SVK nv in the second half of the 20th and first decade of the 21st century in the locality Belsele-Waas, part of the town of Sint-Niklaas (East- Flanders province).

Formal

Date: May 2023

Cite as: NCS-addition

7.1 Characterizing description

The Belsele-Waas Member consists of very silty grey clay, very low in carbonate and in organic matter and forms the base of the Boom Clay Formation. In the Waasland area (Figure 1a) the silt-enriched clay is divided in two parts by a thinner 50-60 cm clay horizon (bed 3 heading IV in Figure 12) (Vandenberghe, 1978 photo 9; Vandenberghe, 1980 p 162; Vandenberghe 2017 fig. 8). In the top of the lower thick silt layer occasionally small and poorly consolidated septaria-like carbonate nodules have been observed (labelled S05 in Figure 12). Compared to the Waasland area, in the subsurface of the Campine area an

additional thick silty layer overlain by another thinner clay bed occurs at the base of the geophysically interpreted Belsele-Waas Member (labelled 0 in Figure 11).

Grain-size analyses of the member in the Waas area in Vandenberghe and Van Echelpoel (1987, fig. 12) show the sand fraction to be limited to 20-30% except for the very basal part. Analyses in the On-Mol-1 borehole show an upward decreasing sand content, from about 70% at the very base to about 5% in the top (Frederickx, 2019 fig. 35); the coarsest samples occur in the level 0 at the base of the Belsele-Waas Member in the Mol-Dessel area (Figure 11).

Compared to the overlying part of the Boom Clay, the alternation of clay and silty beds is missing in the Belsele-Waas Member. Still banding as stacked silt layers is present (Vandenberghe 1978; Vandenberghe, 2017 fig. 8) and its origin is explained in Vandenberghe et al. (2014 §4.2.1.). Characteristic regionally-consistent flat gully levels indicating wave erosion at the sea bottom are present in the silty clay (Vandenberghe, 1978 photo 8 p 37; Vandenberghe, 2017 fig. 10) and occasionally even a gutter fill was observed (Vandenberghe et al., 2002 fig. 3). Beds of *Pycnodonta callifera* (Lamarck, 1810) have been reported although these oysters were also found in the Ruisbroek Sand (Vandenberghe and Van Echelpoel, 1987). According to Marquet & Herman (2012) *Arctica islandica rotundata* (Agassiz, 1845) is characteristic for the lowermost part of the Belsele-Waas Member.

7.2 Type section, type locality, type borehole, type CPT and/or geophysical borehole

In the past several decades, the now abandoned clay exploitation pits of the company Scheerders-Van Kerkhove (S.V.K.) at Sint-Niklaas, Belsele-Waas, have been the reference for studies of the Belsele-Waas Member (topographic map sheet 15/5-6 Sint-Niklaas-Temse, last open pit located at X = 132.500, Y = 205.000, Z = + 17 m). Sections, analyses and photographs can be found in Vandenberghe (1978; 2017) and Vandenberghe & Van Echelpoel (1987).

The cored and geophysically logged Reet borehole is the type section of the Belsele-Waas Member in the Boom Clay Formation reference area (Figure 11). The geophysical silt and clay intervals labelled 1, 2, 3 and 4 in Figure 11 can be well traced to the actual grain-size analysis of the member in Vandenberghe & Van Echelpoel (1987 fig. 12); note that the labelling of the layers in Figure 11 is not related to the labelling systems in reference Figure 12 and only serves the purpose of comparing the Reet and ON-Dessel-1 boreholes in this particular Figure 11. The reference section of the member in the Campine subsurface is based on the ON-Mol-1 and ON-Dessel-1 boreholes presented in Figure 12. The relationship between the Rupel area and the Mol-Dessel area is illustrated in Figure 11 displaying the thickening of the Belsele-Waas Member towards the northeast as discussed in 1. (from Vandenberghe et al., 2001, fig. 7).

7.3 Description upper boundary

Based on the grain-size evolution, the Belsele-Waas Member originally was defined as the unit between the base of the Boom Clay and the base of septaria or calcareous bed S10 (see Vandenberghe et al., 2001, fig. 2; Vandenberghe et al., 2014 fig. 12). However on geophysical resistivity logs, the thick silt layers at the base delineate an easily recognizable unit that is much more practical for subsurface correlation purposes. As geophysical borehole logging has become a common practice, the top of the thick silty layers is now chosen as the top of the Belsele-Waas Member (many examples can be found in the figures in Vandenberghe et al. (2001) with the present top indicated as 'top silt B-W'). The original definition, below S10, is often labelled as 'original boundary' on past stratigraphic schemes.

7.4 Description lower boundary

The silt-enriched Belsele-Waas Member overlies the sand-enriched Ruisbroek Member of the Zelzate Formation (Tongeren Group). This lithology change can be easily observed in occasional excavations as figured in the SVK exploitation pit at Belsele-Waas itself (Vandenberghe, 2017 fig. 8). Also on resistivity logs the boundary can fairly accurately be picked where the signal markedly changes as shown on the Reet and ON-Dessel-1 borehole logs in Figure 11.

At the basis of the Belsele-Waas Member in its type area, a gravelly layer of cms to dm scale fragments of mainly phosphatised internal shell molds and worm tracks has been observed. The phosphate impregnated sediment is the fine glauconite bearing sand of the underlying Ruisbroek Sand (Vandenberghe, 1978; Janssen, 1981) and also bivalves typical for the Ruisbroek Sand occur in the phosphate bed (Marquet & Herman, 2012). These last authors have given a detailed description of the bed composition and proposed a formal bed status to this phosphorite horizon as part of the Ruisbroek Sand. However Vandenberghe and Van Echelpoel (1987) and Vandenberghe et al. (2002) argued the horizon was broken up at the base of the transgressive Belsele-Waas Member meaning that the fragmented phosphorite horizon could be considered part of the latter member. Also, as no indications of this bed have been observed in the subsurface outside the type area, a formal bed status remains debatable.

7.5 Thickness

The thickness of the Belsele-Waas Member is usually slightly less than 10 m.

7.6 Occurrence

The Belsele-Waas Member is accessible in the shallow subsurface of the Waasland and Rupel area and it can be systematically mapped on the Mechelen and Aarschot map sheets 1:50 000 (Buffel et al., 2009; Schiltz et al., 1993). To the north, in the deeper subsurface, the Belsele-Waas Member overlying Ruisbroek Sand has been observed in the Herentals and the Geel-Mol-Dessel-Balen area (Figures 7,8).

7.7 Regional correlations

The Belsele-Waas Member is the silt-enriched base of the Boom Clay Formation and laterally to the east and to the south in the direction of the Oligocene coast, the silt is replaced by sand, the Berg Sand of the Bilzen Formation. The transition occurs in the subsurface and probably is gradual (Figures 7, 8a, 8b, 8c, 8d). This lateral correlation is supported by the lowest part of the NP23 nannoplankton biozone present in the Belsele-Waas Member and the Berg Sand. In southern direction, Berg Sand is unmistakably present in the Leuven area (Vandenberghe et al., 2001, fig.4) and in the eastern direction the transition occurs around the border of the provinces Antwerpen and Limburg (Balen and Kerkhoven boreholes in Vandenberghe et al., 2001 fig. 5) (Figures 7, 8a).

7.8 Age

The transition between the underlying Ruisbroek Sand and the Belsele-Waas Member coincides with the transition of the NP 22 to NP23 nannoplankton biozones dated at 32 Ma (Figure 5).

8 Terhagen Clay Member (Boom Formation)

Unit: Terhagen Member

Hierarchical unit: Boom Clay Formation, Rupel Group

Type: Member

Code: BmTe

Authors LIS: Vandenberghe Noël and Wouters Laurent

Alternative names: In a now obsolete twofold subdivision of the Boom Clay, Vandenberghe (1974, fig. 8.1. and p. 186; 1978) distinguished a lower grey clay and an upper black clay, respectively named Waasland clay and Putte clay. The Waasland clay included the present Belsele-Waas and Terhagen Members. In the section by Vandenberghe (1980) it was indicated as part of the 'Argile grise'.

The Terhagen Member of the Boom Clay Formation is included pro parte in the unit labelled R2c on the geological map 1:40 000 (Anonymous, 1892,1896,1900,1909) and pro parte in the unit labelled R2b in the Stratigraphic Register (Anonymous, 1929, 1932). On the recent 1: 50 000 geological maps the Terhagen Member is coded BmTe.

Origin of the name: The name Terhagen Member refers to the locality Terhagen along the Rupel cuesta, presently part of the municipality of Rumst in the Antwerpen province. The name was first introduced by the Nationale Commissie Stratigrafie (1988) (see also Marechal, 1993) as the middle member of a threefold subdivision of the Boom Clay Formation.

Formal

Date: May 2023

Cite as: **NCS-addition**

8.1 Characterizing description

The Terhagen Member is the part of the Boom Clay in between the Belsele-Waas Member and the Putte Member. If the former member is not present, the Terhagen Member occurs at the base of the Boom Clay Formation above the Bilzen Formation. The Terhagen Member is a banded pale grey clay consisting of a several-dm-scale alternation of silt-enriched and clay-enriched layers (Figure 12). This banded nature is in contrast with the thick silt layers of the underlying Belsele-Waas Member. The pale grey colour is in contrast with the overlying Putte Member which is darker grey to even black stained. The black staining is due to layers with a few percent silt-sized detrital plant particles and such layers in the Terhagen Member are well expressed only at two levels, although under particular conditions a few more very subtle ones can be observed (Figures 13, 14, 15, 16). In the middle of the Terhagen Member occurs a characteristic pinkish to brownish stained silty layer labelled R-horizon (Figures 12, 14, 15, 16). In its part below the R-horizon the clay is calcareous (Figure 15), above the R-horizon carbonate is only occasionally present (Vandenberghe et al., 2014 fig. 11). *Septaria* horizons S10, S20 (key layer for correlation), S30 and S40 (Figures 12, 13, 14 and photographs 2 & 7 in Vandenberghe (1978)) occur in the Terhagen Member. In the subsurface of the Mol-Dessel area a geophysical continuous carbonate

content log has shown a periodicity in the carbonate content all along the complete Boom Clay section, also in the Terhagen Member (Vandenberghe et al., 2022).

8.2 Type section, type area, type borehole, type CPT and/or geophysical log

The Terhagen Member type area is the Rupel-cuesta exploitation area where it general forms the lower part of the extracted clay. The active clay extraction pits have shifted in the past but are located around $x= 154\ 000$, $y= 197\ 500$ and $Z =+30$. An almost complete section of the Terhagen Member is given by Vandenberghe (1978, photo 2 p. 25). In the field and on geophysical well logs, the Terhagen Member is fairly easily picked between the top of the silty Belsele-Waas Member (Figures 2 and 15) and the overlying Putte Member (Figures 13, 16). The boundary with the Belsele-Waas Member is identified by the sudden incursion of clay expressed by a low resistivity signal (lowest oblique black arrow 1 on logs in Vandenberghe et al., 2001 figs. 3, 5-7 /Figures 8a, 8b, 8c, 8d, 11). On geophysical GR logs the boundary with the overlying Putte Member is identified by a sudden increase in GR announcing the organic richer Putte Member (Figure 2).

8.3 Description upper boundary

The limit of the Terhagen Members occurs at the first black organic rich horizon marking the start of the overlying Putte Member (bed 32 of Vandenberghe 1978) (Figures 13, 16, 17). On geophysical logs the sudden increase of the gamma ray signal can be used to delineate the top of the Terhagen Member (see 2).

8.4 Description lower boundary

The lower boundary is marked by the thick silty beds of the Belsele-Waas Member: two in the type area, or three in the Campine subsurface (see LIS Belsele-Waas Member). Therefore the lower boundary of the Terhagen Member coincides with the start of the regular alternation of a few dm-thick silt-enriched and clay-enriched beds (Vandenberghe, 1978 in the middle of photo 8; Vandenberghe, 2017, fig. 8 at top of black vertical arrow) (Figures 12 and 15). On geophysical logs the base of the Terhagen Member occurs at the first sudden low resistivity signal indicating clay incursion above the Belsele-Waas Member silty clay (Figure 2) and labelled by oblique black arrow 1 on logs in Vandenberghe et al. (2001 figs. 3, 5-7) (Figures 8a, 8b, 8c, 8d).

8.5 Thickness

The thickness varies between 20 and 25 m.

8.6 Occurrence

The Terhagen Member occurs in the same area as the Boom Clay Formation. The Boom Clay Formation outcrops in the Waasland area, north of the Rupel river, between the Grote Nete and the Dijle-Demer rivers, and in southern Limburg (Figure 1a). North of this outcrop area, the clay occurs in the subsurface except for some locations in the Hageland where the erosion surface underlying the late Miocene Diest Formation has locally removed the Boom Clay Formation.

8.7 Regional Correlations

Towards the east, the lower part of the Terhagen Member with the oblique black arrows and in between the septaria level S10 (Figure 2) and the main part of the Terhagen Member grade into respectively the Kleine-Spouwen Member and the overlying Kerniel Sand, both of the Bilzen Formation (Figures 4 and 5). Therefore the Boom Clay Formation that occurs above the Bilzen Formation in Limburg

starts at a level within the upper part of the Terhagen Member as it is known in the type area and in the Mol-Dessel area (Figures 4 and 5).

8.8 Age

The Terhagen Member contains the lowest part of nannoplankton biozone NP23 (Figure 5).

9 Putte Clay Member (Boom Formation)

Unit: Putte Member

Hierarchical unit: Boom Clay Formation, Rupel Group

Type: Member

Code: BmPu

Authors LIS: Vandenberghe Noël and Wouters Laurent

Alternative names: The Putte Member was included pro parte in the unit labelled R2c on the Geological maps 1: 40 000 (Anonymous 1892,1896, 1900, 1909) and pro parte in the unit labelled R2b in the Stratigraphical register (anonymous 1929,1932). The coding on the recent 1: 50 000 geological maps is BmPu. On the section in Vandenberghe (1980) it was named 'Argile noire'.

Origin of the name: The name Putte Clay has been introduced by Vandenberghe (1974, fig. 8.1., p. 16) and accepted by the National Stratigraphic Commission (Nationale Commissies Stratigrafie Commissie Tertiair, 1988) (see also Marechal, 1993). Putte is a municipality in the south of the Antwerp province (photograph of the abandoned clay pit at Putte in Vandenberghe et al., 2014, fig. 36).

Formal

Date: May 2023

Cite as: **NCS-addition**

9.1 Characterizing description

The Putte Member overlies the Terhagen Member and underlies the Boeretang Member. The Putte Member consists of an alternation of silt-enriched and clay-enriched layers, several dm thick up to over a meter near its top (Vandenberghe & Mertens, 2013). Also the Terhagen Member is layered but in contrast to it, the Putte Member additionally has black stained layers of a few dm at the basis of the clay-enriched layers (Figures 13 and 16). Therefore the Putte Member can be described as a dark grey clay in contrast to the paler grey Terhagen Member (Vandenberghe et al. 2014 fig.10; Vandenberghe, 1978, photo 6, p. 33). Characteristic beds in the Putte Clay are the 2 DB silty beds (Figures 17, 18), the platy septaria bed S50 and the sideritic septaria horizon S60 (Figure 12). From its base to about level S50, the Putte Clay has the thinnest layers of the Boom Clay Formation (Vandenberghe & Mertens, 2013). These features can be particularly well observed in the outcrop area (Figures 13, 16, 17, 18). However in the outcrop area the upper part of the Putte Member is significantly eroded compared to its more complete development in the subsurface. The Putte Clay Member in the subsurface keeps a fairly

constant average gamma-ray and resistivity signal across the small wiggles which reflect the alternating silt-enriched and clay-enriched layers. This constant geophysical signal is in contrast with the overlying Boeretang Member of which the resistivity starts to markedly increase upwards, across the wiggles pointing to a much larger silt content than the underlying Putte Member (Figure 2).

9.2 Type section, type area, type borehole, type CPT and/or geophysical log

The type section of the Putte Member is exposed in the upper part of the active clay exploitation front along the cuesta between Rumst and Boom (topographic map sheet 23/3-4 Boom-Mechelen) around the coordinates $x = 154\ 000$, $y = 197\ 500$, $z = + 30$ m. As along the cuesta since some time the exploitation is limited to the Wienerberger clay pit at Rumst and the exploitation has changed from bucket bagger extraction to dragline excavating, also the Argex clay extraction pit at Kruikebeke-Burcht can serve as reference section. Remark that the Putte Clay Member in the outcrop area is always eroded and incomplete. Therefore boreholes with cores and geophysical logs have also to be considered for reference to the complete Putte Member such as the Mol-Dessel area borehole sections and geophysical logs (Figure 2).

9.3 Description upper boundary

The top of the complete Putte Member can only be observed in the subsurface. It occurs where the resistivity log changes from a fairly constant average value in the Putte Member to marked increasing values (Figure 2). This change occurs at the base of silty bed 99 (under III in Figure 12), the first marked resistivity wiggle and labelled wiggle 0 (under I in Figure 12) in the numbering system of the outspoken silty layers in the overlying Boeretang Member. Silty bed 99 is topped by the clay layer containing the septaria couple S180 & S185 (Figure 12).

9.4 Description of the lower boundary

The base of the Putte Member corresponds to the base of the lowest of a series of black organic rich layers in the dark or black clay of the Putte Clay Member: this base is always a well observable contrast with the underlying grey Terhagen Member in the outcrop area (Figures 13,16,18). It occurs at the base of clay bed 32 (under III in Figure 12) and septaria level S40 is situated almost one meter below the Terhagen/Putte boundary (Figures 12, 13, 18; Vandenberghe et al., 2014 fig. 10). In subsurface conditions the base of the Putte Member is picked at the start of the marked gamma-ray signal increase caused by the uranium content of the organic matter in the black clay (Figure 2).

9.5 Occurrence

The Putte Member occurs in the same area as the Boom Clay Formation; it outcrops in the northeast of the Waasland area as in the clay pits Steendorp-Kruikebeke, north of the Rupel river, between the Grote Nete and the Dijle-Demer rivers, and in southern Limburg (Figure 1a). North of this outcrop area, the Putte Member occurs in the subsurface except for some locations in the Hageland where the erosion surface underlying the late Miocene Diest Formation has locally removed parts and even locally the total Boom Clay Formation.

9.6 Thickness

The maximal thickness is slightly over 50 m in the northern Campine (Weelde SCK 98 borehole) but in the reference outcrop area it is reduced by erosion (15 m in Kruikebeke-Burcht clay section and 8 m along the Rupel cuesta).

9.7 Regional correlations

The lower part of the Putte Member has a widespread consistent occurrence as shown by geophysical log correlations (Vandenberghe et al., 2001). Further east of the Mol-Dessel area in Limburg the Eigenbilzen Formation of the Rupel Group is well developed and replaces the upper part of the Putte Member (Figures 3, 4, 5, 21).

9.8 Age

According to the review in (Figure 5) the nannoplankton biozones NP23 is present in the Putte Member. The presence of the NP24 biozone as reported in literature (see Vandenberghe et al., 2014; Vandenberghe, 2017) is uncertain as the NP24 range figured in De Man et al. (2010), Vandenberghe et al. (2012) and Coccioni et al. (2018) is different from the range in the review in Speijer et al. (2020) and used in the biostratigraphy zonation in Figure 5. The discrepancy is probably linked to the absence in the North Sea Basin of the typical NP24 markers (see discussion in De Man et al. (2010).

10 Boeretang Member (Boom Formation)

Unit: Boeretang Member

Hierarchical unit: Boom Clay Formation, Rupel Group

Type: Member

Code: BmBt

Authors of the LIS: Vandenberghe Noël and Wouters Laurent

Alternative names: Since the particular silty top of the Boom Clay Formation was recognised as an individual component in the wells at Mol, Dessel, Balen and Retie (018E0132), this silty top was designated as 'transition layers' (Neerdael et al., 1981). Because the layers within this silty top component can be well correlated on the basis of characteristic resistivity wiggles on logs, the interval has also been designated as '10-Wig package'. Based on further subdivisions of the geophysical well log signals in the top of this silty Boom Clay, an informal system W0, W1, W2, W3 was applied in Vandenberghe et al. (2001).

Origin of the name: Boeretang is small locality in the municipality of Mol. The introduction of the term Boeretang Member for the upper interval in the Boom Clay with outspoken silt layering and particularly well expressed in geophysical resistivity logs, is the outcome of extensive borehole investigations related to the NIRAS-ONDRAF nuclear waste disposal research in the Campine area and in particular at the Mol-Dessel research site (Mertens & Wouters, 2003). The term has been approved by the National Stratigraphic Commission (Vandenberghe & Wouters, 2011).

Formal

Date: May 2023

Cite as: **NCS-addition**

10.1 Characterizing description

The Boeretang Member occurs in the top of the Boom Clay Formation and exclusively in the subsurface where it is well characterised by geophysical borehole logs. It differs from the underlying Putte Member by its steadily increasing resistivity values on the geophysical log and by the prominent high resistivity values of the silt-enriched layers leading to marked wiggles on the curve. However the grain size of the Boeretang Member, expressed on a silt-sand-clay triangular diagram, is similar to the grain size of the Putte and Terhagen Members (see Vandenberghe et al., 2014 fig. 27 and Frederickx, 2019 fig. 35). The Boeretang Member silt layers that alternate with the clay layers can be well identified in cores. The pronounced expression on the geophysical logs of the silt and clay layers makes it possible to apply a coherent numbering of the silt beds and to correlate boreholes (Figure 2 and 12). The full Boeretang Member detailed lithological layering, including septaria horizons S180, S185, S190 and S200, was established by Mertens and Wouters (2003) (Figure 12 with codes under heading I).

10.2 Type section, type area, type borehole, type CPT and/or geophysical log

The reference boreholes are located in the Mol-Dessel area and in Weelde (SCK-NIRAS 98). The geophysical borehole measurements are presented in Vandenberghe et al. (2001 figs. 5 & 6; 2014 fig. 13) (Figure 2). Foraminifera and dinoflagellate cyst data in the Weelde SCK 98 borehole are described respectively in De Man (2006) and Van Simaey (2004), and Sr-isotope dating is reported in De Man et al. (2010).

10.3 Description upper boundary

The upper boundary corresponds to the upper boundary of the Boom Clay Formation. The top of the Boeretang Member is characterized by the change in lithology from its silt and clay dominated lithology to the sandy lithology of the overlying units, either Neogene or Chattian glauconite sand units or even the very-fine-sand dominated Eigenbilzen Formation of the Rupel Group. In geophysical borehole logs of the overlying Eigenbilzen Formation, the signals of cyclic clayey and silty layers are organized in broader lobes instead of in a coarsening upward trend like in the Boeretang Member. Conform the NIRAS-ONDRAF practice in the Mol-Dessel area, the top of the Boeretang Member is put at the top of resistivity wiggle 9 (Figure 2), or wiggle 9b in the reference section of the area by Mertens and Wouters (2003) (Figure 12 under heading I).

10.4 Description lower boundary

As the Boeretang Member only occurs in the subsurface, geophysical borehole logs are required to designate a proper lower boundary. The base of the upward increasing resistivity log is the level with the best correlation potential and therefore used as the base of the Boeretang Member. This level corresponds to the base of the resistivity wiggle 0 (Figures 2, 12 under heading I) and corresponds to the base of silt bed 99 in Figure 12 (under heading III).

10.5 Thickness

When completely developed with the wiggles 0 to 9 present, the thickness of the Boeretang Member varies between 23 and 29 m.

10.6 Occurrence

The Boeretang Member is typically present in the northern Antwerp Campine subsurface. It is absent in borehole ON-Doel-2b in the west, but eastwards part of the member is already identified in the boreholes Zoersel and Herentals (see Vandenberghe et al., 2001 figs. 5, 6). Further east of the Mol-Dessel area in Limburg, the Boeretang Member evolves into part C of the Eigenbilzen Formation (see 7. and Figure 4).

10.7 Regional Correlations

Eastwards in Limburg geometrical considerations supported by similar resistivity patterns, indicate that the Boeretang Member of the Antwerp Campine is relayed by part C of the sandy Eigenbilzen Formation (Figure 4). The geophysical similarity consists of the upward coarsening trend superimposed on well-expressed cyclic high resistivity signals that even allows a numbering of the wiggles as demonstrated for example in the Koewijde borehole (Figure 9).

10.8 Age

The lower part of the Boeretang Member, up to almost S190 level, has nannoplankton biozone NP23. Possibly also biozone NP24 occurs above (De Man et al., 2010). However the presence of the NP24

biozone as reported in literature (see Vandenberghe et al., 2014; Vandenberghe, 2017) is uncertain as the NP24 range figured in De Man et al. (2010), Vandenberghe et al. (2012) and Coccioni et al. (2018) is different from the range in the review in Speijer et al. (2020) and used in the biostratigraphy zonation in Figure 5. The discrepancy is probably linked to the absence in the North Sea Basin of the typical NP24 markers (see discussion in De Man et al. (2010)).

11 Eigenbilzen Formation

Unit: Eigenbilzen Formation

Hierarchical name unit: Rupel Group

Type: Formation

Code: Eg

Authors LIS: Noël Vandenberghe and Laurent Wouters

Alternative names: The Eigenbilzen Formation is a sandy unit lying above the Boom Clay that was already recognized in Limburg by Van den Broeck (1884, 1893) and coded by the symbol R2d in his stratigraphic system as well as in the legends of the 1:40 000 geological maps (Anonymous 1892, 1896, 1900, 1909). On the recent 1:50 000 geological map the Eigenbilzen Formation is coded Eg.

Origin of the name: Gulinck (Archives Geological Survey of Belgium-document MG/75/338) introduced the term Eigenbilzen Sand in his borehole descriptions for the sand meant by Van den Broeck (1884, 1893). Eigenbilzen is a village belonging to the municipality of Bilzen in the Limburg province (Figure 1a).

Formal

Date: May 2023

Cite as: NCS-addition

11.1 Characterizing description

The Eigenbilzen Formation consists of grey to grey-green clayey fine sand and silt containing some glauconite pellets especially towards the top. It contains bioturbations but no macroscopic fossils. The Eigenbilzen Formation is well studied in the subsurface of the map sheet 25 Hasselt (Matthijs, 1999) where a consistent threefold subdivision could be demonstrated and characterized by typical resistivity and gamma-ray signatures, labeled A,B,C on Figures 19 and 20. These subdivisions A,B,C have also been identified in geophysical borehole logs outside the Hasselt map sheet and it was demonstrated that the sandy units A and B laterally grade into clay to the west (Vandenberghe et al., 2001) (Figure 4). The unit C is characterized by a coarsening upward trend with higher frequency cycles superposed very similar to the signal of the Boeretang Member of the Boom Clay Formation. Above this part C with high frequency cycles, a sandier top called unit D in Figure 4 is recognized; it was already reported by Matthijs (1999, p. 37) east of the map sheet Hasselt. Matthijs (1999) in his study on the map sheet 25 Hasselt confirmed

the lateral transition of the Eigenbilzen Formation into the Boom Clay Formation also to the north (Matthijs, 1999 fig.11) (Figure 19). These units A,B,C,D in the Eigenbilzen Formation have not been ranked as official subdivisions of the formation. Geophysical logs (Figures 2, 6, 9) and the few outcrops (Vandenberghe, 1978 fig 1.1e) show the presence of more clayey and more sandy layers in the formation.

In the Mol area the Eigenbilzen Formation unit D always contains a few percent $>125\ \mu\text{m}$ size grains and about 20 to 75 % $>62\ \mu\text{m}$ grains, in contrast to the underlying Boeretang Member of the Boom Clay Formation with $<1\%$ $>125\ \mu\text{m}$ grains and $<10\%$ $>62\ \mu\text{m}$ grains (a.o. Frederickx, 2019). In the Hasselt-Diepenbeek area (Vandenberghe, 1978 fig. 1.1e) the $>32\ \mu\text{m}$ content is about 60% in the more clayey layers and about 80% in the sandy layers, similarly to the about 50 to 70% reported in the Mol area. In the Antwerp Campine subsurface, the Eigenbilzen Formation unit D consists of almost-10 m-sized resistivity lobes or intervals superposed on shorter alternating several-dm-sized clay and silt layers (Figure 2); the latter is confirmed by core inspection (see Weelde borehole in Figure 2) and by the geophysical pattern of the formation in the Weelde and Meer boreholes (see Vandenberghe et al., 2001 fig. 6).

11.2 Type section, type locality, type borehole, type CPT and/or geophysical borehole logs

No permanent outcrop of the Eigenbilzen Formation exists and the formation is seldom exposed. The sand has been studied in temporary outcrops during the works for the extension of the locks on the Albert Canal near Diepenbeek and Hasselt (Vandenberghe, 1978 fig. 1.1e), and during the enlargement of the same canal near Gellik (Steurbaut et al., 1999) (Figure 3). The latter outcrop allowed a calibration of the boundary between the Boom Clay and the Eigenbilzen Sand near the place of its original definition by Halet (1932), the village of Eigenbilzen (Vandenberghe et al., 2001).

The interpreted geophysical logs of the boreholes Genk (KB136/ 77E0300) and Houthalen (62E0269 and 62E0266) in the map sheet 25 Hasselt and figured and interpreted by Matthijs (1999, fig. 10) can be used as reference geophysical borehole logs (Figure 20). The Eigenbilzen Sand section thickens to the north and an additional unit D can be identified as shown for the Koewijde KS2 borehole in Figures 3 and 9 ; note however that to the north the Eigenbilzen Formation becomes more clay-enriched (boreholes in Vandenberghe et al., 2001 fig. 9 and Matthijs, 1999 fig. 12) (see also Figure 21). Matthijs (1999) suggests that changes in thickness and clay content can be influenced by late Oligocene differential tectonic activity in the area.

11.3 Description upper boundary

Where the Eigenbilzen Formation is overlain by the Chattian Voort Member of the Veldhoven Formation (Dusar & Vandenberghe, 2020) the boundary can easily be picked by lithology because in contrast to the grey to grey-greenish fine sands without macrofossils of the Eigenbilzen Formation, the Voort Sand is dark green, rich in glauconite pellets, shell bearing and coarser grained with grains $>250\ \mu\text{m}$ (see grain-size profiles of the boreholes 62E0223 at Houthalen-Molenberg and 62E0261 at Helchteren figured in Matthijs 1999 fig. 11). This lithology contrast is reflected in the resistivity and gamma-ray borehole logs as shown on Figures 19 and 20.

11.4 Description lower boundary

Generally the boundary between the underlying clay-enriched Boom Clay Formation and the sandy Eigenbilzen Formation is sharp as was observed in the outcrops along the Albert Canal (Vandenberghe,

1978, fig. 1.1e; Vandenberghe et al., 2001 fig. 10). Also on the geophysical logs a marked contact is well expressed (Figures 6, 19, 20) although in boreholes there are transitions towards the Boom Clay Formation where the boundary is harder to trace as discussed by Matthijs (1999) (see also Figure 9). Therefore the option remains to include the interval A within the Boom Formation rather than in the Eigenbilzen Formation. In the subsurface of Limburg the three intervals A,B,C in the Eigenbilzen Formation (see 11.1.) have different clay contents, most clay-rich at the base of interval A and least clay in the upper part C. Geometric considerations and correlation of key horizons in the Boom Clay Formation show that the base of the interval A, hence the base of the Eigenbilzen Formation, correlates in the west to a level some meter above the DB in the Putte Member of the Boom Clay and the boundary between A and B intervals to a level somewhere in the higher part of the Putte Member (Figure 4).

11.5 Occurrence

The formation crops out along the Albert Canal east of Hasselt (Figure 1a). Borehole log analysis in the Antwerp and Limburg provinces indicates the systematic presence of the Eigenbilzen Formation in the subsurface of Limburg north of its outcrop zone (Figure 21).

The most western occurrence of the Eigenbilzen Formation overlying the Boeretang Member of the Boom Clay Formation is situated in the Antwerp Campine (a.o. Weelde, Meer, Lichtaart, Geel boreholes) (Figures 1a & 1b). In this area it can be distinguished from the Boeretang Member by its higher sand content (see 11.1.) as also expressed on geophysical logs (Figure 2). For geometric reasons this most western extension of the Eigenbilzen Formation probably corresponds to the uppermost parts of the Eigenbilzen Formation in the Limburg province (see 11.7.) (Figures 4 and 5).

11.6 Thickness

On the Tongeren geological map the Eigenbilzen Formation is generally eroded and only 5 to 10 m thickness is left (Claes et al., 2001); this is the case in the eroded Albert Canal section near Eigenbilzen where thickness is about 10 m. Where the formation is complete under the Voort Sand as in the Hasselt geological map area, the Eigenbilzen Formation is about 50 m thick. In the most western occurrence area of the Eigenbilzen Formation thickness is reduced to 20 m or less.

11.7 Regional correlations

Geometrically the Eigenbilzen Formation in the Limburg Campine occurs laterally from the Boom Clay Formation in the Antwerp Campine and there are many indications that the sandy Eigenbilzen Formation is a lateral facies development of the Boom Clay Fm (Vandenberghe et al., 2001; Vandenberghe, 2017) (Figure 4). The Mol-Dessel area succession of Putte and Boeretang Members overlain by Eigenbilzen Formation can be traced on geophysical logs at least as far as the boreholes Balen, Kerkhoven KB 186, Hemelburg KS13 (Figure 21). Further eastwards the A and B units of the Eigenbilzen Formation are the lateral sandy developments of the Putte Member of the Boom Fm; the base of the unit A, at the base of the Eigenbilzen Formation, correlates to a level a few meter above the DB layer in the Putte Member of the Boom Clay Formation (Figure 4). The base of the unit C in the Eigenbilzen Formation is the start of a coarsening upwards trend consisting of a succession of clay-silt alternations, possibly numbered as for example in Figure 9, and very similar to the geophysical pattern in the Boeretang Mbr of the Boom Fm (Figures 4, 6, 9). Therefore this unit C correlates with the Boeretang Member. Logically the top, about 10 m, of the Eigenbilzen Formation lacking the regular layering of silt and clay layers on the geophysical logs and indicated as unit D (Figures 4, 9), correlates

with the Eigenbilzen Fm above the Boeretang Member in the Mol-Dessel area and further westwards (Figures 4 & 5). Unfortunately in the Limburg Campine subsurface neither sediment nor micropaleontological analyses are available to further characterize and calibrate the geophysical subdivisions of the Eigenbilzen Formation.

11.8 Age

The chronostratigraphic interpretation of the Eigenbilzen Formation is sketched in Figure 5. Based on data by Steurbaut, literature reports nannoplankton biozone NP24 in the Eigenbilzen Fm unit D (o.a. Vandenberghe et al., 2004). However the position of the NP24 range in the GTS2020 (Speijer et al. 2020 and used in Figure 5) does not fit the range usually assumed in the North Sea Basin, a discrepancy linked to the absence of the typical NP24 markers in the North Sea Basin (see discussion in De Man et al. (2010). According to Munsterman & Deckers (2020) the Eigenbilzen D Sand in the ON-Mol-1 borehole contains dinocyst zone NSO 4b-5a; these authors also invalidate the *Distatodinium biffi* identification by Van Simaey et al. (2005).

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13 Legends Figures

Figure 1a. Location list and map of data points referred to in the text. The coordinates and details of the data points are given in the section 0'

Data set'. The southern outcropping rim of the Rupel Group with the Boom Clay, Bilzen and Eigenbilzen Formations is mapped. The Rupel Group dips slightly northwards where it is accessible in boreholes except where it has been locally eroded under the Diest Formation in the Hageland (see Figure 1b). The faults figured are those affecting the top of the Rupel Group and the pattern is based on Deckers et al. (2019) in <https://dov.vlaanderen.be/page/geologisch-3d-model-g3dv3> (figure designed by VITO)

Figure 1b. Isohypse map of the top of the Rupel Group (Boom Clay Formation and Eigenbilzen Formation). The overlay grid figures the 1:50 000 geological map outlines. The geographic extent is based on the G3Dv3-model (Flemish Government, DOV). In particular the western extent of the Eigenbilzen Formation is based on a thin geophysical borehole log interval above the Boom Clay Formation most probably interpreted as Eigenbilzen Sand (e.g. in boreholes Lichtaart 30E090, Geel 046W0388, Loenhout DZH21 016E0237); note that previous maps show a more restricted western occurrence (based on Welkenhuysen et al., 2011). The faults figured are those affecting the top of the Rupel Group, based on presently available seismic sections and on the 1:50 000 maps (Deckers et al., 2019); note that other fault patterns have been presented on tertiary geology maps (a.o. Vancampenhout, 2004). (figure designed by VITO)

Figure 2. The GR and RES geophysical logs of the Boom and Eigenbilzen Formations of the Rupel Group in the reference wells Mol SCK-15, ON-Mol-1, ON-Dessel-1 and Weelde SCK-98 in the Antwerp Campine. In the Boom Clay Formation, characteristic log signature levels define its 4 members (Belsele-Waas, Terhagen (T), Putte (P) and Boeretang); R and DB horizons are labeled as they can easily be recognized in field section by respectively a slight pink to brownish colour and a very silty character of 2 closely spaced layers. The main flooding surface horizons, mfs, are sequence stratigraphic interpretations with mfs 1 = R horizon and mfs3 is the sideritic septaria layer S60. The sequence boundaries (SB) and transgressive surface (TS) are also sequence stratigraphic interpretations. The boundaries between the formations and members and the labeled horizons allow to link these geophysical logs to the lithological reference section of the same area in Figure 12. The Chattian present in the ON-Mol-1 and ON-Dessel-1 consists of the Voort Sand Member of the Veldhoven Formation. The position of the base of the Chattian Voort Sand is based on the dinoflagellate cyst study by Van Simaey (2004); its precise top position is slightly differently interpreted (stars) by Van Simaey (op.cit) and by Munsterman & Deckers (2020). (figure modified from Vandenberghe et al., 2014 fig. 13)

Figure 3. The Rupel Group in Limburg interpreted in terms of the Bilzen, Boom and Eigenbilzen Formations in the temporary outcrop section along the Albert Canal in northeast Limburg and in the GR

and RES geophysical log signatures of the Koewijde-KS2 borehole. The Eigenbilzen Formation is subdivided in A,B,C,D units following Matthijs (1999). Meaning of the levels labelled db, R, SB, TS is as in Figure 2; codes a to d and 4 to 0 are events recognised in several borehole logs in Limburg (see Vandenberghe et al., 2001 fig. 9). (*figure based on Vandenberghe et al., 2001 and Steurbaut et al., 1999*)

Figure 4. Regional correlation of the Rupel Group in Belgium between the type outcrop areas in the Antwerp and Brabant provinces, the Antwerp Campine and Limburg Campine using characteristic levels, such as the boundaries between formations and between members, the R and db horizons (see Figs. 2 & 3), and several septaria horizons (S) including 2 sideritic horizons (S60 and an upper one identified in Doel2b, Zoersel and Mol SCK-15 boreholes). Note the geometrical lateral correlations of the Belsele-Waas Mbr of the Boom Formation with the Berg Member of the Bilzen Formation, of the Kerniel and Kleine Spouwen Members with the lowest part of the Terhagen Member above Berg Sand or Belsele-Waas Silty Clay, of the Eigenbilzen A and B units with part of the Putte Clay Member and of the Eigenbilzen C unit with the Boeretang Member while the Eigenbilzen D unit is the Eigenbilzen Formation occurring above the Boeretang Member. The codes a to d and 4 to 0 are the events within the Terhagen Member in Limburg as in Figure 3. Note also that below the Rupel Group, the Borgloon Formation of the Tongeren Group is geometrically lateral of the Ruisbroek Member of the Zelzate Formation. (*modified from Vandenberghe et al., 2001 fig. 15 and Vandenberghe et al., 2014 fig. 14*).

Figure 5. Chronostratigraphic position of the Rupel Group. The lithostratigraphic scheme is a synthesis of Figure 4 and the thickness given is for the Mol-Dessel area. The chronostratigraphic scheme is based on the Geological Times Scale 2020 (Speijer et al., 2020). Note that the age for the GSSP Chattian is slightly different (27,82 Ma) from the ICS chart (2023/4). Chronostratigraphic anchoring is based on biostratigraphy, nannoplankton for line 1 and dinoflagellates for line 3 (note that that the identification of *D. biffi* in Van Simaey et al. (2005) has not been withheld (see 5.1 in Munsterman and Deckers, 2020), on magnetostratigraphy for line 2 (Lagrou et al., 2004). In addition age intervals within the Rupel Group are based on the obliquity cycles in the ON-Mol-2D borehole (Vandenberghe et al., 2022) and integrated starting with the base of Rupel Group at 32 Ma (line 1); the corresponding ages obtained are the stippled lines a to line e. The silicified foram event is considered the start of the tectonic tilting with uplift and erosion in the west (De Man et al., 2010). The boundary between the Rupel Group and the overlying Veldhoven Formation (line 4) is a low angle unconformity (Dusar and Vandenberghe, 2020 3.2). In northeast Belgium at this level the RVG graben fault activity resumes depositing much thicker Chattian deposits in the graben. The hiatus between the top of the Rupel Group and the base of the Chattian Voort Sand (line 4) is dated following De Man et al. (2010) and Coccioni et al. (2018). The age of the basal Voort Sand (line 5) is put at the start of the *Svalbardella* interval including the *Asterigerina* horizon almost at the NP24/NP25 boundary (Coccioni et al., 2018 table 1; Speijer et al., 2020 fig.28.11); assuming the latter only slightly deviates from the North Sea NP24*/NP25* proxy (De Man et al., 2010) the Voort Sand outlier in the Antwerp area (line 6) is correlated to this nannoplankton boundary (Vandenberghe et al., 2004). The red dashed curve across the Boom Clay are the sedimentary sequences figured in Vandenberghe (2017, fig. 4 and Vandenberghe et al. 2014 fig. 24). The xxx at the base of the Belsele-Waas Mbr refers to the phosphoritic bed and the black ovoid symbols at the base of the Berg

Sand Mbr refer to the typical flat pebbles occurring at its base. The vvvv symbol at the base of the Putte Mbr symbolises the systematic occurrence of black organic layers in the Putte Mbr of the Boom Clay Formation. Dotted units are sand and oblique-dashed lines are clay, a mixture of dots and dashes refers to very silty clay.

Figure 6. Donderslagse Heide, stratigraphic interpretation of the geophysical borehole logs. The Berg Sand Member is identified by the difference between the SN and LN pointing to a permeable lithology. Note above the Berg Sand a marked clay content increase (black arrow) interpreted as the geometrically lateral position of the Kleine Spouwen Clay. The R and DB levels are the positions of the classical marker layers in the Boom Clay, respectively the slightly pink to brownish key horizon in the outcrop area and two closely spaced very silty horizons identified by the sharp increase in GR signal. P/T is the boundary between the Terhagen (below) and Putte (above) Members of the Boom Clay Fm. A,B,C are the subdivisions of the Eigenbilzen Formation based on the Houthalen KS11 (062E0269) interpretation (Matthijs, 1999 fig. 10) located nearby borehole Donderslagse Heide KS9 (see correlation in Vandenberghe et al. ,2001, fig. 8).

Figure 7. Map showing: in the southeast the presence of the three members of the Bilzen Formation, in the middle part only the Berg Sand Member of the Bilzen Formation occurring below the Terhagen Member of the Boom Clay Formation, in the northwest the area with the Belsele-Waas Member at the base of the Boom Clay Formation and without the Bilzen Formation. The boundaries are mapped based on stratigraphic interpretations in DOV, in Welkenhuysen and De Ceukelaire (2009) and in particular on the borehole interpretations along section lines I (Fig. 8a), II (Gulinck,1975), III (Fig. 8b), IV (Fig.8c) and V (Fig.8d). Distinguishing between Berg Sand and Belsele-Waas Silty Clay in these sections is based on the GR and RES values including the SN-LN difference. It is admitted that interpretations based only on geophysical logs without additional data can be debatable. Modal grain size of the Berg Sand is 150-175 μm evolving to 100-125 μm near the top a few % <44 μm and almost free of clay fraction (Gullentops, 1988; Gulinck, 1966). At the very top the 175-88 μm fraction is dominant with the <44 μm fraction still well below 10 %. In contrast the Belsele-Waas Member of the Boom Clay in its type area (Vandenberghe & Van Echelpoel 1987) barely has a >88 μm size fraction, except for the lowest meter with even a limited >125 μm fraction. The 88-62 μm and 62-32 μm fractions are both 30 to 40 % and the fraction <25 μm contains 30-35%. In the subsurface of the Mol area (Frederickx, 2019) the sand fraction is diminishing upwards from 60% to 20% accompanied with an increase in clay fraction from 25-50%. Not only the grain-size distribution differs between Berg Sand and Belsele-Waas Member but also the heavy mineral content (see Gullentops, 1963, fig.23; Vandenberghe, 1978, p 74,76).

Figure 8a. Section I on Figure 7. Resistivity SN and LN (left) and GR (red,right) curves illustrating the 3 members of the of the Bilzen Formation in the Dornerheide (063E0216) borehole, the Berg Sand Member below the Terhagen Clay Member of the Boom Clay Formation in the Opglabbeek (063W0215) borehole, and the Belsele-Waas Member below the Terhagen Member in the boreholes ON-Dessel-1 (031W0300) and Balen (031E0338). In the Kerkhoven borehole (047W0264) Berg Sand is interpreted from the GR and RES signatures (Vandenberghe et al., 2001) although log quality does not allow to

exclude the Belsele-Waas Member instead. The marked clay increase at black arrow 1 corresponds to the geometrically lateral position of the Kleine Spouwen Clay in the Terhagen Member. Black arrow 2 is another marked clay increase that can be correlated between boreholes ; septaria level S10 (star in ON-Dessel-1 borehole) is situated between the arrows 1 and 2 as shown by the FMI log in ON-Mol-1.

Figure 8b. Section III on Figure 7. Resistivity SN and LN (left) and GR (red,right) curves (Hasselt in Vandenberghe et al., 2001; Geel and Meerhout in Welkenhuysen and De Ceukelaire, 2009). South of Hasselt (borehole Hasselt stad, 092E0503) the 3 members of the Bilzen Formation are identified while north of Hasselt (Hasselt Concentra and Meerhout boreholes) the Berg Sand underlies the Terhagen Member of the Boom Formation (Belsele-Waas Mb is interpreted in the Meerhout borehole by Welkenhuysen and De Ceukelaire, 2009 fig.48 Profiel D). In the Geel borehole the Belsele-Waas Member signature occurs. The black arrows are as in Figure 8a.

Figure 8c. Section IV on Figure 7. The Pellenberg outcrop section shows the Terhagen Clay Member above the Berg Sand Member. Resistivity SN and LN (left) and GR (red,right) curves in the Herselt (060E0289) and Herentals (045W0337) boreholes. Berg Sand below the Terhagen Clay Member of the Boom Clay is interpreted in the borehole Herselt but note the interpretation of a transition between Berg and Belsele-Waas units in Welkenhuysen and De Ceukelaire (2009 , fig. 36). The dashed line with ? is suggesting a possible delineating of a finer upper part in the Berg Sand unit. In the Herentals borehole Belsele-Waas Member is interpreted below the Terhagen Member (Vandenberghe et al., 2001, fig.5). The black arrows 1 & 2 indicating increased clay content are the same as in Figures 8a and 8b.

Figure 8d. Section V on Figure 7. Correlation between outcrop sections in the Boom Clay Formation from Antwerp to Pellenberg-Lubbeek. The paleontological content in the basal meter of the Terhagen Clay below S20 in Pellenberg is similar to S10 in the Kleine Spouwen Clay Member of the Bilzen Formation (see LIS Kleine Spouwen Clay) and to the S10 and S20 interval in the Rupel type area (see Vandenberghe et al., 2001 p.71). Although lithologically the correlation between the top of the outspoken silty Belsele-Waas Member (below arrow 1 in the Rupel and Waasland area section) with the top of the Berg Sand would seem logical, based on the paleontological correlation of S10 with the very base of the Boom Clay in Pellenberg, it is suggested that the top of the silty Belsele-Waas Member correlates with a level near the base of the more fine grained top part of the Berg Sand at arrow 1 (n Pellenberg section); such a correlation also honours the observation of the occurrence of S10 between the 2 major clay influxes labelled by the arrows 1 and 2 (Figure 8a)(see also correlation scheme in Vandenberghe et al., 2001 fig. 4, note however in that figure the previous Belsele-Waas Member definition). *(figure based on Vandenberghe et al., 1998 fig.16; Vandenberghe et al., 2003b Stop 3 fig.4; Vandenberghe et al., 2014, fig.35)*

Figure 9. Stratigraphic interpretation of the Koewijde borehole (064W0259) geophysical logs: the Bilzen Fm with the Berg Sand Member (B), Kleine Spouwen Clay Member (N) and Kerniel Sand Member (K), the Terhagen and Putte Members of the Boom Clay Formation with the R and db (or DB) key horizons,

and the overlying units A,B,C,D of the Eigenbilzen Formation. The layering 1 to 6 in a coarsening upward trend in the Eigenbilzen C unit is interpreted as the similar structuring in the Boeretang Member of the Boom Clay (Figure 4). For codes a to d and 0 to 4 in the Boom Formation, see Figures 3 and 4.

Figure 10. The classical Roelants extraction pit at Lubbeek. Left: Photograph of the subhorizontal contact of the Berg Sand Member with the underlying Heide and Kerkom sand units of the Borgloon Formation (Tongeren Group). For a discussion of the ‘chocolate coloured sand’ see van Riessen & Vandenberghe (1996) and Vandenberghe (2017). Right: Profile combining different outcrop sections around the Roelants sand pit. Note the internal stratified structure of the Berg Sand and its more fine grained top (see also Figure 8). The clear transgressive nature of the Berg Sand Member regionally overlying different coastal plain facies of the Borgloon Formation is the reason for taking the base of the Berg Sand as the base of the Rupel Group although pebbles including typical base Berg Sand black flattened flint pebbles are already arriving in the area at the base of the Heide Sand.

Figure 11. The correlation between the Belsele-Waas and the Terhagen Members of the Boom Clay Formation in the Reet and ON-Dessel-1 boreholes. Note that the numbering of the layers on this figure only serves the purpose of the correlation of signals between the 2 boreholes in the figure and is not related to the reference numbering in Figure 12. The package labelled 0 is interpreted as stratigraphic thickening and contains the most sandy clay in the diagram figured in Vandenberghe et al. (2014 fig. 27). The black arrows pointing to sudden clay incursions are the same as Figures 2 & 8 bed with the lower arrow the lateral geometrical equivalent of the base of the Kleine-Spouwen Member of the Bilzen Formation (see LIS Kleine Spouwen Member). The R and db key horizons are as in Figure 4. (*figure adapted from Vandenberghe et al., 2001*).

Figure 12. Boom Clay Formation reference microstratigraphy elaborated in the Mol-Dessel area by Mertens & Wouters (2003). It is mainly based on the FMI logs of the On-Mol and ON-Dessel boreholes, complemented by observations around the URL and other reliable observations in outcrops and boreholes. Silty-clay layers are stippled yellow, clay-enriched layers are in grey and septaria horizons are shown by white ellipsoids coded S05, S10,..etc. The boundaries between the members of the Boom Clay Formation are indicated. URL is the position of the Euridice underground research laboratory. The main coding used is given under the heading III. In the Boeretang Member geophysical wiggles are easily numbered and are coded under heading I; numbering under headings IV and V (Van Simaey, 2004, fig.C2, p 175) is related to the lowest part of the Boom Clay Formation and the system under heading II is only used in the periodicity study by Abels et al. (2007). (*figure adapted from Mertens & Wouters, 2003*).

Figure 13. Photograph of the clay pit at Schelle (90's 20th century). Note the change from grey coloured clay of the Terhagen Member below to dark stained clay of the Putte Member above. The dark staining is due to the systematic occurrence of organic rich layers. Note also the occurrence of a similar black stained layer in the lower Terhagen Clay (white arrow). Septaria levels S40 and S20 are visible.

Figure 14. Photograph of the Terhagen Member in the lower part of a clay extraction pit at Terhagen-Rumst (70's of the 20th century). Note the alternation of several-dm-scale layers of pale grey silt-enriched clay with darker grey clay-enriched clay. Black arrows at the right side point to blackish-grey organic rich horizons. Other characteristic levels observed are the pink to brown R horizon, with a typical very thin whitish staining at the base (arrow) due to the presence of a layered pyrite. At the top right a septaria of horizon S40 is visible. The levels of septaria horizons S20 and S30 are indicated but on this photograph no septaria can be observed. The altered abandoned clay face in the upper part of the photograph is the Putte Member with only the position of the DB (or db) still recognisable by its darker staining. Note that all the relative shades of grey depend on the humidity conditions of the clay face.

Figure 15. Left photograph shows a part of the Terhagen Member displaying the R horizon and the S30 and S20 septaria in the clay. Right column shows sediment analyses of the lower part of the Terhagen Member in the Rupel cuesta area. The >32 µm content illustrates the alternation in silt-clay enrichment and shows the very silty nature of the Belsele-Waas Member. The low content in organic matter basically varies with the amount of clay fraction and the carbonates are only systematically present below the R horizon. The vvv symbols in the lithological column indicate the position of two black horizons in the Terhagen Member (see also Figures 13 & 14) (*figure from Vandenberghe et al., 2020*).

Figure 16. Photograph Steendorp Bolderik clay pit (2000's). The change from grey coloured clay of the Terhagen Member to dark stained clay of the Putte Member at the white line. Numbering of the beds as in Figure 12 under heading III. Presence of the pink R horizon is indicated. Silty beds are pale and clay rich beds darker stained.

Figure 17. The Putte Member along the Rupel cuesta (Terhagen-Rumst /1986). Alternation of pale grey silt-enriched and darker grey clay-enriched layers; the latter are friable by alteration at the exploitation face. Note the systematic blackish colour at the base of the clay-enriched layers; these black layers are the characteristic feature of the Putte Member of the Boom Clay Formation and one such black layer is particular marked at the base of the Putte Member. Note also the presence of the very silty DB double layer and the whitish hue of the septaria level S41 in its top. Also the S50 septaria level is slightly paler than the other silty layers. Shovel 40 cm for scale.

Figure 18. Boom Clay outcrop in Terhagen-Rumst. The layered nature of the clay, i.e. the alternation of clay-enriched and silty clay layers, is clearly visible. The black staining is due to admixture of land-derived organic matter. Whitish-grey marly bands as one observed at the bottom of the picture at S40 level, contain septaria carbonate concretions. The pronounced two pale grey and closely spaced layers of silty clay in the middle in the middle of the picture correspond to the double band (DB). Note the sharp boundary between the Terhagen and Putte Members of the Boom Clay Formation. (*figure from Vandenberghe et al., 2014 fig.10*).

Figure 19. South-North profile across the geological map sheet 25 Hasselt between Bokrijk (77E0230) and Beringen (62W0302) showing the consistent occurrence of the threefold subdivision of the Eigenbilzen Formation, labelled units A,B,C . Note in the north of the profile the lateral transition of the A and even B units into the clay rich Boom Clay Formation (*figure from Matthijs, 1999 fig. 11*).

Figure 20. Reference boreholes Genk 77E300, Houthalen 62E269 and 62E266 on geological map sheet 25 Hasselt showing the the borehole resistivity and gamma-ray signatures of the threefold subdivision of the Eigenbilzen Formation (*figure from Matthijs, 1999 fig. 10*).

Figure 21. The distribution areas of the stratigraphic succession Putte Mbr – Boeretang Mbr – Eigenbilzen Fm unit D as in the classical Mol-Dessel area (red dots) and the succession with reduced Putte Mbr- unit A and eventually B,C,D of the Eigenbilzen Fm (green dots). The interpretations are based on geophysical log data (Deckers et al.,2019). The blue dots are borehole data with uncertain interpretation of the Boom Formation to Eigenbilzen Formation transition due to poorly constrained geophysical log data. Note that in particular the lack of data in North Belgium make it impossible to determine the orientation of the boundary between the 2 areas with different stratigraphic successions. The coordinates and details of the data points are given in the section 0'

Data set' (*figure from J. Deckers, VITO*).

14 Data set

All data points, boreholes and (temporary) outcrops, referred to in this Rupel Group LIS-document are collected. All essential points have been mentioned in the document. This table refers to the numbers of Figure 1a and Figure 21.

These data are also accessible via the DOV collection 'NCS_Rupel Group_2024', with DOV-URL: <https://www.dov.vlaanderen.be/data/opdracht/2024-041267>

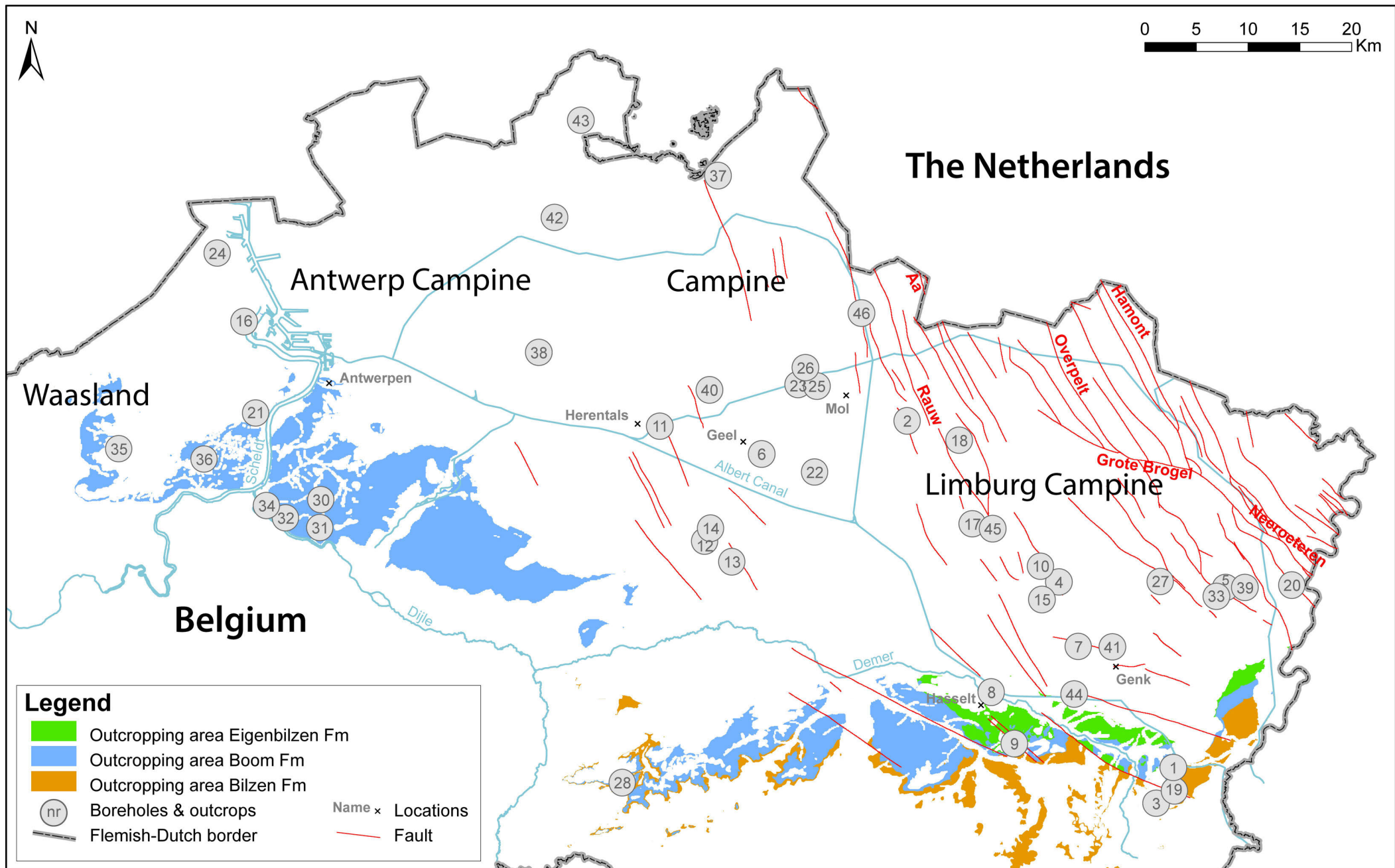
Nr. Figure 1a, Figure 21	Name Figure 1a	Municipality	DOV name	GSB name	X (mL72)	Y (mL72)	Z (mTAW)	Depth (m)	DOV-permkey URL	GSB URL
1	Albert-Canal section (near Eigenbilzen)	Lanaken	kb34d93e-B264	093e0257	236221	174748	78,00	26,64	1930-031273	093e/093e0257.txt
2	Balen B30	Balen	kb17d31e-B320	031e0338	208953	208235	38,00	322	1980-085151	031e/031e0338.txt
3	Berg 'gîte classique de Berg'	Bilzen	kb34d93w-B253 (t.e.m. kb34d93w- B265)	093w0243	233005	171246	100,00	2,7	1972-082725	093w/093w0243.txt
4	Donderslagse Heide	Houthalen-Helchteren	kb25d62e-B274	062e0270	223610	192660	79,19	980,96	1981-103185	062e/062e0270.txt
5	Dornerheide	Maaseik	kb26d63e-B223	063e0216	239730	192120	87,43	1075,5	1980-024463	063e/063e0216.txt
6	Geel	Geel	B/1-1100	046w0388	194861	205033	20,39	205	2006-063660	046w/046w0388.txt
7	Genk	Genk	kb25d77e-B305	077e0300	225504	186415	68,00	805	1979-098935	077e/077e0300.txt
8	Hasselt Concentra	Hasselt	kb25d77w-B390	077w0379	217067	182035	28,93	212	1990-072875	077w/077w0379.txt
9	Hasselt south = stad	Hasselt	kb33d92e-B508	092e0503	219307	177066	62,00	183	1990-044613	092e/092e0503.txt
10	Helchteren	Houthalen-Helchteren	kb25d62e-B265	062e0261	221821	194188	70,50	180	1964-031715	062e/062e0261.txt
11	Herentals	Herentals	BGD045w0337	045w0337	185006	207734	17,71	200	1981-070192	45w0/45w0337.txt
12	Herselt	Herselt	B/1-1115a	060e0289	189384	196607	15,04	165	2005-060166	060e/060e0289.txt
13	Houthalen	Houthalen-Helchteren	kb24d60e-B330	060e0269	192010	194620	17,00	160	1992-084846	060e/060e0269.txt
14	Houthalen	Houthalen-Helchteren	kb24d60e-B274	060e0266	189930	197880	14,00	20	2016-140534	060e/060e0266.txt
15	Houthalen Molenberg	Houthalen-Helchteren	kb25d62e-B225	062e0223	221949	190950	73,20	956,25	1923-084300	062e/062e0223.txt
16	Kallo	Beveren	kb15d27e-B149	027e0148	144820	217840	2,00	622	1965-103793	027e/027e0148.txt

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17	Hemelburg	Beringen	kb17d47w-B258	047w0260	215220	198270	59,12	1200,3	1982-086487	047w/047w0260.txt
18	Kerkhoven	Lommel	kb17d47w-B262	047w0264	213940	206368	46,00	1504,0	1986-038291	047w/047w0264.txt
19	Kleine Spouwen Hill	Bilzen	-	-	between X = 233.18, Y = 170.42, Z = + 117 m and X = 232.860, Y = 170.250, Z = + 122 m.					-
20	Koewijde-KS 2 B73	Dilsen-Stokkem	kb26d64w-B271	064w0259	246160	192360	37,02	1027	2016-123810	064w/064w0259.txt
21	Kruiabeke-Burcht Argex clay pit	Kruiabeke	OVL079.26.01 - Fort van Kruiabeke	-	central location X= 146306, Y = 208655					
22	Meerhout	Meerhout	B/1-1117a	046w0389	200001	203296	24,15	224	2006-067363	046w/046w0389.txt
23	Mol SCK 15	Mol	B/1-0158	031w0237	198406	211750	24,50	577	1975-117398	031w/031w0237.txt
24	ON-Doel 2	Doel	BGD014e0242	014e0242	142228	224453	8,07	173,49	1998-170939	014e/014e0242.txt
25	ON-Mol-1	Mol	ON-Mol-1	031w0314	200191	211622	24,88	572,5	1997-160115	031w/031w0314.txt
26	ON-Dessel-1	Dessel	ON-Dessel-1	031w0300	199117	213382	24,76	613,49	1993-160110	031w/031w0300.txt
27	Opglabbeek Industrie	Opglabbeek	kb26d63w-B218	063w0215	233420	192710	86,75	1228	1983-098675	063w/063w0215.txt
28	Pellenberg Lubbeek Roelants pit	Lubbeek	TO-20171107	-	181416	173274	88,00	2	2017-164496	
29	Point 163 in Glibert & de Heinzelin 1954	Borgloon	kb33d106e-B4	106e0004	220326	167532	101,00	0	1878-044493	106e/106e0004.txt
30	Reet watertoren	Reet	B/1-0709	043w0301	152250	200607	25,40	108	1990-081839	043w/043w0301.txt
31	Rumst Wienerberger clay pit	Rumst	ANT009.51.15 - Eikerveld Voskenshoek	-	central location X = 152645, Y = 198041					
32	Rupel cuesta	Rumst	-	-	around X = 154000, Y = 197500, Z = + 30 m					
33	Ruwmortelsheide	Maaseik	kb26d63e-B229	063e0222	238820	191250	90,52	1236	1984-111198	063e/063e0222.txt
34	Schelle , Damman Clay pit	Schelle	ANT003.41.01 - Boerenhoek	-	central location X = 149114, Y = 200786					
35	SVK Sint-Niklaas clay pit	Sint-Niklaas	kb15d42w-B207	042w0190	132733	205521	17,00	15,5	1957-122096	042w/042w0190.txt
36	Steendorp Bolderik clay pit	Temse	OVL069.52.01 - Bolderik Temerik Steendorp	-	central location = 142323, Y = 202871					
37	Weelde SCK 98	Weelde	kb8d8e-B161	008e0159	190649	231963	30,90	528,5	1996-098751	008e/008e0159.txt
38	Zoersel	Zoersel	kb16d29e-B393	029e0348	173321	214841	13,09	300	1996-069600	029e/029e0348.txt
39	Driepaalhoeve	Dilsen-Stokkem	kb26d63e-B224	063e0217	241570	192130	90,69	1188,4	1980-082436	063e/063e0217.txt

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40	Lichtaart	Lichtaart	B/1-0414	030e0290	189825	211238	15,32	132	1981-001260	030e/030e0290.txt
41	Winterslag	Genk	kb26d78w-B207	078w0206	228762	186354	76,50	700,75	2016-124625	078w/078w0206.txt
42	Loenhout	Loenhout	BGD016e0237	016e0237	174826	227929	32,70	505	1995-166563	016e/016e0237.txt
43	Meer-geothermie	Meer	kb8d7e-B224	007e0205	177378	237304	13,22	2517	1981-082884	007e/007e0205.txt
44	Bokrijk	Diepenbeek	kb25d77e-B232	077e0230	225077	181828	44,80	12,92	1928-035676	077e/077e0230.txt
45	Beringen-Fonteintje	Beringen	kb25d62w-B305	062w0302	217190	197810	66,76	982,4	1981-084407	062w/062w0302.txt
46	Retie	Retie	kb9d18e-B174	018e0132	204520	218665	29,00	344	1981-122355	018e/018e0132.txt
47	-	Kinrooi	kb18d49w-B226	049w0226	247649	207767	33,50	1767	1987-042705	049w/049w0226.txt
48	-	Leopoldsburg	kb17d47w-B264	047w0266	210820	202945	40,00	1570	1986-086500	047w/047w0266.txt
49	-	Bree	BGD048e0294	048e0294	238725	201000	51,00	571,15	2002-107078	048e/048e0294.txt
50	-	Meeuwen-Gruitrode	kb18d48w-B186	048w0185	233844	199424	71,65	1371	1984-024471	048w/048w0185.txt
51	-	Bree	kb18d48w-B193	048w0191	232861	203199	63,75	822	1989-103732	048w/048w0191.txt
52	-	Houthalen-Helchteren	kb25d62e-B276	062e0272	220808	196448	74,36	994,9	1982-084327	062e/062e0272.txt
53	-	Houthalen-Helchteren	kb25d62e-B279	062e0275	218941	196299	68,00	1279,5	1985-024505	062e/062e0275.txt
54	-	Houthalen-Helchteren	kb25d62e-B284	062e0280	224182	194629	77,26	1269,4	1987-024507	062e/062e0280.txt
55	-	Houthalen-Helchteren	kb25d62e-B285	062e0281	220899	195001	71,00	1322	1987-024508	062e/062e0281.txt
56	-	Peer	kb25d62e-B294	062e0290	224826	196069	75,36	1348	1992-031722	062e/062e0290.txt
57	-	Beringen	kb25d62w-B308	062w0305	216948	196936	63,00	1414,2	1988-024511	062w/062w0305.txt
58	-	Heusden-Zolder	kb25d62w-B313	062w0310	217219	193456	65,00	429	1989-084420	062w/062w0310.txt
59	-	Opglabbeek	kb26d63e-B225	063e0218	238210	194690	62,33	1342	1983-111196	063e/063e0218.txt
60	-	Maaseik	KOEN-B179	063e0223	240546	194697	81,85	1264,72	2016-143505	063e/063e0223.txt
61	-	Opglabbeek	kb26d63e-B232	063e0225	234101	194478	84,46	872	1984-084812	063e/063e0225.txt
62	-	Houthalen-Helchteren	kb25d62e-B277	062e0273	220191	195831	69,75	1289,8	1985-024504	062e/062e0273.txt
63	-	Houthalen-Helchteren	kb25d62e-B270	062e0266	225530	190190	81,21	1023,7	1980-084318	062e/062e0266.txt
64	-	Heusden-Zolder	B/7-0556	062w0411	217722	190541	40,64	160	2006-000298	062w/062w0411.txt
65	-	Houthalen-Helchteren	kb26d63w-B215	063w0212	226180	192030	81,61	1111,3	2016-143702	063w/063w0212.txt
66	-	Zonhoven	kb25d77e-B312	077e0307	219156	186256	41,50	312	1986-043921	077e/077e0307.txt
67	-	Heusden-Zolder	kb25d77w-B389	077w0378	212989	186359	29,86	276	1987-084657	077w/077w0378.txt



Name	Nr
Albert-Canal section (near Eigenbilzen)	1
Balen B30	2
Berg 'gîte classique de Berg	3
Donderslagse Heide	4
Dornerheide	5
Geel	6
Genk	7
Hasselt Concentra	8
Hasselt south = stad	9
Helchteren	10
Herentals	11
Herselt	12
Houthalen	13
Houthalen	14
Houthalen Molenberg	15
Kallo	16

Name	Nr
Hemelburg	17
Kerkhoven	18
Kleine Spouwen hill	19
Koewijde-KS 2 B73	20
Kruikeke-Burcht Argex Clay pit	21
Meerhout	22
Mol SCK 15	23
ON-Doel 2	24
ON-Mol-1	25
ON-Dessel-1	26
Opglabbeek Industrie	27
Pellenberg Lubbeek Roelants pit	28
Point 163 in Glibert & de Heinzelin 1954	29
Reet watertoren	30
Rumst Wienerberger Clay pit	31
Rupel cuesta	32

Name	Nr
Ruwmortelsheide	33
Schelle Damman Clay pit	34
SVK Sint-Niklaas Clay pit	35
Steendorp Bolderik Clay pit	36
Weelde SCK 98	37
Zoersel	38
Driepaalhoeve	39
Lichtaart	40
Winterslag	41
Loenhout	42
Meer-geothermie	43
Bokrijk	44
Beringen-Fonteintje	45
Retie	46

Figure 1a

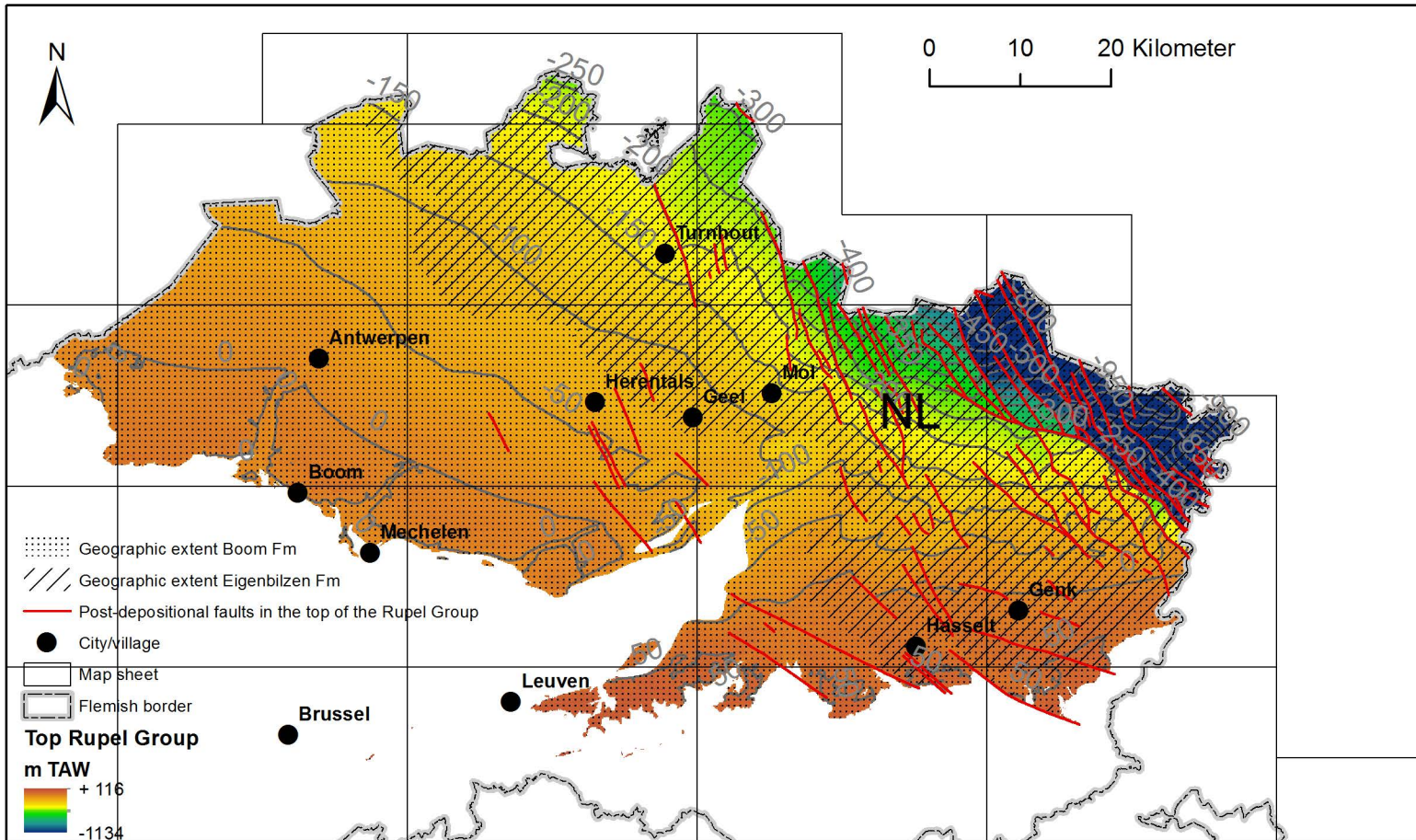
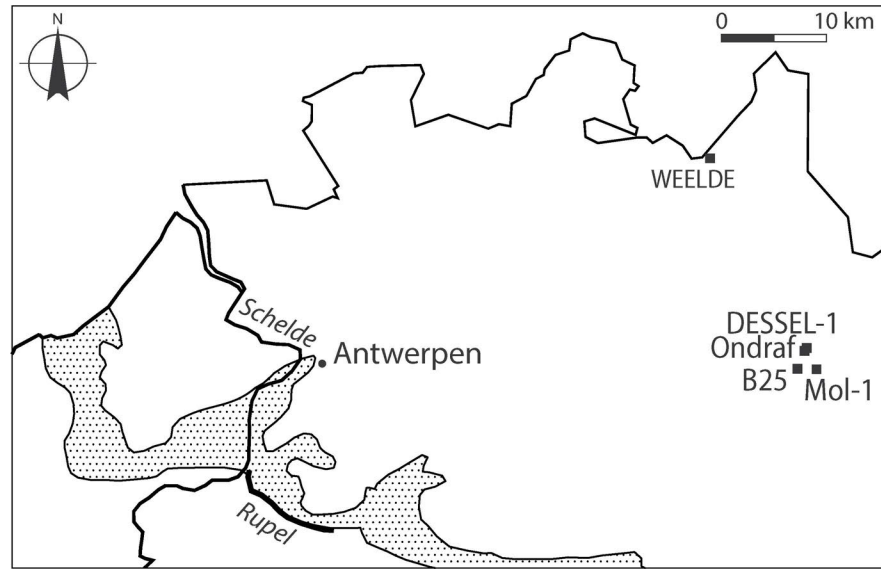
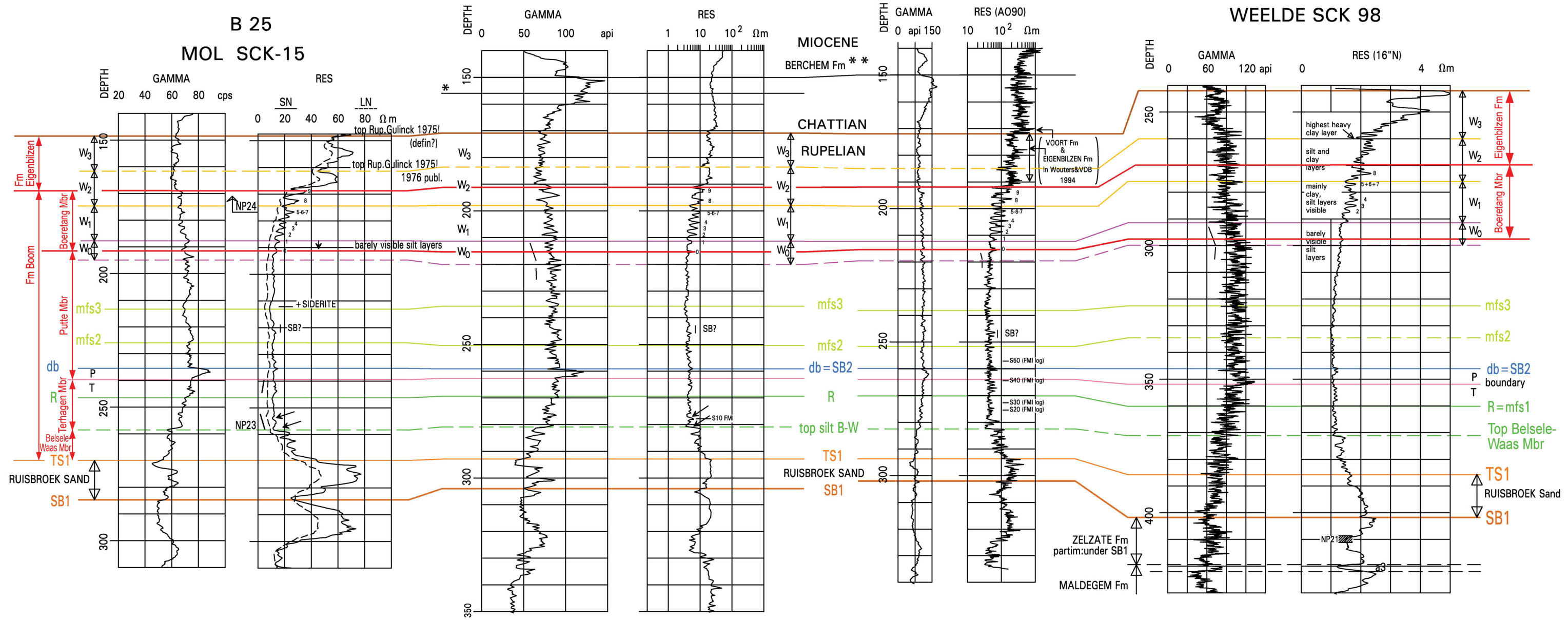


Figure 1b



ON - MOL-1

ON - DESSEL-1



** Interpretation Van Simaey 2004, Fig 1.4

* Interpretation Munsterman & Deckers (2020)

Figure 2

064W0259
kb26d64w-B271

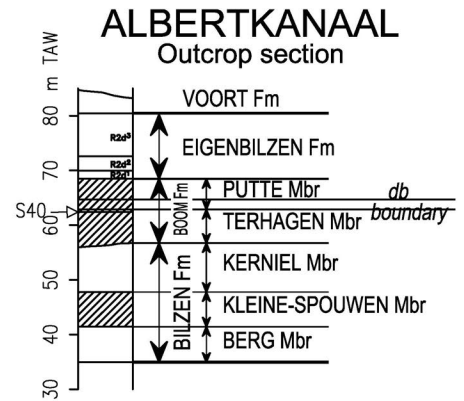
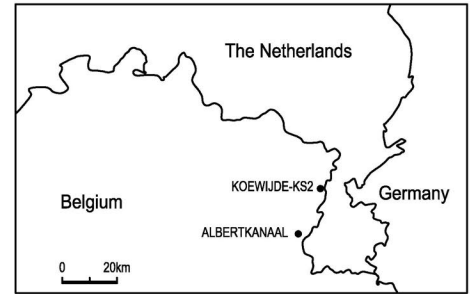
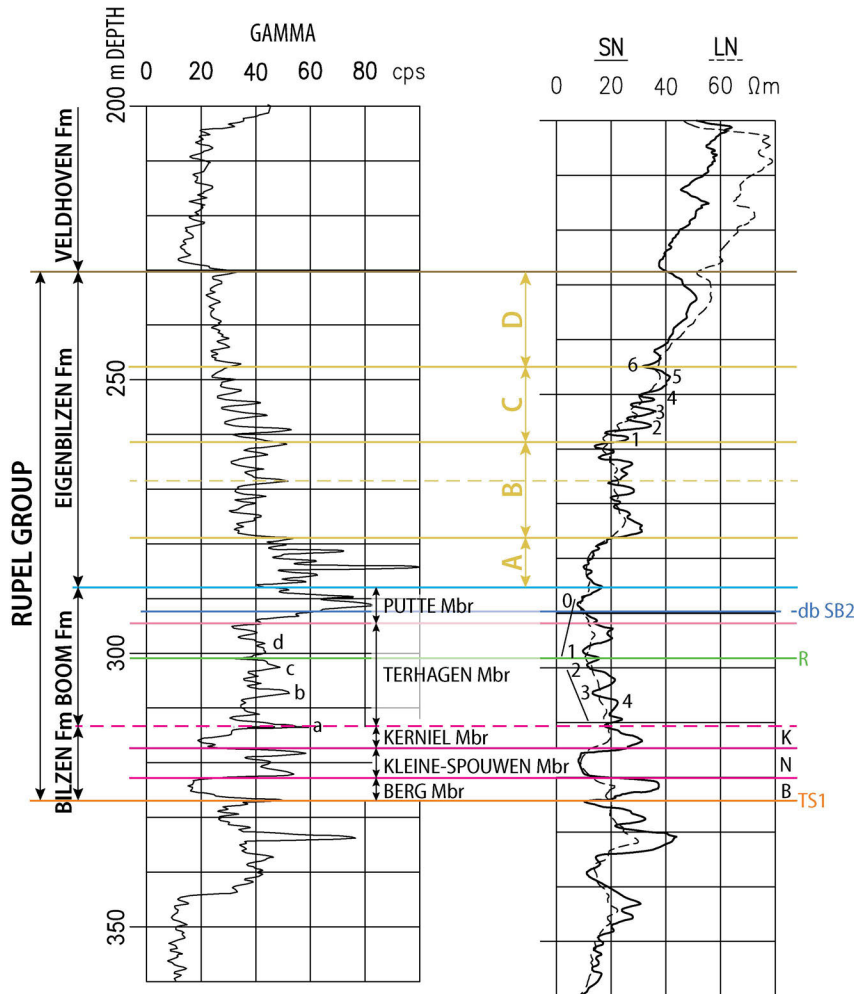


Figure 3

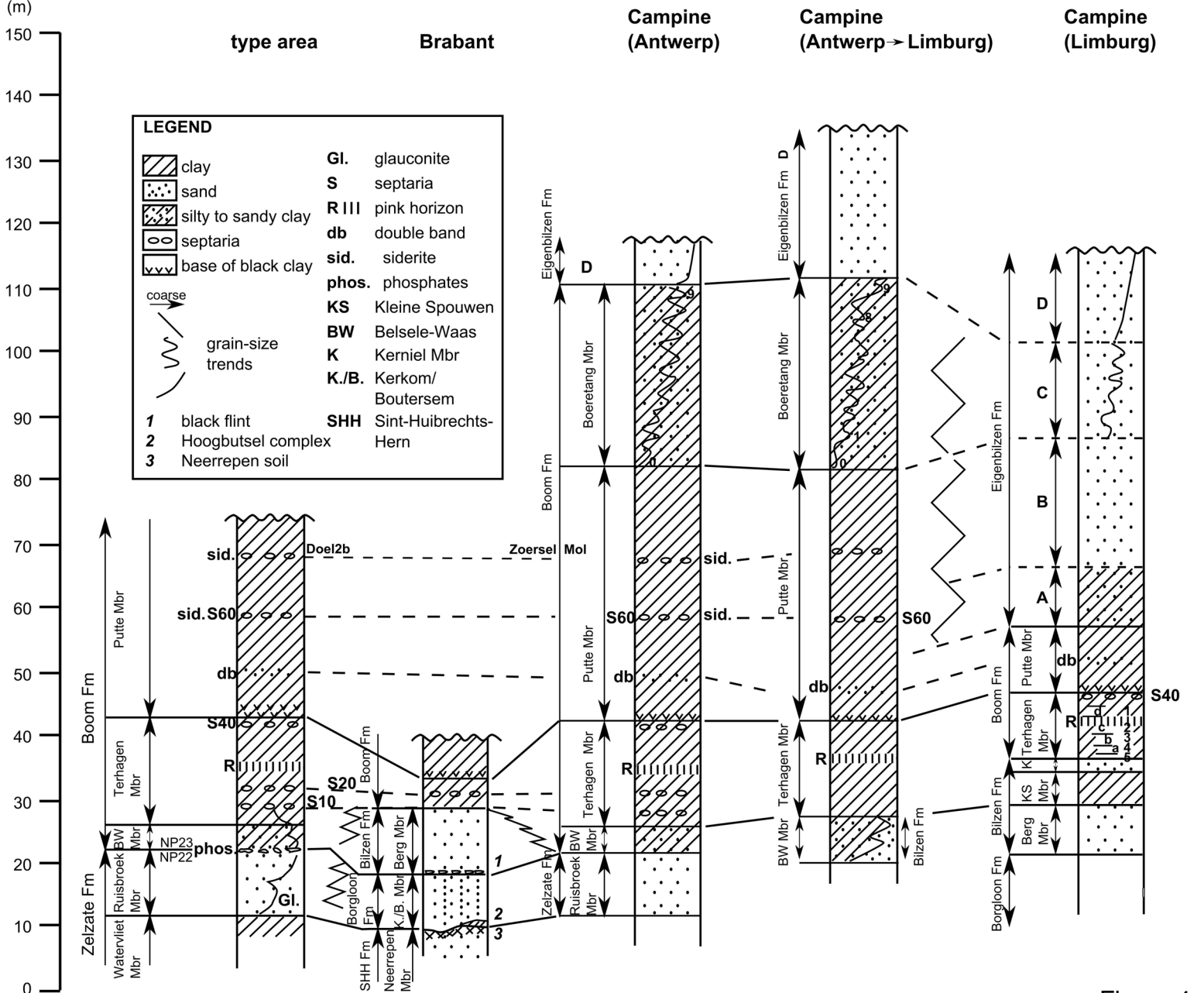


Figure 4

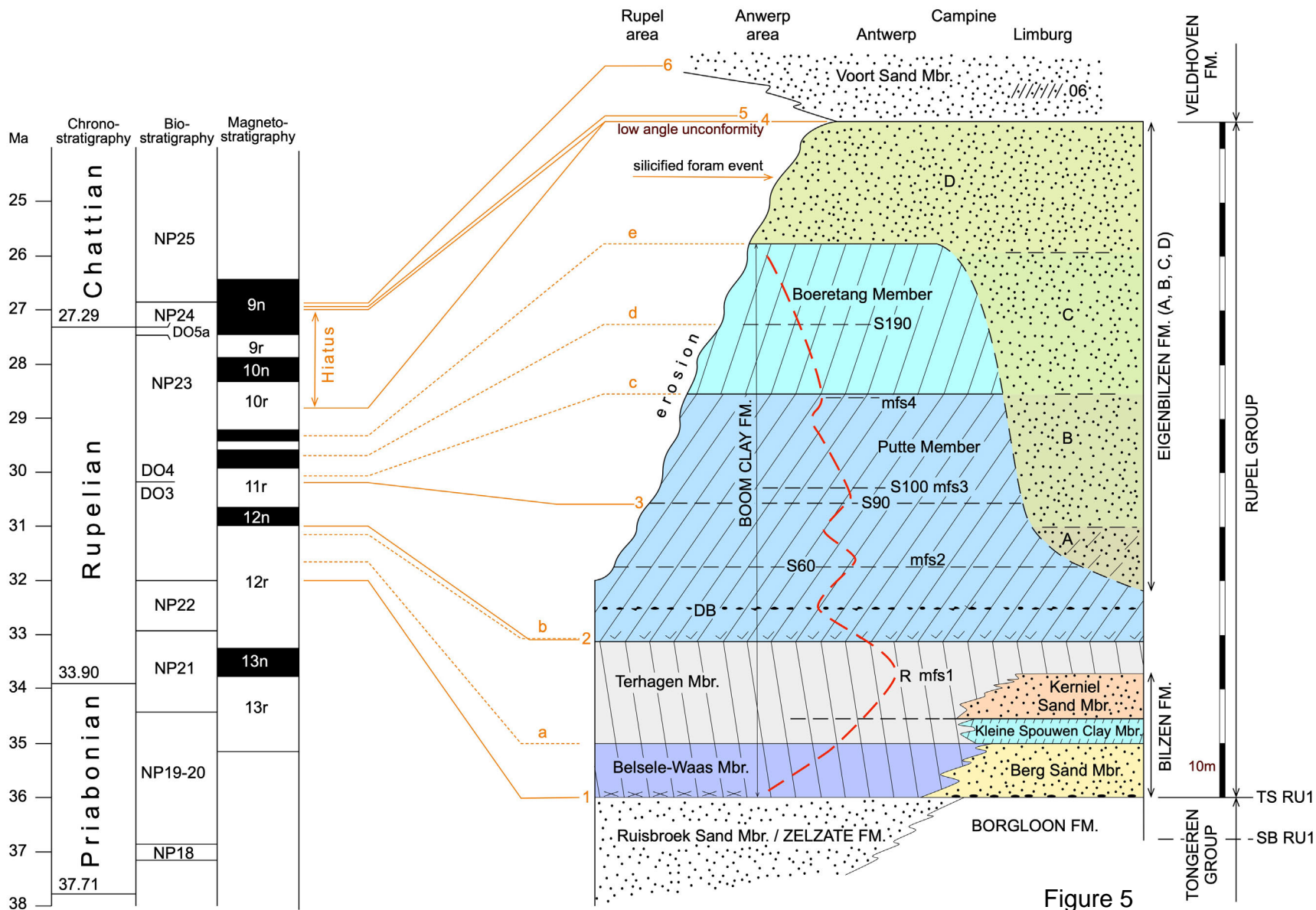


Figure 5

Donderslagseheide - KS 9
 062E0270
 kb25d62e-B274

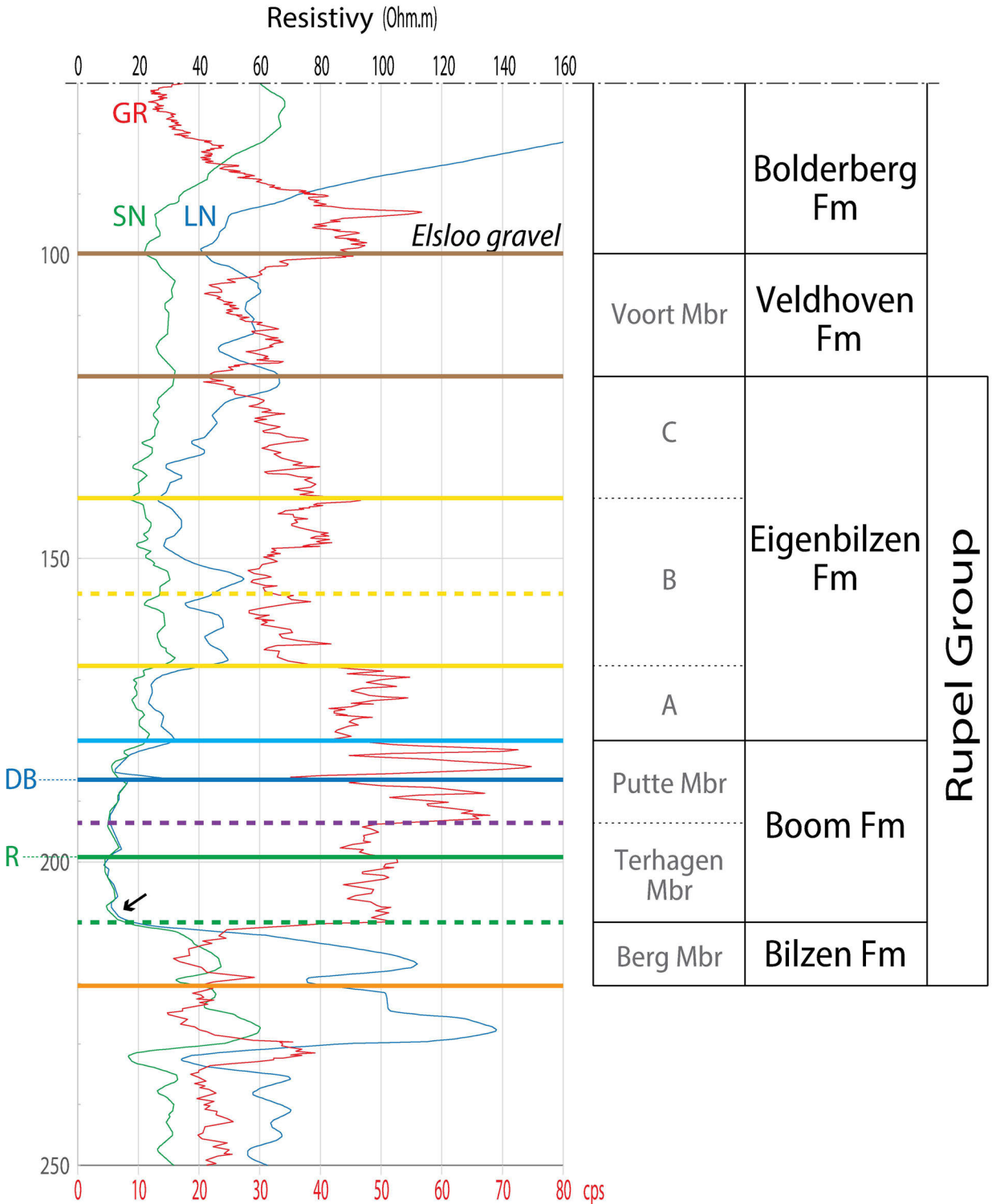


Figure 6

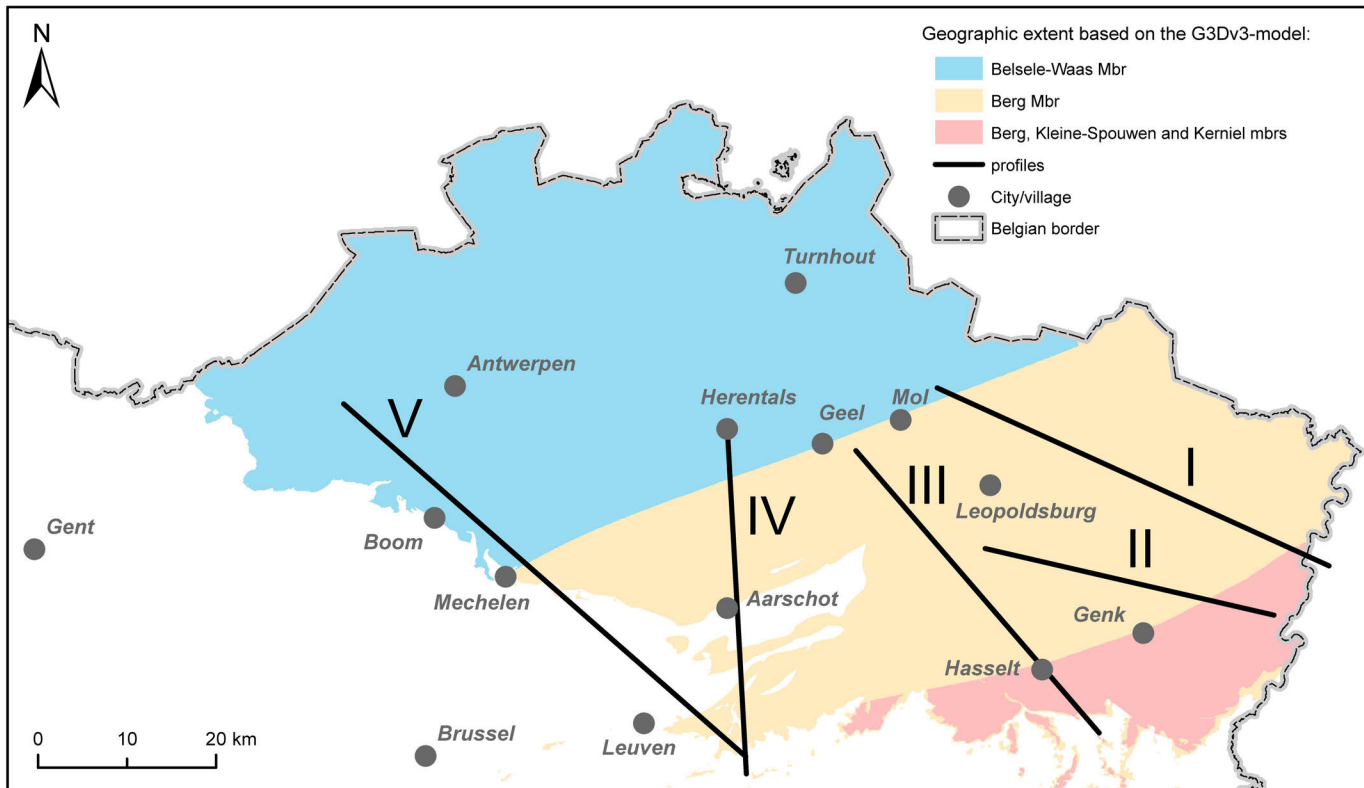


Figure 7

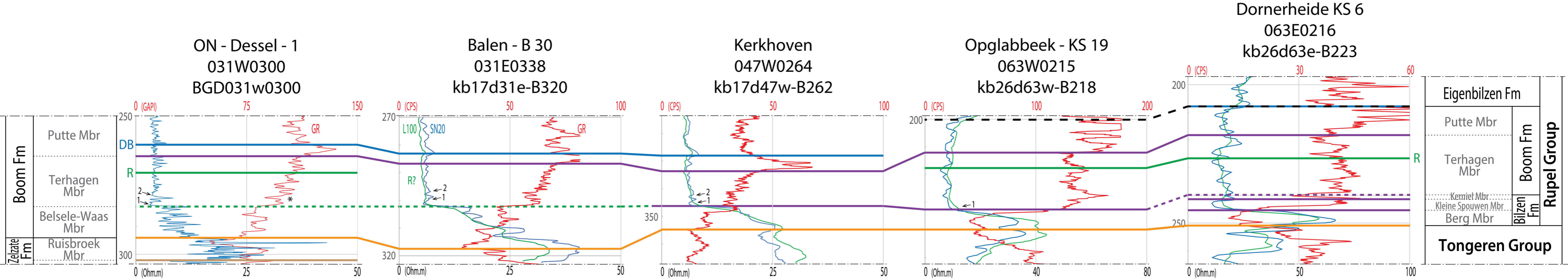


Figure 8a

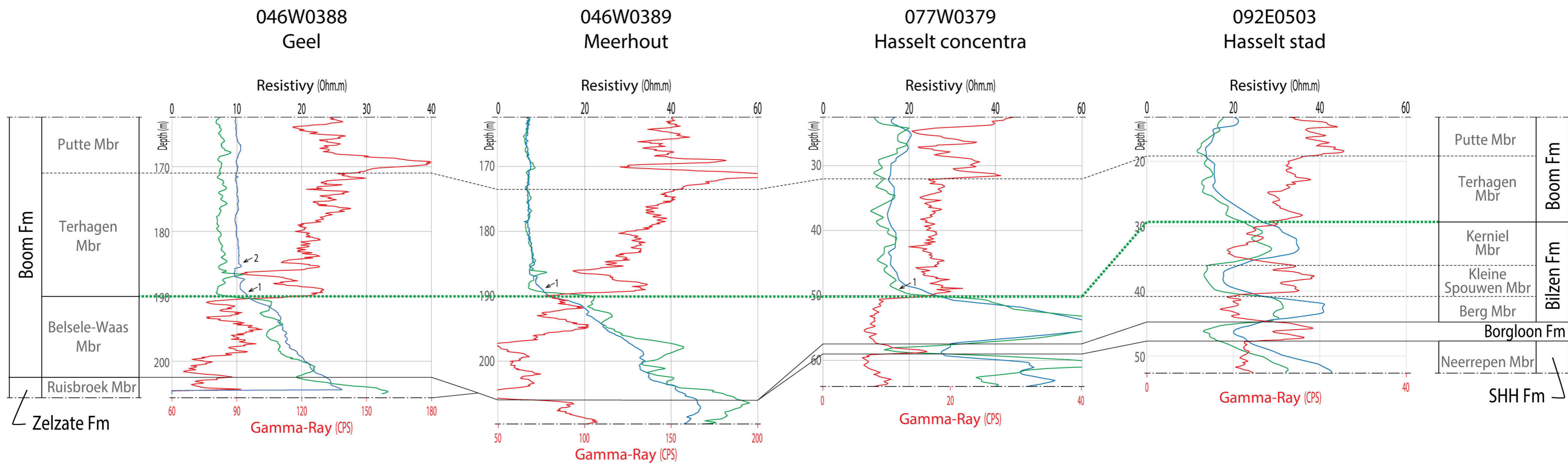


Figure 8b

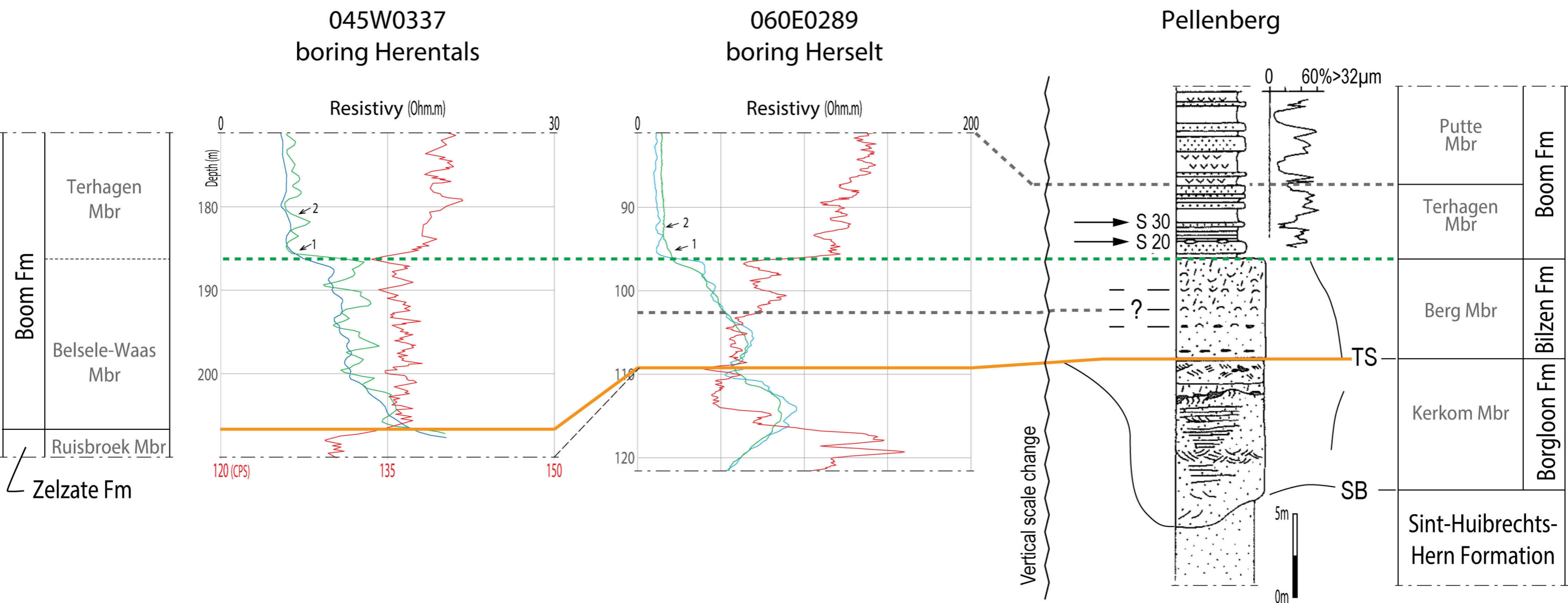
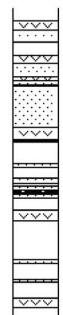


Figure 8c

ANTWERPEN
SUBSURFACE
SECTION



0 5% ORG.MAT.
0 50% > 32 μm
0 5% CaCO₃

GRAINSIZE
COARSE →

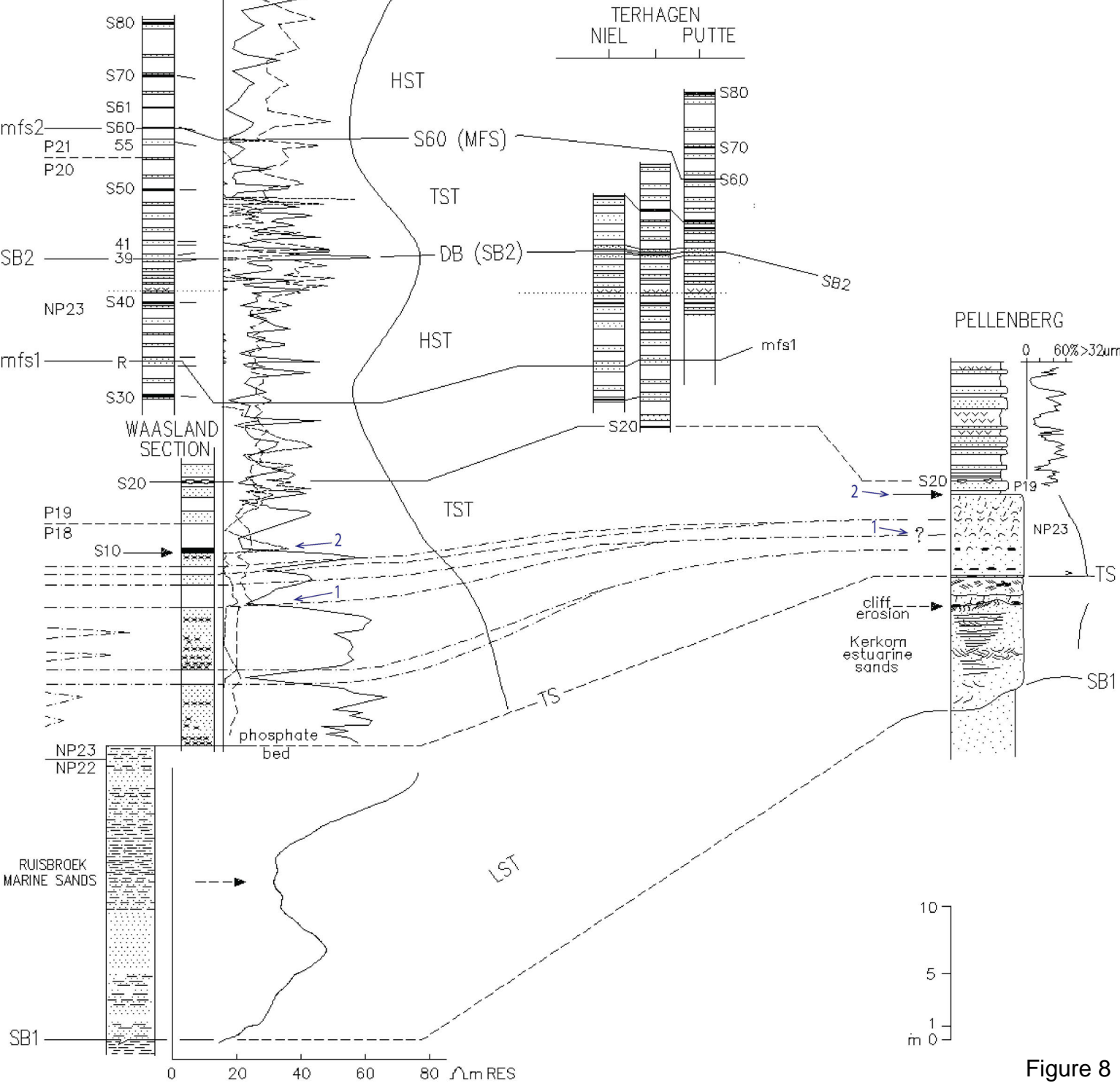
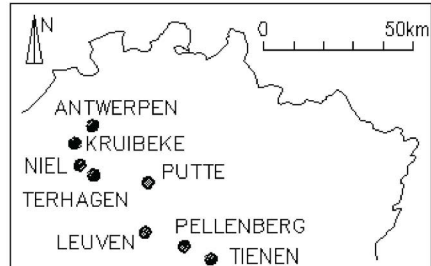


Figure 8

064W0259 kb26d64w-B271

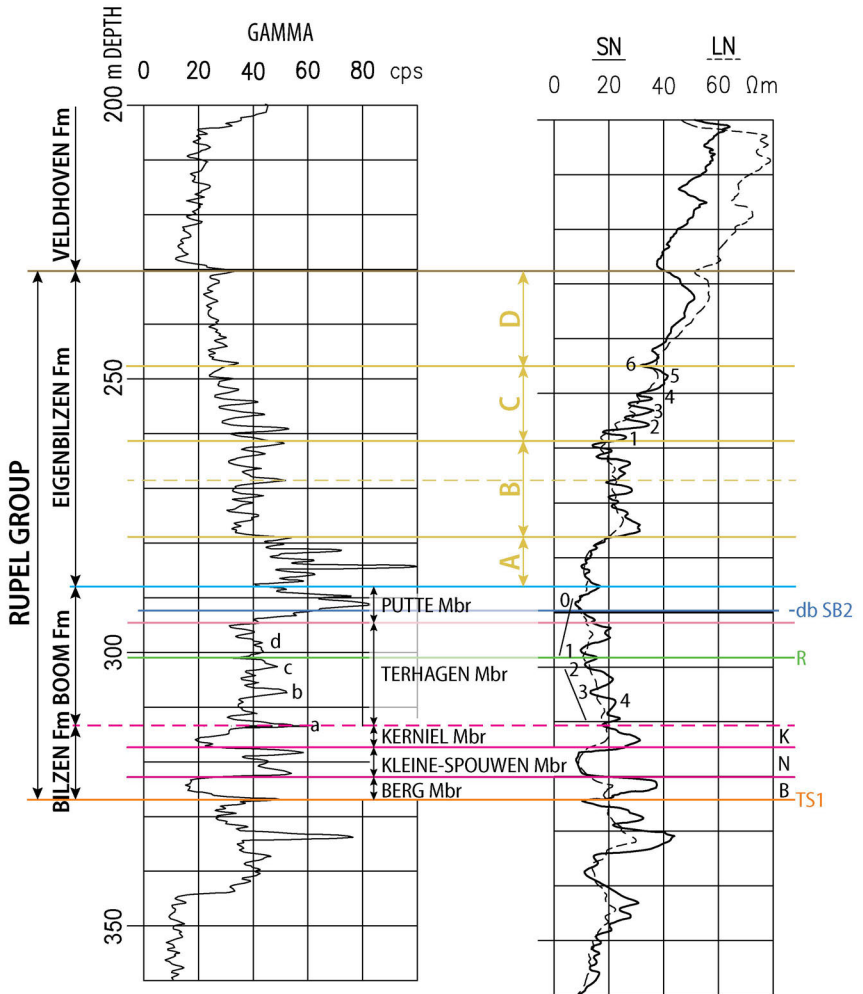


Figure 9

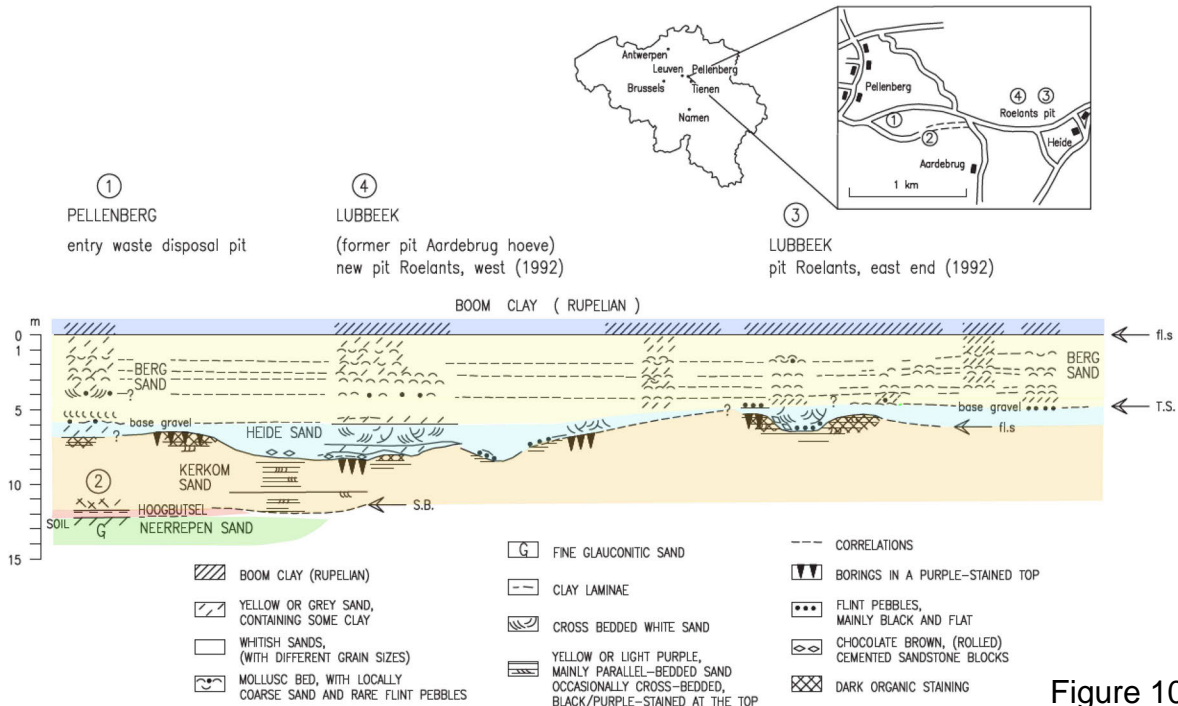
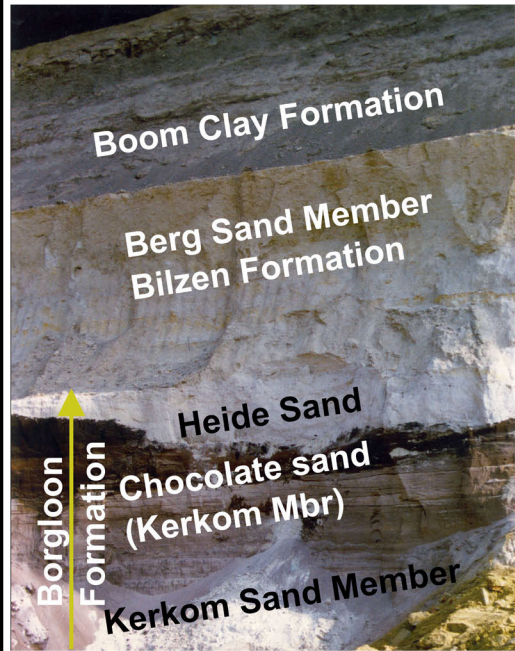
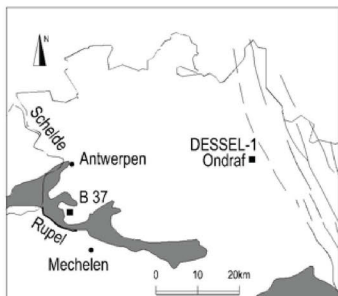


Figure 10



B 37
REET

DESSEL-1 ONDRAF
031W0300

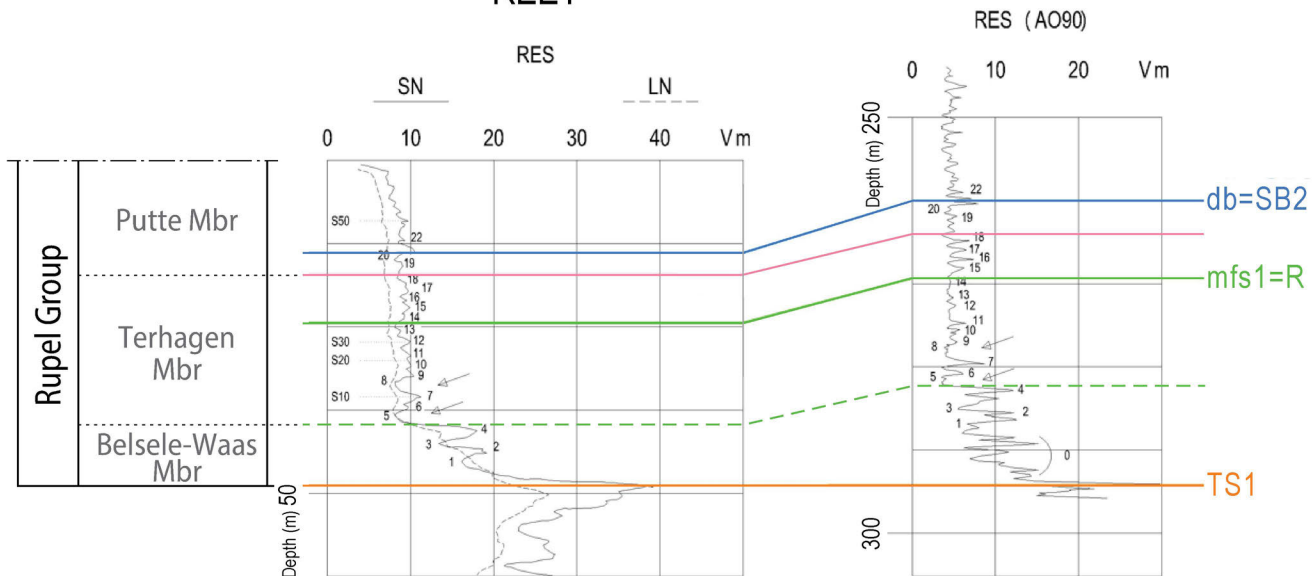
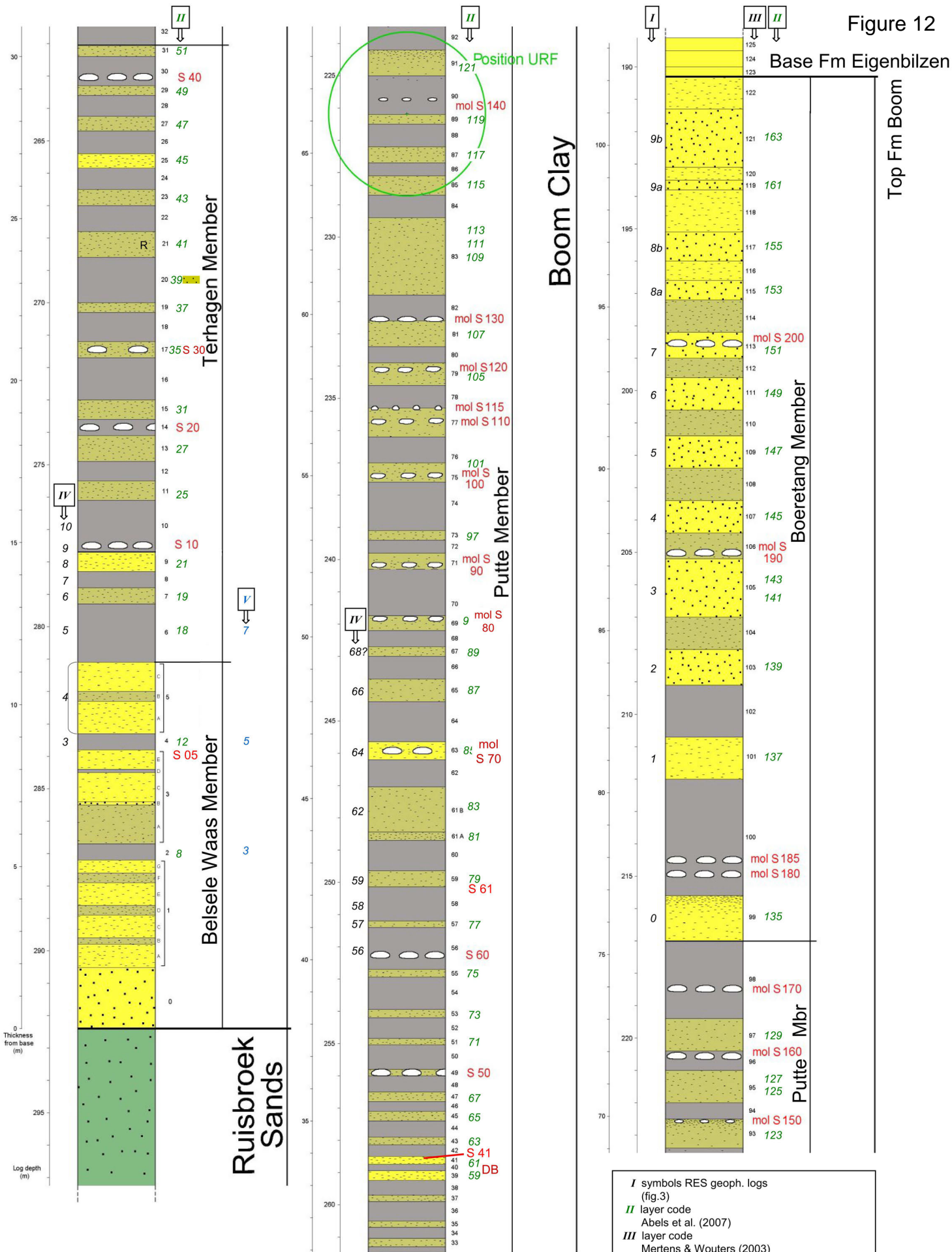


Figure 11

Figure 12



Microstratigraphic lithology of the Boom Formation based on the FMI (Full bore Formation Micro Imager) of the boreholes ON-Mol-1 en ON-Dessel-1 (Mertens & Wouters, 2003). The existing numbering systems of the layers (Abels et al., 2007; Vandenberghe, 1978; Van Simaey, 2004) are plotted in several columns in parallel to the layer codes introduced by Mertens & Wouters (2003) for their lithology.

Figure 13



Putte Member

Terhagen Member

S20

S40



Figure 14



D.B.

← S40

← R

S30 horizon

S20 horizon

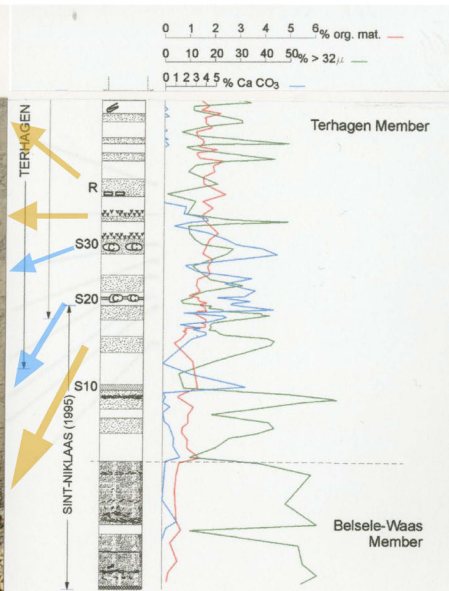


Figure 15

Figure 16



Base Putte Member

31

Top Terhagen Member

29

27

25

23

R 21

19

17

Figure 17



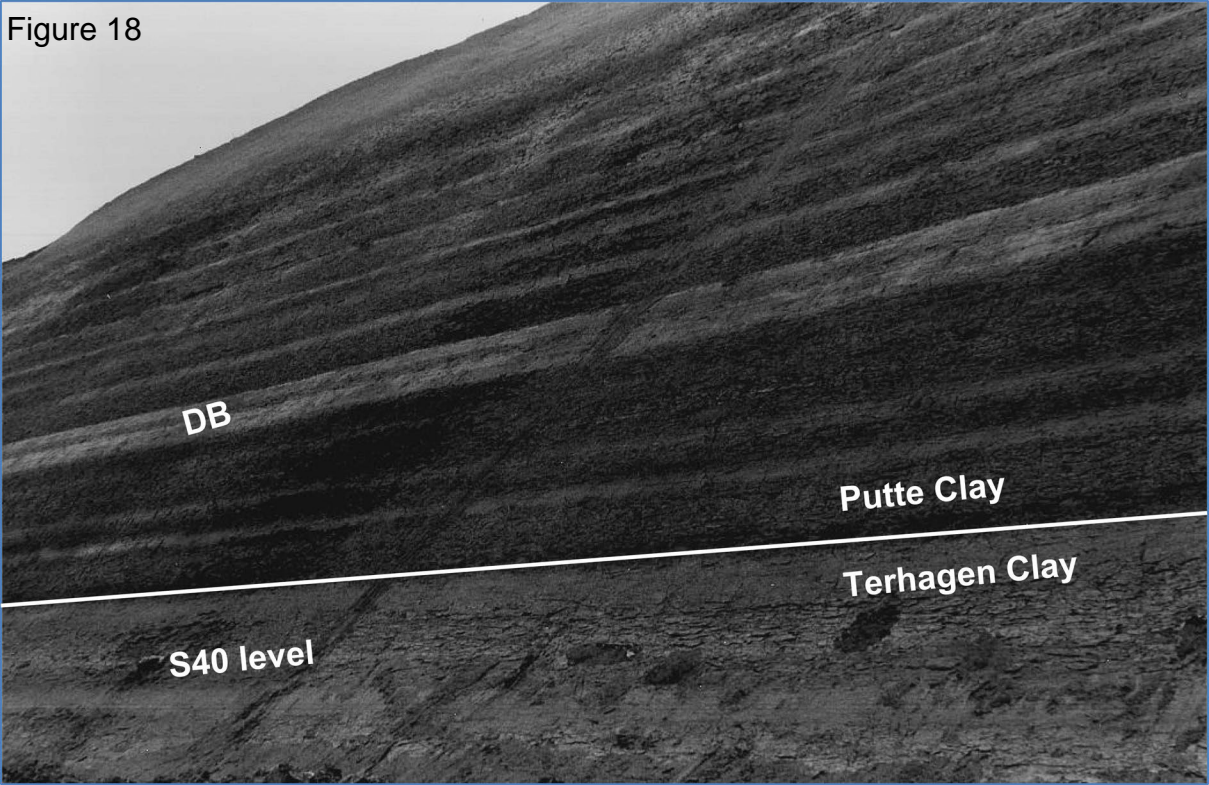
S50

S41

D.B.

Base Putte Mbr.

Figure 18



DB

Putte Clay

Terhagen Clay

S40 level

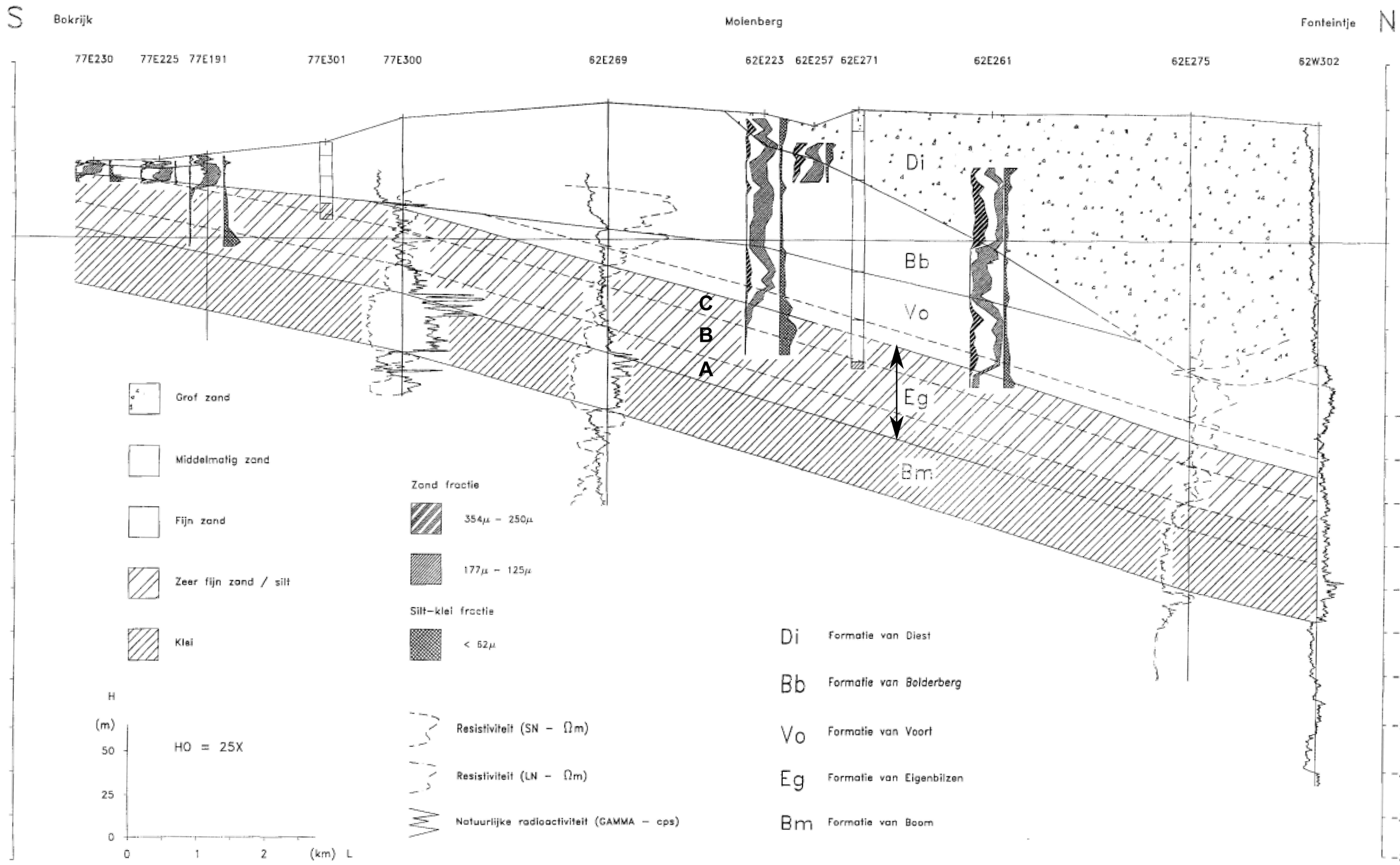
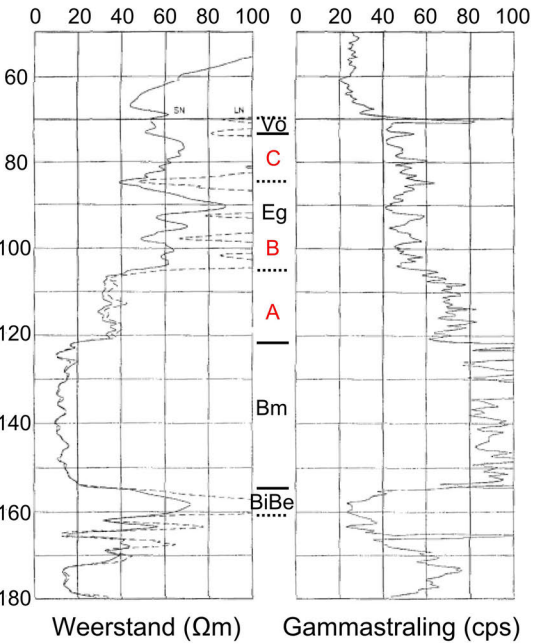
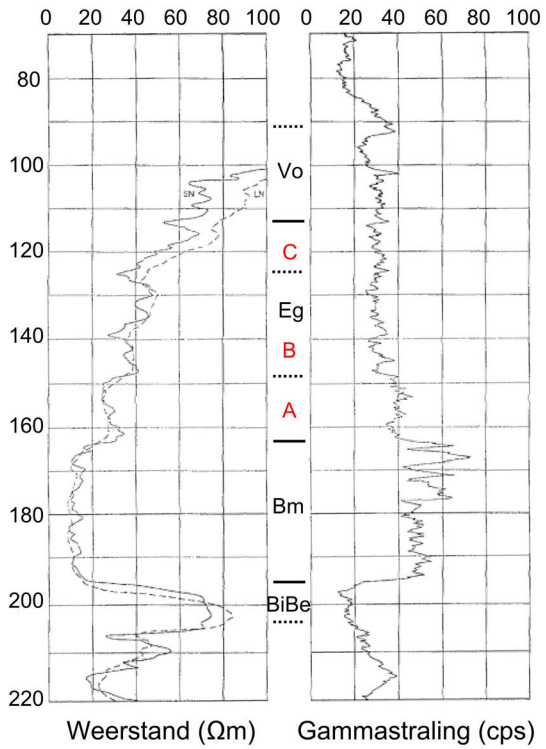


Figure 19

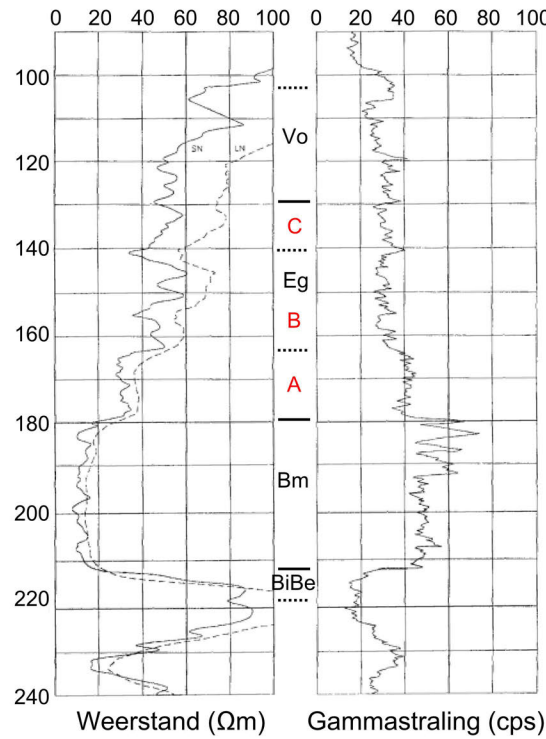
Genk - BGD077E0300

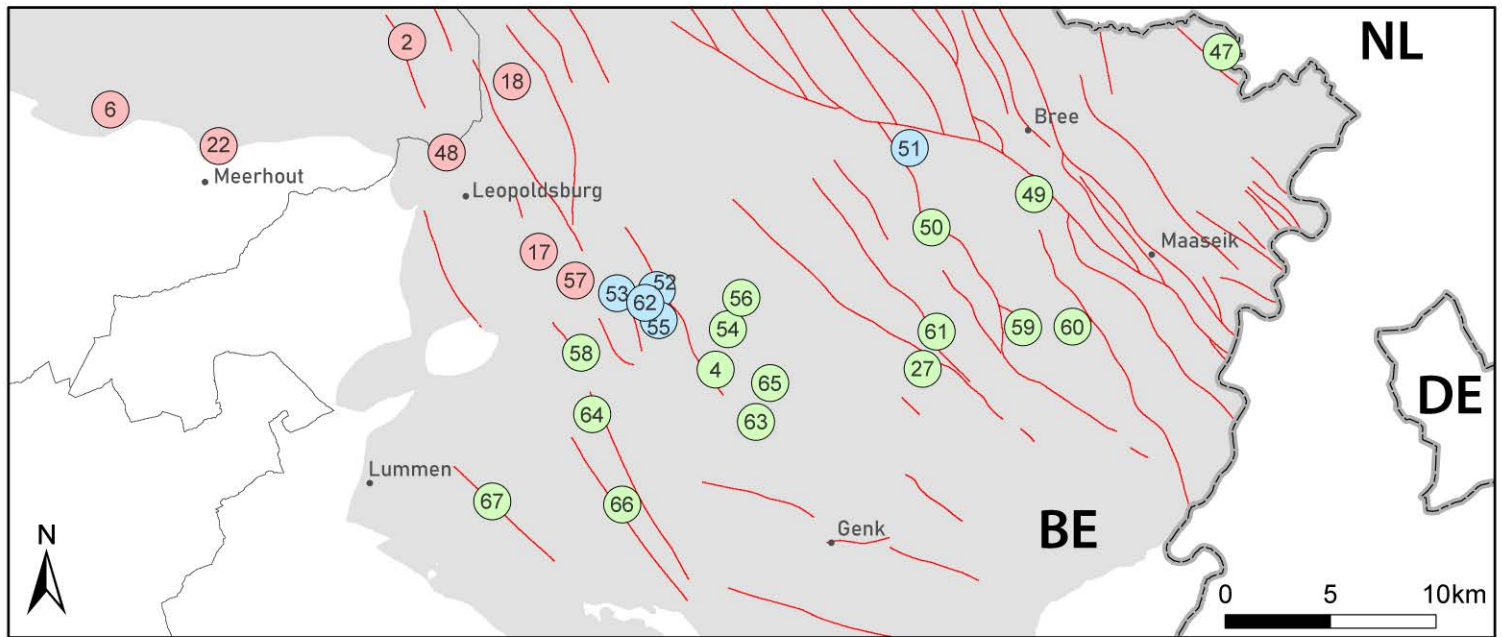


Houthalen KS 11 - BGD062E0269











Houthalen KS 5 - BGD062E0266





Legend

-  Country boundary
-  Province boundary
-  City/village
-  Post-depositional faults in the top of the Rupel Group
-  Geographic extent Eigenbilzen Fm
-  Eigenbilzen A and eventually B, C, D overlies the Putte Mbr
-  Eigenbilzen D overlies the Boeretang Mbr
-  Boom Fm transition to Eigenbilzen Fm uncertain

DOV	GSB	Nr
kb17d31e-B320	031e0338	2
kb25d62e-B274	062e0270	4
B/1-1100	046w0388	6
kb17d47w-B258	047w0260	17
kb17d47w-B262	047w0264	18
B/1-1117a	046w0389	22
kb26d63w-B218	063w0215	27
kb18d49w-B226	049W0226	47
kb17d47w-B264	047w0266	48
BGD048e0294	048e0294	49
kb18d48w-B186	048w0185	50
kb18d48w-B193	048w0191	51
kb25d62e-B276	062E0272	52
kb25d62e-B279	062e0275	53

DOV	GSB	Nr
kb25d62e-B284	062e0280	54
kb25d62e-B285	062e0281	55
kb25d62e-B294	062e0290	56
kb25d62w-B308	062w0305	57
kb25d62w-B313	062w0310	58
kb26d63e-B225	063e0218	59
KOEN-B179	063e0223	60
kb26d63e-B232	063e0225	61
kb25d62e-B277	062e0273	62
kb25d62e-B270	062e0266	63
B/7-0556	062W0411	64
kb26d63w-B215	063w0212	65
kb25d77e-B312	077e0307	66
kb25d77w-B389	077w0378	67

Figure 21