NCS Subcommission Paleogene-Neogene

Discussion Text

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Brussels Formation

Name

The Brussels Formation corresponds to a marine sand layer that was and is well exposed at Brussels (Bruxelles, Brussel). Dumont (1839) formalized a stratigraphic name already in use at the time, by introducing the "système bruxellien". It was defined to incorporate two sedimentary "étages", a lower "sable à grès lustré" and an upper "sable à grès calcarifère". The name “bruxellien” is used on the late 19th century official 1:40,000 geological maps of Belgium; those maps were published long before the systematic distinction between litho- and chronostratigraphy was introduced (Hedberg, 1976). The evolution of the precise stratigraphic significance of the term ‘bruxellien’ since its introduction by Dumont (1839) has been reviewed by Steurbaut and Herman (2006). In response to the need of introducing a proper lithostratigraphic term, the names Formatie van Brussel (Dutch) / Formation de Bruxelles (French) were formalized (Geets, 1988, in Laga, 1988) to designate the depositional unit until then commonly named "bruxellien" or "brusseliaan". The late 20th century revisions of the 1:50,000 geological maps of the Flemish Region and 1:25,000 maps of the Walloon Region adopted the new lithostratigraphic terms.

The present definition allows the equivalent names of **Brussels Formation (Brussels Sand)** (Eng.)**, Formatie van Brussel (Brussel Zand)** (Dutch) and **Formation de Bruxelles (Sables de Bruxelles)** (French), as Brussels, capital of Belgium and Europe, is officially a French and Dutch bilingual city, while its international status has widely promoted the use of the English name.

Extending the name Brussels Sand outside its type area (e.g. Adrichem Boogaert & Kouwe, 1993-1997; De Ondergrond van Nederland, 2003; The geology of the Netherlands, 2007) requires to establish that in those areas the lithostratigraphic properties do correspond sufficiently to the description given below in the reference area in Belgium.

General Description

Colour and grain size

The Brussels Formation consists of white to pale yellowish, greenish yellow or greyish green sand, varying from fine- to coarse-sized sand.

Depositional structures

The deposit is often homogenized by bioturbation; in most outcrops, a large-scale internal master bedding slightly dipping to ESE can be recognized. Many outcrops show dm- to several metres thick cross beds. Some beds are faintly wavy laminated to completely structureless. Apart from the latter beds, burrows are common.

Base gravel

A base gravel is only found in some parts of the outcrop and subcrop area, especially in the southeast sectors. It is probably not continuous and may be thicker in erosional base incisions (see below). In the western half and most of the subcropping northern part of the basin, it is often lacking.

Mineral composition

Quartz grains dominate the deposit. They are mostly well rounded; locally admixtures of angular grains are present. The heavy minerals are dominated by ubiquists, mostly tourmaline, then zircon; in the parametamorphic group contains typically large pleochroic andalousite grains (Geets et al., 1985). The characteristic composition is largely grain-size determined.

The original deposit is calciferous; the carbonate content is strongly reverse-correlated with grain size, i.e. the finer sized sand has higher calcium carbonate contents; the carbonate is mostly very fine grained but also mollusc shells or shell fragments can be preserved. In the outcrop area the sand can be locally or completely decalcified. The colour has then turned to brownish yellow or greenish brown.

Fine-sized pale green glauconite pellets occur in very small quantities throughout the Formation, whenever the fine sand fraction is present; darker and larger glauconite pellets can occur in the coarser-sized sand and although such coarse dark glauconite is lacking in the west and south of the outcrop area, even when coarse sand is found, it is concentrated in the east and northeast and there its content tends to increase towards the east (fig. 1). At the base, coarse dark green glauconite is found over a wider area, but also restricted to the eastern part of the basin.

Fig. 1. Outcrop and subcrop map of the Brussels sand Formation and indication of content of coarse glauconite. Note: Fig. 1-3 are views extracted at the date of this document from a geographical database containing field observations and well interpretations by the first author. This database is continuously being expanded when new observations become available.

Cementations

Occurrence of individual slab- or capriciously shaped cemented zones is a very common aspect of this Formation.

Silicified concretions are so frequent that their presence is almost diagnostic of the Brussels Formation. They are not conclusively diagnostic in the sense that, at rare locations inside the Brussels Formation, no concretions are found at all, while on the other hand, concretions are not unique to the Formation (e.g. silicified concretions occur also in the Mont Panisel Member of the Lower Eocene Hyon Formation). In the Brussels Formation, the siliceous concretions are often very irregularly shaped, sometimes with separately cemented burrow cores ("grès fistuleux"); but also many decimetres wide and about one decimetre thick, very hard, slab-shaped concretions are common ("grès lustrés"). Sometimes, the concretions are remarkably symmetric (this characterizes facies M, see below) or fusiform.

The fine-grained carbonate rich facies contains often parallel, subhorizontal beds of laterally extensive, one to two decimetre thick, carbonate-cemented sandstone (locally named "Diegem sandstone" and "Gobertange sandstone").

In decalcified areas, the carbonate sandstones may have completely disintegrated while siliceous sandstones may have turned friable or crumbly.

In outcrop areas, secondary limonite cementation occurs locally in subhorizontal beds of a few dm thickness, up to several metres thick massive iron-cemented sandstone, such as at Chaumont-Gistoux and Braine-l'Alleud (Brabant Wallon).

Use

Brussels Sand, especially the coarse grained sand, has extensively been and is still being mined for construction sand (in Flanders: Gullentops, 1996; Broothaers, 2000;).

The irregular ‘grès fistuleux’ concretions have locally been used for building walls or for decorating wall tops. A remarkable application was their use for building small devotion caves (‘pierres de grottes’) (Ann.Mines Belg. T XXX Les ressources du sol belge en matières utiles, 1930) . The properties of the Brussels Sand and their exploitation practice in the Brabant Wallon area in the 60's of the previous century are summarised in Mignion (1969).

Carbonate sandstone, especially the Gobertange (Stoops & Nijs, 1996; Tordoir, 2000) and the Diegem sandstone, and iron cemented sandstones have been used for building stones.

Use of building stone in historic and rural constructions provides an indication of where the stone can be found (fig. 2).

Fig. 2. Outcrop and subcrop map of the Brussels sand Formation and (non-exhaustive) indication of historic rural building using either carbonate sandstone or iron sandstone extracted from the Brussels Sands.

The Brussels Formation constitutes, especially in its outcrop area, a very important and productive aquifer (Peeters, 2014). The coarser-grained fills of certain internal erosional troughs have a high hydraulic conductivity. Where it covers sandy or chalk deposits, one merged aquifer is present. In subcrop, the aquifer merges also with the overlying Lede Formation and the sandy members of the Maldegem Formation.

Age

Chronostratigraphy, in particular based on nannoplankton analysis, situates the Brussels Formation at the latest Ypresian and the early Lutetian (NP13, mainly NP14a, NP14b) (Herman et al., 2000); the Brussels sand Formation is time-equivalent with (part of) the Vlierzele Sand Member of the Gentbrugge Formation and with the Aalter Formation. A sequence stratigraphic model relating these lithostratigraphic units is given in Vandenberghe et al. (2004). The exact lateral relationship to (nearly) contemporaneous formations remains to be settled.

Occurrence

The Brussels Sand Formation outcrops in a strip in Central Belgium, east of the Zenne valley, in Brabant, NE Hainaut and N Namur, where it fills a 40 km wide complex erosional incision with its long axis oriented SSW-NNE (fig. 1). This erosional incised complex slightly dips to N - NNE where it is buried under younger strata; it extends over at least some 120 km long. In the south, the continuous occurrence of the Formation is replaced by some isolated patches, which extend the outcrop area unto Nalinnes south of the Sambre river. Apart from the central, contiguous area, two remarkable outliers are present inside the Cassel hill and the Mont des Récollets in northern France.

The base of the Formation in its main occurrence area is highly erosive. Erosive channel- or trough-like depressions may lower the base locally by several tens of metres over short distances.

The Brussels Sand body in the Central Belgium erosional complex overlies from south to north and from east to west: Paleozoic rocks, Mesozoic rocks, the Landen Group and the Ieper Group; in the subsurface it is erosionally covered by the Lede Formation in the west or by the Tongeren Group in the east where the Lede Formation has wedged out.

In its main occurrence area in Central Belgium, the Brussels Formation occupies geometrically the same stratigraphic position as both the Vlierzele Member (Gentbrugge Formation of the Ieper Group) and the Aalter Formation (Zenne Group). However, Brussels Sand does occur on top of the Aalter sand Formation in the Cassel and Mont des Récollets hills of North France and in the Woensdrecht borehole in the southern Netherlands; both occurrences are located very close to the Belgian border and westwards of the Central Belgian Brussels sand body. In the Knokke borehole at the coast and in other locations to the west of the Zenne valley, the occurrence of *Nummulites laevigatus* in the base of the Lede Formation is considered as an erosional remnant of the Brussels Sand; therefore Gulinck & Hacquaert (1954) have suggested that the Brussels Sand once covered the area of East and West-Flanders but was removed before the deposition of the Lede Formation.

The thickness in the central Belgium outcrop area is typically 20 to 40 m; locally, where the base has incised strongly into the underlying deposits, over 80 m.

For reference sections , see lithostratigraphic Members.

Subdivisions of the Brussels Formation

The Brussels Formation is characterized by strong lateral and vertical internal variation between a few sand types that, for practical purposes, display enough lithological identity and spatial extent to justify their status as Member subdivisions. The transitions between the Members are usually gradual but sometimes abrupt. The variation is inherently linked with the sedimentary history of the Formation.

a. The sedimentological building blocks

The basic lithological building blocks of the Brussels Formation consist of the sedimentary facies that have been defined in a comprehensive sedimentological model for the Brussels Sand (Houthuys, 2011). The model explains the spatial variation and transitions of the facies. It cannot predict which particular facies will be found at any given location, nor how spatially extensive it will be, due to the intrinsic variability inside the Formation.
The sedimentary facies are (Houthuys, 2011):

- Bf: bioturbated, fine sand
- Bm: bioturbated, medium sand
- Bc: bioturbated, coarse sand
- Bx: bioturbated thin cross beds
- Xb: cross beds with burrows
- X: thick cross beds
- M: massive or faintly wavy laminated sand (breaching deposits, van den Berg et al., 2017)

The facies are genetically linked. However, they interfinger at a relatively small scale and therefore are not suited as such for use as lithostratigraphic units. Moreover, lithological components, such as carbonate and glauconite content, are not part of the definitions (most facies have variants spanning the range of glauconite and carbonate content), facies are both vertically and laterally transitional (with the exception of facies M), different facies repeat themselves above each other, and their exact identification is only possible in outcrops and in cored boreholes which would set a limit on the use of the available data.

b. Fill style

The preserved body of Brussels Sand in central Belgium is interpreted as the fill of a long marine embayment, tributary to the southern North Sea (Houthuys, 2011). The fill of this 40 km wide and 120 km long embayment occurred at high sea stand. This episode represents the final fill of the large-scale Ypresian depositional cycle. The material was mainly transported inside the embayment by tidal currents and the fill proceeded by lateral accretion from west to east. Synsedimentary erosion events occurred. They created accommodation for vertical stacks of thick cross beds. An alternative explanation for the erosion and tidal currents was provided by Gullentops (in: Gullentops et al., 1988, Gullentops & Broothaers, 1996) postulating a seaway link with the Paris Basin over the present high

Ardennes-Artois axis. Detailed paleogeographic maps of the Paris Basin area at the time of the deposition of the Brussel Sand can be found in Merle (2008).

The formation shows an internal architecture of low-angle master beds that dip to ESE (Houthuys, 2011). These bedding surfaces define clinoforms, that have in general finer-grained toes that display high degrees of bioturbation, and coarsening-upwards slope deposits that often consist of bioturbated, thin cross-beds. Thick, up to nearly 3 m high cross-beds are found in some elongate-depression fills. A process named "breaching" caused thick, massive canyon and clinoform base deposits of medium-grained sand that represents the product of a transfer of shallow shore sand to deeper environments.

c. Objective of the lithostratigraphic subdivisions

In order to allow the regional or vertical extrapolation of observed properties at a certain location in the Brussels Sand, there is a need for more generalized subdivisions of the Formation that may be mapped (see e.g. Gulinck, 1963) and reflect properties defining its use as a raw material or influencing its geotechnical and hydrogeological characteristics. At present, insufficient reliable and calibrated geophysical well logs are available of the Brussels Formation to develop a geophysics based lithostratigraphy; this situation is also related to the problem of obtaining good quality cores from sands containing many cemented stone horizons like the Brussels Sand. To document the present knowledge on this matter, some good quality logs are presented below together with a probable interpretation in terms of the proposed Members. It is observed, however, that this matter needs to be further documented and that new good-quality well evidence is needed.

d. Lithostratigraphic Members

Previous attempts (informal by Houthuys & Fobe, 1988; Gullentops, 1996; Geets, 2000; Vandenberghe & Gullentops, 2001; formally by Laga et al., 2001) have proposed subdivisions that tried to reflect some correlation with the sedimentary facies. However practice did not follow these subdivisions because they were hard to identify in the available data and because of the existence of too many styles of transition between, and vertical repetitions of, the proposed members.

A re-examination of the available data and of an extensive set of non-published data collected by the first author representing several lithological properties, shows that the basic property differentiating the Brussels Sand is grain size. Once a grain-size based subdivision is identified then carbonate content can be evaluated and even glauconite type and content can be used to further document internal differentiation.

Practical reasons also imply some synthesis of the observed properties over a sufficiently thick interval or a sufficient volume and not to be tempted into over-differentiation by the fact that thin intervals of a lithology different from the main mass are often present. If such variations occur, they can be added to detailed descriptions of the data points. Taking into account the classical mapping scales, a minimum reference thickness of about 10 m is suggested to evaluate the lithostratigraphic subdivision.

Also for practical reasons, instead of using sharp grain-size boundaries, diffuse grain-size boundaries have been used to define the members. When in doubt, this would always allow attribution of an observation to one of the members.

Note that the transitions between the members are often gradual and that in most cases, no sharp bounding surface between members can be identified.

Due to the grain-size based definition of the Members and the specific internal arrangement of beds inside the Brussels Formation, they constitute no genetically meaningful geometric relation (i.e. sedimentary time surfaces will systematically cross-cut member boundaries).

Diegem Member

White to pale yellow, very fine to fine sand. The central grain size value (mode, median, …) is **finer than 150-175 µm**; the **carbonate content** (if not decalcified) is **higher than 15%** and consists of fine mud. Carbonate content may locally reach high values, even up to 50%. Macrofossils may be present. This fine-grained member contains a subdominant admixture (much less than 2%) of very fine, light green glauconite pellets.

In flush wells, this member is easily recognized by the white colour of the flushing fluid. In outcrop, it is easily recognized by the fact that on touching the fingers are stained white.

In this member, subhorizontal, ca. 1 to 2 dm thick stone beds, cemented by carbonate, are common. When they occur, often several such subhorizontal sandstone beds are found over the vertical profile, separated by 0.5 to 1 m of uncemented sand. These carbonate sandstones have in the past been used as building stones (fig. 2). At the historic type locality, Brussels and its immediate surroundings, this member is predominantly found near the top of the Formation (Dumont, 1839). According to Rutot & Van den Broeck (1883, p. 176), each excavation work yields enough stone for the construction of pavements or retaining walls. In the area NE of Brussels, the sandstone is called "Diegem sandstone", while in the area between Tienen and Jodoigne, the "Gobertange sandstone" is found. The Gobertange sandstone has in the 19th and first half of the 20th century been quarried and exported as building stone on an almost industrial scale (Tordoir, 2000). This stone is characterized by very thin white marl laminae perforated by burrows, filled with glauconite-rich coarse sand. The Diegem sandstone mostly represents stone from the Brussels Formation but also partially from the Lede Formation sandstone, where it is found on top of the Brussels Formation. Also south and southeast of Brussels, much use has been made of locally found carbonate sandstones (fig. 2).

Capriciously shaped, hard, often small (at most 1 dm) siliceous concretions ("grès fistuleux" and "pierres de grottes") are frequent in this member.

In places where this Member has been decalcified, the Member remains identifiable by its grain size. Decalcification brings about a change in colour: it has turned yellowish or greenish brown due to the fact that non soluble grains such as fine-grained glauconite are concentrated and grains are limonite coated. Decalcification is found only in the outcrop area and there tends to occur primarily near the flanks of the valleys (geomorphology) and near the surface (vadose zone). Decalcification fronts are generally very sharp and may form capricious surfaces.

In the decalcified form, the Member no longer contains carbonate cemented sandstones and the chalcedony cemented concretions have turned brittle.

Correspondence with the sedimentary facies (Houthuys, 2011) :

This Member corresponds to sedimentary facies Bf and Bx (Houthuys, 2011).

Reference section:

Problematic, not permanently exposed. Building sites near Diegem and in Braine-l'Alleud often show this Member. The Waversesteenweg entrance to the RBINS museum at Brussels (Lambert 72 X 150546, Y 169493, outcrop from about 61 to 70 m TAW) showed this Member, but the exposure should be rehabilitated. We propose to locate the stratotype there. An alternative could be the Hussompont sandpit west of Jodoigne (X 183440, Y 158190, outcrop from about 87.5 to 104 m TAW), but it is not easy to obtain access there.

Neerijse Member

White to pale yellow, when glauconiferous greenish yellow, medium sand. The **grain size** is **comprised between a lower value range of 150 to 175 µm and an upper value range of 250 to 300 µm**, with central size values around 175-250 µm. The **carbonate content** (if not decalcified) **is between 2 and 15%**; most of this is fine mud. Macrofossils are often present. Commonly, the sand is moderately sorted and a fraction of fine sand is present. In that case, always a small admixture (much less than 2%) of very fine, light green glauconite pellets is found.

This member has low to medium dark glauconite content variants. In certain areas, a gradually increasing admixture of coarser, dark green to blackish coloured glauconite pellets has been observed (fig. 1).

The dominant primary sedimentary structure is parallel master bedding, inclined at a small angle and dipping to the ESE. The master beds show a gradually decreasing slope near the bottom of the basin. Thin and thicker, up to 1 m thick, cross beds occur and are incorporated in the master fill style. Sometimes they constitute stacks of cross beds. The cross beds have a (very) dominant foreset dip to NNE, with rare occurrences of dips to SSW, and numerous mud drapes testifying to tidal currents. Even more frequently, the sand is strongly homogenized due to bioturbation. Between the opposites of relatively non-bioturbated cross beds and completely homogenized beds, all possible grades of increasing bioturbation occur. Locally, faintly wavy to structureless bedding is present in clearly bounded packages.

In most cases, numerous siliceous concretions, varying from capriciously shaped "grès fistuleux" (including "pierres de grottes") to slab-shaped "grès lustrés", are present. They tend to be very hard and make drilling and excavating difficult. No carbonate stone beds occur. Sometimes, the cementations affect burrows and the surrounding sand.

In places where this Member has been decalcified, the Member remains identifiable by its grain size. Decalcification brings about a change in colour: it has turned yellow, brownish yellow or greenish brown due to the fact that non soluble grains such as glauconite are concentrated and grains are limonite coated. Often, local limonite cementation has occurred during or following decalcification. Decalcification is found only in the outcrop area and in this case tends to occur primarily near the flanks of the valleys (geomorphology) and near the surface (vadose zone). Decalcification fronts are generally sharp and may form capricious surfaces.

In the decalcified Member, the chalcedony cemented concretions have turned brittle.

Correspondence with the sedimentary facies (Houthuys, 2011)

This Member contains sedimentary facies Bm, Bx, Xb and is represented in facies X and M (Houthuys, 2011).

Reference section

De Kock sandpit in Ganzemansstraat, Neerijse (X 167320, Y 167360, lower and middle part of sandpit face, approximately from about 45 to 60 m TAW).

Note: the upper part, from about 60 to 70 m TAW, in the Neerijse sandpit is a decalcified version of the Diegem Member. In the immediate vicinity of this reference section, both calciferous Diegem Member and Bierbeek Member outcrops occur.

Bierbeek Member

White to pale yellow, when glauconiferous greyish green, medium-coarse to coarse sand. The **grain size** is comprised **between a lower value range of 250 to 300 µm and an upper value range of 400 to 500 µm**; the coarsest grains have an angular shape. In a small area in the southeast of the basin, around Eghezée, central values in the order of 1 to 2 mm are found and this very coarse facies is also considered part of this Member as this coarse facies thickness is below the 10 m put forward as the minimum thickness to assign a layer to a Member. In some wells, a bed of similar very coarse sand is found at the base of the Formation, e.g. at Bierbeek and Scherpenheuvel. Such coarse, angular grains can be found admixed in the medium to coarse sand of the thick cross beds at some locations. **Carbonate content** (if not decalcified) is very low, **below 2%**, and consists of fossil remnants. This member can have either moderate to good (in the case of sedimentary facies Bc and M) or moderate to poor sorting (in the case of sedimentary facies Xb and X). A bipolar grain size distribution is often present in the sedimentary facies X.

If a fraction of fine sand is present, a small admixture (much less than 2%) of very fine, light green glauconite pellets is always found. The Bierbeek Member may either contain a considerable admixture (from 5 to up to about 30%) of coarse dark green to blackish glauconite pellets (this tends to be the case in the east of the basin) or it can be devoid of such glauconite (in the west and south of the basin).

The cementations have different shapes and sizes and are of the type with chalcedony cement; also their content may vary. Very well-sorted beds tend to have low numbers of siliceous concretions; beds with mud laminae like in the bottomsets of cross-beds tend to have higher contents of siliceous concretions. Sometimes, the cementations affect burrows and the surrounding sand.

Because of the low original carbonate content, decalcification doesn't alter the aspect of this member much. Limonite cementations are only found in decalcified occurrences of the member.

Correspondence with the sedimentary facies (Houthuys, 2011)

This Member contains sedimentary facies Bc and is represented in facies M, Xb and X (Houthuys, 2011). The coarsest occurrences are in facies X.

Reference section

Godts sandpit, Builoogstraat, Bierbeek (X 176760, Y170650; the exposed section from about 48 to 63 m TAW and the approximately 50 m below it, known from wells, that fills an internal erosion trough).

The facies M

The facies M ("massive sand"), described and interpreted as a turbidite deposit related to breaching, a special type of slope failure (van den Berg, 2002; Houthuys, 2011; van den Berg et al., 2017), is a particular facies type, arranged in both conformal wedge-shaped and highly erosional canyon-shaped beds of varying volume, with bed thicknesses ranging from only a few dm to over 10 m. The facies represents the product of relatively coarse shore sand inside deeper parts of the Brussels Embayment, due to breaching. The facies is, as far as known, restricted to the central area of the Brussels Sand basin where incisions at the base occur (fig. 3). Several instances of facies M may repeat over the vertical direction. The facies M consists of well sorted massive sand lacking clearly developed sedimentary structures, lacking a fine mud fraction, lacking carbonate cemented stones and lacking bioturbations; in non-decalcified location, shells can occur as concentrated shell beds. The richest fossil sites are probably related to such concentrated beds. Siliceous concretions in this facies may be remarkably ellipsoidal to spherical in shape and occur much less frequently than in the other facies. Due to this composition, it is a type of Brussels Sand much sought for exploitation.

This facies is included in the Bierbeek and Neerijse Members. As it can only be recognized in outcrop, no separate bed or member has been defined for it. Due to its intricate interweaving in the fabric of the Brussels Sand, it has no specific lithostratigraphic status. Its occurrence can be reported when describing outcrops.

Fig. 3. Outcrop map of the Brussels Formation, with indication of the occurrence of sedimentary facies M (massive beds).

Summary of Member features

Feature	Diegem Member	Neerijse Member	Bierbeek Member
Lower grain-size value range	not defined	150 – 175 µm	250 – 300 µm
Upper grain-size value range	150 – 175 µm	250 – 300 µm	not defined
$CaCO_3$ content in original undecalcified Member	> 15%	> 2% and < 15%	< 2%
Decalcified form of Member	strong colour difference w.r.t. non-decalcified form; $CaCO_3$ cemented stone beds dissolved; siliceous concretions are decomposed or turned brittle	mild colour difference; siliceous concretions turned brittle	close resemblance to non-decalcified form
Variant of Member containing dark green coarse glauconite pellets	rare or missing	variant exists	variant exists
Sedimentary facies (Houthuys 2011) represented in Member	Bf, Bx	Bm, Bx, Xb, X, M	Bc, Xb, X, M

Expression in geophysical well logs

The recognition of the Brussels sand Formation in well logs is relatively straightforward. Gamma ray response is systematically lower, and resistivity response higher than the surrounding formations. Often, GR decreases upwards while RES increases upwards, which is thought to reflect the overall coarsening upwards grain size trend inside the Brussels Formation.

In the subcrop area, the distinction with the superposed Lede Formation is difficult to make.

Interpretation of members is not well enough documented. There is a clear need of well sampled, described and interpreted logged wells. Also the log examples selected here (Fig. 4: Halle 115E B/2 435a, Overijse 102E0355 and Bierbeek 103E0250) correspond to insufficiently sampled and described wells. The interpretation presented is based on outcrop data and well described nearby drillings. Taking into account the inherent lateral variation of the formation, the interpretation should be considered as preliminary. Though boundaries in fig 4 between members are shown as sharp transitions, the real transition is probably always gradual.

References

Adrichem Boogaert, H.A. & Kouwe, W.F.P., 1993-1997. Stratigraphic Nomenclature of the Netherlands. Revision and update by RGD and NOGEPA. Mededelingen Rijks Geologische Dienst 50, Delft/Haarlem, TNO National Geological Survey

Broothaers, L., 2000. Zandboek Vlaanderen. Ministerie van de Vlaamse Gemeenschap, afdeling Natuurlijke Rijkdommen en Energie, 114p.

Dumont, A., 1839. Rapport sur les travaux de la carte géologique pendant l'année 1839. Bulletins de l'Académie royale de Bruxelles, VI, n° 11, 464-485

Geets, S., De Breuck, W. & Jacobs, P., 1985. De zware-mineraleninhoud van Belgische Mesozoïsche en Cenozoïsche afzettingen. E. Midden- en Boven-Eoceen. *Natuurwetenschappelijk Tijdschrift*, 67: 3-25

Geets, S., 2000. Lithostratigrafie van het Paleogeen in België. http://ncs.naturalsciences.be/paleogene-neogene/publications, consulted on 20 June 2017

Gulinck, M., 1963. Etude des facies du Bruxellien (Eocène moyen). 6° Congrès International de Sédimentologie Belgique et Pays-Bas 1963. Excursions M/N-2°partie , 11p.

Gullentops, F., 1963. Excursion O – P. Etude de divers facies quaternaires et tertiaires dans le Nord et l'Est de la Belgique. 6e congrès international de sédimentologie Belgique et Pays-Bas (stop n° 15, Heverlee)

Gullentops, F., Houthuys, R. & Vandenberghe, N., 1988. The Cenozoic southern North Sea. Field trip B3. In Herbots, A. (ed.), IAS 9th European Regional Meeting Excursion Guidebook Leuven Belgium, 225-260

Gullentops, F., 1996. Tertiaire bouwzanden ten oosten van de Zenne. In: Gullentops, F. & Wouters, L. (eds) , 1996. Delfstoffen in Vlaanderen. Ministerie van de Vlaamse Gemeenschap. Departement EWBL, Brussel, 59-63

Gullentops, F. & Broothaers, L., 1996. De geologische geschiedenis van Vlaanderen. In: Gullentops, F. & Wouters, L. (Eds.), Delfstoffen in Vlaanderen. Ministerie van de Vlaamse Gemeenschap, afdeling Natuurlijke Rijkdommen en Energie, 6-28

Hedberg, H.D. (ed.), 1976. International Stratigraphic Guide. A guide to Stratigraphic Classification, Terminology, and Procedure. New York, Wiley, 200p.

Herman, J., Steurbaut, E., Vandenberghe, N. , 2000. The boundary between the Middel Eocene Brussel Sand and the Lede Sand Formations in the Zaventem-Nederokkerzeel area (Northeast of Brussels, Belgium). Geologica Belgica Vol 3/3-4 :231-256

Houthuys, R. & Fobe, B., 1988. Formatie van Brussel. *In* Maréchal, R. & Laga, P., *Voorstel lithostratigrafische indeling van het Paleogeen*, Belgian Geological Survey, Brussels, 127-135

Houthuys, R., 1990. Vergelijkende studie van de afzettingsstruktuur van getijdenzanden uit het Eoceen en van de huidige Vlaamse Banken. *Aardkundige Mededelingen*, Leuven University Press, 5: 1-137

Houthuys, R., 2011. A sedimentary model of the Brussels Sands, Eocene, Belgium. Geologica Belgica, 14: 55-74

Laga, P., Louwye, S. & Geets, S., 2001. Paleogene and Neogene lithostratigraphic units (Belgium). *Geologica Belgica*, 4 : 135-152

Merlé, D. (coord.) 2008. — *Stratotype Lutétien*. Muséum national d'Histoire naturelle, Paris; Biotope, Mèze; BRGM, Orléans, 288 p.

Mignion, G. , 1969. Les sablières de la province de Hainaut et de la partie wallonne de la province de Brabant. Annalen van de Mijnen van België p 951-981

Mourlon, M., 1905, Le bruxellien des environs de Bruxelles. Ann. Soc. Géol. Belg., 32, M329-M358

Peeters, L. (2014). Brusseliaan aquifer – Sables Bruxelliens. In : Dassargues, A. & Walraevens, K. (2014) (eds .), Watervoerende Lagen en Grondwater in België – Aquifères et Eaux Souterraines en Belgique, Academia Press, Gent, 83-104

Rutot, A. & Van den Broeck, E., 1883. Explication de la feuille de Bruxelles. Musée royal d'histoire naturelle, 210p.

Steurbaut ,E. & Herman, J. , 2006. 5. Bruxellian : in : De Geyter, G., De Man, E., Herman, J., Jacobs, P., Moorkens, T., Steurbaut, E., Vandenberghe, N., 2006 Disused Paleogene regional stages from Belgium: Montian, Heersian, Landenian, Paniselian, Bruxellian, Laekenian, Ledian, Wemmelian and Tongrian. Geologica Belgica 9/1-2 p 206-207

Stoops, G.. & Nijs, R. (eds), 1996. Bouwsteen. In: Gullentops, F. & Wouters, L. (eds.), Delfstoffen in Vlaanderen. Ministerie van de Vlaamse Gemeenschap, afdeling Natuurlijke Rijkdommen en Energie, 85-102

Tordoir, J. (ed.), 2000. La Gobertange. Une pierre, des hommes. Thematic book realized by ASBL Gobertange 2000, 413p

van den Berg, J.H., van Gelder, A. & Mastbergen, D., 2002. The importance of breaching as a mechanism of subaqueous slope failure in fine sand. *Sedimentology*, 40:81-952002

van den Berg, J.H., Martinius, A.W. and Houthuys, R., 2017. Breaching-related turbidites in fluvial and estuarine channels: examples from outcrop and core and implications to reservoir models. *Marine and Petroleum Geology*, 82: 178-205

Vandenberghe, N. & Gullentops, F., 2001. Kaartblad 32 Leuven. *Toelichtingen bij de geologische kaart van België - Vlaams Gewest*. Belgische Geologische Dienst en Afdeling Natuurlijke Rijkdommen en Energie, Brussel. 78 p., 34 fig., 4 foto's

Vandenberghe, N., Van Simaeys, S., Steurbaut, E., Jagt, J.W.M. & Felder, P.J., 2004. Stratigraphic architecture of the Upper Cretaceous and Cenozoic along the southern border of the North Sea Basin in Belgium. *Geologie en Mijnbouw*, 83: 155-171