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REVIEW OF THE LITHOSTRATIGRAPHY OF THE MIDDLE EOCENE IN NORTHERN BELGIUM

BART FOBE
GEOLOGISCH INSTITUUT
UNIVERSITEIT GENT
GENT, BELGIUM

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The lithology of Middle Eocene deposits, and that of stone layers in particular, was studied in subcrops in northwestern Belgium, allowing the following conclusions regarding their lithostratigraphy to be drawn. On account of its brown colour (lignite), the upper part of the Pittem Member (Gent Formation) has proved to often be a conspicuous key horizon. On the basis of a study of the geometry of the deposits in various boreholes and of the sandstone facies it can now be confirmed that the Beernem Member (previously referred to the Aalter or Knesselare formations) in fact belongs to the Vlierzele Formation. The Oedelem Formation (new name) consists of fossil-rich sand (Aalter Member or Aalter sands *sensu stricto*) on top of which rests the Evergem Member (new name), which comprises glauconitic sand. In borehole interpretations, this unit has been confused with the Vlierzele sand or with the Wemmel sand. Previous records of Lede Formation strata in the area between Gent and the North Sea coast are here confirmed.

Key words — Eocene, Belgium, lithostratigraphy.

B. Fobe, dr. sc., Geologisch Instituut, Universiteit Gent, Krijgslaan 281 S8, B-9000 Gent, Belgium; and, Herentalsesteenweg 66, B-2220 Heist-op-den-Berg, Belgium.

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INTRODUCTION

This paper presents a new interpretation of the lithostratigraphy of Middle Eocene strata in the area between Antwerp and the North Sea coast (NW Belgium), where these deposits are almost exclusively known from boreholes.

In part, results presented here are based on a petrographic investigation of cemented layers which occur in these deposits, with particular reference to the lateral and vertical distribution of stone facies and their lithostratigraphic significance rather than to diagenetic aspects of these. Stone layers in the Belgian Eocene often show typical petrographic features, which makes them useful in lithostratigraphic interpretations and correlations. Comparable studies have recently been made of the lithostratigraphy of the Kallo (Fobe, 1988), Ursel-Maldegem (De Breuck *et al.*, 1989), Mol, Oostham and Kwaadmechelen (Fobe, 1989), Beerzel, Booischot and Rillaar (Fobe, 1993a) boreholes. The stone facies recorded from boreholes were compared with those occurring in the outcrop area in northern Belgium.

Both calcite- and silica- (opal or chalcedony-) cemented stone layers occur in the deposits studied. Their origin will not be discussed in the present paper; the reader is referred to Fobe (1990) for a discussion of silica-cemented sandstones and to Fobe (1986) for that of sandy limestones.

Thin sections were stained following the method described by Evamy (1963) in order to distinguish ferroan from non-ferroan calcite. Whenever necessary, X-ray diffraction analysis (XRD) was used to check the mineralogy.

Figure 1 shows the location of the outcrops and boreholes studied, while Fig. 2 gives the key to the lithology of all other figures, except Fig. 6.

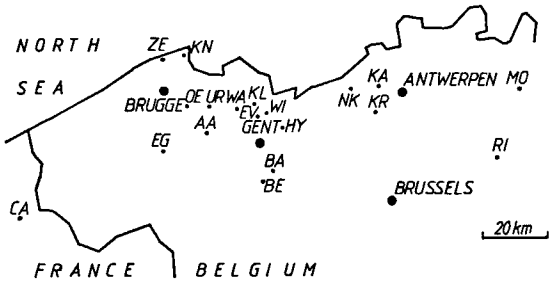

Fig. 1. Map of northwestern Belgium and contiguous French territory, showing the location of outcrops and boreholes studied for the present paper. Abbreviations are as follows: AA - Aalter, BA - Balegem, BE - Beerlegem, EG - Egem, EV - Evergem, HY - Hijfte, KA - Kallo, KL - Kluizen, KN - Knokke, KR - Kruibeke, MO - Mol, NK - Nieuwkerke-Waas, OE - Oedelem, RI - Rillaar, UR - Ursel, WA - Waarschoot, WI - Wippelgem, ZE - Zeebrugge.

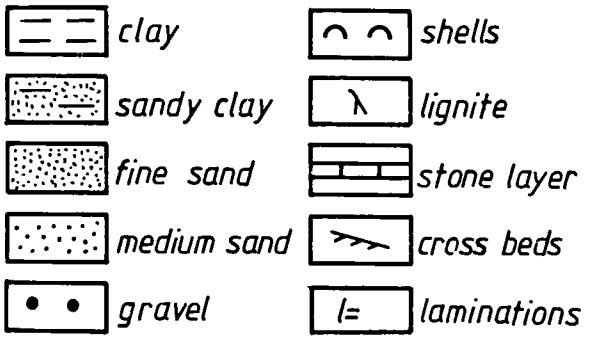

Fig. 2 Key to the lithological logs in Figs 3-5 and 7-10. Abbreviations used in these figures are as follows: Fm. - Formation, Mbr. - Member, We - Wemmel Member, B.N. - Bande Noire, EV - Evergem Member, AA - Aalter Member, DR - Drongengoed Member, BE - Beernem Member, OO - Oosterzele Member, LO - Lochristi Member, HY - Hijfte Member, PI - Pittem Member, ME - Merelbeke Member and EG - Egem Member.

LITHOSTRATIGRAPHIC FRAMEWORK

1 - Ieper Formation

Underlying the stratigraphic sequence studied in the present paper is the Egem Member (sand) of the Ieper Formation of Early Eocene age.

2 - Gent Formation

The Gent Formation was introduced by Maréchal & Laga (1988) to comprise the Merelbeke, Pittem and Vlierzele members. In the present study, use of the Gent Formation follows Fobe's (1996) new definition, in which it comprises only the Merelbeke and Pittem members.

3 - Vlierzele Formation

The Vlierzele Formation was defined by Steurbaut & Nolf (1986), who showed that in its type section, the Ursel-Maldegem borehole, this unit comprised the Pittem sandy clay and the Vlierzele sands (*sensu stricto*) of previous authors. Fobe (1996) presented a new definition and excluded the Pittem sandy clay. In the area between Gent and the North Sea coast, the Vlierzele Formation was described from and established in auxiliary stratotypes in the Hijfte and Ursel-Maldegem boreholes. According to Fobe (1996), the formation has a sharp lower and upper boundary and can be subdivided into five members, from bottom to top: Hijfte (gravel and sand), Lochristi (clayey sand), Oosterzele (sand), Beernem (clayey sand) and Drongengoed (sand). When compared with the legend to the new geological map (Jacobs *et al.*, 1993b), the Vlierzele Formation corresponds to the (undifferentiated) Vlierzele Member. Fobe (1996) argued that the concept of an undifferentiated Vlierzele sand unit which passes downwards gradually into the Pittem Member (sandy clay) as used in the legend to the geological map, may lead to correlation errors. The validity of the Vlierzele Formation as proposed by Fobe (1996) will be further discussed in the present paper.

4 - Oedelem Formation

In the area between Gent and the North Sea coast, resting on top of the Vlierzele sands are poorly exposed sands, which were referred to as 'Upper Paniselian' on the old geological map (scale 1:40 000). The name 'Aalter sands' was introduced by Leriche (1941).

Nolf (1972) established the Den Hoorn Formation to comprise the Oedelem and Aalter members, with the latter occurring in gullies incised into the former. Jacobs & Geets (1977) added the Beernem Member as the lowermost unit in what they defined as the Knesselare Formation, concluding that only the Oedelem Member extended throughout nearly the entire area between Gent and the North Sea coast. Jacobs & Geets (1977) described the Aalter Member (corresponding to the Aalter sands *s. str.*) as an infilling of local (i.e. at Aalter and Gent) gullies in the Oedelem Member. The areal extension of the Beernem Member was limited to the region south/southeast of Brugge, which means that the Knesselare Formation mainly comprised only the Oedelem Member.

For a number of years now, the name Aalter Formation has appeared in the literature; it is also used in the legend

to the geological map (Jacobs *et al.*, 1993a, b). The reason why the Knesselare Formation was abandoned is that the fossiliferous sands exposed in the Aalter type section and the Oedelem Member of boreholes north of Aalter were assumed to be equivalent deposits (Jacobs *et al.*, 1993a; Maréchal, 1993). The Aalter Formation of the new geological map (scale 1:50 000; Jacobs *et al.*, 1993a, b) comprises the Beernem and Oedelem members. However, the Aalter Formation has never been defined formally according to the guidelines for lithostratigraphic nomenclature (Hedberg, 1976). Occasionally, reference has been made to Steurbaut & Nolf's (1989) comprehensive bio- and chronostratigraphic study of the Aalter sands at the type locality. However, Steurbaut & Nolf (1989) did not provide a definition nor a discussion of the lithostratigraphic position of these sands, nor did they discuss their relationship with previously defined lithostratigraphic units, e.g. the Oedelem Member. Somewhat confusing also is the use of the facies name 'Aalter equivalent' as a part of the Aalter Formation, covering the Oedelem Member in boreholes in the North Sea (Jacobs & Sevens, 1993).

Fobe (1996) proposed to reassign the Beernem Member and probably also the basal part of the Oedelem Member (Drongengoed Member) to the Vlierzele Formation, in view of the fact that the Beernem Member has also been encountered (as a sandy clay or clayey sand intercalation) outside the area designated by Jacobs *et al.* (1993b) on the geological map, but within the confines of the Vlierzele Formation, and within the Vlierzele Member of the geological map, there considered to be undifferentiated.

A definition of the Oedelem Formation will be given below.

5 - Brussels Formation

The main outcrop area of this formation is located between the Zenne and Gete rivers; it has been encountered in boreholes north of this area. In the study area, the Brussels Formation has only been recognised in the Kallo borehole (Fobe, 1988).

6 - Lede Formation

This formation is accessible mainly on outliers and hill ridges between the Scheldt and Dijle rivers. Its presence has also been confirmed in boreholes in northern Belgium.

Both on the old (1:40 000) and new (1:50 000) geological maps (Jacobs *et al.*, 1993b), the Lede Formation is absent in subcrops in the area between Gent and the North Sea coast. On the 1:40 000 map it is shown to thin out between the Vlierzele sands and the Asse clay, a few kilometres northwest of Gent. On the new map, the Lede sands pinch out between the Oedelem sand and the Wemmel sand in the same area.

The presence of the Lede Formation has recently been recorded at Aalter (Steurbaut & Nolf, 1989) and in the Ursel-Maldegem area (De Breuck *et al.*, 1989).

7 - Maldegem Formation

This unit (formerly referred to as Meetjesland Formation or Kallo Formation) consists of an alternation of sandy clay and clay deposits (Jacobs & Sevens, 1988). At its base, below the Asse Member (glauconitic sandy clay), occurs either a glauconitic sand, with upward-increasing clay content (Wemmel Member) or a glauconite-rich, occasionally fossil-rich gravelly sand layer (a few decimetres thick) known as the 'Bande Noire'.

The Wemmel Member is known from the Brussels area and from the area between Gent and the coast; the latter area is of interest in the present study. On the geological map (Jacobs *et al.*, 1993b), the Wemmel Member rests upon the Aalter Formation and, as usual, is in turn overlain by the Asse Member. However, in the Ursel-Maldegem boreholes, the lower part of the glauconitic sands traditionally assigned to the Wemmel Member have been correlated with the Lede Formation on palaeontological and petrographic evidence (De Breuck *et al.*, 1989). Below, this problem is discussed further.

STUDY OF BOREHOLE SECTIONS AND STONE LAYERS

A - Boreholes between Gent and the North Sea coast

Knokke

Description — Total depth reached in the Knokke borehole (BGS 11 E 138; co-ordinates x = 78.776, y = 226.370, alt = + 5 m) was 433 m, ending in the Cambro-Silurian basement. For a lithologic description the reader is referred to Vandenberghe *et al.* (1990). Under a cover of Quaternary deposits (0-30 m) occurs the Eocene (Maldegem Formation), with the base of the Asse Member at 71.95 m. The section between 71.95 and 104.6 m consists of fine, sometimes clayey sand with glauconite, shells and shell beds and stone layers (71.95-74 m Wemmel sands, 74-79 m Brussels Formation and 79-104.6 m Oedelem Formation).

The interval between 104.6 and 124 m corresponds to the Vlierzele Formation (*sensu* Fobe, 1996): 124.75-124.2 m Hijfte Member, 122-124.2 m Lochristi Member, 116-122 m Oosterzele Member, 108.5-116 m Beernem Member and 104.5-110 m Drongengoed Member (see also units 3 to 7 as described by King, 1990 and the 'Mt Panisel Formation' of the Knokke borehole).

The sandy to silty clay between 124.75 and 133 m was

correlated with the Pittem Member, the clay between 133 and 135 m with the Merelbeke Member and from 135 m, the Egem Member.

Stone layers were sampled from the Oedelem Formation (at depths of 92.8, 94.4 and 98.3 m), the Vlierzele Formation (at depths of 114.4, 117.2 and 124.2 m) and from the Pittem Member (at depths of 125.3, 127.5, 129.5, 130.1 and 131.5 m).

Petrography of stone layers — Between 79 and 104.6 m (Oedelem Formation), the coherent beds at depths of 92.8, 94.4 and 98.3 m are calcite cemented. They consist of 45% of quartz, 45% of clear ferroan calcite cement with some micritic inclusions, 5% of glauconite and 5% of calcareous fossils, mainly bivalve shells and foraminifera.

The calcite-cemented beds in this interval are comparable to sandy limestones of the Oedelem Formation in the Kallo borehole (BGS 27 E 148) between 200 and 206 m depth (Fobe, 1988) and in the Ursel-Maldegem boreholes at a depth of 34.5 m (De Breuck *et al.*, 1989).

The sandstone bed at 114.4 m is fine grained, opal-CT cemented, with some 40% of quartz, 50% of cement and 10% of glauconite. The opal matrix is rich in calcareous particles and contains a minor amount of small wood fragments.

The sandstone at 117.2 m is a coarse-grained opal-cemented concretion. The larger quartz grains (59%) are of a size comparable to that of the surrounding sand. Glauconite grains (8%) are mainly rounded. The cement matrix (33%) is quite pure, with only a minor amount of calcareous particles and pyrite. Sorting is poor and the texture very heterogeneous. In places, the quartz grains are very closely packed, while elsewhere pockets with fine sand and more cement are found.

A scanning electron microscopy analysis (Philips SEM 535, Philips-Eindhoven) has shown the cement of this concretion to consist also of typical opal-CT lepispheres, 5-10 μm in size.

The sandstone at 124.2 m is an opal-cemented sandstone as well. Point-counting has shown this level to contain about 26% of quartz grains, 38% of opal and 6% of glauconite.

Between 124.75 and 133.0 m, sandstone beds occur in sandy clay, brownish-grey in colour on account of the presence of fragments of wood. Only the lowermost metre is greenish grey in colour. The sandstone beds in this section are cemented by opal. The opal matrix contains pyrite and numerous calcareous silt particles. The quartz grains are poorly sorted. Glauconite grains are rounded to lobate. Some calcareous fossils are present, mainly foraminifera and bivalve shell fragments. Siliceous fossils are scarce; small wood fragments, present in all samples, are opaque and do not preserve cell structures. The sandstone bed at 129.5 m has yielded remains of a possible root structure, with the epidermal layer fairly well preserved.

Point-counting has shown the quartz grains to be rather loosely packed (35%), with 55% of opal matrix and about 10% of glauconite. Some stone layers are laminated, with an alternation of sandy and more opaline beds, while others show a mottled texture. In the laminated samples (123.5 and 127.5 m), lignite is concentrated in fine-grained layers.

An SEM analysis has allowed the observation of well-shaped opal-CT lepispheres, which formed nearly the whole cement. The size of the lepispheres is about 5 μm. Within the lepispheres, blocky or platy calcite fragments, 10-20 μm large, are found; these probably are remains of disintegrated calcareous skeletons. Some framboidal pyrite concretions (7-10 μm large) have also been found. Most of them are spherical, others elongated. Some blady clay was found between opal-CT lepispheres.

Oedelem

Description — Of this cored borehole (BGS 23 E 88, co-ordinates x = 77.185, y = 208.902, alt = + 10 m), no results have been published yet; a preliminary description in the files of the Belgian Geological Survey is as follows:

0-3 m	Wemmel sand
3-23 m	Oedelem sand
23-46 m	Vlierzele sand
46-53 m	Pittem sandy clay
53-60 m	Merelbeke clay
60-65 m	Egem Sand (final depth)

My own interpretation largely matches this preliminary description:

0-3 m	Wemmel Member
3-23 m	Oedelem Formation
23-44 m	Vlierzele Formation
23-33 m	Beernem Member
33-40 m	Oosterzele Member
40-43 m	Lochristi Member
43-44 m	Hijfte Member
44-60 m	Gent Formation
46-53 m	Pittem Member
53-60 m	Merelbeke Member
60-65 m	Ieper Formation, Egem Member (final depth)

According to sheet 13 (Brugge) of the geological map (Jacobs *et al.*, 1993b), the Oedelem borehole is situated within the provenance area of the Beernem Member (Aalter Formation; see above).

Stone layers were encountered at depths of 26.95, 27.6, 28.8, 34.4, 44.95 and 47.6 m.

Petrography of sandstone beds — Stone layers from depths of 26.95, 27.6 and 28.8 m consist of very fine sand and coarse silt, cemented by opal-CT. The cement contains calcareous particles and clay. A few mica plates, moulds of sponge spicules (empty or refilled with chalcedony) and

small bivalve shell fragments have also been encountered in small amounts. The main composing elements are quartz grains (50%), opal cement (40%) and glauconite grains (10%). The sample from 27.6 m contains somewhat coarser quartz than the other beds, while that from 26.95 m is laminated (quartz-opal alternations).

The stone layer at a depth of 34.4 m is coarser grained than those from the 26-29 m interval. The cement also consists of opal-CT, and two size populations of quartz occur. The size of most of the grains is about 70-90 μm, but a minor group is coarser to about 150 μm. Glauconite grains (5%) belong to the larger size population. This sandstone level occurred in lignitic sand and is very rich in wood fragments, up to 2 mm in size. The texture is mottled and quartz and cement are unevenly distributed. Wood fragments are found mainly in opal-rich patches.

Of the stone layers in the 44-53 m interval, the one at 44.95 m is also an opal-cemented sandstone with poorly sorted, bimodal quartz (around 100-400 μm but with a smaller fraction around 30-50 μm). The sandstone contains a few bivalve shell fragments, the matrix also yielding calcite particles and wood fragments. Glauconite grains (10%) are strongly lobate and belong to the population of the coarsest quartz grains.

The sandstone bed at 47.6 m is comparable in quartz and glauconite grain size to the bed at 44.95 m. Intense bioturbation yielded a strongly mottled texture. A few burrow walls are partially preserved; they are lined by a rim of opal. Remains of previously destroyed burrows are preserved as opaline patches, of diameters up to 3 mm. Generally, this sample contains less lignite and fewer calcite fragments than the 44.95 m level and its cement appears very pure.

Ursel-Maldegem

Of two boreholes, BGS 39 W 212 (co-ordinates x = 87.910, y = 204.260, alt = + 29 m) and BGS 39 W 213 (co-ordinates x = 86.860, y = 205.900, alt = + 21 m), detailed descriptions were published by De Breuck *et al.* (1989). The main subdivisions are (see also Fobe, 1996):

0-26 m	Maldegem Formation
24-29 m	Lede Formation
29-44 m	Oedelem Formation
44-69 m	Vlierzele Formation
69-84 m	Gent Formation
69-79 m	Pittem Member
79-84 m	Merelbeke Member
84-102 m	Ieper Formation, Egem Member (final depth)

Stone levels have been studied from depths of 26 and 28.9 m (sandy limestones of the Lede Formation), 34.5 m (Oedelem Formation, named Oedelem Member of the Knesselare Formation by De Breuck *et al.*, 1989), 56.5 and 60.6 m (opal-cemented, medium-grained sandstones from the Vlierzele Formation, level 60.6 m containing wood fragments) and from 72.25 and 79.0 m (opal-cemented sandstones of the Pittem Member).

Waarschoot

In this borehole (BGS 39 E 48, x = 97.325, y = 205.275, alt = + 8 m), calcareous sands, overlain by clays of Bartonian age, were encountered at a depth of 26 m. In the original well description, these sands were assigned to the Lede Formation, but a sandy limestone sampled at 29.8 m (39 E 48/15) showed them to belong to the Oedelem Formation, the petrographic facies of the sample being comparable to stone beds in the Knokke (90-104 m), Ursel-Maldegem (34.5 m) and Kallo (200-206 m) boreholes.

Wippelgem (Evergem)

BGS 40 W 346 (co-ordinates x = 105.416, y = 203.232, alt = + 6.7 m) is a cored borehole, the description of which is as follows (Jacobs & De Ceukelaire, 1992a):

0-26.3 m	Pleistocene
26.3-36.65 m	Maldegem Formation
26.3-29.9 m	Asse Member
29.9-36.65 m	Wemmel Member
36.6-44.7 m	Aalter Formation, Oedelem Member
44.7-60.0 m	Gent Formation, Vlierzele Member

Samples of cemented layers at depths of 29.7 and 41.9 m both represent ferroan calcite-cemented beds, showing characteristics similar to that of the Oedelem Formation facies in the Ursel-Maldegem, Kallo and Knokke boreholes. In a preliminary interpretation (Jacobs & De Ceukelaire, 1992a), the uppermost cemented layer (29.7 m) is assigned to the Maldegem Formation.

The sample from 32.6 m was identified as a pyrite concretion, which showed no further particular characteristics.

Hijfte

Description — Of this cored borehole BGS 40 E 373 (co-ordinates x = 111.130, y = 200.390, alt = + 8 m), Jacobs & De Ceukelaire (1992b) presented a preliminary description:

0-18.0 m	Pleistocene
18.0-36.0 m	Maldegem Formation
18.0-26.5 m	Ursel Member
26.5-28.2 m	Asse Member
28.2-36.0 m	Wemmel Member
36.0-43.0 m	Aalter Formation, Oedelem Member
43.0-74.4 m	Gent Formation

43.0-58.6 m Vlierzele Member
58.6-74.4 m Pittem Member
74.7-77.0 m Tielt Formation, Egem Member (final depth)

It has been argued (Fobe, 1996) that the upper part of the Pittem Member (58.6-67.5 m) is clearly different in colour (greenish grey) and lithology (very fine clayey sand, with thin clay laminae) from the lower part (67.8-74 m), which consists of brown-grey, slightly lignitic sandy clay with stone layers and which strongly resembles the Pittem Clay facies from the cored Oedelem, Ursel-Maldegem and Knokke boreholes. Both are separated by a sandy intercalation with a marked, 10-15 cm thick, basal gravel of clay chips (67.7-67.8 m), considered to represent the Hijfte Member (base of Vlierzele Formation):

43.0-67.8 m Vlierzele Formation
43.0-49.8 m Drongengoed Member
49.8-53.7 m Beernem Member
53.7-59.0 m Oosterzele Member
59.0-67.5 m Lochristi Member
67.5-67.8 m Hijfte Member
67.8-74 m Gent Formation, Pittem Member

Description of stone layers — The sample from 30.6 m comprises a cemented layer of very fine-grained sandy limestone with a ferroan calcite cement. In its fine grain of quartz, glauconite content and cement texture, it resembles the sandy limestones at depths of 26 and 28 m in the Ursel-Maldegem borehole, which were identified as a facies of the Balegem stone (Lede Formation).

The sample from 32.2 m is a ferroan calcite-cemented sandy limestone comparable to the Oedelem stone facies.

The sample from 53.5 m is a concretion of a silica-cemented sandstone, its cement consisting of a sequence of opal rims around detrital grains, followed by chalcedony in the remaining intergranular space. This is the typical facies of sandstones from the Vlierzele Formation, and in particular of those developed in the Beernem Member.

Samples from 68.3, 68.95 and 72.3 m are mottled opal-cemented sandstones with wood fragments. The concretion from 68.3 m is rather coarse, silt sized.

Kallo

In the Kallo borehole (BGS 27 E 148; co-ordinates x = 144.85, y = 218.0, alt = + 3 m) sandy limestones of the Oedelem Member (201, 202 and 206.9 m), showing the same characteristics as those in the Ursel-Maldegem (34.5 m) and Knokke (92.8, 94.4 and 98.3 m) boreholes, are separated by stone layers of the Lede Formation (180-188 m) by a sequence with sandy limestone beds of the Brussels Formation (Fobe, 1988).

B - Outcrop area

Balegem

Exposed in the Balegem sandpit (co-ordinates x = 110.8, y = 179.1, alt = + 66 m) are the Vlierzele Formation (Oosterzele Member), overlain by the entire Lede Formation (5.5 m thick) and the basal part of the Maldegem Formation. The Lede Formation contains two levels of the characteristic Balegem sandy limestone at its base and at 0.5-0.8 m above the base. Balegem stone contains about 40-50% of quartz grains, dominated by the 63-125 μm fraction, with a small (3%) but significant amount of rounded grains coarser than 250 μm. Glauconite content rarely exceeds 5%, while fossils (mainly foraminifera, echinoid remains and bivalve shell fragments) amount to about 10%. The cement consists of ferroan (3% of $FeCO_3$) microsparite.

Egem

Exposed in the Egem sand and claypit (co-ordinates x = 70.275, y = 189.575, alt = + 46 m) is the Egem Member (20 m of sand with thin clay layers), overlain by the Pittem Member (5 m, sandy clay with sandstone beds). The base of the latter member consists of a 60 cm thick sandstone, coarse-grained at its base and containing reworked macrofossils from the Egem Member (e.g. the benthic foraminifer *Nummulites planulatus* Bruguière, 1792).

Oosterzele-Betsberg

In a borehole on the Betsberg (co-ordinates x = 109.9, y = 183.25, alt = + 53 m), the following sequence could be studied: 0-1.7 m Quaternary, 1.7-1.9 m Maldegem Formation, 1.9-8.9 m Lede Formation, and 8.9-19 m Vlierzele Formation. The Vlierzele Formation (Beernem Member) consists of an alternation of sand and clay, with sand layers containing compact sandstones (opal-chalcedony cement). Some sand and clay levels are dark brown and rich in lignite.

Beerlegem

The Beerlegem sandpit (co-ordinates x = 104.5, y = 178.05, alt = + 56 m) is situated in the outcrop area of the Vlierzele sands, southeast of Gent. Two facies were exposed in the period 1982-1985, the lower 4-6 m consisting of cross-stratified glauconitic sand with very thin clay beds (Oosterzele Member), the upper three metres including sandstone beds. The lower levels were very brittle, were not arranged in beds, lay parallel to the cross-bedded portions, and contained small fragments of wood. Exposed in the uppermost metre were two levels of

more consistent sandstone blocks (40 cm thick), with many (often silicified) wood fragments.

The upper unit (Beernem Member) was about 3 m thick. It showed a subhorizontal alternation of clay and sand layers. Often, sand and clay layers were only 5 cm thick. In thicker sand intercalations (of at least 10 cm), very hard and compact sandstone beds (up to 20 cm thick) often occurred. A number of eleven sandstone beds were counted, with a cumulative thickness of about 1.2 m. Sand intercalations often showed subhorizontal laminations.

Except for two layers, all sandstones were closely packed and cemented by a sequence of opal coatings, short fibrous chalcedony and radiaxial chalcedony (see also Fobe, 1990). The two other layers were slightly less densely packed and had a cement dominated by clear opal with a minor amount of chalcedony. The opal-chalcedony cemented sandstones from the Oosterzele and Beernem members are typical stone facies of the undifferentiated 'Vlierzele Member' of the traditional lithostratigraphic scheme, and were also encountered in smaller outcrops in the area southeast of Gent (Fobe, 1986).

Brugge

Early in 1986 there was a temporary exposure for the construction of a sewage collector along the Kerkebeek, south of the town of Brugge (co-ordinates x = 68.20, y = 207.55, alt = + 5 m). At the base of the section exposed, 10 cm of grey glauconitic sand was noted, on top of which rested 50 cm of grey clay with wood fragments. Above the clay, about 2 m of glauconitic sands with lignite were exposed, containing small sandstone concretions.

The basal sand is assigned to the Hijfte Member, while the clay of the Lochristi Member is in turn overlain by the Oosterzele Member.

The sandstone beds in this exposure showed a heterogeneous texture, ranging from closely packed sandstone with an opal-chalcedony cement to loosely packed patches cemented by opal. Wood fragments may be abundant. This sandstone facies is comparable to the level sampled at a depth of 34.4 m in the Oedelem borehole.

Aalter

Steurbaut & Nolf (1989) described a temporary outcrop near Aalter and sampled two sandy limestone levels. Petrographic investigation of these levels revealed that the uppermost bed (level 'L' of Steurbaut & Nolf, 1989) was the base of the Lede Formation, which confirmed those authors' interpretation. The lowermost bed (level 11 of Steurbaut & Nolf, 1989) is a sandy limestone, comparable with the stone facies of the Oedelem Member. The ferroan calcite cement is finer grained and less rich in iron than usual. The stone layer further contains 2% of glauconite, some patches of non-ferroan micrite and macrofossils such as tubes of the serpulid worm *Ditrupa strangulata* Deshayes, 1825 and bivalve shells.

STRATIGRAPHY OF STONE LAYERS

1 - Gent Formation, Pittem Member

The Pittem Member contains several laminated to mottled (bioturbated) opal-cemented sandstone beds. They were sampled in the Knokke, Oedelem, Ursel-Maldegem and Hijfte boreholes. Glauconite, calcareous bioclasts and wood fragments are the commonest secondary components.

This type of sandstone is fairly common in the Belgian Eocene and has no formation-specific characteristics. All these sandstone beds occur in a brownish (on account of the presence of wood fragments) grey sandy clay. The amount of wood decreases lower in the section. The combination of sandstones in a brownish grey clay constitutes a conspicuous horizon in borehole sections in northwestern Belgium. It differs from the overlying greenish grey sandy and sandy clay members by its colour (see discussion in Fobe, 1996) and is even detectable in flush wells.

Figure 3 presents a correlation of lithological units and their stone layers in the Gent Formation between boreholes in NW Belgium, illustrating the lateral distribution of the lignite-containing Pittem Member.

2 - Vlierzele Formation

This formation contains several facies of silica-cemented sandstones (see also Fig. 3). At the level of the sandy Oosterzele Member, poorly sorted, medium- to coarse-grained closely packed sandstones with a rather pure opal-CT cement were found. Wood fragments may be present to abundant (Oedelem borehole, Brugge outcrop). In the Ursel-Maldegem borehole, a similar opal-cemented sandstone layer (with wood fragments) was noted (De Breuck *et al.*, 1989), but its grain size was better sorted.

The Beernem Member in the Knokke and Oedelem boreholes contains stone layers consisting of very fine sand and coarse silt, cemented by opal-CT. The cement contains calcareous particles and clay, mica plates, moulds of sponge spicules, a minor amount of wood fragments and small bivalve shell fragments. Their appearance is comparable to the common type of sandstone beds in the Pittem Member.

At Ursel-Maldegem and Hijfte, the Beernem Member contains sandstone beds which more closely resemble the facies of the Oosterzele and Beernem members in their outcrop areas: closely packed, well-sorted, medium-sized sandstones with a cement of pure opal-CT or opal-chalcedony. Just as in the outcrop area (e.g. the Beerlegem sandpit) these sandstones occur in the sandy portions of sand-clay couplets of the lower part of the Beernem Member (Fig. 4).

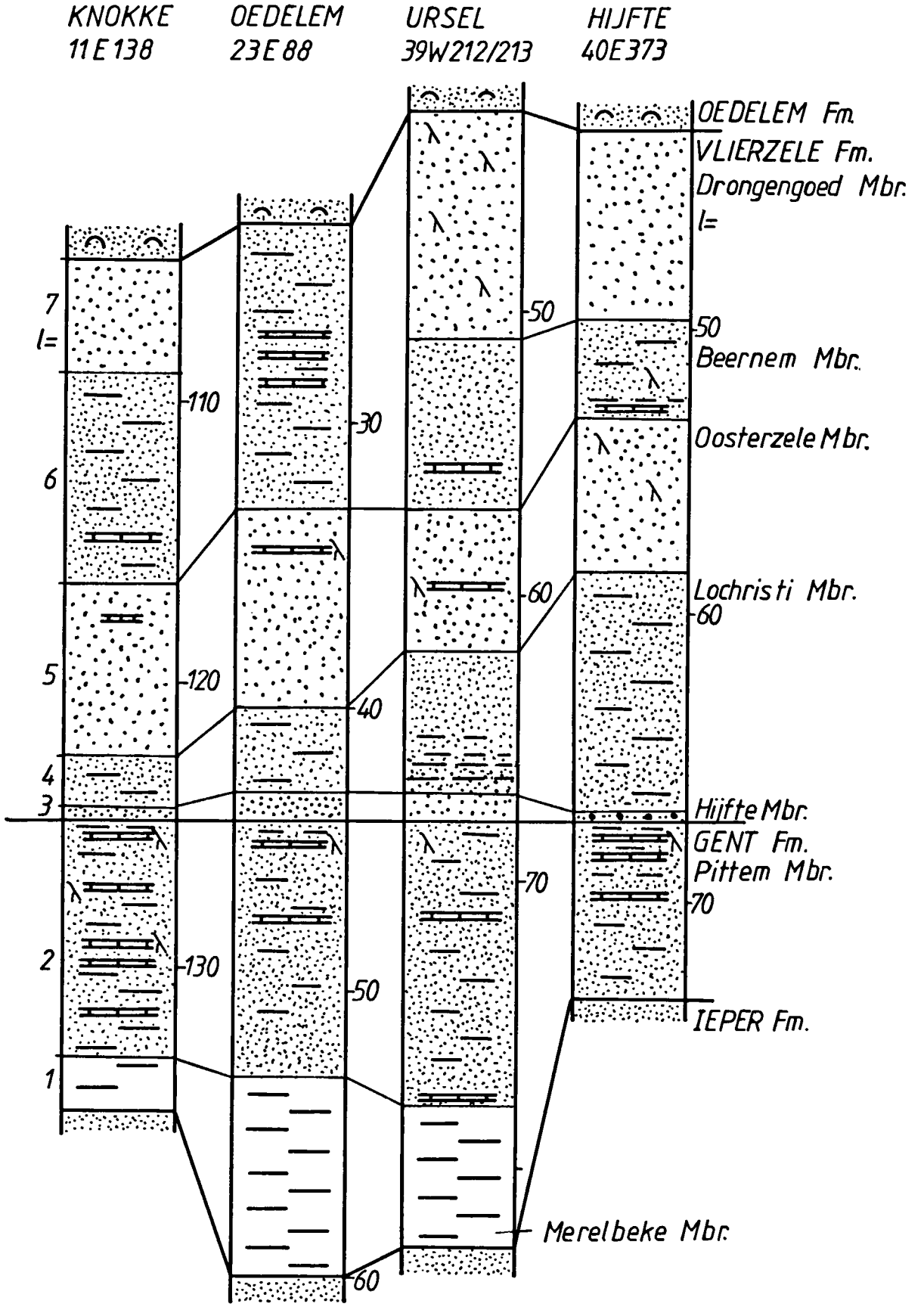

Fig. 3. Correlation of lithological units and their stone layers in the Gent and Vlierzele formations recorded from the Knokke, Oedelem, Ursel and Hijfte boreholes.

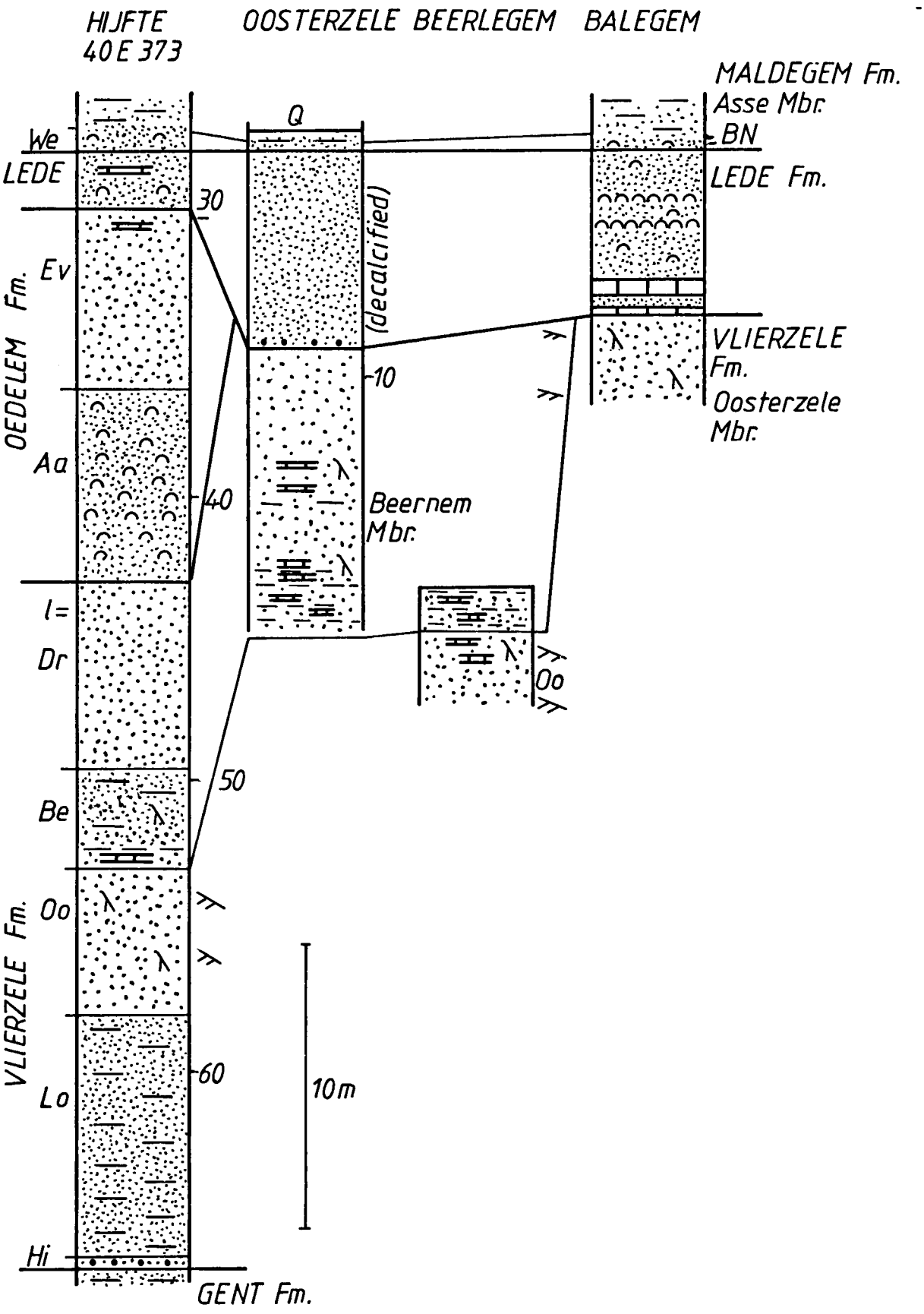

Fig. 4. Correlation of lithological units and their stone layers in the Vlierzele and Lede formations recorded from the Hijfte borehole and in the Oosterzele, Beerlegem and Balegem outcrops (southeast of Gent).

In both stone-containing members, there seems to be an evolution in lithology, since in the northwest (Knokke, Oedelem) loosely packed, poorly sorted opal-cemented sandstones prevail, while in a southeasterly direction (going from Ursel to the outcrop area southeast of Gent) closely packed and coarser-grained opal-chalcedony cements are commoner.

3 - Oedelem Formation

The stone facies of the Oedelem Formation is characterised by a ferroan calcite-cemented sandy limestones, mixed with non-ferroan lime mud, displaying a rather distinct facies throughout the study area in northern Belgium (Knokke, Ursel-Maldegem, Waarschoot, Wippelgem, Hijfte and Kallo boreholes, Aalter outcrop), altogether over an area of at least 85 km (Knokke-Kallo).

4 - Lede Formation

The stone facies assigned to the Lede Formation in the Ursel-Maldegem boreholes (De Breuck *et al.*, 1989) was also encountered in the Hijfte borehole. The facies is comparable to Balegem stone from the outcrop area of the Lede Formation (Fig. 4).

DISCUSSION

A - Ieper-Gent formations

Attention is drawn to the occurrence of a 2 m thick intercalation between the Merelbeke and Pittem members of the Gent Formation (*sensu* Fobe, 1996), which often is partially cemented by opal-CT (e.g. Ursel-Maldegem borehole at 79.0 m). This problem will be discussed further by Fobe (submitted), who proposes a correlation with the 60 cm thick sandstone layer at the base of the Pittem Member in the Egem sandpit.

B - Oedelem Formation

Lithostratigraphic significance of stone layers — In boreholes and outcrops in NW Belgium, the Oedelem Formation contains a characteristic sandy limestone facies, recognised in the Kallo, Hijfte, Wippelgem, Knokke and Ursel-Maldegem wells and in the Aalter outcrop. In the Hijfte and Wippelgem boreholes, this facies was identified in stone levels in the unit referred to as Wemmel Member by Jacobs & De Ceukelaire (1992a, 1992b). The presumed Wemmel Member in the latter description comprises fine sands, slightly fossiliferous or barren, with small humic spots and becoming slightly clayey down section.

This leads to the conclusion that the Oedelem Formation in NW Belgium consists of two main units, viz. a fossil-rich lower part and a less fossiliferous or barren upper part (Fig. 5).

The upper, poorly fossiliferous or barren, glauconitic sand resembles the Vlierzele sand. This explains why it was actually confused with the Vlierzele sands in the Kluizen flush well (Fobe, 1993b) and with the Wemmel sand in the Wippelgem and Hijfte boreholes by Jacobs & De Ceukelaire (1992a, b). Its thickness is about 6-7 m in the Hijfte and Wippelgem boreholes. It most probably corresponds to unit 12 of Steurbaut & Nolf (1989) at Aalter, which is only 2.3 m thick and truncated by the Lede Formation there, and which reaches some 5 m (29-34.5 m) at Ursel-Maldegem.

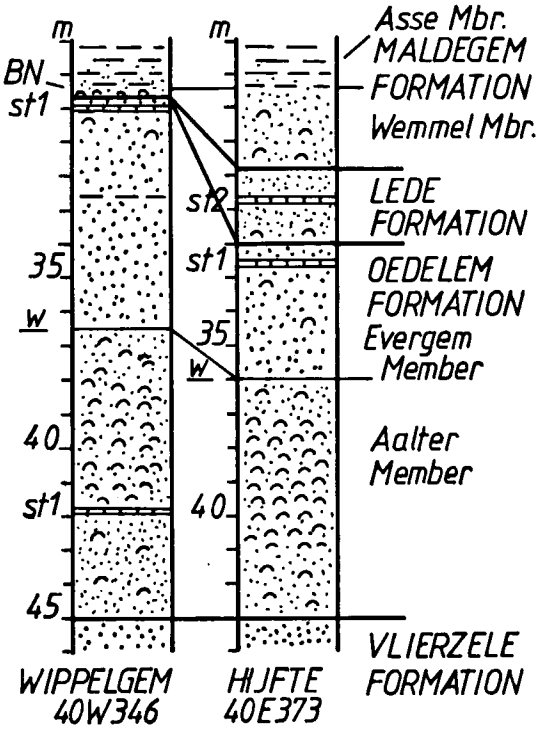

Fig. 5. Correlation of lithological units and their stone layers in the Oedelem and Lede formations recorded from the Hijfte and Wippelgem boreholes.

Obviously, these 'Vlierzele-like' sands may be cause for confusion in borehole interpretations. The similarities between the Vlierzele sands and the upper sands of the Oedelem Formation are probably the reason why the occurrence of the latter was not noted on the old geological map in the area between Gent and Aalter, where the basal fossil-rich portion emerged locally from the Pleistocene cover (Fig. 6).

Comparison with previous definitions: the Den Hoorn, Knesselare and Aalter formations — In the Oedelem area, Nolf (1972) and Jacobs & Geets (1977) described the following sequence: lignitic sands (Aalterbrugge facies of the Vlierzele sands), overlain by some 10-12 m of sandy

clay (Oedelem Member of Nolf, 1972; Beernem Member of Jacobs & Geets, 1977) and by fossiliferous sands (named Oedelem and/or Aalter sands in Nolf, 1972; Jacobs & Geets, 1977) (Fig. 7). In the present interpretation, the lignitic sands are correlated with the Oosterzele Member (Fobe, 1996). Nolf (1972) described the Aalter Member as a channel deposit, cut into the Oedelem Member. Correlations show that the Beernem Member also belongs to the Vlierzele Formation, but the unit which normally overlies it, the Drongengoed Member (Vlierzele Formation) (see Fobe, 1996), is either thin or missing in the Oedelem area.

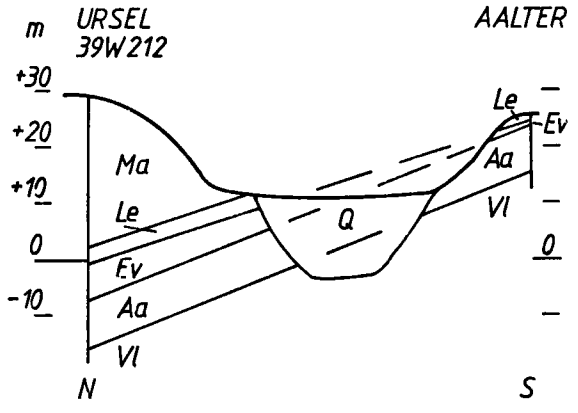

Fig. 6. Correlation of lithological units of the Oedelem Formation between the Ursel borehole and the Aalter outcrop, illustrating the thinning-out of the Evergem Member (upper glauconitic, non-fossiliferous sands of the Oedelem Formation).

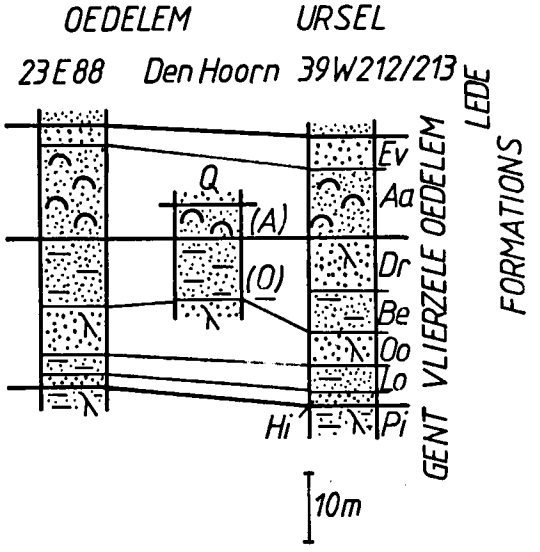

Fig. 7. Correlation of lithological units of the Oedelem Formation between the Ursel and Oedelem boreholes and the Den Hoorn borehole (after Nolf, 1972).

It should be stressed (Fig. 7) that the original Oedelem Member of Nolf (1972) in fact matches the Beernem Member of Jacobs & Geets (1977). The latter authors also described a 3 m thick poorly fossiliferous base of the Oedelem Member (representing, in fact, the Aalter Member of Nolf, 1972), but this deposit did not equate with the non-fossiliferous sands in Nolf (1972), but probably corresponded to Steurbaut & Nolf's (1989) poorly fossiliferous unit 1.

In the area between Ursel and Aalter (Fig. 6), a similar sequence is encountered (type section of the Aalter Member of Nolf, 1972; Jacobs & Geets, 1977), resting directly on lignitic Vlierzele sands. However, according to the interpretation of the Ursel-Maldegem boreholes (De Breuck *et al.*, 1989), the Drongengoed Member is also lignitic in that area. The lignitic level in the Oosterzele Member, which was very well developed in the Oedelem area, was also recognised in the Ursel-Maldegem boreholes (stone layer at 60.6 m). Therefore, the first appearance of lignitic Vlierzele sands ('the Aalterbrugge facies'), on which the lithostratigraphy of the Den Hoorn or Knesselare Formation was based (Nolf, 1972; Jacobs & Geets, 1977; Steurbaut & Nolf, 1989) cannot be used as marker bed. This makes the concept of the shelly Aalter Sands, locally occurring in deep gullies incised into the underlying Oedelem sands (Nolf, 1972) invalid, since it was based on a mix-up of the two lignitic sand levels in the Vlierzele Formation.

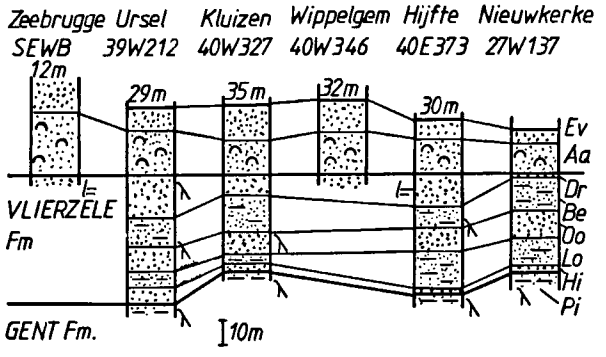

Fig. 8. Correlation of lithological units of the Vlierzele and Oedelem formations recorded in the Zeebrugge, Ursel, Kluizen, Wippelgem, Hijfte and Nieuwkerke-Waas boreholes.

The Aalter Formation on the legend to the new geological map (Jacobs *et al.*, 1993a, b) comprises the Beernem and Oedelem members. The fossiliferous sands exposed in the Aalter type section and occurring in the Oedelem Member in borehole sections north of Aalter are considered to be equivalent deposits. Basically, this assumption is correct, but the legend completely ignores the poorly fossiliferous or barren, glauconitic 'Vlierzele-like' sands occurring above them, which are confused with the Wemmel Member. As demonstrated previously (Fobe, 1996) as well as in the present paper, the Beernem Member also occurs

beyond its type area and belongs to the Vlierzele Formation.

Definition of the Oedelem Formation — The Oedelem Formation roughly corresponds to the stratigraphic interval formerly known as 'Upper Paniselian', 'Den Hoorn Formation' (*pro parte*), 'Knesselare Formation' (except for the Beernem Member), 'Aalter sands' and 'Aalter Formation'. It differs from the previous concepts mainly on account of its different sequence. While the Den Hoorn, Knesselare and Aalter formations were described as a lower sandy unit (Oedelem Member) overlain by an upper, ravinating shelly unit (Aalter Member, Aalter sands *s. str.*), the Oedelem Formation is defined as a shelly unit overlain by a sandy unit. The Oedelem Formation is subdivided into two members, the Aalter and Evergem members. The Oedelem Formation occurs in northern Belgium, north of the line Antwerp-Sint Niklaas-Gent-Brugge; the original extension of the unit is at present unknown (Figs 8, 9).

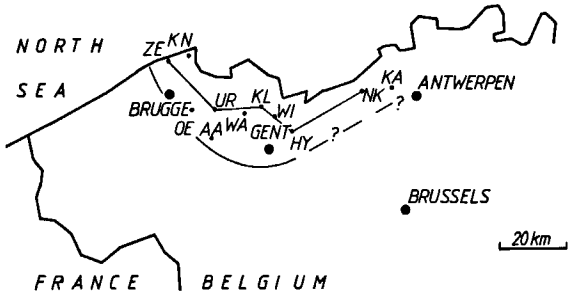

Fig. 9. Distribution of the Oedelem Formation, showing also the location of the cross section illustrated in Fig. 8.

Lectostratotype is the Wippelgem borehole BGS 40 W 346 (co-ordinates x = 105.416, y = 203.232, alt = + 6.7 m), depth 30-45 m, in the municipality of Evergem. Parastratotype is the Hijfte borehole BGS 40 E 373 (co-ordinates x = 111.130, y = 200.390, alt = + 8 m), depth 31-43 m.

Aalter Member

Name — after the municipality of Aalter.
Rank — an existing name for the shelly part of the formation originally assigned to the upper part of the Knesselare or the Den Hoorn formations.
Holostratotype — municipality of Aalter (see Steurbaut & Nolf, 1989: units 1-10).
Parastratotype — Hijfte borehole BGS 40 E 373, between 37 and 43 m.
Lithology — This member consists of medium- or coarse-grained glauconitic fossiliferous sand, with several shell beds.
Underlying unit — Vlierzele Formation (Drongengoed or Beernem members), sharp lower boundary.
Overlying unit — Evergem Member (Oedelem Formation), ravinated by the Lede Formation (Aalter, Gent) in a southerly direction.
Thickness — between 7 and 12 m.
Distribution — as for the Oedelem Formation.

Evergem Member

Name — after the municipality of Evergem.
Rank — new member.
Holostratotype — Wippelgem borehole BGS 40 W 346 (co-ordinates x = 105.416, y = 203.232, alt = + 6.7 m), depth 30-36.5 m.
Parastratotype — Hijfte borehole BGS 40 E 373, depth 31-37 m.
Lithology — This member consists of fine- to medium-glauconitic sand with a few humic patches, shells and a few clay layers.
Underlying unit — Aalter Member (Oedelem Formation).
Overlying unit — Lede or Maldegem formations.
Thickness — about 6 to 10 m.
Former correlations — generally erroneous correlations with the Wemmel Member, the Lede Formation or the sandy members of the Vlierzele Formation.
Distribution — as for the Aalter Member; because of ravination by the Lede Formation, the Evergem Member is missing in the outcrop area of the Oedelem Formation.

Details on the distribution of the Oedelem Formation — The application of the above-defined lithostratigraphic units enables a revision of previous borehole interpretations.

Zeebrugge

The offshore borehole SEWB was described by Jacobs & Sevens (1993), with the Oedelem Member (Aalter Formation) subdivided into the Beernem Member (43.0-33.1 m), Oedelem Member (33.1-19.2 m) and the 'Aalter equivalent' (12.0-19.2 m). According to the description of borehole SEWB (Jacobs *et al.*, 1990), the section 19.2-32 m was highly fossiliferous. The 'Aalter equivalent' consists of glauconitic sand and may well represent the Evergem Member of the Oedelem Formation. The fossiliferous sands of 19.2-32.0 m correlate with the Aalter Member. Laminated sands, described from between 32.0-33.1 m correspond to the Drongengoed Member of the Vlierzele Formation (Fig. 8).

Kluizen

According to Fobe (1993, 1996), resting on top of the Ypresian in borehole Kluizen, BGS 40 W 327 (co-ordinates x = 103.550, y = 204.300, alt = + 5 m) was the Maldegem Formation at a depth of 35 m. The remainder of the section was as follows: 35-43 m - medium sand with

sandstone (Drongengoed Member); 43-51 m - fine sand and clayey sand with sandstone, rich in shells (Beernem Member); 51-56 m - coarse sand (Oosterzele Member); 56-64 m - medium sand and 64-67 m - fine sand (Lochristi Member); 67-70 m - coarse sand (Hijfte Member) (Vlierzele Formation); 70-78 m - silty clay, greenish grey, brown at the top (Pittem Member); 78-86 m - clay (Merelbeke Member); 86-90 m - very fine clayey sand (Egem Member) (Ieper Formation).

The Kluizen borehole (flush well) was drilled only a few kilometres away from the cored Wippelgem well. The following revision is proposed (Fig. 8):

Oedelem Formation
- 35-43 m Evergem Member
- 43-50 m Aalter Member

Vlierzele Formation
- 50-54 m Drongengoed Member (medium sand comparable to the 35-43 m section)
- 54-62 m Beernem Member (fine sand)
- 62-65 m Oosterzele Member (brown, medium sand)
- 65-67 m Lochristi Member
- 67-70 m Hijfte Member (coarse sand)

Nieuwkerke-Waas

The section of borehole BGS 27 W 137 (co-ordinates x = 136.650, y = 210.780, alt = + 8 m) was originally interpreted as follows: 121-127 m - medium sand with sandstone (Drongengoed Member); 127-136 m - sandy clay with sandstone, fossil-rich sandy clay and sandy clay (Beernem Member); 136-139 m - medium sand (Oosterzele Member); 139-142 m - fine sand with clay (Lochristi Member); 142-145 m - medium to coarse sand (Hijfte Member) (Vlierzele Formation); 145-153 m - sandy clay, usually green, but brown in the uppermost two metres (Pittem Member); 153-170 m - clay (Merelbeke Member); 170-184 m - very fine sand with *Nummulites planulatus* (Egem Member) (Ieper Formation).

A review of data, inclusive of unpublished geophysical logs, has now shown that the section between 121-127 and 127-136 m corresponds to the Evergem and Aalter members of the Oedelem Formation, respectively (Fig. 8).

Kruibeke

In the Kruibeke borehole BGS 42 E 314 (co-ordinates x = 142.350, y = 205.850, alt = + 11 m), described by Fobe (1993, 1996) as well, there was no indication of the presence of the Oedelem Formation. This could mean that the Oedelem Formation thins out in subcrop south of Sint Niklaas.

C - Lede Formation, Wemmel Member

The glauconitic sands between the Aalter sands and the Asse clay have been (Jacobs *et al.*, 1993b) correlated with the Wemmel Member. In the Ursel-Maldegem boreholes (De Breuck *et al.*, 1989), the lower part of this unit, with sandy limestone beds, was correlated with the Lede Formation, mainly on account of stone facies, grain-size distribution and micropalaeontological characteristics. They are overlain by glauconitic sand, fining-upward, referred to as the Wemmel Member. The Hijfte borehole shows a comparable sequence, consisting of glauconitic sand with a cemented layer (at 29.7-32.0 m) with a sharp basal limit, overlain by fining-upward sand, grading into sandy clay. In the Wippelgem borehole, the glauconitic sand with a cemented bed is absent and resting on the Aalter sands is a thin (20-30 cm) 'Bande Noire', passing immediately into the Asse Member.

CONCLUSIONS

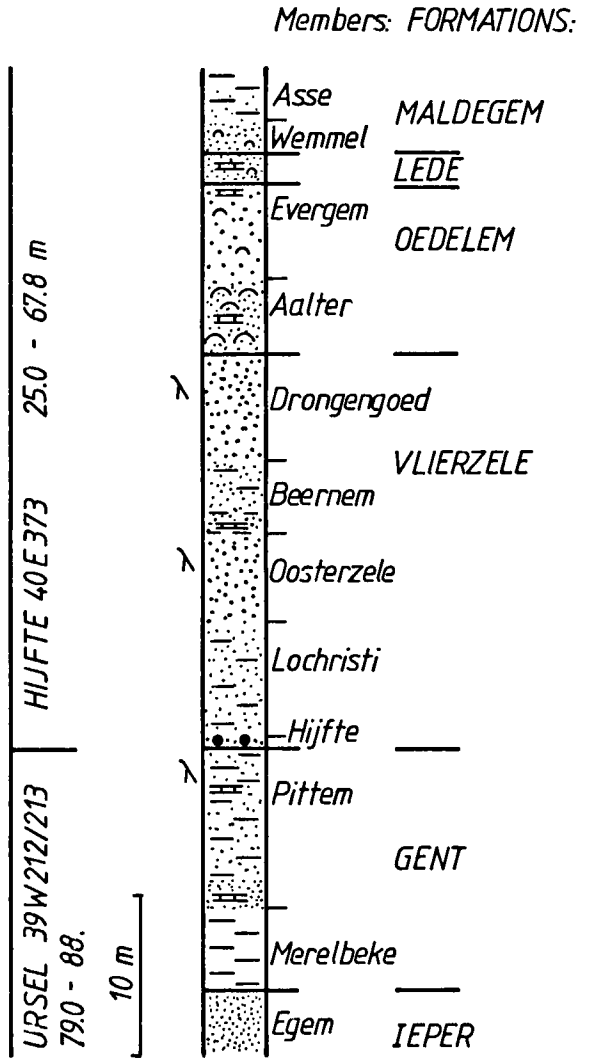

Fig. 10. Composite section of Middle Eocene formations and members in northwestern Belgium.

Figure 10 illustrates a composite section of Middle Eocene formations, as compiled from the Ursel and Hijfte borehole sections. In the present study, the validity of the Vlierzele Formation as a separate unit and its subdivision into five members (Fobe, 1996) is confirmed by analyses of stone facies.

The Vlierzele Formation is overlain by the Oedelem Formation (new name), which comprises a lower fossiliferous unit (Aalter Member) and an upper sandy unit (Evergem Member; new name). It proved possible to determine the upper limit of the Oedelem Formation by means of an analysis of stone facies.

The Lede Formation represents a discontinuous deposit between the Oedelem and Maldegem formations. The Wemmel Member is less important in thickness than previously thought, being reduced to the 'Bande Noire' in the area.

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Table 1. Previous lithostratigraphic schemes of the Middle Eocene of northwestern Belgium compared with the scheme proposed in the present paper.

OEDELEM AREA (NOLF 1972)	OEDELEM AREA (JACOBS et al. 1993)	AALTER AREA (JACOBS et al. 1993)	URSEL (DE BREUCK et al. 1993)	THIS STUDY
MALDEGEM Fm. Wemmel Mbr.	MALDEGEM Fm. Wemmel Mbr.	MALDEGEM Fm. Wemmel Mbr.	MALDEGEM Fm. Wemmel Mbr.	MALDEGEM Fm. Wemmel/BN
			LEDE Fm.	LEDE Fm.
			KNESSELARE Fm. Oedelem Mbr	OEDELEM Fm. Evergem Mbr. (λ)
DEN HOORN Fm. Aalter Mbr.	AALTER Fm. Oedelem Mbr.	AALTER Fm. Oedelem Mbr.		Aalter Mbr.
Oedelem Mbr.		GENT Fm. Vlierzele Mbr.λ	MT. PANISEL Fm. Vlierzele Mbr.λ	VLIERZELE Fm. Drongengoed Mbr.λ
	Beernem Mbr.			*Beernem Mbr.*
MT PANISEL Fm. Vlierzele Mbr.λ	GENT Fm. Vlierzele Mbr.λ		λ	Oosterzele Mbr.λ
		Pittem Mbr.		*Lochristi Mbr.*
				Hijfte Mbr.
(not studied)	*Pittem Mbr.*		*Pittem Mbr.*	GENT Fm. *Pittem Mbr.* λ
	Merelbeke Mbr.	Merelbeke Mbr.	Merelbeke Mbr.	Merelbeke Mbr.
LITHOLOGY KEY : Merelbeke Mbr. : clay - *Pittem Mbr.* : sandy clay - λ : lignite				