Contr. Tert. Quatern. Geol. | 29(1-2) | 9-20 14 figs. Leiden, June 1992

SEDIMENTOLOGY AND FACIES DISTRIBUTION OF THE LEDE FORMATION (EOCENE) IN BELGIUM AND NORTHERN FRANCE

B. FOBE

and

V. SPIERS
University of Gent
Gent, Belgium

Fobe, B., & V. Spiers. Sedimentology and facies distribution of the Lede Formation (Eocene) in Belgium and northern France. —Contr. Tert. Quatern. Geol., 29(1-2): 9-20, 14 figs. Leiden, June 1992.

In outcrop and borehole sections of the Lede Formation (Eocene, Lutetian) in the Belgian Basin three facies have been recognised. Between Gent, Brussel and Ronse (the Meldert facies), the formation shows a general fining-upward trend in grain size distribution. This facies is characterised by the presence of various gravelly beds on top of erosion surfaces, marking the base of smaller-scale fining-upward sequences. Associated gravel and shell beds and sandy limestones display sedimentary structures typical of storm deposits. In a northerly and westerly direction, coarse-grained beds are missing since the sea here became deeper and the sea floor was no longer within reach of storm waves (the Mont des Récollets facies). Near Ronse, the Lede Formation partly consists of brown medium sand with silicifications (the Einsdale facies). It probably marks the northernmost extension of a very shallow marine deposit. The cyclic sedimentation seen in the Lede Formation has been brought about by tectonic movements of the southern border of the Brabant Massif. The facies distribution of the formation is largely similar to the thickness evolution of the underlying Cretaceous strata, which were also subject to movements of the Brabant Massif.

Key words — Lede Formation, Eocene (Lutetian), Belgium, northern France, sedimentology, facies distribution.

B. Fobe and V. Spiers, Laboratorium voor Mineralogie, Petrografie en Micropedologie, Universiteit Gent, Krijgslaan 281 S8, B-9000 Gent, Belgium.

CONTENTS

INTRODUCTION

The term 'Sables de Lede' was first used by Mourlon (1873) in a stratigraphic table, but without any explanation. These sands formed part of the Lakenian, as defined by Dumont (1851) and originally included all Eocene deposits younger than what is now called the Brussel Formation. Between 1878 and 1887, several boundaries were established at gravelly beds within the Lakenian; these beds were considered to represent the lower limit of depositional cycles. First of all, the Wemmelian was introduced by Rutot & Vincent (1878). Then the Wemmelian itself was subdivided into a sandy part, the Wemmelian s. str. and a clayey upper part, for which the term Assian was proposed (Rutot, 1882). Vincent (1887) and Mourlon (1887) independently came to the conclusion, based on observations near Brussel and Balegem, respectively, that the Wemmelian s. str. comprised two depositional cycles. For the lower part the term Ledian was coined by Mourlon (1887). The subdivision of the upper part of the Eocene as then employed (Lakenian, Ledian, Wemmelian, Assian) was used for the legend of the Belgian geological map.

Shortly after the publication of this map, Leriche (1912) included the Lakenian in the Ledian, because of the fact that there was no lithological or palaeon-

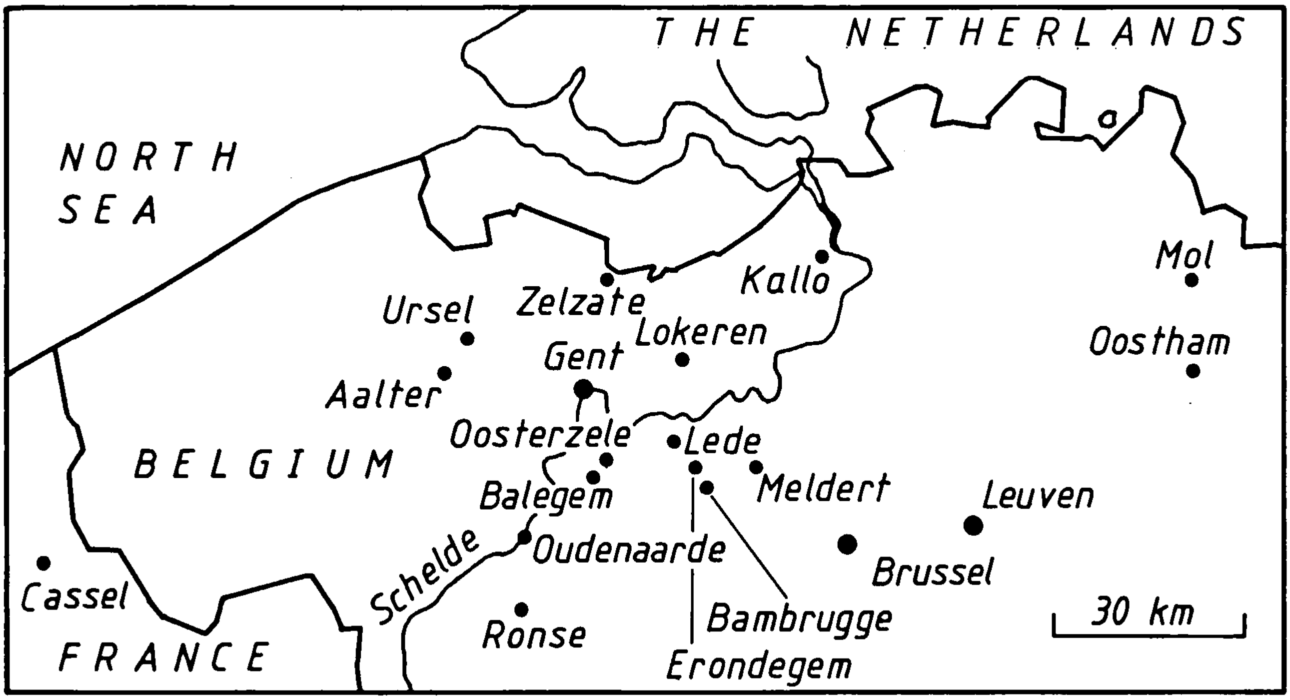

Fig. 1. Map showing localities mentioned in the text.

tological evidence for the distinction between these units. In the regional stratigraphic scheme of northwestern Europe, the Ledian was at that time still considered a stage between the Lutetian and the Bartonian. However, many authors were of the opinion that the Ledian was but a part of the Bartonian. This matter was discussed by Leriche (1937), who personally considered the Ledian to be a separate unit, and who correlated the Ledian with the Beauchamps Sand (Auversian, thought to be of Bartonian age by Leriche's opponents) of the Paris Basin, as both units yielded the index benthic foraminifer *Nummulites variolarius* Lamarck, 1801. Kaasschieter (1961) proposed to incorporate the Ledian into the Bartonian, after having studied the foraminifer faunas.

The matter was finally resolved by Pomerol (1961), who demonstrated that the classic index for the Ledian Stage, *N. variolarius* had lost its value, as it had been collected from deposits of Lutetian age in the Paris Basin. On the basis of micropalaeontological studies Pomerol (1961) came to the conclusion that the Ledian had to be included in the Lutetian.

LITHOLOGY

The Lede Formation consists of very fine calcareous sand, containing small amounts of glauconite (0.5%). The calcareous fraction consists mainly of lime silt, bivalve shells and tests of *N. variolarius*. Sedimentary structures are rarely visible. Several layers of sandy limestone (the so-called Balegem Stone), of up to 60 cm thickness may be seen. The formation also contains a number of fossiliferous beds (mostly concentrations of bivalve shells, nummulitids or tubes of the serpulid genus *Ditrupa*. Coarse-grained quartz beds may also occur. Shell or gravel beds are often found to be associated with stone layers. The $CaCO_3$ content amounts to 20% in the sand and to *c* 55-60% in the stone layers. Towards the south, the sands are often decalcified due to percolation of rainwater containing CO_2.

The limestone layers, called Balegem or Lede Stone, are cemented by calcite, contain up to 4% of $FeCO_3$ substitutions, and represent intervals of lower terrigenous supply, during which more biogenic calcareous sediment of authigenic origin formed. Much of the calcareous sediment was reworked during storm activity, leading to intercalations of coarse material rich in fossils and laminated deposits (Fobe, 1986).

The Lede Formation was laid down in the southern part of the Eocene North Sea Basin, its deposition being preceded by the closure of the connection with the Paris Basin (Delattre *et al.*, 1973). Kaasschieter (1961) interpreted the Ledian sea as a shallow shelf, comparable to the present-day shelf off Trinidad. On a decrease in number of foraminifera in a northerly direction Kaasschieter concluded that the Ledian sea became deeper to the north of Lokeren, and also suggested the possibility of the development of reefs in the Ledian sea, on account of the presence of the bryozoan genus *Fabularia*, nowadays known exclusively from the Great Barrier Reef (Australia).

In the present study, the results of grain size distribution analyses of the most important outcrops of the Lede Formation (Fig. 1) are presented. Particular attention is paid to vertical and lateral changes. Especially the area around Ronse was investigated, because of the occurrence there of an unusual facies, recorded previously by Baudet (1941) and Kaasschieter (1961). Samples were either collected by the authors or provided by the Belgian Geological Survey (BGS).

Figure 2 provides the key to the lithological sections (Figs 3-8) of the studied outcrops and the grain size distribution of the sediments exposed. The results are based on decalcified material. Analyses of coarse-grained beds cause too much visual deformation and are therefore omitted from the figures, as these are principally meant to emphasise the evolution in the sands that separate the gravels.

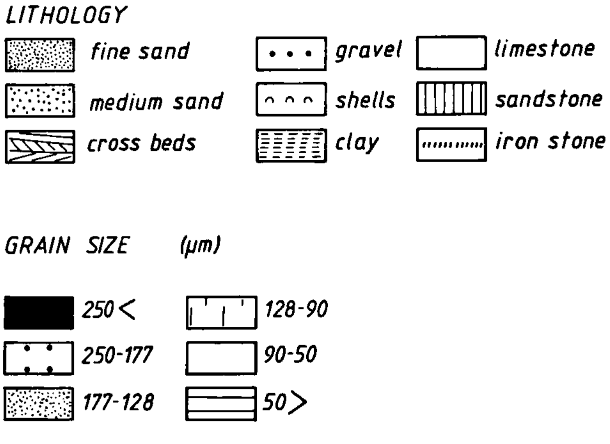

Fig. 2. Key to lithologic logs of Figs 3-8.

Extension of the Lede Formation

The classic exposures of the Lede Formation are located in the area between Gent and Brussel. Most of the outcrops near Brussel have fallen victim to the recent expansion of the city area. The westernmost key locality in this area is the Blandijnberg at Gent, where outcrops are also found in urban areas. Between Gent and the North Sea, the Lede Formation is generally missing, but below some recently discovered isolated outcrops will be described. Towards the south and southwest, the Lede Formation has been recorded from the hills of the Vlaamse Ardennen near Ronse and from isolated outcrops near Cassel in northern France. Between Brussel and Leuven, the Lede Formation is poorly exposed. East of Leuven, Eocene deposits thin out between the Palaeocene and Oligocene (Halet, 1932). In boreholes sunk in northern Belgium, the Lede Formation is found to be present between the Oostham-Kwaadmechelen area and Zelzate. The formation overlies the Knesselare Formation (Lutetian) between the North Sea and Gent (in so far as the former is present in this area), the Vlierzele Formation (Ypresian) between Gent and Brussel and the Brussel Formation (Lutetian) north and east of Brussel and near Cassel, and is itself overlain by the Kallo Formation (Bartonian).

Localities

— The area between Gent and Brussel

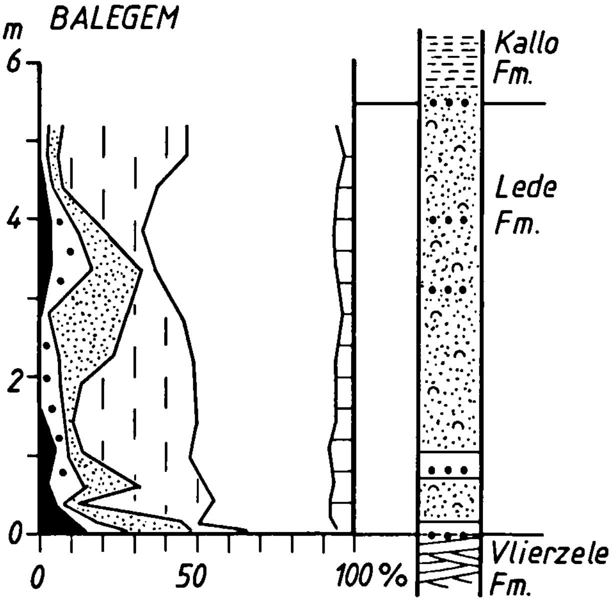

Fig. 3. Lithology and grain size distribution of the Balegem sandpit.

- Balegem: Verlee sandpit, co-ordinates: x = 110.8, y = 179.1. There is a working sandpit in the hill where Mourlon (1887) defined the Ledian, who in that paper in fact presented a review of the stratigraphy of a sandpit he had described previously (Mourlon, 1880). The entire Lede Formation, about 5.5 m thick, is exposed (Fig. 3). As usual, a basal gravel bed is observed, containing remanié material, including fossils (*e.g.* the foraminifer *Nummulites* *laevigatus* (Bruguière, 1792), bivalve shells and sharks' teeth) and perforated cobbles. Three coarser-grained beds occur within the sand: these are found at 0.8 m (rich in *Ditrupa, N. variolarius* and bivalve shells), at 3.2 m (rich in *N. variolarius*) and at 4.0 m (rich in bivalve shells) above the basal gravel. Sandy limestones are found near the basal gravel and around the second coarse-grained bed. In the description presented by Mourlon (1880), a third stone layer was recorded near the upper coarse-grained bed.

Cumulative grain size distribution curves are dominated by the fraction between 90 and 50 µm (about 50% of the sand fraction) and contain a low amount (<10%) of silt and clay (Fig. 3). Between the basal gravel and the second coarse-grained bed, a gradual fining-upward trend in grain size is observed. Between the second and third gravel bed, the fraction between 177 and 125 µm is less important in the lower part (<15%) than in the upper metre (ca. 30%). Between the third and the fourth gravel bed, the fractions coarser than 177 µm (15%) and 125 µm (up to 30%) are significant, although the sediment shows a fining-upward trend. On top of the fourth gravel, less than 10% of the sand is coarser than 125 µm.

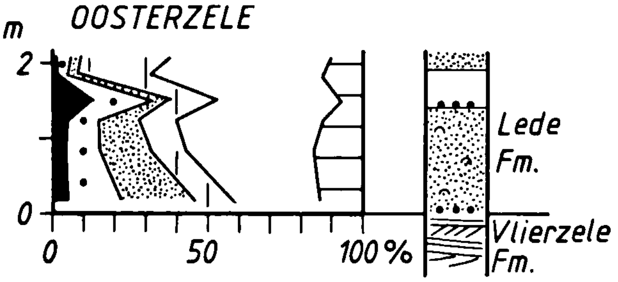

Fig. 4. Lithology and grain size distribution of the Oosterzele outcrop.

- Oosterzele: road cut, co-ordinates: x = 111.3, y = 181.6. The lower part of the Lede Formation was temporarily exposed (1984) in a road cut near Oosterzele. A stone layer, up to 50 cm thick, was present at 1.25 m above the basal gravel (Fig. 4). The lowermost centimetres of the stone contained coarse quartz grains. Above the stone, the sand was decalcified. In the sand between the basal gravel and the stone layer, a gradual fining-upward trend of the grain size was observed. The fraction coarser than 250 µm remained fairly constant, about 5%. The amount of the coarser-grained fractions gradually decreases (>177 µm: from 23% to 15%; >125 µm: from 47% to 28%; >90 µm: from 60% to 40%).

The sand on top of the second gravel is coarser than the sediment below this layer, but again the importance of the coarse fractions decreases. Between the base of the stone layer and the sample taken 30 cm higher up, the following evolution was observed: >250 µm: from 13% to 2%; >177 µm: from 33% to 3%; >125 µm: from 38% to 6%; >90 µm: from 56% to 35%.

- Lede: filled-in sandpits [BGS 71 E 53, co-ordinates: x = 122.9, y = 183.3; BGS 71 E 57, co-ordinates: x = 123.4, y = 183.9]. The type locality of the Lede Formation is situated on a hillock. There are but few descriptions of outcrops here. The Ledian was defined by Mourlon (1887) in a quarry at Balegem. Later, he published (Mourlon, 1888) on the Ledian in its type locality, as exposed in two sandpits. Descriptions of sections seen in these outcrops are recorded in the files of the Belgian Geological Survey (71 E 53 and 71 E 57). Only the lower part of the formation, with two fossiliferous stone layers was exposed.

- Meldert: disused sandpit, co-ordinates: x = 133.9,

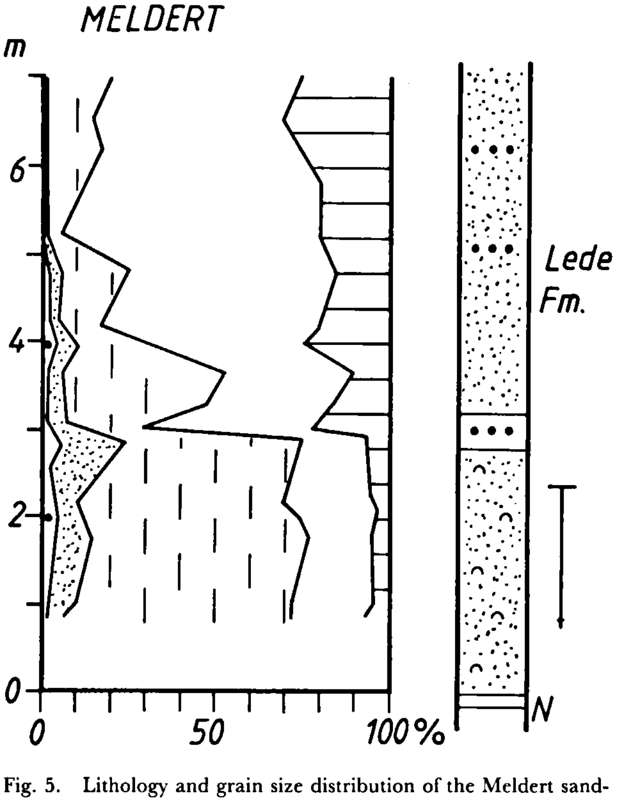

Fig. 5. Lithology and grain size distribution of the Meldert sandpit. The arrow on the right-hand side indicates the section sampled with an auger borehole. N = position of a stone layer recorded by Nolf (1974); this was not reached during the present study because of slumping of the borehole under the water table.

y = 180.2. Decalcified sand covering a limestone layer was excavated here. The stone layer is now exposed over a large surface. Many holes have been dug in it, enabling studies of the underlying unweathered sand. A second stone layer was recorded by Nolf (1974) at 3 m below the limestone bed exposed at present. The exposure offers good conditions for studying the sedimentary structures of storm deposits in the stone layer. Above an erosional surface and a gravelly layer, yielding numerous *N. variolarius*, subhorizontal laminations and finally trough cross stratification occurs. In the northern part of the outcrop, decalcified sand, which overlies the stone layer was studied. It contains two additional beds of coarse quartz grains. The sand underlying the stone layer was sampled in two auger boreholes, but the layer recorded by Nolf (1974) was not reached because of slumping of the boreholes under the water table.

The grain size distribution of the sand clearly differs on either side of the stone layer (Fig. 5). Above the stone, the sediment contains more clay (15-30%) than below (<10%), while the sand fractions coarser than 90 µm and 177 µm decrease from 90% to 70% and from 15% to 5%, respectively. Above the next coarse-grained bed, only 5% of the sediment is coarser than 90 µm and sand coarser than 177 µm is missing. No changes in grain size distribution were observed above the third coarse-grained layer.

- Bambrugge: disused sandpit, co-ordinates: x = 120.0, y = 179.5. Balegem stone was formerly extracted from this quarry. Nowadays, the pit is flooded and its walls have slumped. Detailed descriptions were furnished by Leriche (1926) and Gulinck (1961). Storm-generated sedimentary structures with concentrations of *N. variolarius*, similar to those seen at Meldert, were observed in stone slabs. According to Leriche and Gulinck, this level was the middle one of three stone beds, the upper one being rich in bivalve shells and the lower one being 60 cm thick and massive. This sequence is comparable to the one exposed at the Balegem sandpit, where the fourth gravel is yields many bivalve shells, the third one is rich in *N. variolarius* and the second one appears as a massive stone layer, also observed at Oosterzele. A stone layer at the basal gravel has not been recorded for Bambrugge.

- Erondegem: railroad trench, co-ordinates: x = 120.8, y = 180.7. Along the railroad track from Gent to Brussel, between the villages of Ottergem and Erondegem, a stone layer is exposed, showing sedimentary structures similar to those seen at Meldert and Bambrugge.

- Brussel: railroad trench, co-ordinates: x = 151.8, y = 167.5. In Etterbeek, in the eastern part of the urban area, a large outcrop was accessible during the construction of the railroad track from Brussel to Namur (Mourlon, 1910). The Lede Formation was between 7 and 10 m thick and several limestone levels were observed, one of them yielding numerous *N. variolarius* and resembling the stone layer encountered in the Meldert and Erondegem areas. It has been pointed out (Fobe, 1986) that the similar-looking nummulitid-rich stone layers observed at Etterbeek, Meldert, Bambrugge and Erondegem and the third gravel bed at Balegem might be a single continuous level.

— Outliers

- Aalter and Ursel: Aalter, temporary outcrop (1988), co-ordinates: x = 85.9, y = 197.8; Ursel, borehole BGS 39 W 212, co-ordinates: x = 87.9, y = 204.2. An outcrop exposing the base of the Lede Formation has recently been described by Steurbaut & Nolf (1989) in the village of Aalter. A sample of the stone layer was provided to the authors by Dr. E. Steurbaut. A petrographical analysis confirmed that the sandy limestone is characteristic of the basal gravel of the Lede Formation. The formation was also encountered in a borehole near Ursel (de Breuck *et al.*, 1989). Two layers of sandy limestone were observed, but no coarse-grained beds. The Lede Formation was thought to be missing in the area between Gent and the North Sea coast.

- Cassel: disused sandpit at the Mont des Récollets, co-ordinates: x = 18.5, y = 167.2. Cassel is situated at 70 km from the nearest exposure of the Lede Formation on Belgian territory. Disused sandpits described by Leriche (1921) have lately been reinvestigated (Nolf & Steurbaut, 1990). The Lede Formation is about 7 m thick and contains seven stone layers (Fig. 6). However, with the exception of the stone layer associated with the basal gravel and of the uppermost bed (rich in bivalve shells), no coarse-grained layers have been observed. From two stone layers, Leriche (1921) recorded two characteristic macrofossils [the gastropod *Campanile giganteum* (Lamarck, 1804) and the cephalopod *Nautilus burtini*

Galeotti, 1837], but beds of coarse-grained quartz were missing.

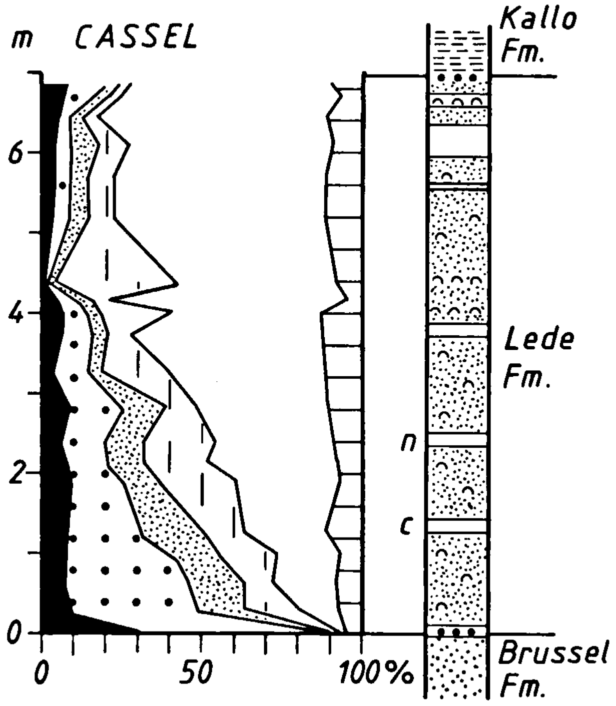

Fig. 6. Lithology and grain size distribution of the disused sandpit at the Mont des Récollets near Cassel (northern France); c = *Campanile giganteum* level, n = *Nautilus burtini* level (Leriche, 1912).

Grain size distribution shows a clear fining-upward trend (Fig. 6). In the lowermost metre, about 50 % of the sediment is coarser than 177 µm. In the upper part of the formation, this fraction still amounts to 15%. Throughout the entire formation, a slight amount of sand coarser than 250 µm is found. As in the other outcrops studied, the sediment in the upper half of the Lede Formation is dominated by the sand fraction between 90 and 125 µm. The amount of silt and clay varies between 5 and 10%.

— The Ronse area

- Louise-Marie: sandpit, co-ordinates: x = 99.478, y = 162.388. A complete section, 7 m thick (Fig. 7) of decalcified sands of the Lede Formation is exposed in a sandpit in the hamlet of Louise-Marie, northeast of Ronse (Fig. 8). Layers of coarse-grained quartz occur at 3.9 and 5.9 m above the basal gravel. In the lowermost metre, a gradual fining-upward sequence, starting from the basal gravel, is seen. Between the second gravel bed and the top of the formation, the fraction coarser than 90 µm gradually diminishes (from 70 to 30%). Above the third coarse bed, the total sand fraction is also reduced from 90 to 70 %.

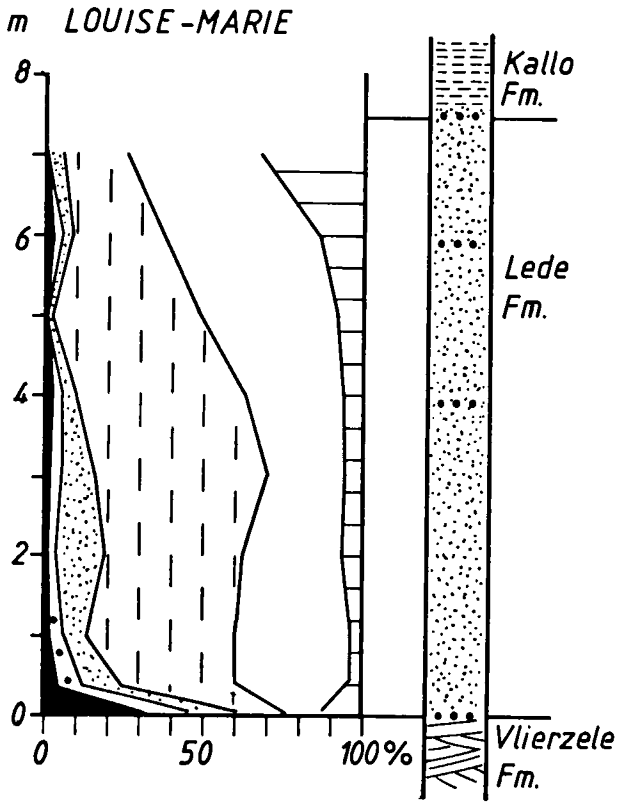

Fig. 7. Lithology and grain size distribution of the Louise-Marie sandpit.

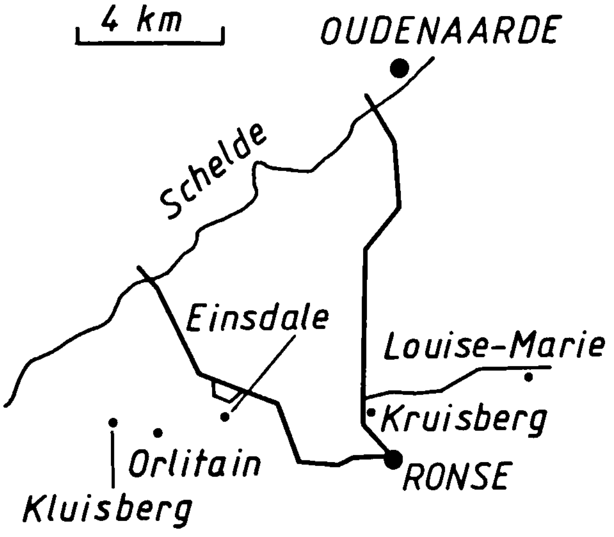

Fig. 8. Map showing location of outcrops in the Ronse area.

- Einsdale: In the hills northwest of Ronse, a different facies of the Lede Formation has been encountered. The area is situated in a hill ridge with altitudes up to +150 m above present sea level. The facies has been observed near the hamlet of

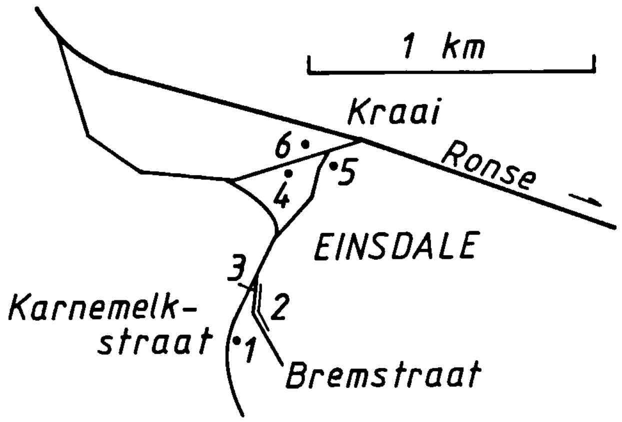

Fig. 9. Detailed map showing location of the outcrops in the Einsdale area. 1 – outcrop of the Vlierzele Formation along the Bremstraat, 2 – outcrop of the Lede and Kallo Formations along the Bremstraat, 3 – outcrop of stone layers in the Lede Formation, 4 – disused sandpit exposing stone layers in the Lede Formation, 5 – disused sandpit described by Geets (1969), 6 – disused sandpit described by Mourlon (1889).

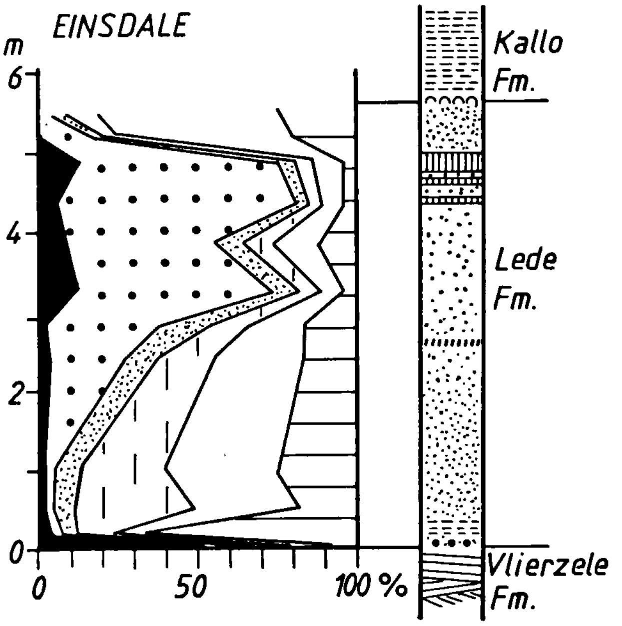

Fig. 10. Lithology and grain size distribution of the Lede Formation at Einsdale.

Einsdale, at the southern slope of the east-west oriented hills (Fig. 8). From Einsdale, two roads run downhill towards the hamlet of Tribury (Fig. 9), and bifurcate at altitude +120 m and rejoin each other tens of metres lower. The western branch (Karnemelkstraat) runs across a disused sandpit the southern limit of which is still visible at +110 m (Fig. 9, locality 1). Cross-stratified glauconitic sand is exposed here, characteristic of the Vlierzele Formation, which is the unit underlying the Lede Formation in the sandpits of Balegem and Louise-Marie. The eastern branch (Bremstraat) marks the eastern border of the former sandpit and runs along an outcrop of white and brown sand. In the uppermost part, glauconitic brownish grey clay of the Kallo Formation is seen. This formation overlies the Lede Formation at Balegem, Cassel and Louise-Marie. The largest outcrop was situated between the bifurcation of the Karnemelkstraat and the Bremstraat at +120 m and an angle of 90° in the slope along the Bremstraat (Fig. 2, locality 2), near +110 m. An auger borehole near this corner revealed the presence of the Vlierzele Formation. The deposit encountered between the Vlierzele and Kallo Formations along the Bremstraat clearly corresponds with the stratigraphical position of the Lede Formation.

Einsdale: disused sandpit and road exposure, coordinates: x = 91.4, y = 161.5. From observations in

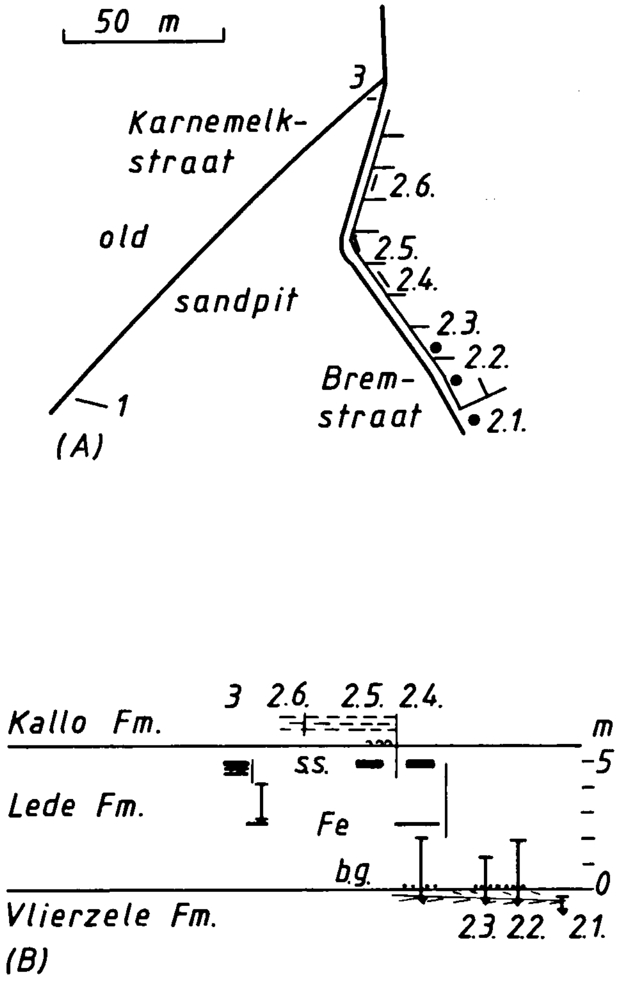

Fig. 11. Detailed map showing location of the localities sampled in the Einsdale outcrop (A) and of the sections studied at each locality (B). Fe = ferruginous sandstone, b.g. = basal gravel of the Lede Formation, s.s. = siliceous sandstone. Arrows indicate auger boreholes.

small outcrops (the section being disturbed by faults) combined with auger boreholes a complete section was obtained (Fig. 10), by correlation of several points of observation (Fig. 11). At Einsdale, the Lede Formation consists of a basal gravel (20 cm) overlain by white clay (20 cm) and slightly coarsening-upward pale grey sand. At about 2.3 m above the base of the formation, a thin layer (2 cm) of ferruginous sandstone is seen. The surrounding sand has a rusty brown stain. Next, rusty brown medium-grained sand (1.75 m thick) is seen. The upper part of the sequence comprises 65 cm of an alternation of white sandstones with brown patches, and brown sand. Near the bifurcation of the Karnemelkstraat and the Bremstraat (Fig. 9, locality 3), three such stone layers occur, 13 cm, 10 cm and 25 cm in thickness, respectively. They contain external and internal moulds of bivalve shells. The stone is covered by 65 cm of ochrous sand, clearly finer-grained than the underlying sediment. The base of the Kallo Formation (glauconitic sandy clay) is developed as a thin layer of broken bivalve shells.

The results of grain size distribution analyses for the lower part of the Lede Formation at Einsdale are comparable to those of other outcrops (Fig. 10). At 1 m above the base, the sand becomes gradually enriched in grains coarser than 125 µm. The fraction between 177 and 250 µm in particular becomes important. Between 3 and 5 m above the base, 60% of the sand is coarser than 177 µm. In the uppermost 65 cm, finer sediment is observed again, with only 20% coarser than 90 µm and less than 5% coarser than 177 µm.

A petrographical analysis has shown that the white sandstones sampled in the upper part of the section exposed at Einsdale are cemented by epitaxial quartz rims surrounding the detrital quartz grains (Fig. 12). Opaque inclusions delimit the original detrital grains. Intergranular pore filling is occasionally incomplete. SEM observations sometimes showed well-developed crystal faces at the outer border of grains. When infilling is complete, the cleavage surface does not go around but right through the grains, yielding a quartzite-like surface. Several silicified fossils, mainly bivalve shells and tests of *N. variolarius*, show replacement of the original calcite by fine-grained equidimensional quartz. Due to the presence of opaque material, the original structure of the nummulitids is visible. In places, an epitaxial rim of an adjoining quartz grain has penetrated the nummulitid test. The opaque inclusions of the fossil have remained intact, but the fine-grained quartz in the foraminifer has been partially replaced by the monocrystalline structure of the rim (Fig. 12). The texture of the silicified sandstones at Einsdale differs completely from the commoner Balegem limestone with its fine-grained quartz and calcite cement (Fig. 13).

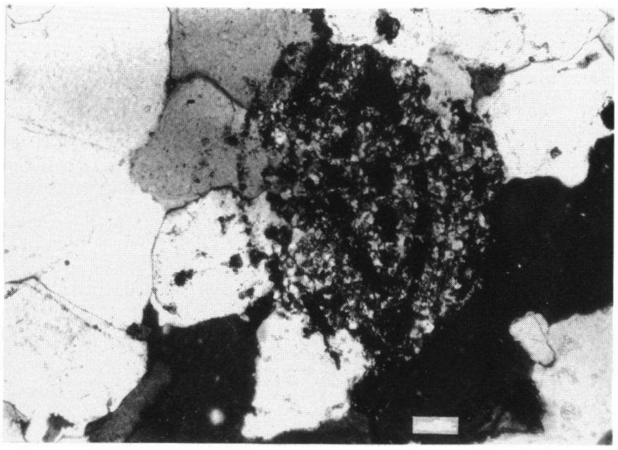

Fig. 12. Photomicrograph of a sandstone sample from Einsdale. The cement consists of epitaxial rims of quartz, deposited upon detrital quartz grains. The original outer margins of the grains are discernable because of opaque inclusions. A test of *N. variolarius* has been replaced by fine-grained quartz and its chambers are filled with opaque material. Epitaxial rims of adjoining quartz grains have in places replaced the fine-grained texture in the silicified test, but the original outline of the nummulitid is still visible due to opaque inclusions. Scale bar equals 200 µm.

The shell bed at the base of the Asse Clay has been preserved on account of its fossils being silicified. The shells have been replaced by microcrystalline quartz, but remnants of the original structure are visible due to opaque inclusions.

The 2 cm thick layer of ferruginous sandstone

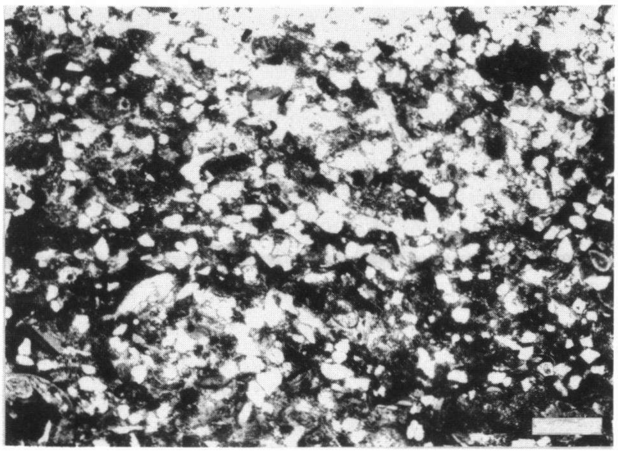

Fig. 13. Photomicrograph of a typical sandy limestone (Balegem Stone) from the Lede Formation. Cement consists of fine-grained calcite. Scale bare equals 50 µm.

from the middle part of the Lede Formation consists of quartz grains cemented by goethite. In comparison with the surrounding sand, also studied in thin sections, the ferruginous stone layer does not show any particular grain size distribution. The sample from below the stone bed still contains a large fraction of very fine sand. In the stone layer and in the overlying sand, this fraction is gradually replaced by medium-sized quartz grains, an evolution that has also been observed during grain size distribution analyses.

Chemical analyses of free iron and aluminium by means of dithionite extraction (Mehra & Jackson, 1960) show that the red brown medium sand in the middle of the formation contains between 2.2 and 3.9% of Fe_2O_3. Lower in the section, in the pale grey fine sand, lower concentrations were measured (between 0.7 and 1.3% Fe_2O_3). The lowest amounts were found in the uppermost 65 cm of fine sand above the white stone layers (0.6% Fe_2O_3). The concentrations of Al_2O_3 in the red brown medium sand varied between 0.11 and 0.74%. In the grey fine sands in the lower part, Al_2O_3 content ranged between 0.39 and 0.58%. The ratio Fe_2O_3/Al_2O_3 was fairly constant in the grey sand (between 2 and 3.5) and varied between 7 and 25 in the red brown medium sand.

As to the lateral extension of the facies the following observations can be made. The upper part of the Einsdale facies, containing white sandstone beds, is visible in a small disused sandpit in the hamlet of De Kraai, a few hundreds of metres north of the Bremstraat outcrops (Fig. 9, locality 4). The facies was also exposed in a large sandpit, now completely filled in, south of De Kraai (Fig. 9, locality 5). The outcrop was described by Geets (1969), who provided grain size analyses from the Lede Formation as exposed in the sandpit. The sediment and the patterns of its grain size distribution are similar to the ones seen for the Bremstraat outcrop. The sand is characterised by a coarsening-upward and in the middle of the formation, red brown sand appears, containing a thin bed of ferruginous sandstone and, in the upper part, several sandstone beds occur. Immediately north of De Kraai, there is another sandpit exposing the Einsdale facies of the Lede Formation; the section was described by Mourlon (1889) (Fig. 9, locality 6). From the lowermost metre of the formation, a second gravel bed was recorded, immediately above the clay intercalation that was also encountered in the section along the Bremstraat.

In a westerly direction, between Einsdale and the River Schelde, delimiting the hill ridge of Ronse, a facies similar to the one recorded at Einsdale was recorded by Baudet (1941) from two sandpits at Orlitain and at the Kluisberg, the westernmost hill of the ridge (Fig. 8). Between the Kluisberg and the hills near Cassel (60-70 km), topography is too low and Lede Formation strata do not occur.

Towards the east, the Einsdale facies is missing from the sandpit of Louise-Marie, described above, situated at 6.5 km east of Einsdale. In a filled-in sandpit at the Kruisberg (3.4 km east of Einsdale), the Lede Formation was 4.7 m thick and the uppermost 80 cm consisted of medium sand ('sable quartzeux') with sandstone beds (Mourlon, 1889). Thus, the Einsdale facies is found over a distance of 5.4 km between the Kruisberg to the east and the Kluisberg to the west, where its extension is limited by the valley of the River Schelde.

The Einsdale facies is characterised by a coarsening-upward sequence, a relatively high amount of goethite in the coarsest sand and the occurrence of silicifications. For each of the characteristic features of the Einsdale facies, several explanations are possible. Both the brown stain of the sand and the silicification may have formed during any weathering or decalcification process at any time subsequent to the deposition of the Lede Formation. Yet it must be emphasised that these facies characteristics have not been encountered separately anywhere else in a decalcified section of the Lede Formation. The coarsening-upward sand containing goethite probably represents a remnant of a palaeosol within the Lede Formation. The sand was deposited under shallowing conditions and subsequently subject to an oxidising environment. This hypothesis is supported by the joint occurrence of medium sand and iron oxides. Both are rather sharply truncated within the Lede Formation itself and overlain by fine sand of the normal Ledian facies with a common iron content. The silicifications are also linked to this phenomenon, as they are found in the upper part of the reddish medium sand.

The age of the silicifications is difficult to assess. The occurrence of a bed of silicified shells at the base of the Asse Clay suggests that the fossils were reworked in that state. The source of the silica is also problematic. In the Belgian Eocene, several formations contain siliceous sandstones cemented by opal and chalcedony, originating from biogenic silica. Concretions of this kind do not occur in the Lede Formation. The sandstones from the Einsdale facies are cemented by epitaxial rims of quartz, as in quartzite. This type of cementation was not found anywhere else in the Belgian Eocene. Quartzite-like sandstones have been described from continental deposits of the Palaeocene Landen Formation (de Geyter, 1980). These originated from silcrete-like soil formation. However, the Landenian sandstones contain structures of continental origin, such as plant roots and silicified wood fragments.

— Northern Belgium

- Kallo borehole [BGS 27 E 148], co-ordinates: x = 144.9, y = 218.0; Mol borehole [BGS 31 W 237], co-ordinates: x = 198.4, y = 211.8; Oostham boreholes [BGS 46 E 179], co-ordinates: x = 204.5, y = 198.7/[BGS 46 E 180], co-ordinates: x = 206.7, y = 199.3. The Lede Formation in northern Belgium has been studied in borehole sections at Kallo (between 180 and 188 m) (Fobe, 1988), Mol (between 315.9 and 336.4 m), Kwaadmechelen (BGS 46 E 179, between 202.90 and 209.05 m) and Oostham (BGS 46 E 180, between 220 and 231.5 m) (Fobe, 1989). With the exception of the basal gravel, no coarse-grained deposits have been found associated with stone layers. Grain size distributions of several samples from Kallo and Mol have been analysed. They are more or less similar to those determined for the outcrop areas. Little vertical evolution is observed in each borehole. At Kallo, between 20 and 30% of the sand is coarser than 125 µm. At Mol, where the Lede Formation is at least twice as thick (20 m) as normal, a slight fining-upward trend has been observed in the lowermost 5 m, followed by a slight coarsening-upward trend. The fraction coarser than 125 µm nowhere exceeds 10%.

FACIES DISTRIBUTION

Due to tectonic movements, the southern border of the Cambro-Silurian Brabant Massif was inundated several times subsequent to the Cretaceous. In the Ronse area, Cretaceous and Palaeocene deposits are very thin or even missing. In the underground of Cassel, the Cretaceous is more than 100 m thick (Legrand, 1968). Furthermore, the Eocene sequence here is more complete than in the Ronse area and it resembles the succession recorded in the Kallo borehole in northern Belgium.

The Ronse area was influenced to a greater extent by the oscillating movements of the Brabant Massif, which may also have occurred during the Late Eocene. This might explain the occurrence of the Einsdale facies, with its palaeosol, in the Ronse hills. To the north of this area, between Gent and Brussel, the Lede Formation is characterised by sedimentary breaks, accompanied by calcareous sediments, erosion and internal reworking of coarse-grained elements in times when the sea floor came under the influence of storm waves. As already mentioned, such storm deposits sometimes show a lateral extension of tens of kilometres in the region between Gent and Brussel.

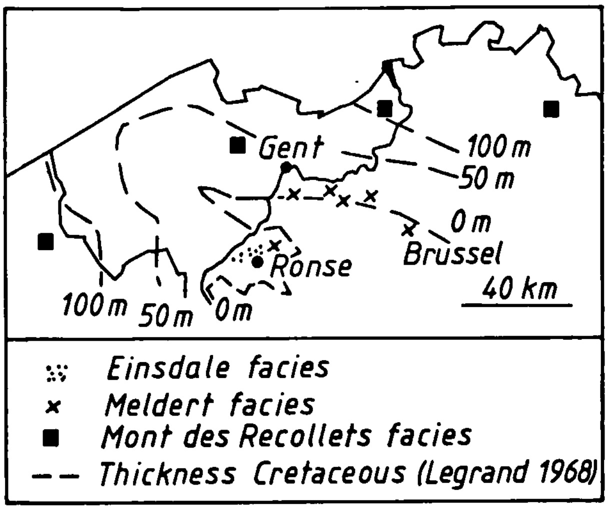

Fig. 14. Facies distribution of the Lede Formation in the Belgian Basin, compared with the thickness evolution of the Cretaceous (Legrand, 1968).

In boreholes in northern Belgium, the gravelly beds seem to be missing. Probably, the sea was too deep to allow storm waves to reach the sea floor. This increase in depth of the Ledian sea in northern Belgium was also mentioned by Kaasschieter (1961). The Lede Formation in the Ursel borehole and at Cassel belong to this facies belt as well. Although only a few observation points are available, the facies distribution of the Lede Formation appears to reflect the thickness pattern of the underlying Cretaceous, as mapped by Legrand (1968).

CONCLUSIONS

Three depositional facies (the Meldert, Mont des Récollets and Einsdale facies) are recognised within the Lede Formation. Their distribution is shown in Fig. 14, together with the thickness evolution of the underlying Cretaceous (data from Legrand, 1968). In the Meldert facies, which outcrops between Gent, Brussel and Ronse, the formation is characterised by a general fining-upward trend of the grain size distribution. The total amount of sand remains constant, but fractions coarser than 90 µm gradually disappear. Several internal erosion surfaces occur within the Lede Formation, often associated with sandy limestone layers. Such complexes of limestone and gravel may persist laterally over tens of kilometres and they show storm-generated sedimentary structures. Between each of the gravel beds, a fining-upward cycle is observed.

The Mont des Récollets facies, as found at Cassel, Ursel and in northern Belgium, resembles the Meldert facies, but gravelly intercalations are absent. Limestone layers mark lower siliciclastic sedimentation rates without erosion. This could indicate deposition in deeper water, under storm wave base. Often, the formation is thicker and contains more stone layers than does the Meldert facies.

The Einsdale facies, a coarse-grained facies with silicifications and possibly containing a palaeosol, was found near Ronse. In its type locality, sands of the Meldert facies pass gradually into the Einsdale facies and also occur above the latter, with a sharp contact between the two. The Einsdale facies was probably deposited under shallow nearshore conditions.

Oscillations of the Brabant Massif may have influenced the whole mechanism of cyclic sedimentation in the Lede Formation. Siliciclastic sedimentation was interrupted by phases of non-deposition during which the sand was enriched in authigenic calcareous material of biogenic origin. Immediately north of Ronse, between Gent and Brussel, the sea was shallow enough for the sea floor to be under the influence of storm waves during periods of the lowest sea level. Storm layers are encountered at the base of cycles. In northern Belgium and in the Cassel area, sedimentation took place in deeper water and phases of lower siliciclastic deposition are only marked by limestone layers, without erosional surfaces. Such conditions seem to have prevailed in the Cassel area, situated at the same latitude as Ronse, but in an area less affected by movements of the Brabant Massif.

ACKNOWLEDGEMENTS

We wish to extend our best thanks to Drs D. Nolf and E. Steurbaut for critical reading of an earlier draft of the manuscript.

REFERENCES

Baudet, J., 1941. Sur les gîtes et niveaux fossilifères éocènes de la région de Renaix. — Bull. Soc. belge Géol., 50: 86-91.

Breuck, W. de, B. Fobe, L. Lebbe, E. Steurbaut, E. van Dijck & K. Walraevens, 1989. De boringen van Ursel en Maldegem. Bijdrage tot de kennis van het Eoceen van noordwest België. — Belg. Geol. Dienst, Prof. Paper, 236: 98 pp.

Delattre, C., E. Meriaux & G. Waterlot, 1973. Région du Nord. Guides Géologiques Régionaux. Paris (Masson et Cie), 176 pp.

Dumont, A., 1851: Note sur la position de l'argile rupélienne et sur le synchronisme des formations tertiaires de la Belgique, de l'Angleterre et du nord de la France. — Bull. Acad. roy. Belgique, Cl. Sci., (1)18(2): 179-195.

Fobe, B., 1986. Petrografisch onderzoek van de coherente gesteenten van het Eoceen in Laag- en Midden-België. Gent (Ph.D. thesis, Rijksuniversiteit Gent), 353 pp. (unpubl.).

Fobe, B., 1988. De steenbanken van het Midden-Eoceen uit de boring van Kallo: lithologie en stratigrafische interpretatie. — Bull. Belg. Ver. Geol., 97: 25-28.

Fobe, B., 1989. Het Eoceen tussen Mol en Beringen. — Belg. Geol. Dienst, Prof. Paper, 239: 13 pp.

Geets, S., 1969. Bijdrage tot de sedimentologische kennis van het Paniseliaan. Gent (Ph.D. thesis, Rijksuniversiteit Gent), 216 pp. (unpubl.).

Geyter, G. de, 1980. Bijdrage tot de kennis van de lithostratigrafie en sedimentpetrologie van de Formatie van Landen in België. Gent (Ph.D. thesis, Rijksuniversiteit Gent), 204 pp. (unpubl.).

Gulinck, M., 1961. Le Lédien, le Bruxellien. *In*: 7ème Coll. Europ. Micropaléont., Guide d'excursions.

Halet, F., 1932. Un relèvement exceptionnel de l'Yprésien aux environs de Corbeek-Lo. — Bull. Soc. belge Géol., 42: 185-194.

Kaasschieter, J., 1961. Foraminifera of the Eocene in Belgium. —Verh. Kon. Belg. Inst. Natuurwet., 147: 271 pp.

Legrand, R., 1968. Le Massif de Brabant. — Mém. Expl. Carte géol. min. Belg., 9: 148 pp.

Leriche, M., 1912. L'Eocène des bassins parisien et belge. Livret-guide de la réunion extraordinaire de la Société géologique de France. — Bull. Soc. géol. France, (4)12: 692-807.

Leriche, M., 1921. Monographie géologique des collines de la Flandre française et de la province belge de la Flandre Occidentale. — Mém. Carte géol. France, Paris (Imprimerie nationale), 121 pp.

Leriche, M., 1926. Quelques observations sur la géologie de l'Entre-Escaut-et-Dendre, au nord des collines de Renaix (Pays de Sottegem). — Bull. Soc. belge Géol., 36: 129-139.

Leriche, M., 1937. Compte-rendu de la Session Extraordinaire de la Soc. belge de Géol et de la Soc. Géol. de Belgique dans le nord et l'est de l'Ile de France. — Bull. Soc. belge Géol., 47: 549-655.

Mehra, O., & M. Jackson, 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. — Clays and Clay Minerals, 7: 317-327.

Mourlon, M., 1873. La Géologie. *In*: Patria belgica, 1: 177-192.

Mourlon, M., 1880. Géologie de la Belgique, 1. Bruxelles (Hayez), 317 pp.

Mourlon, M., 1887. Sur une nouvelle interpretation de quelques dépôts tertiaires. — Bull. Acad. roy. Belgique, (3)14: 15-19.

Mourlon, M., 1888. Sur le Lédien de Lede, près d'Alost. — Ann. Soc. roy. Malacol. Belgique, 23: xix-xxiii.

Mourlon, M., 1889. Sur le Lédien des environs de Renaix. — Ann. Soc. roy. Malacol. Belgique, 24: 10-17.

Mourlon, M., 1910. Texte explicatif du levé géologique de la planchette d'Uccle., 133 pp.

Nolf, D., 1974. De Teleosteï-otolieten uit het Eoceen van het Belgisch Bekken. Reconstructie van de fauna en biostratigrafische toepassing. Gent (Ph.D. thesis, Rijksuniversiteit Gent), 173 pp. (unpubl.).

Nolf, D., & E. Steurbaut, 1990. Stratigraphie de l'Eocène en Flandre Occidentale et dans les régions limitrophes. — Bull. Inform. Géol. Bassin Paris, 27: 9-39.

Pomerol, C., 1961. Etude sédimentologique et micropaléontologique des sables bruxelliens et lédiens à Forest. — Bull. Soc. belge Géol., 70: 151-165.

Rutot, A., 1882. Résultats de nouvelles récherches dans l'Eocène supérieur en Belgique, 4: Résolution de la question du Tongrien et du Wemmelien. Création du système Asschien. —Ann. Soc. roy. Malacol. Belgique, 17: 181-185.

Rutot, A., & E. Vincent, 1878. Note sur l'absence du système Diestien aux environs de Bruxelles et sur les observations nouvelles rélatives au système Laekenien. — Ann. Soc. géol. Belg., 5: M 56-M 66.

Steurbaut, E., & D. Nolf, 1989. The stratotype of the Aalter sands (Eocene of NW Belgium): stratigraphy and calcareous nannoplankton. — Meded. Werkgr. Tert. Kwart. Geol., 26: 11-28.

Vincent, E., 1887. Sur quelques coupes visibles sur le territoire de la planchette de Saventhem. — Ann. Soc. roy. Malacol. Belgique, 22: 40-46.

Manuscript received 28 December 1991, revised version accepted 13 May 1992.