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NOTE CONCERNING THE ORIGIN OF SCHELDT ESTUARY BOTTOM SEDIMENTS (BELGIUM, THE NETHERLANDS)

BY

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(With 1 figure and 2 photographs)

ABSTRACT

The analyses of gravels, shells and foraminifera of bottom sediments in the Scheldt estuary reveal a correlation between these sediments and the substratum. This is particularly so for the foraminifera assemblages. The results indicate on the one hand an erosion of Tertiary and Quaternary deposits and, on the other hand, a prevailing downstream sediment transport between the river Rupel and Antwerp and an up- as a downstream sediment transport as well in the river Western-Scheldt.

RESUME

L'analyse des graviers, mollusques et foraminifères des sédiments du fond de l'estuaire de l'Escaut montre une correlation entre les sédiments récents et le substratum. Ceci est particulièrement le cas pour les foraminifères. Les résultats indiquent d'une part une érosion des dépôts Tertiaires et Quaternaires. D'autre part le transport des sédiments est orienté vers l'aval entre le Rupel et Anvers et vers l'aval ainsi bien que vers l'amont dans l'Escaut Occidental.

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INTRODUCTION

The Scheldt-estuary (Belgium, The Netherlands) sediments potentially derive from two sources : 1) The Scheldt river basin and 2) the North Sea. Former studies paid attention to the balance between both sources (DE GROOT, 1964, WOLLAST, 1972, PETERS and STERLING, 1976, WARTEL, 1977, SALOMONS *et al.*, 1981). In fact a third source must be considered, i.e. local erosion. Indeed the recent sediment layer in the river channel between the river Rupel and Antwerp is relatively thin and at many places even absent and thus Quaternary or Tertiary subbottom deposits can be eroded ((Wartel 1979, 1980). A clear distinction should also be made between three sediment populations i.e. gravels ($\geqslant$ 2 mm), sands (2-0.063 mm) and « fines » : silt and clay ($\leqslant$ 0.063 mm). They not only differ in transport mechanism but they can also differ in origin.

In this paper attention will be paid to the coarser populations (gravels, shells) and to the foraminifera assemblages (sand).

Their relation to underlying Quaternary or Tertiary deposits will be discussed.

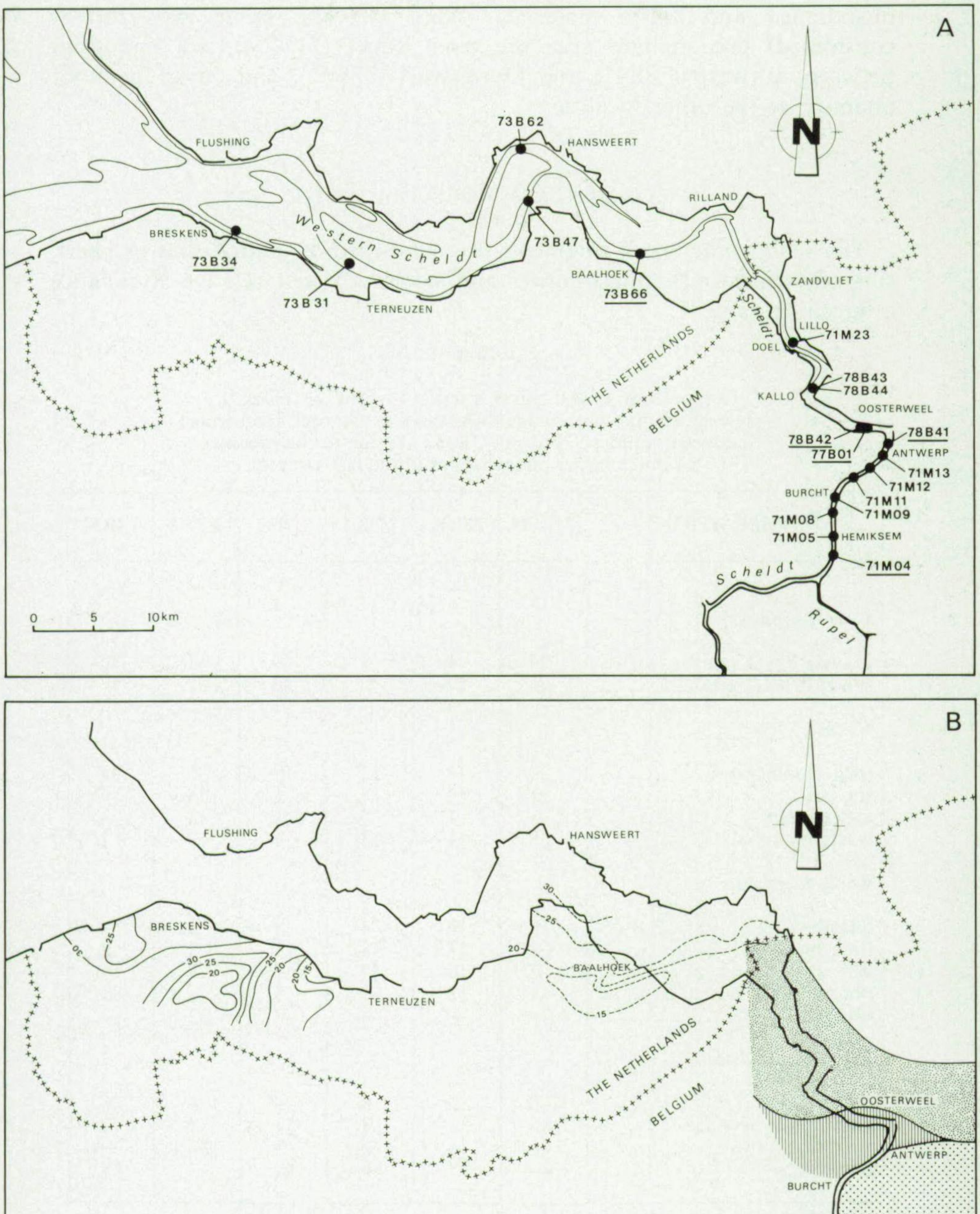
METHODS

Eighteen samples, taken with a « Shipek » bottom-sampler in the river channel during several sampling programs (1971-1978), were analysed. The gravels (found in 6 samples) were examined microscopically and, where mentioned, chemically (CHEM), by X-ray diffraction (XRD) or scanning electron microscopy (SEM) combined with semi-quantitative energy dispersive X-ray analysis (EDAX). Where possible (in 4 « gravel »-samples) the observed molluscs and fish remnants were also identified. The foraminifera (17 samples) were separated from the sand fraction by the CCL_4-flotation method.

GRAVELS AND SHELLS

Gravel and shell deposits were observed essentially at four places in the Scheldt estuary (figure 1) : near the river Rupel (71M04), near Oosterweel (78B42), near Baalhoek (73B66), near Breskens (73B34), and occasionally between Antwerp and Oosterweel (78B41 and 77B01). Former studies mentioned gravel deposits between Lillo and Zandvliet (LELOUP and KONIETZKO, 1956) and near Rilland (Antwerpse Zeediensten, unpublished data). These deposits have not been observed during this study.

Fig. 1. — The Scheldt estuary, location and sampling stations (gravel samples are underlined) (A) and geological outline map (B) (After VAN RUMMELEN, 1965 and LAGA, 1973).
N.B. : the belgian ordnance level is at − 2.40 m N. A. P.


A
N
FLUSHING
73 B 62
HANSWEERT
RILLAND
BRESKENS
Western Scheldt
73 B 47
73 B 34
73 B 31
TERNEUZEN
BAALHOEK
73 B 66
ZANDVLIET
Scheldt
LILLO
71 M 23
DOEL
THE NETHERLANDS
BELGIUM
78 B 43
78 B 44
KALLO
OOSTERWEEL
78 B 42
77 B 01
78 B 41
ANTWERP
71 M 13
71 M 12
BURCHT
71 M 11
71 M 09
71 M 08
71 M 05
HEMIKSEM
71 M 04
Scheldt
Rupel
0 5 10 km
B
N
FLUSHING
HANSWEERT
BRESKENS
TERNEUZEN
BAALHOEK
THE NETHERLANDS
BELGIUM
OOSTERWEEL
ANTWERP
BURCHT
HEMIKSEM
PLIOCENE
MIOCENE
OLIGOCENE
Lillo Formation
Berchem Formation
Boom Clay
Kattendijk Formation
Top of Boom Clay (meters below N.A.P)
Top of Sands of Merksem (meters below N.A.P)
0 5 10 km

The gravel deposits are composed of sedimentary rock fragments, shells, miscellanea and waste materials (table 1). The latter (not further considered) predominate near the river Rupel (71M04), are important between Antwerp (78B41) and Oosterweel (77B01), and occur in minor quantity at the other localities.

SEDIMENTARY ROCK FRAGMENTS

The sedimentary rock fragments are composed of quartz, flint or chert, silt- and sandstones, phosphorites and siderites. Their relative abundance is given in table 1.

TABLE 1

Composition of the gravel fraction (weight percentages).
The substantial percentage differences of the rock fragments between samples 77B01 and 78B42 are due to the presence of much larger phosphorites in the last sample.

COMPOSITION	71M04	78B41	77B01	78B42	73B66	73B34
Gravel-sand ratio						
gravels (> 2 mm)	24	1	1	80	51	83
sand (0.063-2 mm)	76	99	99	20	49	17
Gravels						
rock fragments	20	14	12	19	35	49
shells	11	74	75	76	58	50
miscellanea	—	1	—	1	2	—
waste material	69	11	13	4	5	1
Rock fragments						
quartz	19	30	4	8	6	1
flint or chert	74	37	48	13	3	2
silt- and sandstones	7	16	47	31	58	14
phosphorites	—	17	1	8	1	83
siderites	—	—	—	—	32	—
Silt- and sandstones						
quartz —	100	—	8	—	6	26
glauconite —	—	51	8	51	8	1
jarosite —	—	—	—	—	86	—
limonite —	—	49	84	49	—	73

a) Q u a r t z : Well rounded to rounded; 2 to 4 mm and exceptionally 10 mm in diameter; transparent to translucent, white, milky-yellow or pink; inclusions (yellow, green or black) are common and often abundant.

b) Flint or chert : (No attempt was made to distinguish) Subangular to angular with rounded edges; 2 to 4 mm, exceptionally 20 mm, in diameter; light-brown to almost black on fresh facture planes, otherwise covered with a white to grey (also green in sample 78B41) weathered crust.

c) Silt- and sandstones : Loose rounded to subangular aggregates; 2 to 4 mm and, in samples 78B42 and 73B34 up to 10 mm, in diameter; composed of silt- to fine sand-sized detrital quartz grains. Some silt- and sandstones contain an appreciable amount of glauconite (glauconite silt- and sandstones in table 1). The jarosite silt- and sandstones are composed of irregular loose aggregates of fine sand- to silt-sized particles (mainly quartz and Ca-carbonate) with conspicuous white, yellow or orange specks outside but pitch-black inside. Minerals of the jarosite-group and gypsum are identified (XRD, VAN TASSEL, R., private communication, 1980) in the yellow and orange specks. Semi-quantitative EDAX-analyses indicate that all iron-bearing particles in the yellow or orange specks show weight percentages for K: 8-9 %, Fe : 52-57 %; S : 35-40 %, comparable to the calculated content in jarosite (K : 12 %, Fe : 50 %, S : 38 %).

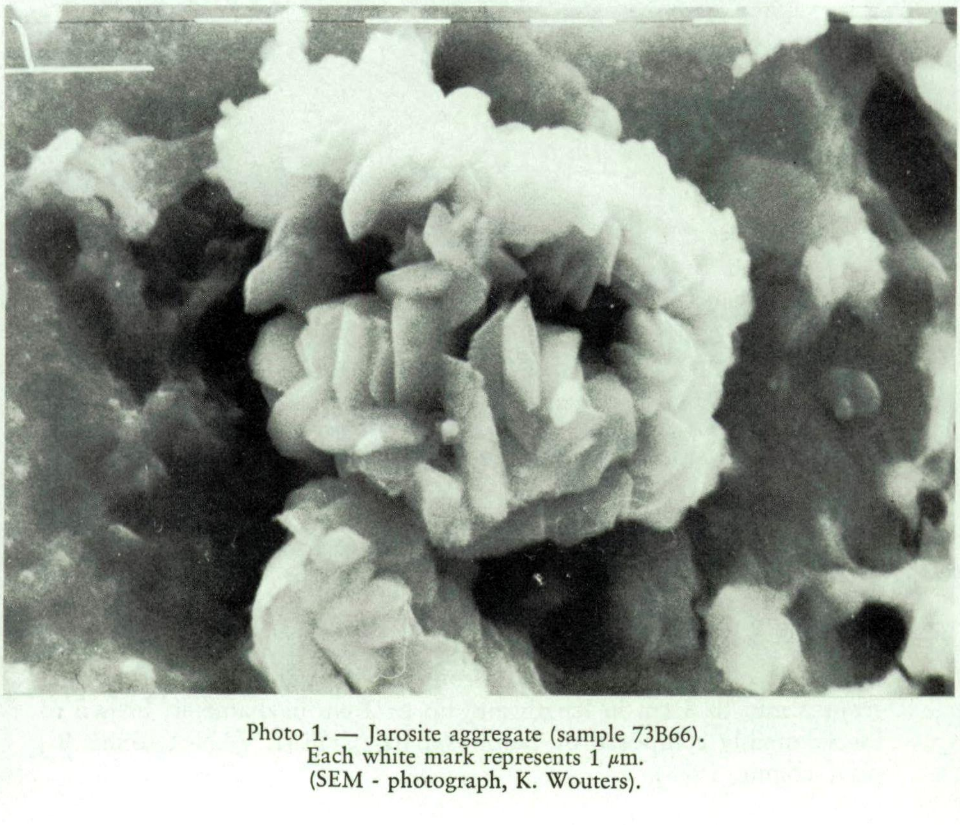


Photo 1. — Jarosite aggregate (sample 73B66).
Each white mark represents 1 µm.
(SEM - photograph, K. Wouters).

The jarosite occurs as clay-sized, very platy, angular particles, either isolated or aggregated (photo 1). Well-crystallized gypsum, up to 60 μm in length, sparsely occurs on the surface of these gravels, but does not seem to be restricted to the yellow or orange specks nor to a given locality. At other localities also (Kallo) gypsum has been observed. Inside the jarosite silt- and sandstones numerous small irregular clay-sized spheres of pyrite (photo 2, insert) (determined by XRD and semi-quantitative EDAX analyses) occur. Silt-sized sulphur particles (showing only sulphur with EDAX) have also been observed (photo 2). Numerous silt- and sandstones (78B41, 77B01, 78B42 and 73B34), mainly light yellow to yellow brown coloured (limonite silt- and sandstones, table 1) occur. They constitute a very heterogeneous group and are further not considered.

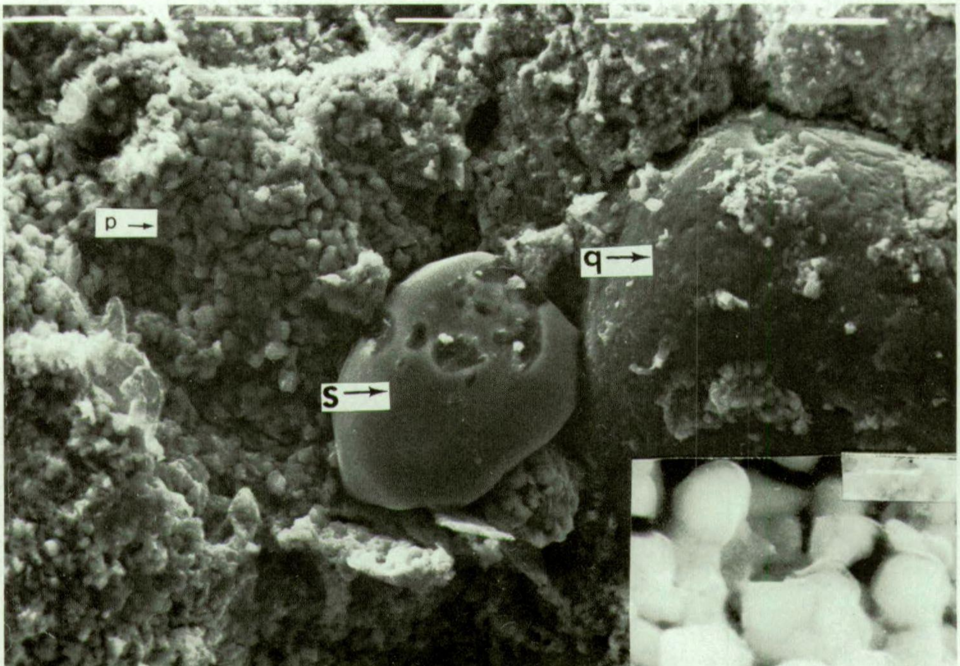


Photo 2. — Quartz (q), sulphur (s) and pyrite (p) (sample 73B66).
Each white mark represents 10 μ m.
Insert shows magnified pyrite spherules (white mark is 1 μ m).
(SEM - photograph, K. Wouters).

d) P h o s p h o r i t e s : Very well-rounded elongated gravels; ranging from 2 mm to 8 cm in length and up to 2 cm in diameter; brown to black; mainly composed of Ca-phosphate (CHEM, VAN TASSEL R., priv. comm. 1978).

e) S i d e r i t e s : Very fine to medium sand-sized, rounded, platy, brown aggregates; mainly composed of siderite (XRD, VAN TASSEL R., priv. comm. 1980).

Before passing on to the discussion of the gravel analyses the reader should consider that, consequently to the relatively small sample sizes and the large differences in gravel-sand ratio (table 1), the given weight percentages will only approximate the composition of the gravel deposit.

Nevertheless, as will be seen, four different gravel populations can be discerned, each occurring at a given locality and related to subjacent Quaternary or Tertiary deposits.

The gravel population of sample 71M04 consists of quartz and flint with some quartz sandstones. PAEPE and VAN HOORNE (1967) and BEECKMANS and VERBRUGGEN (1974) describe a Quaternary basal gravel layer, composed of quartz and flint, occurring on top of the Boom clay between the river Rupel and Burcht.

Furthermore subbottom (WARTEL, 1980) and seismic research (HELDENS, 1979) showed that, between the river Rupel and Antwerp, the Boom Clay reaches the Scheldt bottom and is eroded by it. Thus it seems obvious that the quartz and flint gravels of sample 71M04 are a lag deposit, derived from this Quaternary basal gravel layer.

In the Antwerp-Oosterweel area (77B01, 78B41, 78B42) quartz and flint occur but also glauconite silt- and sandstones and phosphorites.

The glauconite silt- and sandstones are without any doubt eroded from glauconite-rich Miocene (Berchem Formation) (*) deposits (up to 60 % glauconite in the total sediment (BASTIN, 1966)). In this context it is worth noting that also in samples 71M13, 78B41, 77B01 and 78B42 an appreciable amount of glauconite is found (13 to 20 % in the 125-250 μm fraction) in comparison with samples from the upstream (7 to 11 % in the 125-250 μm fraction) and downstream (1 to 12 % in the 125-250 μm fraction) parts of the estuary. The phosphorites are probably derived from Pliocene (Kattendijk Formation) gravel layers (XRD, VAN TASSEL R., priv. comm., 1979; LAGA, 1972). The occurrence of Miocene and Pliocene deposits in this area has been shown by subbottom profiling (WARTEL, 1980). Quartz and flint are probably derived from the Quaternary basal gravel layer, eroded by the river Scheldt in the Oosterweel area as well as upstream of it (WARTEL 1978, 1980).

In the neighbourhood of Baalhoek (73B66) siderites and jarosite silt- and sandstones occur. Siderites occur in some tubular concretions (Tasselia Ordam, de HEINZELIN, 1964) which from important layers in the Sands of Merksem (Lillo Formation) (VAN TASSEL, 1964) and were also observed on the tidal flats near Lillo (LELOUP and KONIETZKO, 1956) indicating erosion of them in this area. However, in the Baalhoek area the top of the Sands of Merksem occurs at − 22.5 to − 27.5 m below

(*) The lithostratigraphical units mentioned are these described in DE MEUTER and LAGA, 1977.

the Belgian ordnance level (VAN RUMMELEN, 1965) (Fig. 1B) and thus erosion of it can only be considered in the deeper parts of the channel (up to − 30 m). The origin of the jarositic-minerals is problematical. Jarositic-minerals have been observed by VAN TASSEL (1956) in several outcrops of the Kempen Clay (Quaternary) as a weathering product of pyrite. Also the gypsum crystals found in the jarosite gravels can be seen as a weathering product of pyrite in the presence of Ca-carbonate. It is not clear however whether this weathering has taken place in the river Western-Scheldt or elsewhere. Between Baalhoek and Breskens no gravel deposits have been found in the river channel (*) but in the Breskens area a gravel deposit, on top of a clay bed, occurs in a tidal gully near the left bank (73B34). According to the geological map of the Netherlands (VAN RUMMELEN, 1965) this clay bed can be identified as the Boom Clay (Fig. 1B). The gravels contain an appreciable amount of phosphorites. However, compared with samples 78B41, 77B01 and 78B42, glauconite silt- and sandstones are almost absent, which agrees with the absence of lower Miocene deposits in the substratum. According to VAN RUMMELEN (1965) the Boom Clay is here overlain with a relatively thin layer of Upper Miocene (Berchem Formation) deposits on top of which are Pliocene (Kattendijk Formation) deposits.

Summarizing the results of the gravel analyses a local origin for most gravels can be postulated. No evidence for a considerable horizontal transport has been found.

SHELLS AND MISCELLANEA

The shell fraction consists mainly of molluscs (most broken and only in four samples identifiable). The ratio of shells to rock fragments is roughly 1 : 2 near the river Rupel (71M04), 5 :1 in the Antwerp-Oosterweel area (78B41, 77B01, 78B42) and 1 : 1 in the Western-Sheldt (73B66, 73B34).

A list of identifiable molluscs is given in table 2. Table 3 summarizes their probable origin. As will be seen these data supplement the assumptions made from the gravel analysis. Also a new assumption regarding sample 71M04, taken near the river Rupel, can be made. At least half, and probably most, of the molluscs in this sample differ in origin from the accompanying gravels.

Furthermore indications as « fresh water », « stagnant or slowly running water » are irrelevant to the river Scheldt in this area. These molluscs thus probably derive from the upstream (or lateral) part of the Scheldt river basin. The molluscs found in the Oosterweel area belong to the Kattendijk and Lillo Formations. No distinction can be made with the

(*) In the river Western-Scheldt only soft, flat clay-balls (up to 20 mm in diameter and 5 mm in thickness) occur at the bottom of the channel between Terneuzen and Hansweert (FAAS and WARTEL, 1973).

TABLE 2

Identifiable molluscs with their probable origin.

Sample	Species	Origin
71M04	*Planorbis leucostoma* (MILL.)	Fresh stagnant water - recent
	Valvata piscinalis (MÜLL.)	Fresh stagnant or slowly running water - recent
	Dreissema polymorpha (PALL).	Fresh stagnant water and rivers - recent
	Pisidium amnicum (MÜLL.)	Fresh stagnant water and rivers - recent
	Sphaerium solidum (NORM.)	Fresh water, rivers - recent
	Sphaerium vivicola (LAM.)	Fresh water, rivers - recent
	Physa acuta (DRAP.)	Fresh or brackish, stagnant water - recent
	Lymnaea peregra (MÜLL.)	Fresh or brackish water, stagnant or running, also out of water - recent
	Lymnaea palustris (MÜLL.)	Fresh or bracking water, also out of water - recent
	Bithynia tentaculata (L.)	Fresh or brackish, stagnant or slowly running water - recent
	Theodoxus fluviatilis (L.)	Fresh or brackish, running water - recent
	Remnants of Unio sp.	
78B42	*Astarte basteroti* (JONK.)	Lillo formation (Upper Pliocene)
	Astarte obliquata obliquata (SOW.)	Lillo formation (Upper Pliocene)
	Lucinoma borealis (L.)	Lillo formation (Upper Pliocene)
	Cyclocardia chamaeformis (SOW.)	Lillo formation (Upper Pliocene)
	Lyropecten opercularis (L.)	Lillo formation (Upper Pliocene)
	Angulus benedeni (N. et W.)	Lillo formation (Upper Pliocene)
	Corbula gibba gibba (OLIVI)	Lillo formation (Upper Pliocene)
	Turritella sp.	Lillo formation (Upper Pliocene)
	Astarte omalii (JONK.)	Kattendijk formation (Lower Pliocene)
	Astarte obliquata burtinea (JONK.)	Kattendijk formation (Lower Pliocene)
73B66	*Littorina littorea* (L.)	Brackish and salt water - recent
	Hydrobio sp.	Brackish and salt water - recent
	Cerastoderma edule (L.)	Brackish and salt water - recent
	Hinia reticulata (L.)	Lillo formation (Upper Pliocene)
	Neptunia contraria (L.)	Lillo formation (Upper Pliocene)
	Turritella sp.	Lillo formation (Upper Pliocene)
	Corbula gibba gibba (OLIVI)	Lillo formation (Upper Pliocene)
	Laevicardium decorticatum (W.)	Lillo formation (Upper Pliocene)
	Astarte basteroti (JONK.)	Lillo formation (Upper Pliocene)
	Ostrea edulis edulis (L.)	Lillo formation (Upper Pliocene)
	Pygocardium rustica (SOW.)	Lillo formation (Upper Pliocene)
	Cyclocardium chamaeformis (SOW.)	Lillo formation (Upper Pliocene)
	Artica islandica (L.)	Lillo formation (Upper Pliocene)
	Mytilus edulis (L.)	Lillo formation (Upper Pliocene)
	Dosinia exoleta (L.)	Lillo formation (Upper Pliocene)
73B34	*Ostrea edulis edulis* (L.)	Brackish and salt water - recent
	Mytilus edulis (L.)	Brackish and salt water - recent
	Cerastoderma edule (L.)	Brackish and salt water - recent

TABLE 3

Summary of the origin of identifiable molluscs listed in table 2.

(+++ = 100 %, ++ = > 50 %, + = < 50 %, — = absent).

Sample	Tertiary			Quaternary	
	Miocene	Pliocene			
	Berchem formation	Kattendijk formation	Lillo formation	Fluviatile	Marine
71M04	+	+	—	++	—
78B42	—	+	++	—	—
73B66	—	—	++	—	+
73B34	—	—	—	—	+++

Quaternary basal gravel layer, which holds the same species. Here a similar origin as the gravels can be postulated. The same reasoning holds for sample 73B66 (Baalhoek). Most of the molluscs in this sample belong to the Lillo Formation. Near Breskens (73B34) no Tertiary molluscs were observed (all species are recent and marine) notwithstanding the phosphorites (Kattendijk Formation ?) occuring in this sample.

The miscellanea (table 1) comprise fish teeth, coprolite-like and tubular concretions. In two samples fish remnants were found. For sample 78B42 : a crown of a tooth with part of the root (Carcharinus sp., Mio-Pliocene), two parts of a theeth (Myliobatis sp., Quaternary basal gravel), part of a dorsal vertebra (Teleostei, unknown origin) and for sample 73B66 : part of a tooth (Isorodei, Lillo Formation) (all determinations by Herman J., 1980). The origin of these fish remnants corroborates the previous results. The coprolite-like concretions (73B66), approximately 10 mm long and 1 to 2 mm in diameter, are pointed at both ends and composed of silt- and clay-sized particles. They are of unknown origin. The tubular concretions are 1) in sample 78B41 : 7 mm long, 0,5 mm in diameter, grey coloured, composed of pyrite (XRD, VAN TASSEL R., priv. comm., 1980), similar pyrite concretions are known from the Boom Clay (VANDENBERGHE, 1978) and 2) in sample 73B66 : 1 to 2 mm in diameter, yellowish-brown to brown, composed of silt-sized particles in a brown coloured matrix of siderite (XRD, VAN TASSEL R., priv. comm., 1980), probably eroded from the Sands of Merksem (Lillo Formation). Summarizing it can be said that, supplementary to the results of the gravel analyses, also the molluscs (except for sample 71M04), fish remnants and tubular concretions have a local origin.

FORAMINIFERA

At least an inportant part of the gravel fraction (rock fragments, shells) constitutes apparently a lag deposit, inherited from eroded Tertiary or Quaternary deposits. In order to ascertain to what extent this observation is also valuable for the accompanying sand fraction, the foraminifera from the gravel samples and, for comparative purposes, also from 12 sand samples, taken at intermediate positions between the gravel samples (Fig. 1A), were analysed. Reference could be made to detailed studies of the benthonic foraminifera from the Miocene, Pliocene and Pleistocene deposits of northern Belgium (LAGA, 1972 and DE MEUTER, 1974). Comparison was made easy inasmuch as the foraminifera of most samples did not show traces of alteration.

Apparently they were not subjected to a long distance transport.

From table 4 and the geological outline-map (Fig. 1B) following deductions can be made :

1) Souh of Hemiksem (71M04) only Paleogene nummulites occur, clearly indicating a downstream transport.
2) Between Hemiksen and Antwerp (71M05 to 78B41) Kattendijk Formation — and, to a less degree, Berchem Formation foraminifera occur in the bottom sediments. It can be seen from the geological outline-map (Fig. 1B) that both formations occur in the substratum and thus the hypothesis of a local origin of these bottom sediments is very acceptable.
3) Between Oosterweel and Hansweert (78B42 to 73B47) foraminifera from the Lillo Formation predominate in accordance with the substratum. Foraminifera from the Kattendijk formation decrease in number between Oosterweel and Kallo (78B43, 78B44) indicating a prevailing downstream transport.
4) Between Hansweert and Terneuzen (73B62 to 73B31) foraminifera from the Lillo Formation decrease and these from the Kattendijk Formation increase. This is understandable when considering the geological substratum since the top of the Kattendijk Formation occurs westward of Terneuzen at depths erodible by the river, but dipping eastward, it lies too deep near Hansweert to be erodible (VAN RUMMELEN, 1965). The upstream decreasing amount of Kattendijk Formation foraminifera is an indication for upstream sediment transport. However the downstream amount of foraminifera from the Lillo Formation indicates also a downstream sediment transport. The overall image is that of mixing by tidal activity.
5) Near Breskens (73B34) only recent foraminifera occur, and no correlation with the substratum can be made.

TABLE 4

Summary of the origin of foraminifera assemblages.
(+++ = 100 %, ++ = > 50 %, + = < 50 %, — = absent).

Sample	Paleogene	Tertiary			Quaternary
		Miocene	Pliocene		
		Berchem formation	Kattendijk formation	Lillo formation	
71M04	+++	—	—	—	—
71M05	—	+	++	—	—
71M08	—	—	+++	—	—
71M09	—	+	++	—	—
71M11	—	—	+++	—	—
71M12	—	++	+	—	—
71M13	—	++	+	—	—
78B41	—	+	++	—	—
78B42	—	—	++	+	—
78B43	—	—	+	++	—
78B44	—	—	+	++	—
71M23	—	—	—	+++	—
73B66	—	—	—	+++	+
73B62	—	—	+	++	+
73B47	—	—	+	++	+
73B31	—	—	++	+	+
73B34	—	—	—	—	+++

DISCUSSION

The foregoing analyses reveal new evidences on the origin of the gravel and sand fractions of recent Scheldt estuary bottom sediments. They also corroborate previously observed erosion of Quaternary and Tertiary formations in the river channel (WARTEL, 1980). It appears from these analyses that the gravels and most shells are lag deposits, showing no evidence for a horizontal sediment transport. The foraminifera assemblages also refer to a local origin. Hence it can be assumed that at least an important part of the recent sand population consists of reworked subbottom deposits. Horizontal transport of the sand fraction, as far as it can be deduced from the foraminifera analyses, is limited and has a prevailing downstream component between the river Rupel and Kallo and a down- as upstream component as well in the river Western-Scheldt. The question whether recent North Sea sands are transported landinward can not be answered on the hand of the analyses discussed in this paper. However if such a supply exists than the analyses suggest that it will be significant only in the lower part of the river Western-Scheldt (e.g. up to Hansweert) and will decrease towards Zandvliet.

SALOMONS et al. (1981), in a study of heavy metals in the Scheldt estuary, observed in the suspended sediments of the Antwerp-Zandvliet area higher concentrations for Fe and P than one would deduce from a theoretical mixing curve for marine and fluvial sediments. In the same area however phosphorites and siderite gravels occur on the channel bottom and a possible correlation with the high Fe and P concentrations must be considered.

Finally it should be noted that the assumption of estuarine erosion and reworking of older sediments as a source for recent bottom sediments is not limited to the Scheldt estuary. COLQUHOUN et al. (1974) arrived at a similar conclusion for the coastal plain estuaries of the Atlantic coast of North America.

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