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Grain size-, facies- and sequence analysis of West Belgian Eocene continental shelf deposits

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With 14 figures and 2 tables in the text

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Abstract: Grain size trends and sedimentary structures of Eocene continental shelf deposits from offshore and onshore drillings in West Belgium were combined for reconstruction of depositional environments.

The VAIL-model for siliciclastic sedimentation on shelf margins allows systems tracts identification on basis of grain size signals. The (put into revision) Eocene lithostratigraphy could therefore be transferred into sequence stratigraphy.

Sediment genetic interpretation of sedimentary structures and grain size trends, together with sediment supply indications, suggest a Pre-Rhine-Meuse-Scheldt delta high on the shelf as depositional system.

Key words: Korngrößentrend, Faziesanalyse, Sequenzstratigraphie, Kontinentalschelfablagerungen, Eozän, Westbelgien.

Kurzfassung: Trends der Korngrößenverteilung und das Sedimentgefüge von eozänen Kontinentalschelfablagerungen aus "offshore"- und "onshore"-Bohrungen in Westbelgien werden kombiniert, um das Ablagerungsmilieu zu rekonstruieren.

Das VAIL-Modell für die siliziklastische Sedimentation am Schelfrand dient zur Identifizierung von Sedimentgenerationen aufgrund ihres Korngrößensignals. Dadurch ist es möglich, die (geänderte) Eozän-Lithostratigraphie in die Sequenzstratigraphie zu übersetzen.

Sedimentgenetische Interpretationen von Sedimentgefügen und Korngrößenverteilungen, zusammen mit Indikatoren der Sedimentherkunft, lassen auf ein hoch am Schelf gelegenes Prä-Rhein-Maas-Schelde-Delta als Ablagerungssystem schließen.

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Purpose

Grain size analysis - especially grain size trends - is a powerful tool in facies analysis, and thus in sequence stratigraphy. When no sediment structures can be observed, nor paleoenvironmental control can be provided by lack of fossils, it is the only tool available for sediment description and for depositional environment reconstruction, leading to intra-basinal correlation.

Eocene stratigraphy

Belgian stratigraphy was already well known at the end of the 19th century (MOURLON 1888, RUTOT 1882, 1883). Ypresian and Rupelian stratotypes e. g. were chosen in Belgian type localities. The stratigraphical column of the geological map (1900) underwent only minor changes in the Stratigraphical Register (1929-1932), inspired by LERICHE (1922), and is under revision now, according to the rules of the International Subcommission on Lithostratigraphy (Ed. HEDBERG 1970) (Geological Congress of Montreal, Canada).

The Paleogene in Belgium was revised by a subcommission of the Belgian Stratigraphical Commission. Their proposal (eds. MARECHAL & LAGA 1988) is based on mappable units with well defined boundaries and homogeneous characteristics within a well known areal extent. Table 1 summarizes the present state of the art for the Paleogene in West Belgium.

The basal Landen Group is mainly a sandy to clayey unit, with a marine (lower) and a continental (upper) depositional environment. The Ieper Group is mainly a marine clayey deposit of about 100 m thickness, with a sandy top, followed by the sandy Zenne Group deposits. A marine clayey sedimentation with sandy intercalations is again installed with the deposition of the Kallo Formation (Fm) (or Maldegem Group), gradually passing into a sandy depositional environment in the Tongeren Group, with a marine basal part and a continental top part, well developed in East Belgium, and a mainly sandy sedimentation (Zelzate Fm) in West Belgium. The Paleogene ends with the deposition of the marine clayey Rupel Group sediments. The Kortrijk and Tielt Fms correspond with the Ypres clay of old nomenclature, the Kallo Fm with the Barton clay. But most of the new lithostratigraphical units kept their old name.

Lower to Lower-Middle Eocene deposits

On basis of 16,000 km seismic lines shot in the southern bight of the North Sea by the RCMG Seismostratigraphy Unit (DE BATIST 1989, HENRIET et al. 1989), four wells have been drilled by the Belgian Geological Survey in front of the Belgian coast, which form a nearly complete composite section in the Eocene deposits (Fig. 1).

Descriptions (lithology, sediment structures), analyses (grain size, organic matter, $CaCO_3$ content) and interpretation are completed for the SEWB and SWB wells.

Table 1. Paleogene lithostratigraphy in West Belgium (slightly modified after MARECHAL & LAGA 1988).
Tab. 1. Paläogene Lithostratigraphie in Westbelgien (modifiziert nach MARECHAL & LAGA 1988).

PALEOGENE LITHOSTRATIGRAPHY

GROUPS	FORMATIONS		MEMBERS		
(VOORT)	VOORT		Veldhoven		
RUPEL (M.OLIGOCENE)	EIGENBILZEN		Belsele-Waas		
	BOOM		Putte Terhagen		
	BILZEN		Kerniel Kleine Spouwen Berg		
TONGEREN (E.OLIGOCENE)	ZELZATE	BORGLOON	Ruisbroek	Kerkom Boutersem	Oude Biezen Henis
		S.H.HERN	Watervliet Bassevelde	Neerrepen Grimmertingen	
(MALDEGEM) (L.EOCENE)	KALLO		Onderdijke Buisputten Zomergem Onderdale Ursel Asse Wemmel		
ZENNE (M.EOCENE)	LEDE				
	BRUSSEL		Chaumont-Gistoux Neerijse	Diegem	Bois de la Houssière Archennes
	KNESSELARE		Aalter Oedelem Beernem		
IEPER (E.EOCENE)	GENT		Vlierzele Pittem Merelbeke		
	TIELT		Egem Kortemark		
	KORTRIJK		Aalbeke Moen Saint-Maur Mont-Héribu		
LANDEN (L.PALEOCENE)	TIENEN		Knokke Erquelinnes		Loksbergen Dormaal
	HANNUT		Grandglise		
			Chercq	Halen Waterschei	Lincent
	BERTAIMONT	HEERS			Gelinden Orp
HAINE-HASPENGOUW (PALEOCENE-CRETACEOUS)	HAININ	OPGLABBEEK			Eisden Opoeteren Maasmechelen
	MONS				
	CIPLY	HOUTHEM			

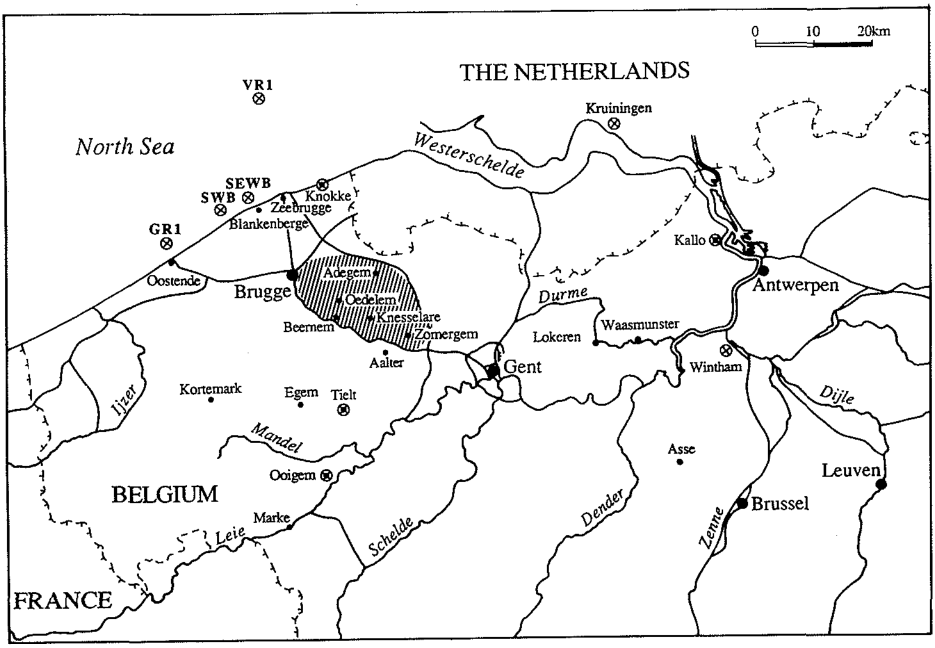


Fig. 1. Study area with location of discussed wells (⊙) and outcrop area (hatched).
Abb. 1. Lage des Arbeitsgebiets mit Angaben zur Position der im Text erwähnten Bohrungen (⊙) und der Aufschlußzone (gestrichelt).

In the SWB well (coordinates: 51°18'79" N; 3°03'24" E) (Fig. 2), 13 subunits can be identified:

58.00 to 51.75 m: (subunits 1-2)	grey-green clay, lenticularly laminated, with sideritized sand laminae; towards the top, homogeneous grey clay with bioturbations, topped by a sedimentation hiatus. (Top of Aalbeke Member).
51.75 to 44.00 m: (subunit 3)	grey-green silty clay, with thin burrows, sharply bounded by a 20 cm thick, parallel laminated sand layer; thinner sand layers bioturbated; at the base sharp contact with underlaying unit with cm-thick burrows. (Kortemark Member).
44.00 to 34.81 m: (subunits 4-5)	grey-green glauconiferous, nearly homogeneous fine sand with sporadically mm-thin clay laminae; at the base hummocky cross stratification. Alternation of sharply bounded horizontally laminated grey-green fine sand with strongly bioturbated grey-green clayey fine sand with a patchy texture. (Egem Member).
34.81 to 23.70 m: (subunit 6)	grey-green lenticular clay, with thin and dispersed sand laminae; gradual transition from underlaying unit;

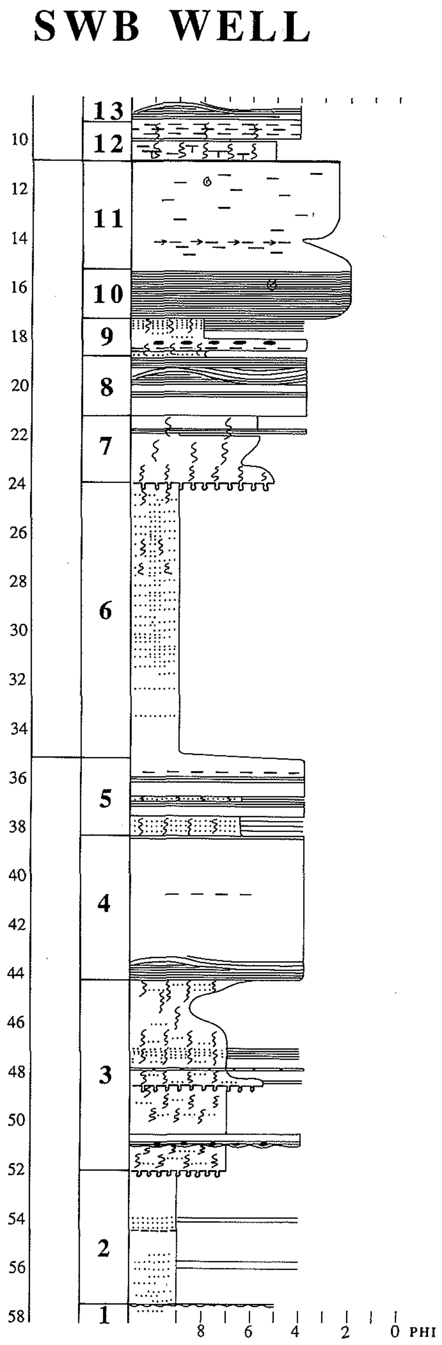


Fig. 2. SWB well litholog.

Abb. 2. SWB Bohrung Litholog.

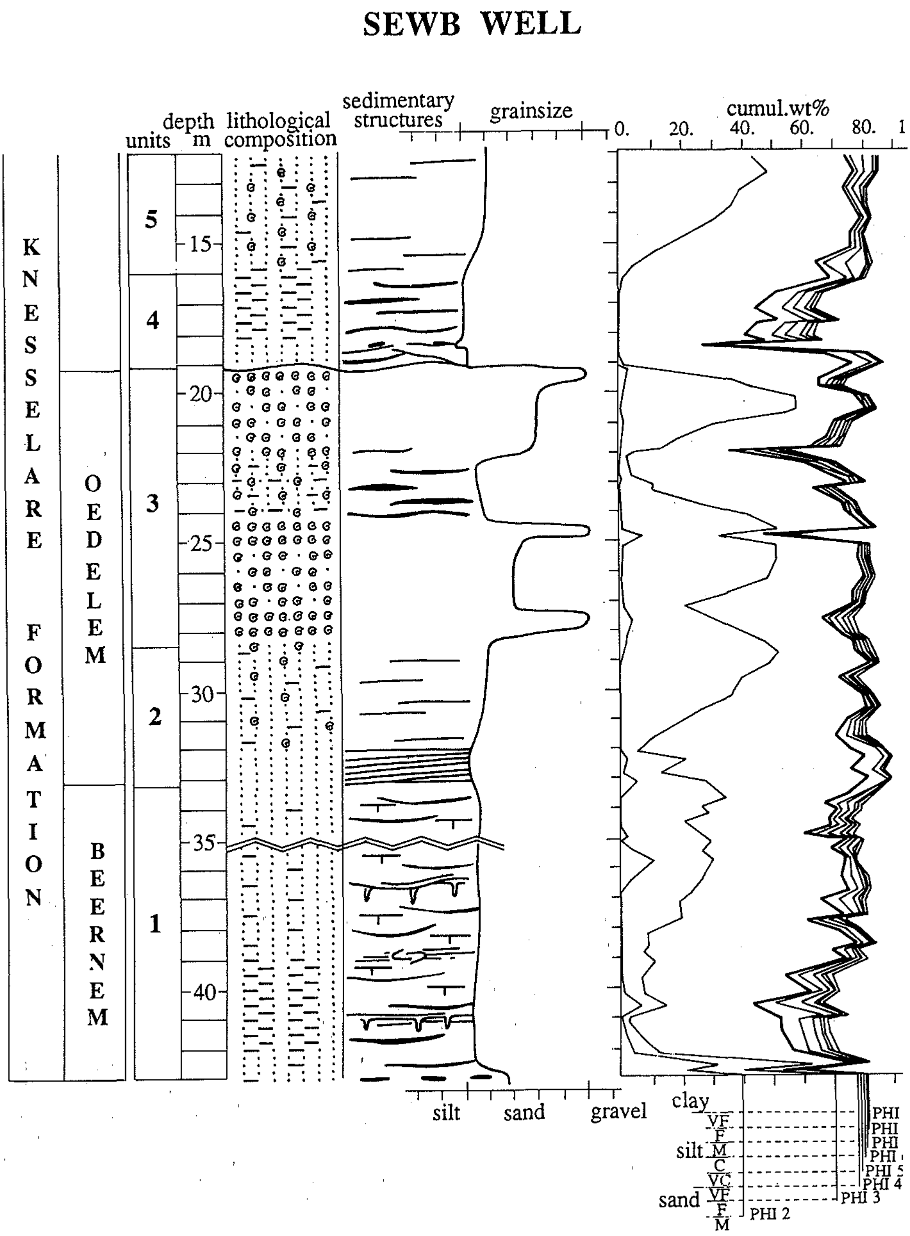


Fig. 3. SEWB well litho- and granulolog.

Abb. 3. SEWB Bohrung Litho- und Granulolog.

	at the top grey-green silty clay; big horizontal and vertical burrows filled with fine sand from overlaying unit with sharp contact; homogeneously bioturbated matrix. (Merelbeke Member).
23.70 to 17.00 m: (subunits 7-8-9)	grey-green clayey fine sand with intense bioturbation diminishing towards the top; followed by a green glauconiferous fine sand with slightly inclined parallel lamination; topped by a grey-green lenticular clay with cm-thick parallel sand laminae. (Pittem Member).
17.00 to 10.59 m: (subunits 10-11)	green glauconiferous fine to medium fine sand; slightly inclined parallel laminated with alternating heavy minerals and shell grit concentrations; sharp basal contact; towards the top more homogeneous; between 13.5 and 14.5 m homogeneous brown clayey matrix, wood fragments and lignite lenses (pedogenesis?); separation from unit 9 by mm-thin organic-rich layer. (Vlierzele Member).
10.59 to 8.00 m: (subunits 12-13)	grey-green glauconiferous fine sand with clay laminae; locally cemented; at the base somewhat coarser, more cemented; bioturbated coarse interlayered bedding grading upwards into a rhythmic interlayered bedding with decreasing bioturbation; at the top mainly parallel laminated fine sand, not bioturbated and without clay laminae. (Base of Beernem Member).

In the SEWB well (coordinates: 51°19'89" N; 3°07'25" E) (Fig. 3) 5 subunits can be identified:

43.00 to 33.1 m: (subunit 1)	at the base, silty medium sand, highly bioturbated with clay clasts; grading upwards into a glauconiferous clayey fine sand, locally weakly to moderately cemented, with coarse interlayered bedding, displaying a varying degree of bioturbation with vertical burrows at reactivation surfaces (Fig. 4). Sedimentgenetic interpretation: at the base, deposition in subtidal gullies, with a transition towards a mainly mixed intertidal flat sedimentation at the top. (Beernem Member).
33.1 to 28.5 m: (subunit 2)	glauconiferous fine sand, with subhorizontal stratification near the base, poorly bioturbated; grading upwards into a bioturbated fine sand, with mm-thick clay lenses and fossil debris (Fig. 5); gradual transition to the overlaying unit. Submarine facies of a coastal barrier: the laminated sand is deposited in the shallow parts, the more clayey facies in the deeper water. (Base of Oedelem Member).
28.5 to 19.2 m: (subunit 3)	mainly glauconiferous, highly fossiliferous clayey fine sand and shell beds (Fig. 6); near the base, occurrence of large specimens of *Venericardium planicosta;* central zone with less shells but intensive clay lamination masked by strong bioturbation. Reworking of shell material from storm deposits in a lagoonal environment. (Oedelem Member).

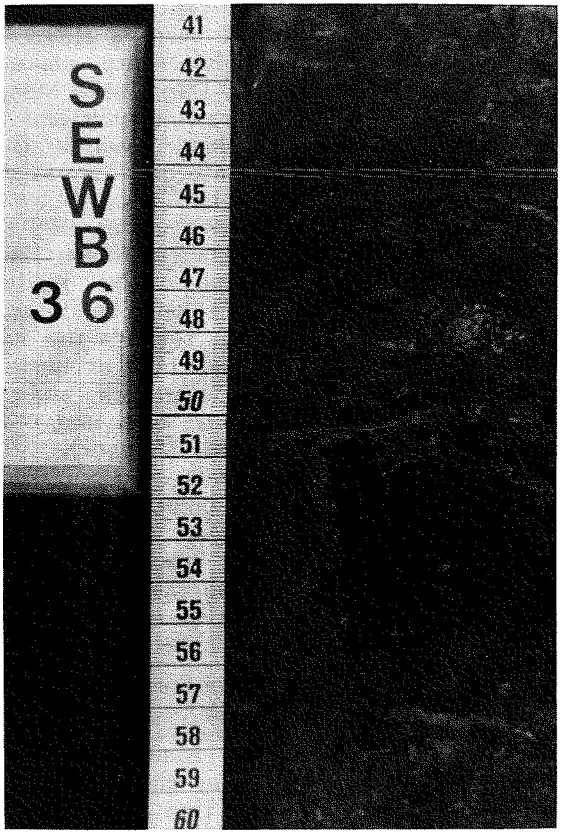


Fig. 4. Vertical burrows on reactivation surfaces and a varying degree of bioturbation are caused by an alternation of periods of slack water with periods of current activity. Periods of higher sedimentation rates preserved sedimentary structures otherwise completely obliterated by bioturbation.
Abb. 4. Vertikale Grabgänge auf Reaktivationsflächen und die wechselnde Bioturbationsintensität werden auf Perioden mit Stillwasser und auf solche mit höherer Strömungsintensität zurückgeführt. Sedimentstrukturen können bei Perioden mit höheren Sedimentationsraten erhalten bleiben, normalerweise werden sie jedoch durch Bioturbation zerstört.

19.2 to 16.0 m: (subunit 4)	abrupt transition into a glauconiferous fine sand with hummocky cross stratification and at the top clay clasts (Fig. 7); followed by a bioturbated glauconiferous sandy clay to very clayey sand, grading upwards into a glauconiferous clayey fine sand with intensive clay lamination masked by strong bioturbation (Fig. 8). The sharp lower boundary of the laminated sand points towards an erosive phase, due to either emersion or a very high-energetic sedimentation environment.

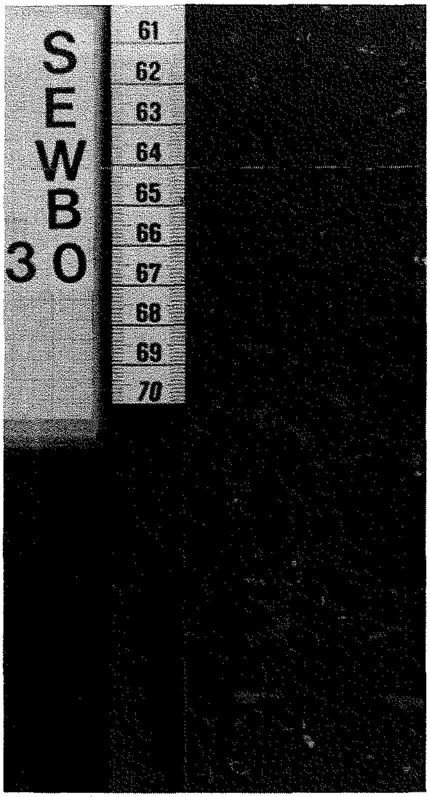


Fig. 5. Bioturbated sand contains mm-thick clay laminae and fossil debris, indicating a decrease of the influence of wave energy.
Abb. 5. Bioturbate Sande mit mm-dicken Tonlaminae und Fossiliengrus, was auf den Rückgang der Wellenenergie schließen läßt.

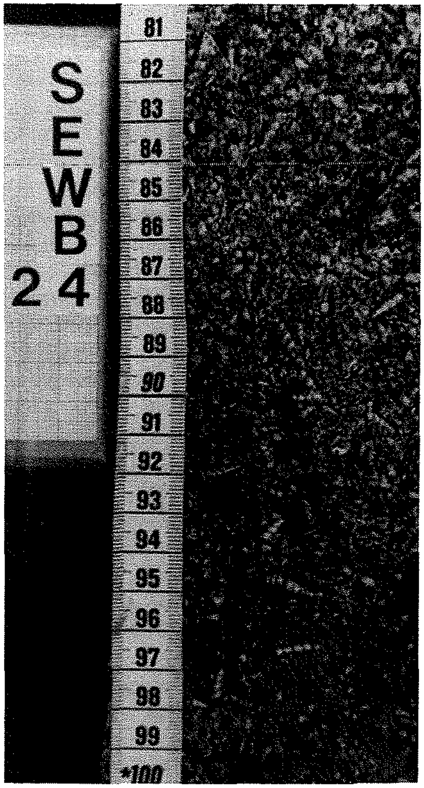


Fig. 6. Shell beds dominated by the presence of *Turritella*, are probably storm-generated.

Abb. 6. Muschellagen meistens mit *Turritella*, wahrscheinlich Sturmlagen.

	Transition towards the bioturbated clayey facies can be related to a constantly regressing coastline. (Aalter equivalent Member).
16.0 to 12.0 m: (subunit 5)	glauconiferous and fossiliferous fine sand, with locally few mm-thick clay lenses and few horizontal burrows. Completely reworked clayey sand with uniformly dispersed shells points most probably towards a lagoonal deposition environment. (Aalter equivalent Member).

Sediment-genetically, the Knesselare Formation starts with a tidally dominated channel facies. The Beernem Member shows a predominantly intertidal flat facies. At the base of the Oedelem Member, a submarine

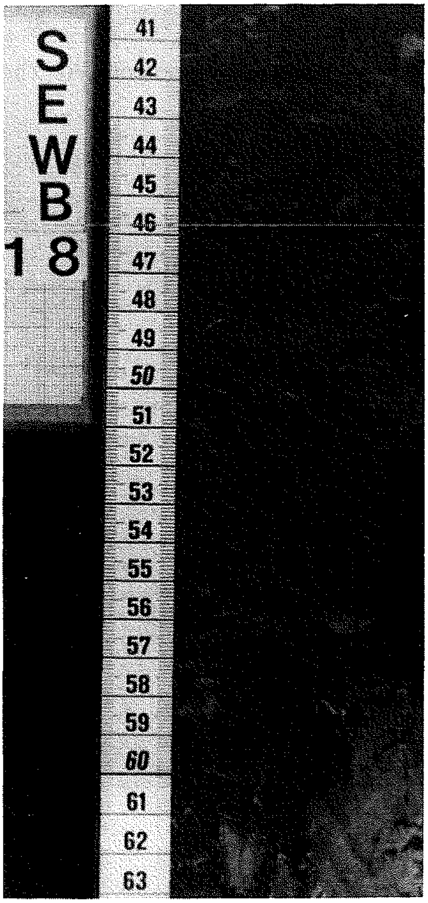


Fig. 7. Very clayey sand with at the base clay clasts but upwards showing clay lamination obliterated by intense bioturbation, is either related to tidal flat sedimentation or to a lagoonal sedimentation environment.

Abb. 7. Sehr tonreicher Sand mit basalen Tongeröllen, die von durch Bioturbation zerstörten Tonlaminae überlagert werden. Die Sedimentation wird dem Wattbereich oder dem lagunären Milieu zugeordnet.

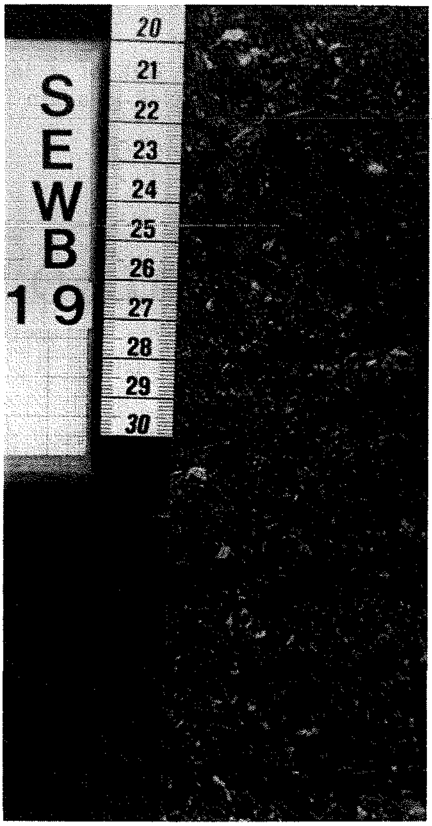


Fig. 8. The lateral continuity of a bioturbated clayey sand with a low shell content suggests deposition on a lagoon floor.

Abb. 8. Bioturbater, toniger Sand mit einer guten lateralen Kontinuität und einem geringen Muschelgehalt, der sich auf dem Lagunenboden ablagerte.

coastal barrier facies is followed by a lagoonal floor facies. At the base of the Aalter equivalent Member (as its relationship with the Aalter Member is not yet clear) it grades abruptly into a nearshore facies, followed by a tidal flat or a lagoonal sedimentation environment. At the top the lagoonal facies is again installed.

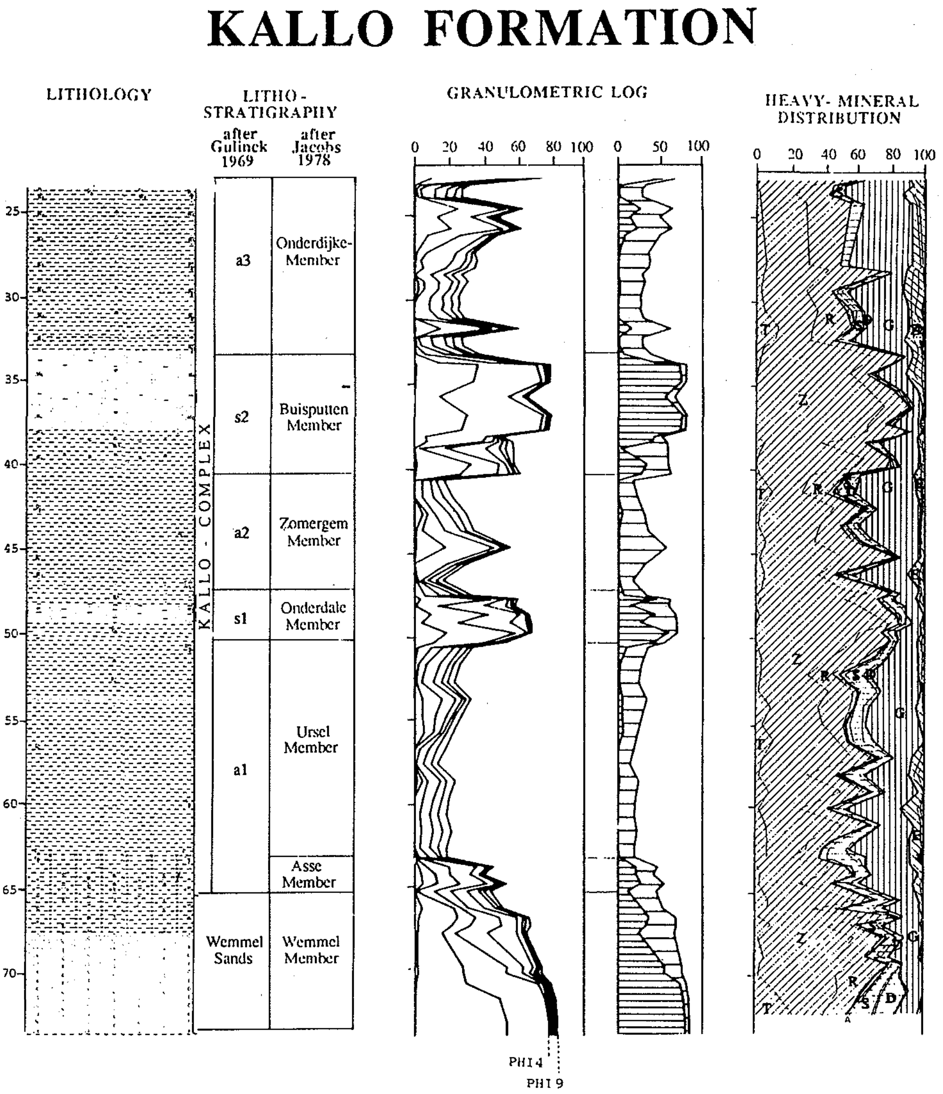


Fig. 9. Litho- and granulolog, and heavy mineral distribution of the compiled Kallo Formation section in the type area.

Abb. 9. Litho- und Granulolog sowie die Schwermineralverteilung aus zusammengesetzten Profilen der Kallo-Formation im Typusgebiet.

Upper Eocene deposits

Upper Eocene (or Eo-Oligocene transitional) deposits outcrop onshore in the Oedelem - Zomergem - Adegem area (Fig. 1, hatched zone), where the Kallo Fm occurs just underneath the surface under a very thin Quaternary cover (JACOBS 1975, 1978).

The Wemmel Member (Fig. 9) is at the base a glauconiferous, calcareous fine sand with shell debris. On the contact with any underlaying unit, small rounded fossiliferous calcarenite pebbles occur, together with quartz grains and shell debris. The base of the Wemmel Member passes with a gradual transition into a calcareous glauconiferous heavy clay with shell debris and sand spots. The base of the Asse Member is characterized by a greensand (the so-called 'bande noire'). The bulk of the sediment consists of a heavy clay, with pyrite concretions, shell debris and a high glauconite content. The granular glauconite particles occur either dispersed in the clay matrix or concentrated in thin dark or pale green lenses and spots. There is a gradual transition, characterized by the loss of glauconite, from the Asse Member into the Ursel Member, a homogeneous heavy clay with pyrite concretions and rare sandy spots.

The alternation of homogeneous glauconiferous medium fine to fine sand and heavy clay with pyrite concretions, sporadically containing fine sand, was subdivided into the Onderdale (sand), Zomergem (clay), Buisputten (sand) and Onderdijke (clay) Members (JACOBS 1975, 1978). The sedimentation of the Kallo Formation ends at the top with several thin peaty layers and perforations filled with peaty sand (GULINCK 1969a, 1969b). The upper Onderdijke Member may be lacking to the southeast outside the type area, probably due to an erosional phase before the deposition of the next unit.

The base of the Zelzate Formation (JACOBS 1975, 1978) (Fig. 10) is characterized by a thin broken flint and white quartz pebble bed. In the basal part of the Bassevelde Member fine shell debris occur. The bulk of the sediment is a silty medium fine to fine sand, glauconiferous, with pyrite concretions and sporadically friable arenite concretions and 10 cm thick sandy clay layers. According to JACOBS (1978) the Bassevelde Member passes gradually into the Watervliet Member, a glauconiferous sandy clay, consisting of an alternation of 3 to 5 cm thick sandy clay, clay and glauconiferous clayey fine sand layers. Pyrite concretions are absent. In the Kallo well and in the region south of Antwerp extending along the Rupel, STEURBAUT (1986a, 1986b) regarded a micaceous silty clay as the Watervliet Member. Here, this unit is covered by a predominantly clayey fine sand (Ruisbroek Member), defined as the upper limit of the Zelzate Formation. On basis of calcareous nannoplankton, STEURBAUT situates the Eo-Oligocene boundary between the Bassevelde and Ruisbroek Members.

Litho- and granulolog (Fig. 9) show a permanent cyclic sedimentation shifting between deposition of sands and clays with gradual transitions in between.

As coring did not allow sediment structure observation, grain size trends are the only tools to rely on.

In the base of the Kallo Formation, sediment of the underlaying unit is reworked. Gradually, the tidal flat sedimentation depositing the Wemmel sand Member changes into an open mud shelf sedimentation producing

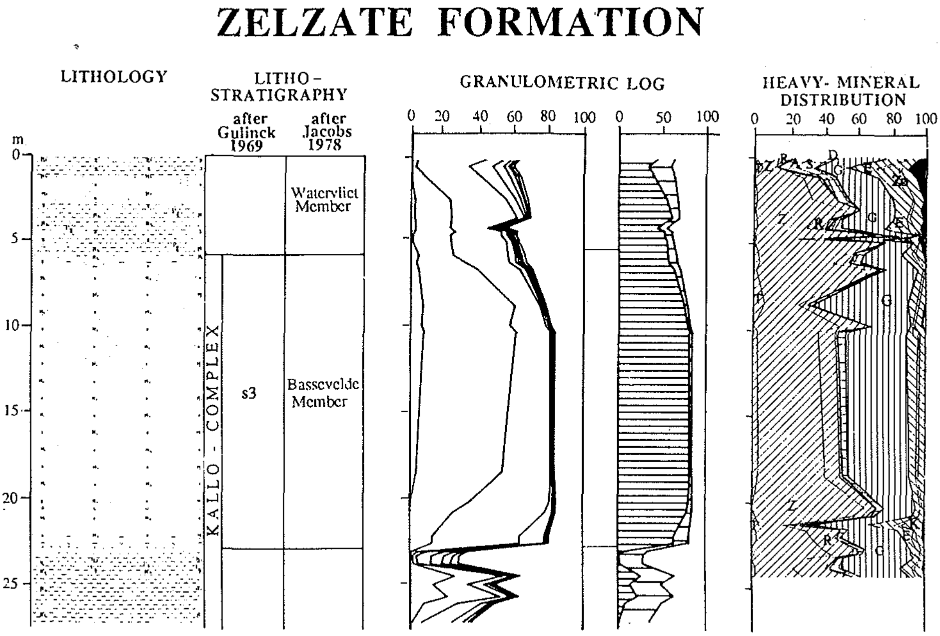


Fig. 10. Litho- and granulolog, and heavy mineral distribution of the compiled Zelzate Formation section in the type area.
Abb. 10. Litho- und Granulolog sowie die Schwermineralverteilung aus zusammengesetzten Profilen der Zelzate-Formation im Typusgebiet.

the Asse and Ursel clay Members. During their deposition, circumstances must have been favourable for the formation of glauconite. The large quantities formed during the Wemmel and Asse Member deposition may have served as an important source for the formation of detrital glauconite or glauconitic minerals by addition of mica. These swelling minerals of the nontronite type are frequently occurring in all younger Kallo Fm units.

The cyclic variation of the younger clay and sand Kallo Formation members probably indicates a rhythmical shifting between an open mud shelf and a tidal flat sedimentation, interrupted after the deposition of the Onderdijke Member. The thin peaty layers at the top of the Kallo Formation, perforated by burrowing organisms, represent an emersion period (JACOBS & SEVENS 1988).

The boundary between the Kallo and Zelzate Formations matches a sedimentary hiatus. The thin flint and white quartz pebble bed at the base of the Zelzate Formation bears witness of an old erosion surface. During the Zelzate Formation deposition time, the tidal flat regime was installed again (JACOBS & SEVENS 1988).

Grain size trends (Figs. 9 and 10) are clearly demonstrated by an alternation of fining and coarsening upwards sequences, respectively with minima in the middle of the clay and maxima in the middle of the sand deposits.

Two abrupt changes in granulometry can be observed:

- at the Wemmel Member base with the basal gravel,
- at the Onderdijke Member top with thin peaty layers and burrows filled with peaty sand from the above Zelzate Fm basal part.

Both are in relation to periods of non-deposition or erosion, related to major changes in sedimentation environment.

JACOBS & SEVENS (1988) pointed out that sedimentation during deposition of the (Upper Eocene) Kallo and Zelzate Fms took place in a shallow marine environment, with very low sedimentation rates and with sedimentation breaks at the Wemmel Member base and the Onderdijke Member top. The sedimentation environment shifted in a rhythmical way between an open mud shelf for the clay and a tidal flat for the sand deposits. Grain size data interpretation according to DOEGLAS (1968) indicates indices characteristic for lagoonal, tidal flat, shallow marine and deltaic sedimentation conditions.

In general, Upper Eocene sediments become thinner towards the south and towards the east. The contact with the underlaying sediments is always erosional and marked by a thin but distinct gravel bed present almost everywhere.

Lower Eocene deposits

GEETS (1988) studied the grain size distribution (Fig. 11) of Lower Eocene deposits (lower and middle part of the Ieper Fm) in the Knokke, Ooigem and Tielt wells in West Belgium (Fig. 1).

The thickness of the complete section ranges here to some 120 to 150 m, according to the localization of the wells. Coring did not permit sediment structure study.

Again, fining and coarsening upwards sequences can be observed, allowing correlation between the different wells, although throughout the complete section, sedimentation in this shallow marine environment stays mainly clayey and/or silty in nature.

Interpretation criteria for outcrops and wells

In various publications, VAIL et al. (1977, 1981, 1984, 1987) cite criteria for interpretation of outcrop and well data in terms of sequence stratigraphy (Fig. 12). Roughly they can be summarized as follows, always taken into account the shallow marine environment, on the higher part of the continental shelf and thus near the coast, where minor relative sea level changes might have a much larger expression than deeper into the basin, and where distal and proximal positions give rise to different responses to the same sea level change event.

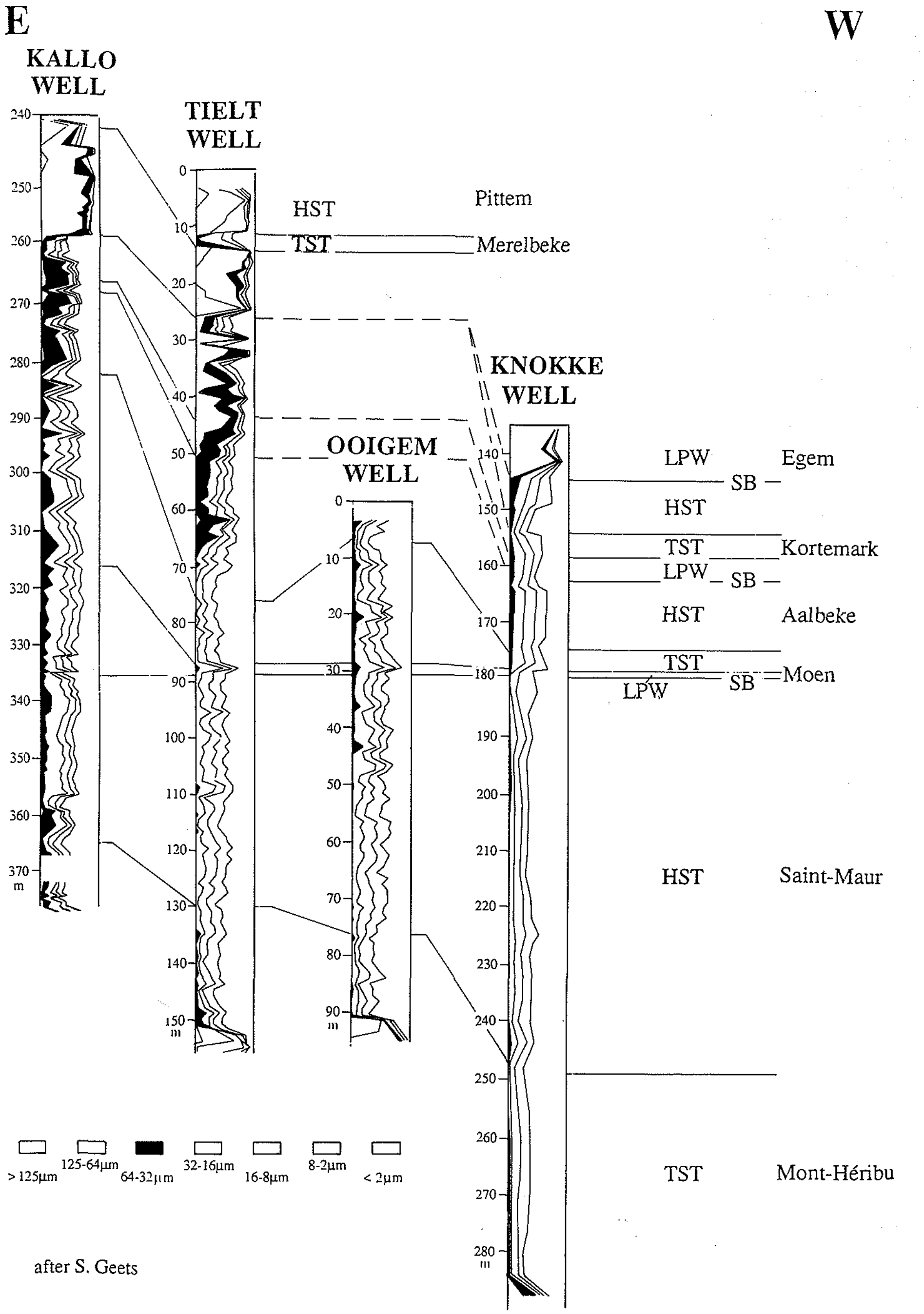


Fig. 11. Eastern coarsening trend in Kortrijk and Tielt Formation sediments.
Abb. 11. Sedimente der Kortrijk- und Tielt-Formation weisen eine Kornvergröberungstendenz nach Osten auf.

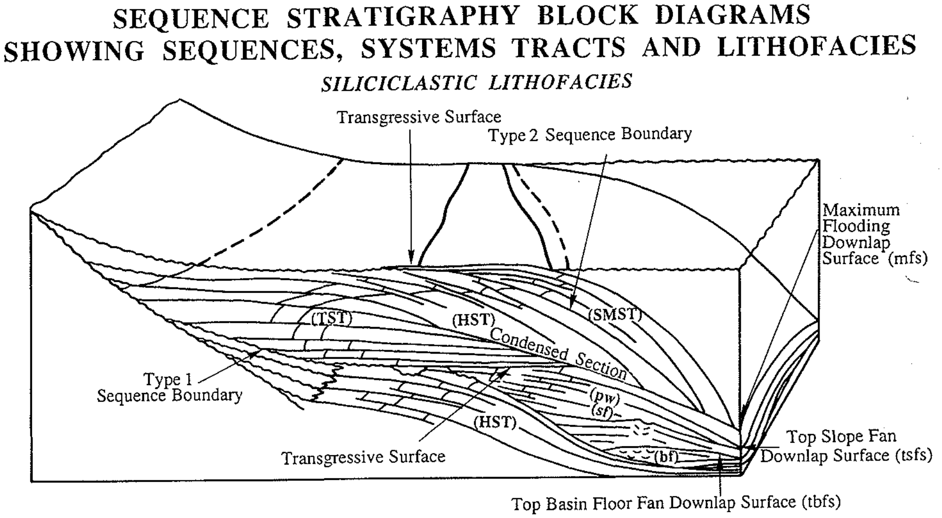
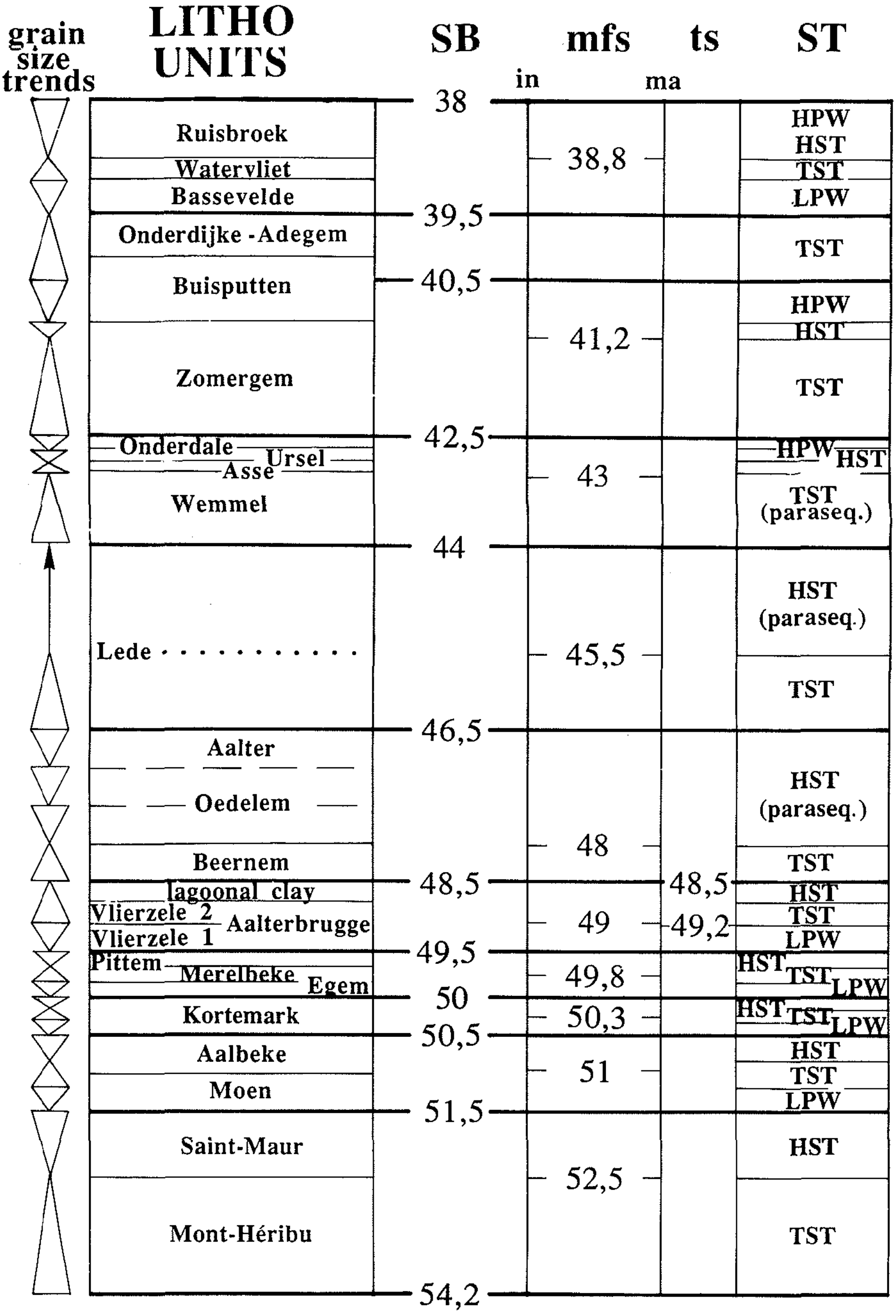


Fig. 12. Sequence stratigraphy block diagram showing sequences, systems tracts and lithofacies in siliciclastic sediments (after VAIL).
Abb. 12. Blockbild zur Sequenzstratigraphie mit Sequenzen, Sedimentgenerationen und Lithofazies in siliziklastischen Sedimenten (nach VAIL).

Lowstand Prograding Wedge (LPW):
. abrupt start of coarsening upwards
. much more massive character than Highstand Prograding Wedge (HPW)
. much thicker than HPW
Transgressive Systems Tract (TST):
. backstapping parasequences
. fining upwards
. massive (blocky) sands at the base
. aggradational character (glauconite, dunes)
. expression of relative sea level rise
Highstand Systems Tract (HST):
. prograding shallowing upwards parasequences
. gradually coarsening upwards, more interbedded
. no blocky sands at the base
. seawards: coal, lakes
landwards: point bars, incised valleys
. expression of relative sea level rise, decreasing in time
maximum flooding surface (mfs):
. glauconite, phosphate and burrows.

Table 2. West Belgian Eocene sequence stratigraphy systems tracts.
Tab. 2. Sequenzstratigraphie mit Sedimentgenerationen im Eozän Westbelgiens.



LITHO UNITS	SB (in ma)	mfs	ts	ST
	38			
Ruisbroek		38,8		HPW HST
Watervliet				TST
Bassevelde				LPW
	39,5			
Onderdijke-Adegem				TST
	40,5			
Buisputten				HPW
Zomergem		41,2		HST TST
	42,5			
Onderdale Ursel Asse				HPW HST
Wemmel		43		TST (paraseq.)
	44			
Lede		45,5		HST (paraseq.) TST
	46,5			
Aalter Oedelem		48		HST (paraseq.)
Beernem				TST
	48,5		48,5	
lagoonal clay				HST
Vlierzele 2 Aalterbrugge		49	49,2	TST
Vlierzele 1				LPW
	49,5			
Pittem Merelbeke Egem		49,8		HST TST LPW
	50			
Kortemark		50,3		HST TST LPW
	50,5			
Aalbeke		51		HST
Moen				TST LPW
	51,5			
Saint-Maur		52,5		HST
Mont-Héribu				TST
	54,2			

Eocene sequence stratigraphy

Combining
- sediment structures and their genetic interpretation,
- grain size trends in terms of coarsening or fining upwards sequences,
- (absolute and relative) age dating of boundaries and surfaces provided by the VAIL coastal onlap curve,
- interpretation criteria for outcrop and well sequence stratigraphy,

enables systems tracts characterization of all West Belgian Eocene deposits (Table 2).

Biostratigraphical and chronostratigraphical control is provided by STEURBAUT's nannoplankton zonations (1987) and by KEPPENS' Rb-Sr age dating on "bande noire" glauconite (1981), respectively.

The VAIL systems tracts model is perfectly applicable to the Belgian Eocene siliciclastic sediment deposition on the part of the shelf above the shelf edge. Even higher on the shelf (more eastwards in the direction of the mainland) the model provides valid information on the facies changes within the systems tracts. In the Kruiningen well (Fig. 13) the Eo-Oligocene transitional layer (Kallo and Zelzate Fms) sediments were expected to be finer if only dip is taken into account (0.3-0.5 % in NNE direction). Surprisingly this is not the case, as the granulolog in agreement with the well logs of the Rijks Geologische Dienst (RGD) shows. The sedimentation became much more sandy. The Kallo well, in a similar more eastward position as the Kruiningen well, also shows a much more sandy sedimentation for the Kortrijk and Tielt Fms of the Ieper Group, in comparison with the more westward (and southward) situated Tielt, Ooigem and Knokke wells (Fig. 11).

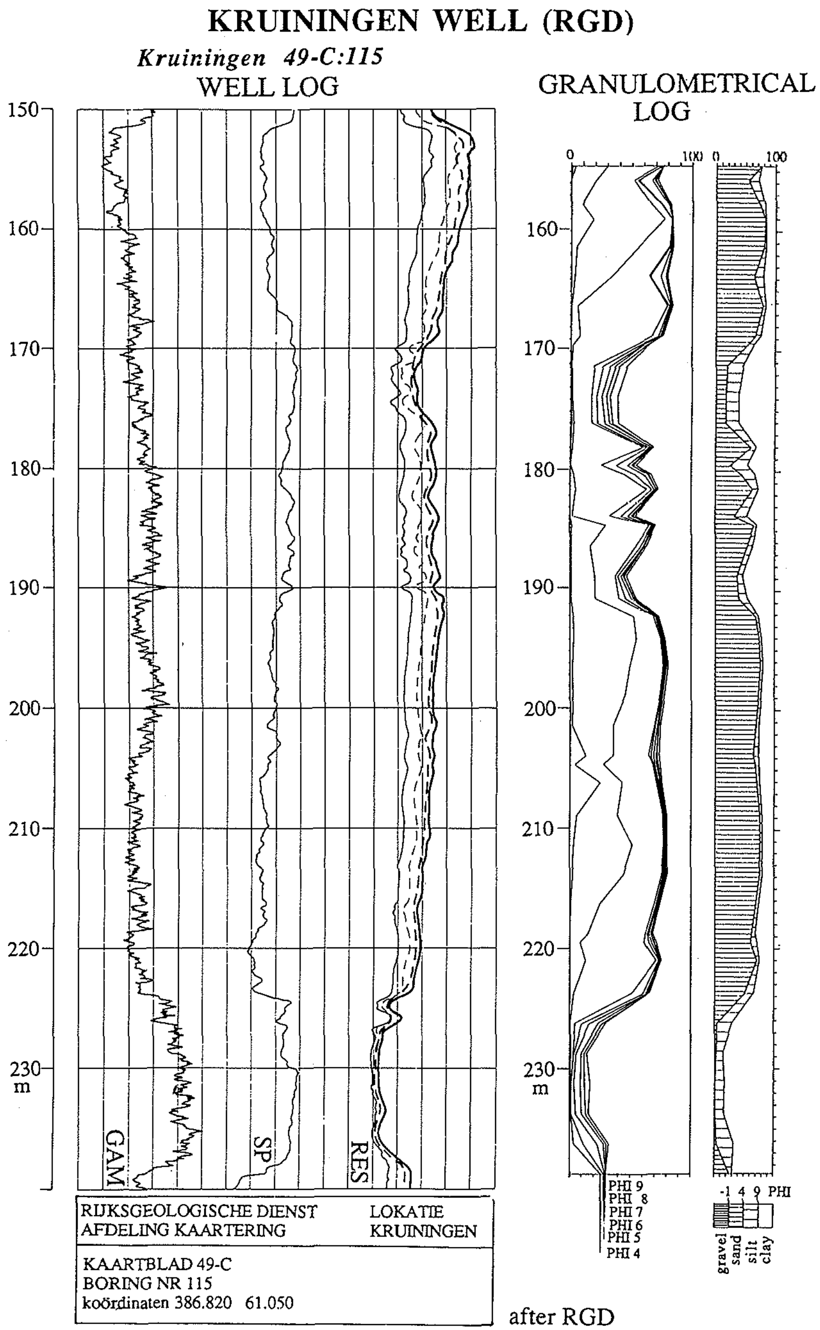
The explanation for this non-hasardeous feature is again in the VAIL model. The more sandy sedimentation represents a more proximal sedimentation environment, in agreement with VAIL's general pattern of strata predicting a coarser sediment supply within the same lithostratigraphical units or sequences.

Belgian Eocene sedimentation model

In an oversimplified way, the Belgian Eocene can be described as an alternation of sands and clays, with a much more clay-dominant sedimentation at the base, a much more sand-dominant in the middle, and again a much more clay-dominant sedimentation at the top.

Belgian marine Eocene clays have long been considered to be deposited in fairly deep environments. Grain size parameter interpretation (JACOBS 1975) considered these Kallo and Zelzate Fm clays to be delta front, lagoonal, tidal flat, shallow marine deposits comparable to the actual "wadden". VANDENBERGHE & VAN ECHELPOEL (1987), on basis of genetic interpretation of the septaria, organic matter and grain size rhythmicity in the Oligocene Boom clay, came to a similar conclusion of shallow marine clay sedimentation.

Recently, in the Ieper Group clay deposits (Aalbeke clay Member), sediment structures have been described that closely resemble ripple marks (RANSON 1989). In the Kortemark clay Member, bioturbations and nodules are commonly present, also suggesting a less deep sedimenta-



after RGD

Fig. 13. Granulo- and well log of the Kallo and Zelzate Formation sediments in the Kruiningen well.

Abb. 13. Bohrlochlog und Granulolog von Sedimenten der Kallo- und Zelzate-Formation aus der Bohrung Kruiningen.

tion environment. All these phenomena indicate the clay sedimentation to take place in a mud flat to tidal flat environment.

Sedimentation structures can be observed in many sand units also. The Egem Member displays parallel to cross lamination and the Vlierzele Member beautiful cross-bedding with tidal influence (HOUTHUYS & GULLENTOPS 1988a), indicating shallow sedimentation environments with fluviatile or tidal influence. The Eocene Brussel sand Fm (HOUTHUYS & GULLENTOPS 1988b) and the Miocene Diest sand Member also show a pronounced fluviatile sedimentation pattern with tidal influence. The sedimentation must thus have taken place in a fluviatile environment, in channels, within the tidal range.

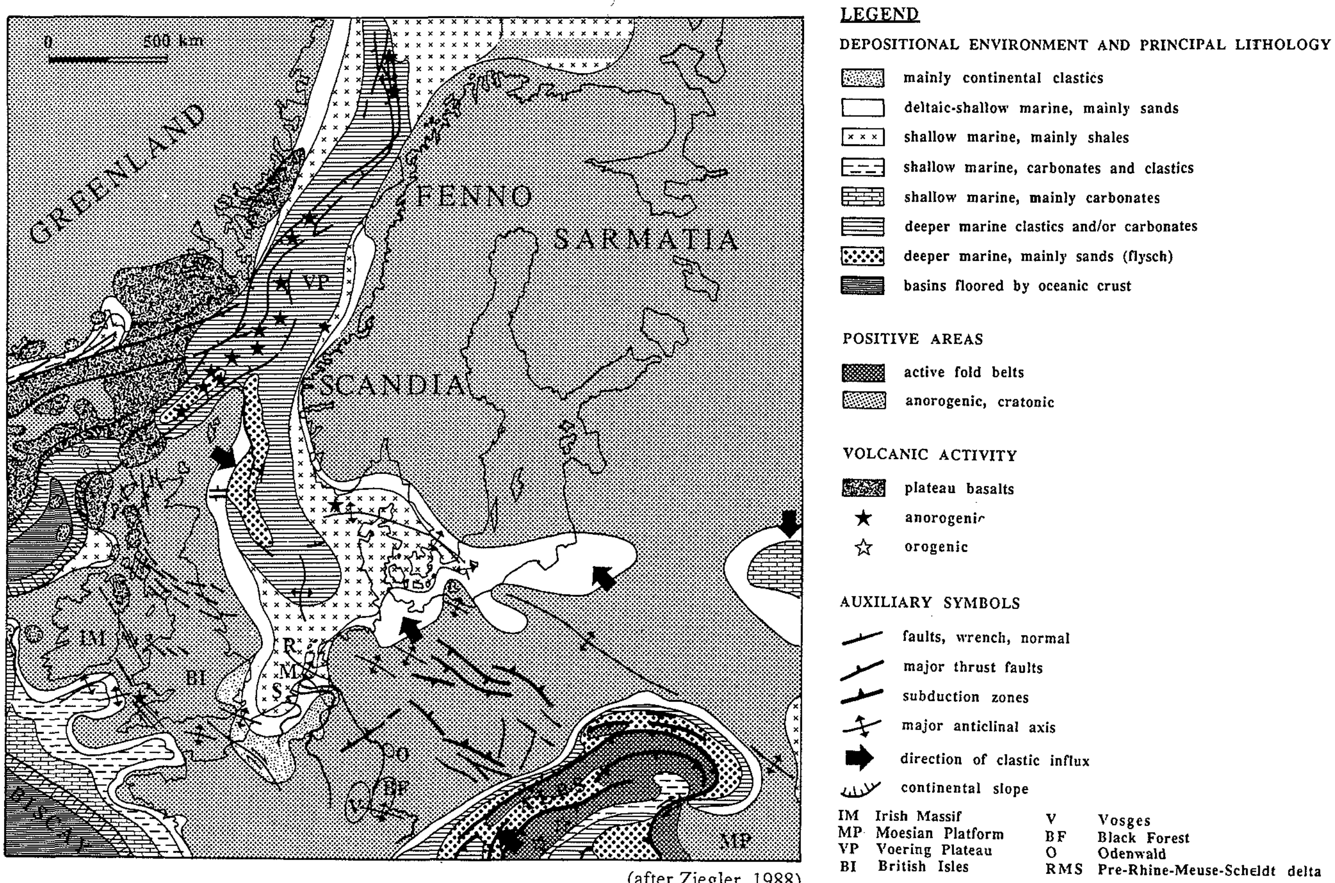
According to the horizontal and vertical distribution of these Eocene sediments, sedimentation architecture points towards a Pre-Rhine-Meuse-Scheldt delta, in a high position on the shelf, with a coastline shifting in response to relative sea level changes. The general model depicts a shallow marine depositional environment with as most proximal part on the higher part of the shelf a fluviatile and tidal sand deposition, as a result of incised meandering valley infill after lowstand as equivalents of the LPW's deeper into the basin; the deltaic and shallow marine clays result from the deposition of fine detrites into the shallow marine southern North Sea bight, as a more distal part of this Pre-Rhine-Meuse-Scheldt delta outbuilding onto the shelf; the deposition of the more sandy sediments of the Kortrijk, Tielt and Gent Fm in Kallo and of the Kallo and Zelzate Fm deposits in Kruiningen is the expression of a more proximal sedimentation in the delta system.

As all clay and sand sediment characteristics are fairly constant through time, the depositional system can be assumed to shift landwards and basinwards through time with a constant amplitude. This means that within the southern bight of the North Sea basin, subsidence rates must have stayed rather constant, and the relative sea level changes must have had comparable amplitudes through time, both mechanisms creating in general a constant space amount for sediment accomodation by constant sediment supply. As a result, the coastline shifts landwards and basinwards with a rather constant amplitude.

Sediment supply

Up to now it was generally accepted that the sands of the Belgian Tertiary have a northern origin (EDELMAN & DOEGLAS 1938, TAVERNIER 1946). According to the heavy mineral distribution, most of them belong to the marine parametamorphic G-province, provided by erosion of the British Isles and/or Fennoscandia (GEETS et al. 1979, 1985, 1986). This northern source rock origin coincided very well with the general idea of northern transgressions, causing low angle (3-5 ‰) dip to the NNE of most of the Tertiary layers in Belgium, and giving rise to a geological map with more or less WNW-ESE parallel outcropping Fms.

Nevertheless, this northern origin concept is in total disagreement with the model of subsidence and sediment supply provided by VAIL et al. The depocentres of the basin are in the middle of the North Sea, with the British Isles and Fennoscandia at their western and eastern side. Rapid subsidence here gave rise to Eocene sediment thicknesses up



(after Ziegler, 1988)

Fig. 14. Early Tertiary North Sea Basin with southern bight Pre-Rhine-Meuse-Scheldt delta and source rock sediment supply (slightly modified after ZIEGLER 1988).

Abb. 14. Frühtertiäres Nordseebecken mit südlicher Bucht, Prä-Rhein-Maas-Schelde-Delta und Abtragungsgebiet für die Sedimentzufuhr (nach ZIEGLER 1988, leicht geändert).

to 2000 m and more (ZIEGLER 1988). These central North Sea depocentres acted as sediment traps difficult or impossible to overcome from the north to reach the southern North Sea bight.

Furthermore, the heavy mineral assemblages of the Belgian Eocene strata only show minor differences throughout the complete stratigraphical column. The rather constant heavy mineral composition points more towards a time persistent reworking of the sediments, indicating a constant shifting before the coast due to longshore currents and tides (just as nowadays), redistributing sediments constantly.

The composition of the heavy mineral assemblages is much more in agreement with a southern sediment origin, supplied by the time persistent Pre-Rhine-Meuse-Scheldt delta, and caused by the constantly uplifted hinterland (Alpine orogeny starting in the lower Cretaceous), giving rise to erosion of e. g. Odenwald, Black Forest and Vosges acting as plutonic and/or metamorphic rock sources (Fig. 14) (JACOBS in press). This southern origin fits into the VAIL's systems tracts framework philosophy and matches the observed (eastern) incised valley infillings during the Egem, Vlierzele, Brussel and Diest deposition times.

Conclusion

Grain size distribution trends and sediment structures in Belgian Eocene deposits allow depositional environment reconstruction, indicating a general shallow marine paleogeography, characterized by a Lowermost Eocene mud flat sedimentation (Kortrijk Fm), a Middle Lower to Upper Middle Eocene tidal flat sedimentation with lagoonal, barrier and storm deposits (Tielt to Knesselare Fm) and an Upper Eocene sedimentation shifting between a mud flat and a tidal flat (Kallo to Zelzate Fm).

Sedimentation takes place on a high position on the shelf, causing distinct sequence stratigraphy systems tracts signatures in response to the relative sea level changes, responsible for a shifting coastline, and displacing the Pre-Rhine-Meuse-Scheldt delta depositional system with his southern sediment supply, seawards and landwards through time.

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