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Preliminary seismic-stratigraphic maps and type sections of the Palaeogene deposits in the Southern Bight of the North Sea.

J.P. HENRIET (1), M. DE BATIST (1)(2), H. DE BRUYNE (1), P. HELDENS (1), J.P. HUYLEBROECK (1), F. MOSTAERT (1), E. SEVENS (1), J.P. AUFFRET (3) and B. D'OLIER (4)

1. Renard Centre of Marine Geology, Geological Institute, State University of Gent, Krijgslaan 281/S8, B-9000 Gent, Belgium.
2. Research Assistant, National Fund for Scientific Research, Belgium.
3. Laboratoire de Géologie Marine, Université de Caen, Département de Géologie, Esplanade de la Paix 14, F-14032 Caen CEDEX, France.
4. Department of Geology, City of London Polytechnic, Walburgh House, Bigland Street, London E1 2NG, United Kingdom.

ABSTRACT

High-resolution reflection seismic investigations carried out from 1978 up to 1984 in the Southern Bight of the North Sea yield a detailed picture of the stratigraphic build-up of the Palaeogene sequences and their spatial distribution in this region. The application of classical concepts of seismic-stratigraphic analysis leads to the identification of 14 depositional sequences.

Several units display characteristic seismic facies features, which can be interpreted in terms of depositional environment and compaction history.

The intention of this paper is to set the general seismic-stratigraphic stage for the Palaeogene sequences of this region, thus yielding a marine data base which could prove useful in correlation studies with lithostratigraphic and chronostratigraphic land observations.

INTRODUCTION

Some years ago, at the 1979 Texel Meeting on Holocene Sedimentation in the North Sea Basin, three investigation teams from City of London Polytechnic, Université de Caen and Rijksuniversiteit Gent decided to join their resources for studying the superficial geology of the southern North Sea, between the coasts of northern France, Belgium and the Thames estuary. The project "Seismic Stratigraphy, Southern Bight, North Sea" (SSSBNS) was born.

At that time, the British sector was fairly well covered by sparker and boomer lines. In the Belgian and French sectors of the continental shelf however, seismic data were scarce. Only a few lines published by

HOUBOLT (1968) and BASTIN (1974), as well as harbour development surveys for Dunkerque and Zeebrugge (HENRIET *et al.*, 1978) were available.

In subsequent years, several cruises have been organized by the aforecited universities, aiming to fill the gap in the seismic coverage on the French/Belgian continental shelf. Vessels were provided by NERC in the United Kingdom and by CNRS and Wimereux Station of Université de Lille in France. In Belgium, support was granted by the Science Police Office, the Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary and the Belgian Navy. In 1982, a detailed seismic mapping of Quaternary deposits off the western Belgian coast was commissioned by the Administration of Mines, within the framework of studies of the environmental impact of dredging activities on sand banks.

This paper reviews our state of knowledge of the seismic stratigraphy of the Palaeogene substratum of the Belgian sector and adjoining areas of the Southern Bight of the North Sea, from surveys carried out up to 1984, the year of the Ghent Colloquy. As such, it presents a working base for subsequent detail studies, such as the Marine Geology programme of the Belgian Science Policy Office and the systematic, detailed mapping programme of the superficial deposits of the Belgian continental shelf, commissioned by the Belgian Geological Survey. These on-going new surveys, implemented with drilling programmes, will no doubt in the future lead to a refinement of the present stratigraphical model.

The seismic grid available by 1984 (figure 1) totalized about 7000 km. It stretched from coast to coast, bridging

Figure 1 Map showing the 1984 seismic coverage on the French, Belgian, Dutch and UK sectors of the continental shelf, between 51°-52°N and 2°-3°30'E.
Full lines indicate seismic profiles shot within the "SSSBNS"-project. Dashed lines indicate previous seismic profiles.

the former gap in the central and northern Belgian sector and linking with Borehole 79/6 of the British Geological Survey in the north, used as reference well. The apparent density of this grid should not be misleading, the represented lines being of varying quality and penetration. However, it forms a working base, which will be completed and enhanced, but which already yields a coherent picture of the stratigraphy of the Palaeogene deposits of this region.

GEOLOGICAL SETTING

The Southern Bight of the North Sea and especially its southwestern part, off the North French and Belgian coasts (area between 2-3°30'E and 51-52°N), is situated on top of the Palaeozoic London-Brabant Massif, which has formed a stable structural high during a long geological period. In post-Palaeozoic times, it was probably submerged for the first time during the Upper Cretaceous sea level high, although possibly structurally controlled local earlier depositions cannot be completely ruled out. This area has always been situated at the southern rim of the subsiding North Sea Basin, which implies that many sea level changes and/or tectonic events are reflected in the lithology and the configuration of its sedimentary cover.

The Upper Cretaceous chalk on top of the London-Brabant Massif is covered by a comprehensive sequence of Palaeogene beds. This sequence has an average dip of about 0.5° in northeastern direction, probably bound to both the subsidence movements of the North Sea Basin and to some Early- to Mid-Tertiary tectonics in the southwest (Weald-Artois anticline). Being directly exposed on the sea bed or only slightly concealed by a thin Quaternary cover, it offers in this region a unique possibility of investigation of its internal structure and facies, with a maximum of resolution.

SEISMIC-STRATIGRAPHIC APPROACH

The seismic-stratigraphic analysis of the Palaeogene was carried out in accordance with the basic principles laid by VAIL *et al.* (1977). It resulted in the identification of depositional sequences, separated by low-angle unconformities or their correlative conformities. These sequences have then been analysed in function of their seismic facies, which often resulted in a better definition of poorly-developed sequence boundaries. A further differentiation of larger sequences into sub-units could thus be achieved on base of striking seismic facies features.

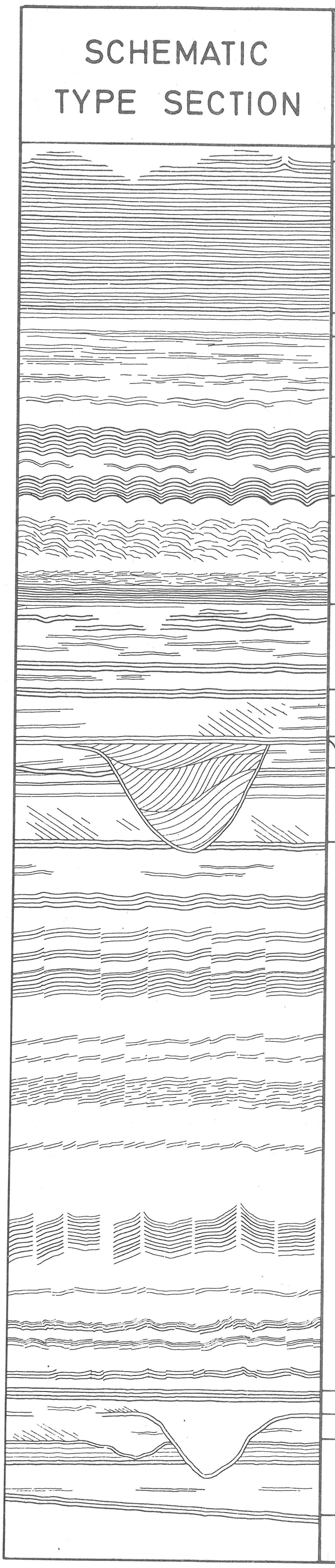
The identified depositional sequences have been labeled with a character-digit symbol, suggesting their most probable chronostratigraphic identity. This preliminary chronostratigraphic interpretation is partly based on a tentative correlation with stratigraphic units in the Belgian coastal plain and the rest of the Flanders area and will presumably have to be revised as soon as micropalaeontological and sedimentological interpretations of judiciously planned boreholes on the Belgian continental shelf will be available.

Until now up to 14 Palaeogene depositional sequences have been identified :

- R1 and R2 (Rupelian),
- P1 (Priabonian),
- B1 and B2 (Bartonian),
- L1 and L2 (Lutetian),
- Y1, Y2, Y3 and YX (Ypresian),
- T1, T2 and T3 (Thanetian).

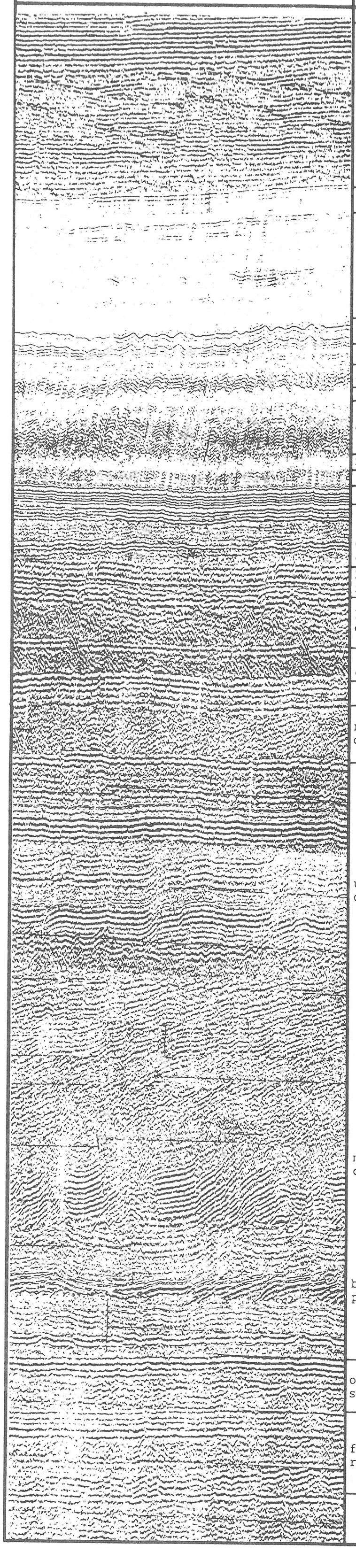
Main reflectors are labeled with the character-digit symbol of the overlying depositional sequence, accompanied by a rank number, both separated by a dot. First order ranks are assigned to sequence boundaries, while higher rank numbers are given to significant internal reflectors.

The results of this detailed seismic-stratigraphic analysis have been compiled into a schematic



DEPOSITIONAL SEQUENCES								
NAME	BOUNDARY					THICKNESS		
	NAME	TYPE	REFLECTOR DESCRIPTION			(ms) two-way time	Vi (m/s)	(m)
			AMPL.	CONT.	FREQ.			
	N1.1	onlap/truncation	low	cont.	low			
R2						max. 120	uphole 1650 ±80	max. 99
	R2.1	concordance	medium	cont.	low			
R1						±10	1700 ?	±8.5
	R1.1	onlap/truncation	low	cont.	low			
P1						40 9-10		34 7.5-8.5
	P1.1	concordance	medium	cont.	low			
B2						8 8		13.5
	B2.1	baselap	high	cont.	low			
B1						5 20 5 5 8		34
	B1.1	truncation	medium	cont.	high			
L2						25-35 ±13	refraction 1580 ±40	21-30 ±11
	L2.1	toplap	high	cont.	low			
L1						15-19	1700?	12.5-16
	L1.1	downlap/truncation	medium	cont.	low			
YX* Y3						10-20	1600	8-16
	Y3.1	baselap/truncation	variable	cont.	low			
Y2						5-15 20-25	downhole 1750 ±50	4.5-13 17.5-22
	Y2.1	downlap	high	cont.	low			
Y1						200-220	uphole 1620 ±50	162-178
	Y1.1	concordance	high	cont.	low			
T3						11-13	well correlation ±1800	10-11.5
	T3.1	downlap/truncation	medium	discont.	low			
T2						9-11		8-10
	T2.1	downlap/truncation	medium	cont.	medium			
T1						18.5-30		16.5-27
	T1.1	onlap	high	cont.	low			

Figure 2 Schematic seismic-stratigraphic sequence chart and correlation table of the Southern Bight Palaeogene deposits.
* for YX see figure 6.

DEPOSITIONAL SEQUENCES			
SEISMIC FACIES		NAME	LITHOSTRA-TIGRAPHIC CORRELATION
TYPE SECTION	DESCRIPTION		
	regular pattern of continuous, parallel, high- to medium-amplitude reflectors	R2	Boom Member (B)
	continuous, parallel, low-amplitude reflectors	R1	Berg Member (B)
	homogeneous pattern of continuous, parallel, low- to medium-amplitude reflectors	P1	Zelzate Formation (B)
	continuous, parallel, draping reflectors of variable amplitude		
	reflection-free + low-amplitude, discontinuous, draping reflector	B2	Meetjesland Formation (B)
	medium-amplitude, draping reflectors		
	reflection-free interval	B1	
	convex mounds of medium-amplitude, prograding, hummocky reflectors		
	reflection-free interval		
	hummocky reflectors with a shingled reflector on top		
	regular set of continuous, parallel, high-frequent reflectors		
	2 to 3 discontinuous, subparallel, very high-amplitude reflectors	L2	Oedelem Member (B)
	discontinuous, parallel to subparallel reflectors of variable amplitude		
	2 continuous, high-amplitude, parallel reflectors in the south a third, discontinuous, low-amplitude reflector		
	low-amplitude, parallel reflectors or parallel-oblique clinoforms or reflection-free	L1	
	low-amplitude, discontinuous, parallel reflectors or parallel-oblique clinoforms	Y3	Merelbeke Member (B)
	continuous, low- to medium-amplitude, parallel reflectors	Y2	Egem Member (B)
	reflection-free or very low-amplitude, parallel-oblique, prograding clinoforms		
	undisplaced, faulted blocks with alternately tilting and downwarping bedding terminations	Y1	London Clay (U.K.) or Flanders Clay (B) (Ieper Clay)
	major tilted blocks, convolute structures with broad synclines and cuspate anticlines, diapyrs		
	block faulting, tilted and bended blocks, randomly dipping fault planes		
	oblique or shingled clinoforms and low-amplitude, discontinuous, subparallel or hummocky reflectors	T3 T2	lagoonal to continental Landen Formation (B)
	few parallel reflectors of variable amplitude, separated by reflection-free intervals	T1	marine Landen Formation (B)

seismic-stratigraphic sequence chart of the Palaeogene deposits. Descriptions of seismic facies and reflector characteristics are added and can be visualized on an accompanying synoptic seismic record, a composite of several seismogram sections acquired with comparable source signatures (figure 2). A detailed seismic-stratigraphic solid map of the Palaeogene on the continental shelf is shown on figure 3. In the following chapters the most striking features of each depositional sequence will be briefly described.

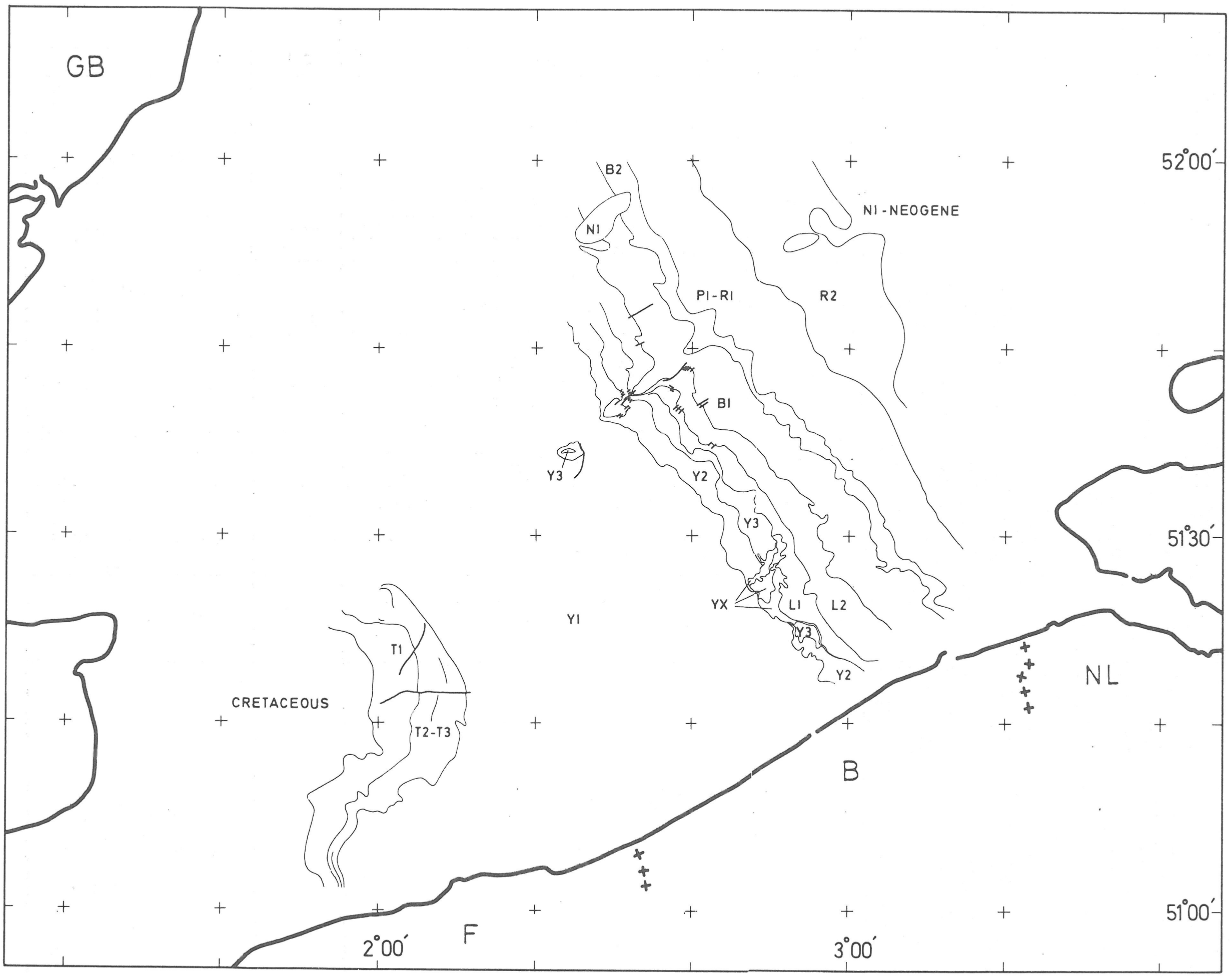


Figure 3 Seismic-stratigraphic solid map of the Southern Bight Palaeogene deposits, acquired by interpretation of seismic profiles shot within the "SSSBNS"-project. Interpretations of previous seismic lines (e.g. UK sector) have not been implemented yet.

THANETIAN

The first three seismic-stratigraphic units (T1, T2 and T3), deposited on top of the relatively thin Upper Cretaceous cover of the London-Brabant Massif, belong to the Late Palaeocene (Late Thanetian) and can be correlated with the Landen Formation in Belgium and with the Thanet and Reading/Woolwich Beds in southeastern England.

T1

The lowermost boundary op the Palaeocene depositional sequences is formed by the unconformity at the top of the Cretaceous chalk (Turonian-Senonian) : reflector T1.1. The overall width of the overlying T1-unit decreases by onlap from about 30 to 18.5 ms (two-way time) towards the southwest. This can very clearly be observed in the northwestern part of the Belgian continental shelf.

T2 and T3

The boundary with the second unit, reflector T2.1, is an erosion surface, locally with well developed gully erosion features, as observed both near the English and French-Belgian coasts. T2.1 in its turn is on some places (figure 4) scoured by the basal reflector T3.1 of the overlying sequence. The seismic facies of both sequences is often characterized by abundant prograding stratifications, hummocky reflection patterns, discontinuous, subparallel reflections and channel-fill reflection configurations (HUYLEBROECK, 1985). The total width of the T2-T3 interval is about 20-24 ms and remains fairly constant, although it may increase substantially in ravinations.

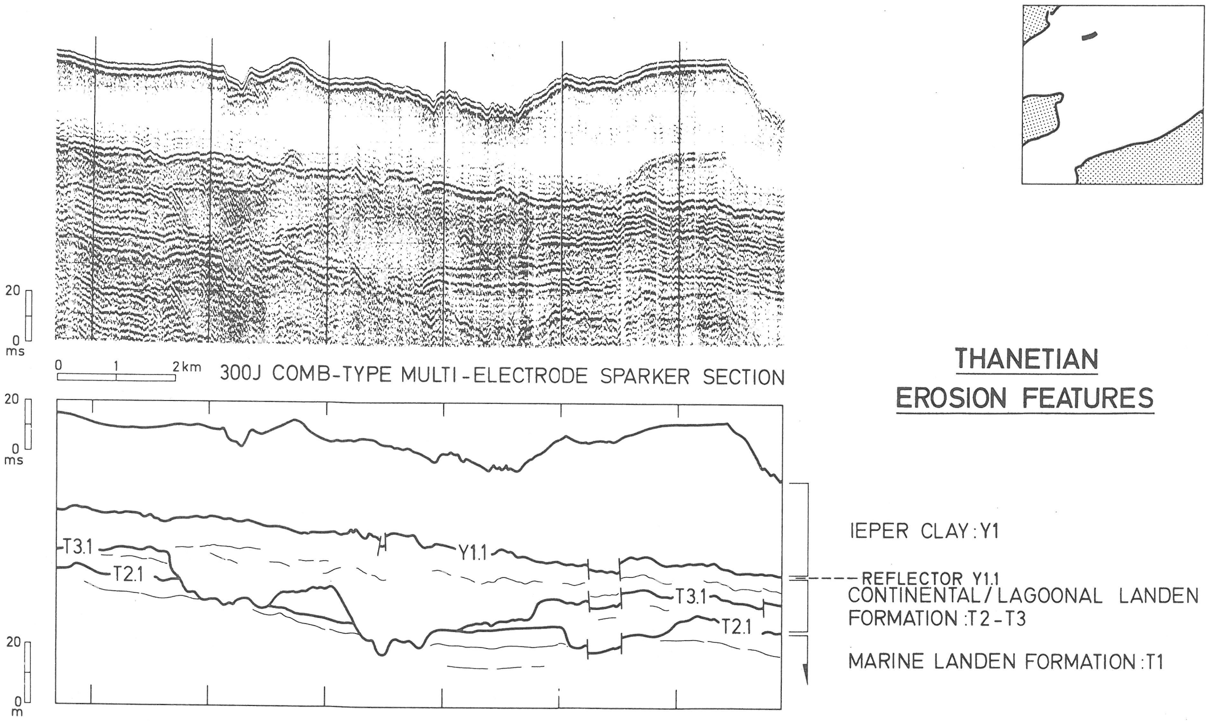


Figure 4 Analog record of a sparker section and interpreted line-drawing showing Thanetian gully erosion features on the UK continental shelf.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an average velocity of 1700 m/s.

An overlying reflector, Y1.1, independently interpreted by British as well as by Belgian investigators as the base of the London/Flanders Clay, is considered to form the upper boundary of the T3-unit, although on many seismic sections the transition between T3 and Y1 does not appear as an unambiguous unconformity.

Through correlation of a seismic calibration line off the Belgian coast with the Ostend boring (BGD 21E-41), where the boundary between the Senonian and the Landen Formation was found at -211 m and the boundary between the Landen Formation and the Flanders Clay at -174 m, an average velocity of about 1800 m/s can be proposed for the three sequences (total width between T1.1 and Y1.1 : 42 ms).

Application of this velocity model results in almost perfect fit of T1 with the marine Landen Formation, as interpreted in the Ostend boring, and of T2-T3 with the overlying lagoonal to continental Landen Formation, a correlation which was already suggested by the seismic facies.

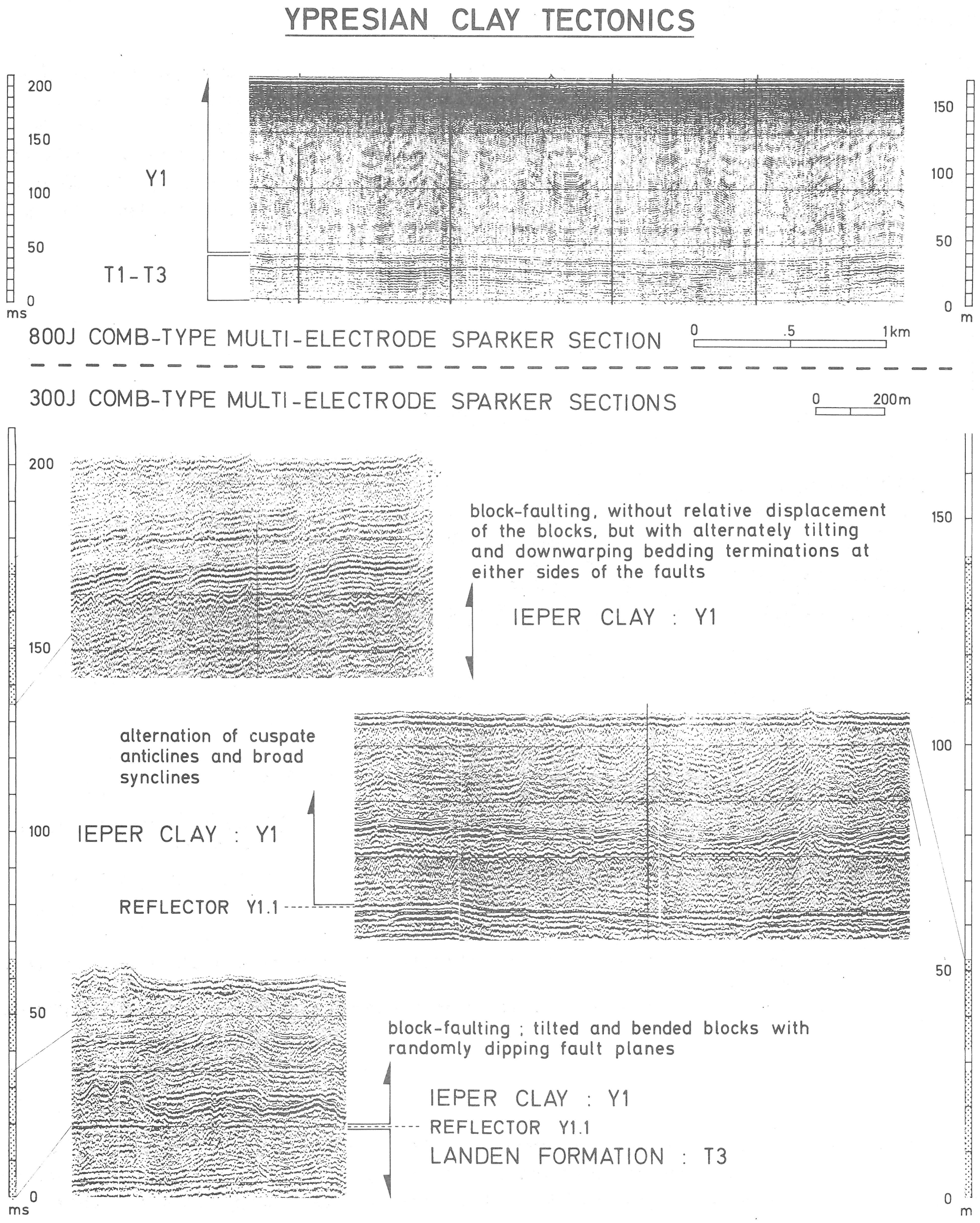


Figure 5 Analog record of a sparker sections showing Ypresian clay-tectonic features.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an interval velocity of 1620 m/s.

YPRESIAN

Y1

The next depositional sequence of major importance, Y1, is most probably entirely built up by the Flanders Clay. The Ypresian lithostratigraphic nomenclature used here is in accordance with STEURBAUT and NOLF (1986). This unit is more or less equivalent to the British London Clay. In field-geological and geotechnical use, it is also commonly referred to as Ieper Clay. Its upper boundary is formed by the distinct reflector Y2.1, one of the most significant seismic-stratigraphic markers of the entire Palaeogene in the Southern Bight of the North Sea.

The more or less homogeneous series of weak parallel reflections, typical for the seismic facies of this unit, might be partly caused by interference phenomena, from reflections at numerous laminae and thin beds of variable grain size and compaction characteristics.

The most striking features of this depositional sequence are beyond doubt the clay-tectonic deformations. These often show a remarkable vertical zonation (DE BATIST *et al.*, this volume). Some typical intervals are shown on figure 5. In some areas however the whole internal reflection pattern may become completely chaotic.

These deformations seem to be confined to the Y1-unit and gradually fade out into the overlying sediments. Their origin could be related to the compaction history of the Ieper Clay (HENRIET *et al.*, 1988).

There is no clear seismic evidence (e.g. diffractions) for the occurrence of septaria or concretions, such as those which have been described in the London Clay (HEWITT, 1982).

A typical reflector at about 8 ms above Y1.1 has been correlated with the Harwich stone band (Personal communication, B. D'OLIER), a hard horizon containing volcanic ash, which can be traced over much of the North Sea Basin and is considered by some authors to form the boundary between the Palaeocene and the Eocene (JACQUE and THOUVENIN, 1975).

Uphole shooting in boreholes in Belgium has yielded an average velocity of 1620 m/s for the Flanders Clay (HELDENS, 1983). The total thickness of the clay varies between 120-140 m in Northwest Belgium (in the Knokke boring BGD 11E-138 even 145 m) to 150 m in Southeast England. Y1's thickness on the Belgian continental shelf reaches about 170 m, when the considered velocity model is applied on a two-way reflection time of about 210 ms.

TRANSITION YPRESIAN-LUTETIAN

Off the Belgian coast, a complex group of depositional sequences heralds a distinct change in depositional circumstances, contrasting with the low-energy facies of the underlying Y1-unit. A peculiar geometry with ravinations and obliquely prograding bedding sets suggests some analogy with Late Ypresian and Lutetian units in Flanders (DE BATIST *et al.*, this volume).

Y2

The boundary Y2.1 between the Ieper Clay and Y2, the first of these depositional units, is locally marked by a weak downlap pattern. Its upper boundary is characterized by strong truncations. The total thickness of Y2 therefore is very variable. Some kilometres off the Belgian coast, it apparently has been entirely removed by erosion, leaving a basinlike depression.

Especially in the north two seismic facies units can be identified in Y2 : the aforecited lower downlapping unit (± 20 ms), apparently no longer affected by the underlying clay-tectonic deformations, and an upper one with a set of parallel reflections. This unit thins towards the south, due to erosional truncation.

Y3

The base of Y3 is formed by the northerly fading reflector Y3.1, defined by discrete baselap of internal reflectors and locally by truncation of reflectors of the underlying unit.

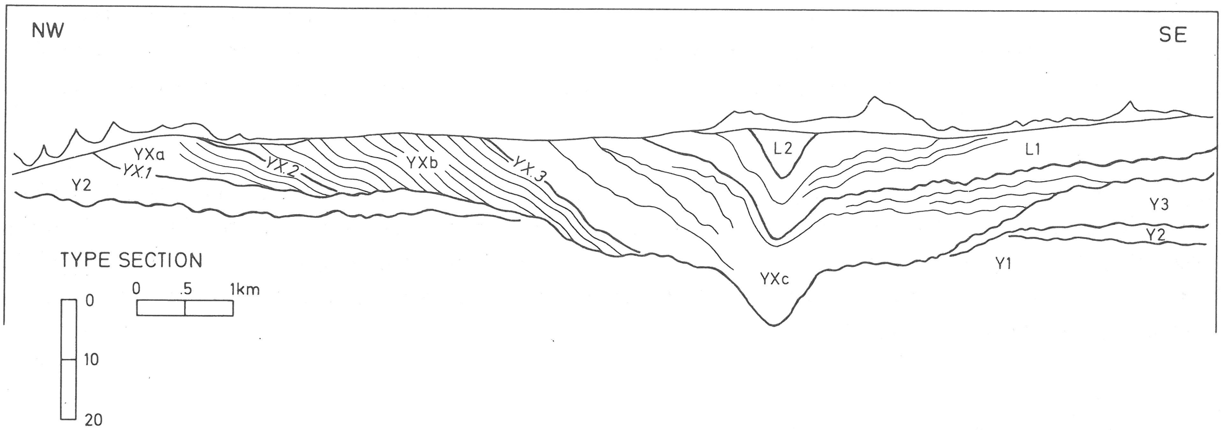
In the central part of the area, no distinction in seismic facies can be made between Y2 and Y3. Further south however, Y3 is characterized by a pattern of tangential oblique clinoforms, gently prograding towards the south.

In some areas off the Belgian coast the Y3-unit has been removed by erosion, but further to the north its thickness becomes constant.

YX

The overlying deposits of the YX-sequence seem to be confined to a basinlike depression, located about 20 km north of Ostend. The basal surface is penetrating into Y3, Y2 and even into the top of the Flanders Clay. Three subsequences can be identified in a prograding basin-fill configuration, respectively named YXa, YXb, and YXc (figure 6). Their detailed configuration is described by DE BATIST *et al.* (this volume).

Neither the exact shape of the erosive basin, obscured by a narrow synclinal fold (figure 6), nor its areal extent towards the east, where it plunges under younger Lutetian deposits, could be revealed yet. Some observations suggest a circular, rather than an elongated shape.



YPRESIAN BASIN-FILL SEQUENCES

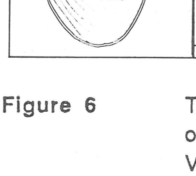
SCHEMATIC TYPE SECTION	DEPOSITIONAL SEQUENCES										
	NAME	BOUNDARY					THICKNESS			SEISMIC FACIES	LITHOSTRATIGRAPHIC CORRELATION
		NAME	TYPE	REFLECTOR DESCRIPTION			(ms) two-way time	Vi (m/s)	(m)	DESCRIPTION	
				AMPL.	CONT.	FREQ.					
	YXc						0-25	1700 ?	0-13	sigmoid or parallel oblique, prograding clinoforms of variable amplitude	Vlierzele Member (B)
		YX.3	baselap/toplap	variable	variable	medium					
	YXb						0-20		0-17	sigmoid or parallel oblique, prograding clinoforms of variable amplitude	
		YX.2	baselap/toplap	variable	variable	medium					
	YXa						0-15		0-21	sigmoid or parallel oblique, prograding clinoforms of variable amplitude	
		YX.1	baselap/truncation	variable	variable	medium					

Figure 6 Type section and seismic-stratigraphic sequence chart and correlation table of Ypresian basin-fill sequences off the Belgian coast.
Vertical scales in m are calculated with an average velocity of 1700 m/s.

LUTETIAN

L1

The base of the following depositional sequence, reflector L1.1, truncates all underlying units within 35 kilometres from the Belgian coast. Further to the north the gradual transition of Y2 into Y3 continues into L1.

Above the northern part of the erosive basin, the seismic facies of L1 is characterized by oblique, northeasterly prograding clinoforms, which laterally grade into parallel, even reflections.

L1's upper boundary, reflector L2.1, is marked by a toplap of the underlying oblique internal stratifications.

L2

The depositional sequence L2, overlying L2.1, is relatively homogeneous, although two main seismic facies units can be observed (figure 2).

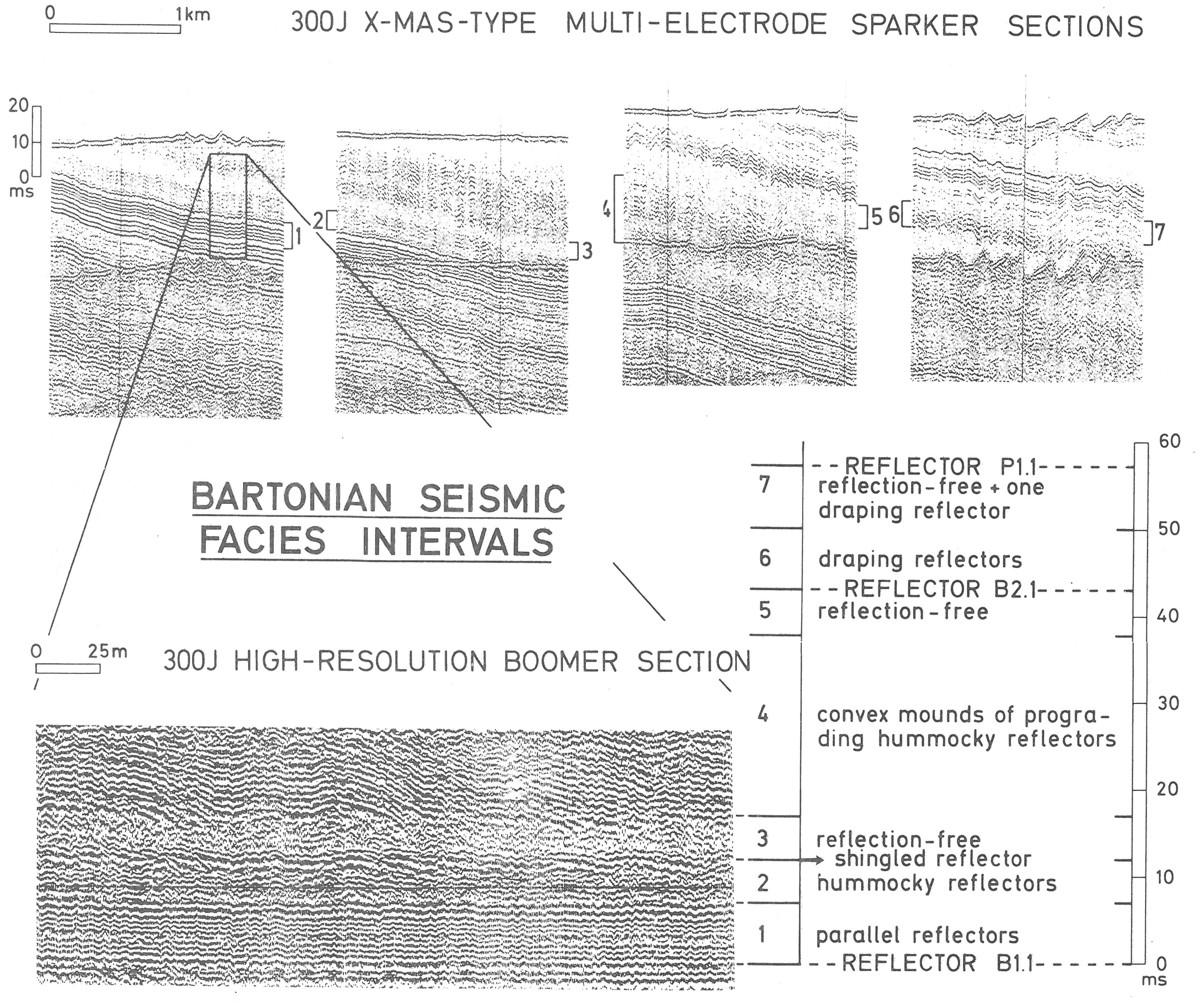


Figure 7 Analog record of a sparker and boomer sections showing 7 Bartonian seismic facies intervals. Vertical scales in ms are two-way time.

Two or three discontinuous but very strong reflectors, observed at the top of the upper seismic facies unit have been identified in a geological study for the Zeebrugge harbour extension (HENRIET *et al.*, 1981) as the glauconitic calcareous sandstone banks, which occur in the upper part of the Oedelem Member.

BARTONIAN

B1

A few milliseconds under the base of the following major sequence B1, a discrete unconformity can locally be observed in the best developed synclinal fold axes. This weakly truncating reflector is however of little interpretative use, especially by its very local character. For this reason, the first overlying continuous reflector has been taken as the lower boundary of B1, labeled B1.1. It has been correlated with the base of the Bartonian clays, the Asse Member, in the Zeebrugge harbour extension study (HENRIET *et al.*, 1978).

In B1 several seismic facies units can be identified (figure 7), probably reflecting the typical sand-clay alternation of the Bartonian Meetjesland Formation in Flanders (JACOBS, 1978).

A lower interval shows a very regular pattern of parallel reflections. By virtue of its lateral continuity and striking appearance, it forms an important seismic-stratigraphic guide. It is followed by an interval with a rather hummocky reflection pattern. On high-resolution profiles the top boundary of this interval displays a characteristic shingled configuration, built up of gently dipping, sigmoid segments prograding in eastnortheastern direction. Another almost reflection-free interval is overlain by a major sequence, showing pronounced prograding hummocky reflection configurations, terminated by convex downlaps on the reflection-free horizon. These moundlike piles of prograding reflections are followed by another reflection-free unit and are finally draped by a set of reflectors of the overlying sequence.

B2

The typically draped base reflector B2.1 of the second major Bartonian sequence B2 is locally marked by a low-angle downlap pattern.

Although lateral facies changes occur towards the northern part of the area, B2 can commonly be divided into two seismic facies units (figures 2 and 7).

The amplitude of the characteristic draping within B2 seems to be progressively decreasing towards the top of the sequence, fading out in the overlying unit. Such a phenomenon could find its origin in differential compaction processes.

PRIABONIAN

P1

The following depositional sequence, P1, has probably to be correlated with Priabonian (Tongrian) deposits (sands of the Zelzate Formation). It also consists of two seismic facies units.

The first unit is a series of parallel reflections, with a typical lateral variation in amplitude.

The second unit, also affected by lateral amplitude variations, has a very regular, homogeneous seismic facies.

RUPELIAN

R1

The R1-sequence is most likely to be correlated with the Rupelian sands (Berg Member).

Its lower boundary, reflector R1.1, is a weak erosion surface, best marked close to the Dutch coast, where it also forms the base of a discrete onlap pattern. Usually, however, little distinction can be made between the seismic facies of R1 and P1.

R2

The uppermost unit of the Palaeogene seismic-stratigraphic sequence can entirely be correlated with the Boom Member, the Rupelian clay deposit of major stratigraphic importance.

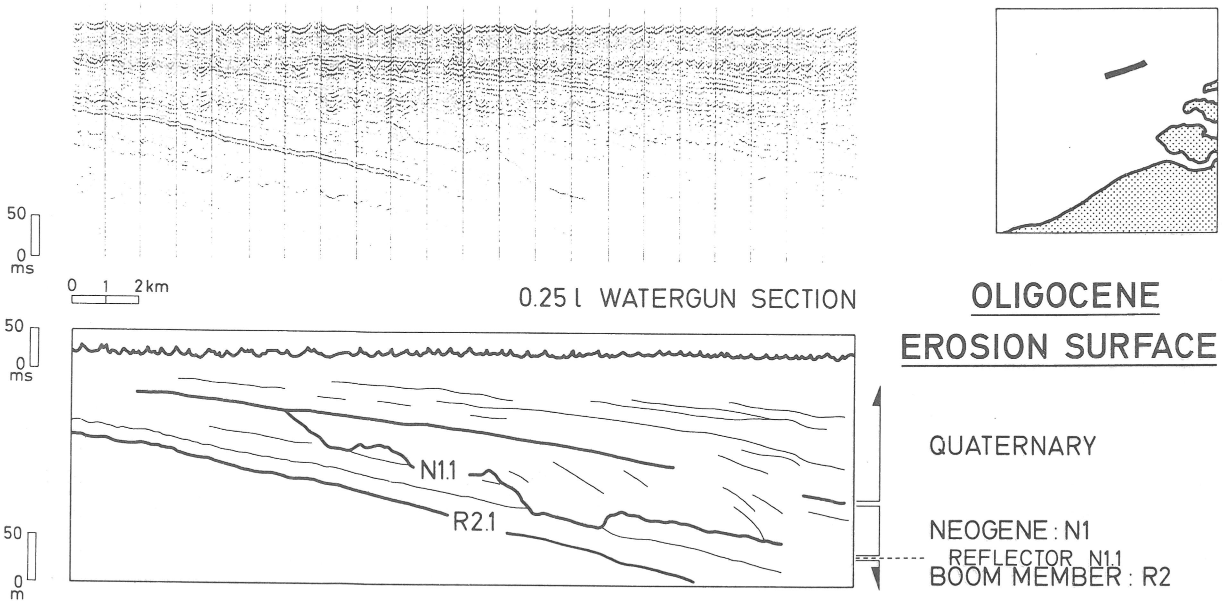


Figure 8 Analog record of a watergun section and interpreted line-drawing showing a Late Oligocene erosion surface on the Dutch continental shelf.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an average velocity of 1600 m/s.

The upper boundary of this unit is clearly defined by a remarkably well preserved erosion surface, with well-developed valley profiles (figure 8). It bears witness of the important Late Oligocene global sea level lowstand (VANNESTE, 1987), an estimated 250 m below present level (HAQ *et al.*, 1986). The freshness of this erosion profile suggests a rapid burial by the subsequent Neogene transgressions. The maximal observed width of R2 amounts to 120 ms.

The seismic facies of R2 is characterized by a very regular pattern of parallel reflectors. On very high-resolution sections, several of these horizons turn out to be built up of an alignment of diffraction hyperbolae (figure 9), each of them corresponding with the reflection at concretions or septaria, which are indeed frequently observed in the Boom Clay (VANDENBERGHE, 1974 ; VANDENBERGHE, 1978).

Up to 25 septaria levels could be identified by seismic reflection investigations on the Scheldt river, carried out for the pre-metro works and storm surge barrier project (HELDENS, 1983). The lowermost of these diffraction horizons has been taken as boundary reflector R2.1, since the base of the Rupelian clay, identified in boreholes a few metres underneath, does not show up as a reliable reflector.

Another striking feature of the Boom Clay is the occurrence of diapiric upwellings, as observed in the Scheldt estuary (figure 10). Such clay diapyrs have also been described on land by LAGA (1966). They are possibly caused by relaxation processes of underconsolidated sediments.

Detailed velocity analyses, carried out in the framework of the same site investigations in the Antwerp region, have provided an interval velocity for the Boom Clay of about 1620 m/s (SCHITTEKAT *et al.*, 1983). This low velocity could account for the distinct polarity change at the top of this sequence in the southern North Sea, where the clay is probably overlain by Pliocene and Pleistocene sands, having higher interval velocities. The important velocity pull-up of the internal B2 reflectors underneath the most important valley incisions (figure 9) also argues for such a velocity inversion.

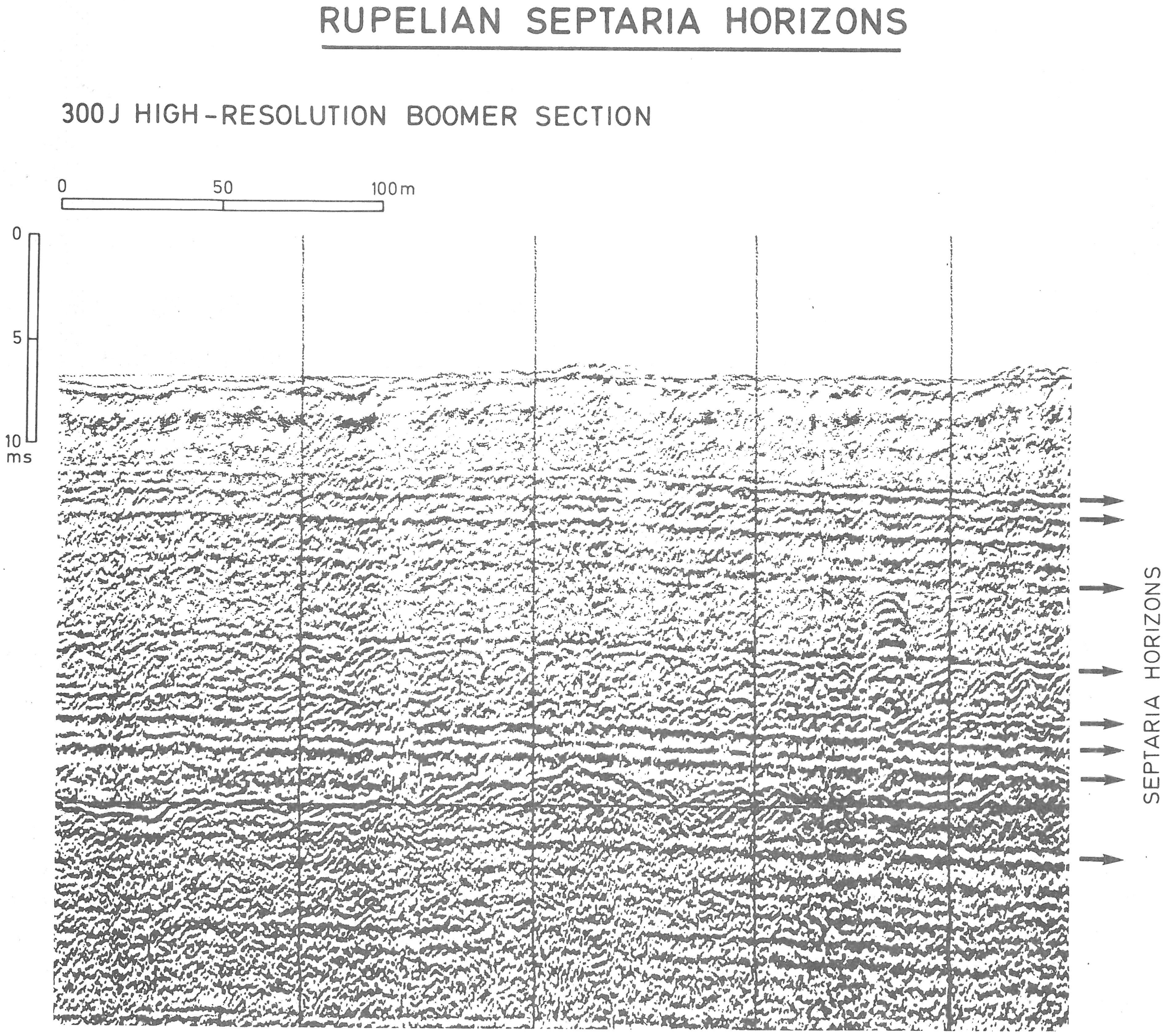


Figure 9 Analog record of a boomer section showing Rupelian septaria horizons on the Scheldt river. Vertical scales in ms are two-way time.

CONCLUSION

The detailed high-resolution reflection seismic mapping of the Southern Bight of the North Sea yields a new insight in the stratigraphic build-up of Palaeogene depositional sequences and in their spatial distribution patterns. Classic principles of seismic-stratigraphic analysis can be applied with success on these sequences, which often do not exceed a few tens of metres in thickness.

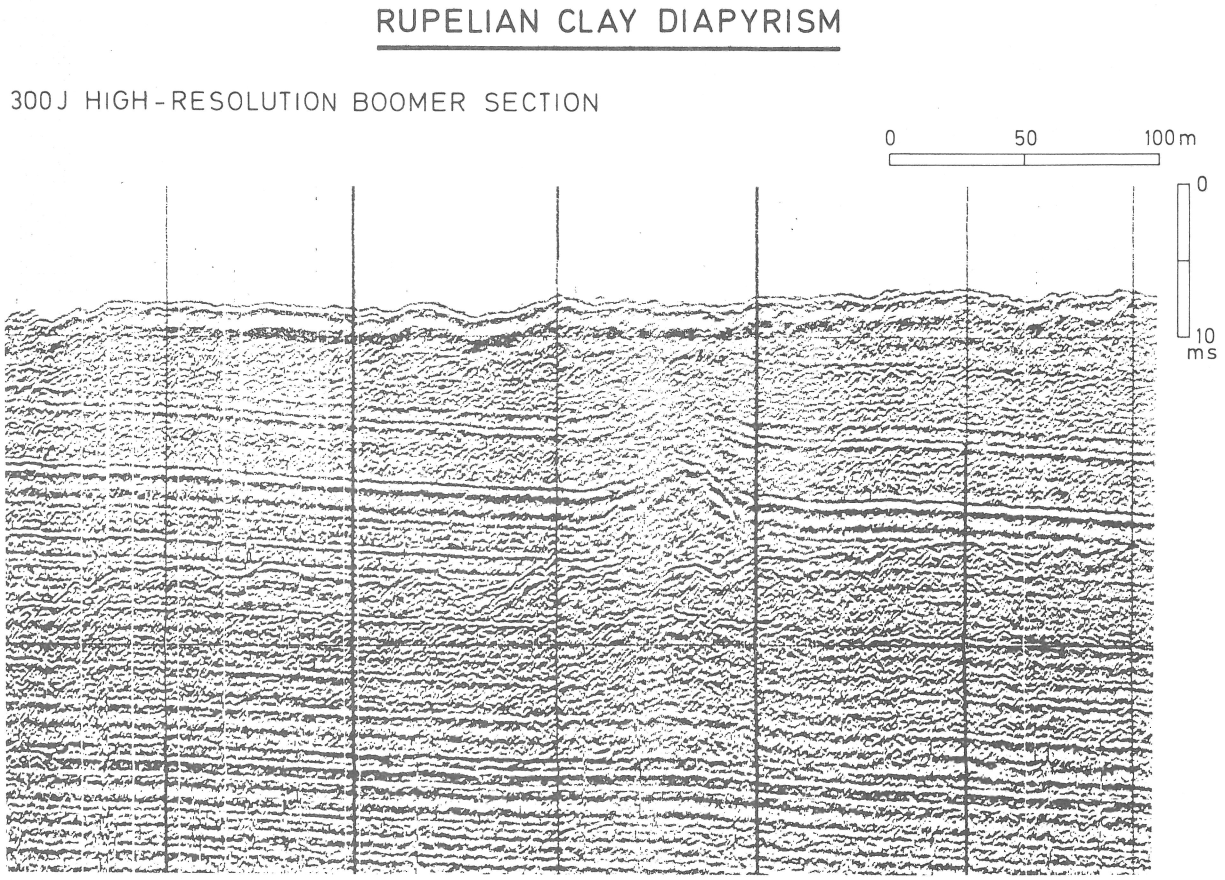


Figure 10 Analog record of a boomer section showing Rupelian clay diapirism on the Scheldt river. Vertical scales in ms are two-way time.

Many units display characteristic seismic facies features, which can be interpreted in terms of sedimentary environment and compaction history.

Correlation of this marine geophysical data base with more classic litho- and chronostratigraphic land observations should enhance our understanding of the Cenozoic geological setting and evolution of the southern North Sea.

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