# Sequence stratigraphy and architecture on a ramp-type continental shelf: the Belgian Palaeogene

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**Abstract:** In Palaeogene times, the 'Southern Bight' of the North Sea functioned as an intracratonic, shallow-marine, siliciclastic basin and accumulated a few hundred metres of gently dipping sediment packages. A fine-scale seismic-stratigraphical model for the Palaeogene was formulated on the basis of a dense, high-resolution reflection seismic grid. In total 13 major seismic-stratigraphical units were defined, based on geometry and seismic facies characteristics. The seismic stratigraphy has been complemented with the results of four cored wells near the Belgian coast, containing a nearly continuous, 200 m thick sediment succession of Eocene age. Facies analyses of these cores suggest that part of these sediments were deposited on a muddy shelf and part in a delta environment. Evidence from relevant onshore outcrops has been used to complete the geological history of the Palaeogene, with special emphasis on the Eocene. A sedimentation model for the Eocene is presented, and relative sea-level changes, regional tectonic events and changes in sediment input are discussed. Genetic interpretation of the various lithological units and the large-scale architecture of the ramp-type margin enable evaluation of sequence-stratigraphical concepts, initially defined for a typical shelf-slope–basin section along an Atlantic-type continental margin.

The concepts of sequence stratigraphy (Vail *et al.* 1977; Posamentier *et al.* 1988; Posamentier & Vail 1988; Van Wagoner *et al.* 1987, 1988) have initiated a tremendous 'revival' in stratigraphical research in the past decade, as they proved – or claimed – to be able to explain stratal geometries and facies distributions in an easy, logical way. They were originally developed for 'typical' Atlantic-type passive margin settings, characterized by clearly defined shelf, slope and basin-floor provinces, by moderate regional subsidence and by continuous sediment supply, and exposed to Mesozoic-type changes in relative sea level. Attempts to apply these concepts to various sedimentary basins around the world have shown that some of the variables that were kept simple in the original model (subsidence, sediment supply, autocyclic shifts of depocentre, tectonics, basin morphology, etc.) may exert a stronger than anticipated influence on the stratigraphical architecture.

In this study we use a dense grid of high-resolution reflection seismic profiles, offshore cores and nearby outcrop observations to establish the sequence stratigraphy and architecture of the Palaeogene – and the Eocene in more detail – in the northwestern part of the Belgian Basin (see also Vandenberghe *et al.* 1996), and to illustrate how the particular characteristics of this basin may impede 'blind' application of the 'simple' sequence-stratigraphical concepts.

## Geological setting

The 'Belgian Basin' (Fig. 1), a bight-like extension of the southernmost North Sea Basin, can be classified as an intracratonic basin in a ramp-type margin shelf setting. The basin developed on top of the London–Brabant Massif, a relatively stable continental block of Palaeozoic age that was not flooded before Late Cretaceous times and continued to shelter the area from strong subsidence throughout the Tertiary. The Cenozoic stratigraphical record consists almost completely of siliciclastic marine to marginal marine sediment series (Ziegler 1982). Throughout the Palaeogene, a shallow shelf environment persisted and the area was periodically flooded during periods of high relative sea level. Water depths during these highstand periods probably never exceeded 100 m as demonstrated by sedimentological and micropalaeontological studies of comparable deposits in the UK southern North Sea sectors (Cameron *et al.* 1992). During Thanetian and Ypresian times the shallow sea extended westwards, well into the English channel. The rising Weald–Artois High started to form a barrier closing the connection to the English Channel from Lutetian times onwards (Cameron *et al.* 1992) and possibly even earlier (Dupuis *et al.* 1984). The Neogene was a period of sediment starvation as the depocentre shifted even further northward into the main North Sea Basin (Balson 1989; Cameron *et al.* 1989). In

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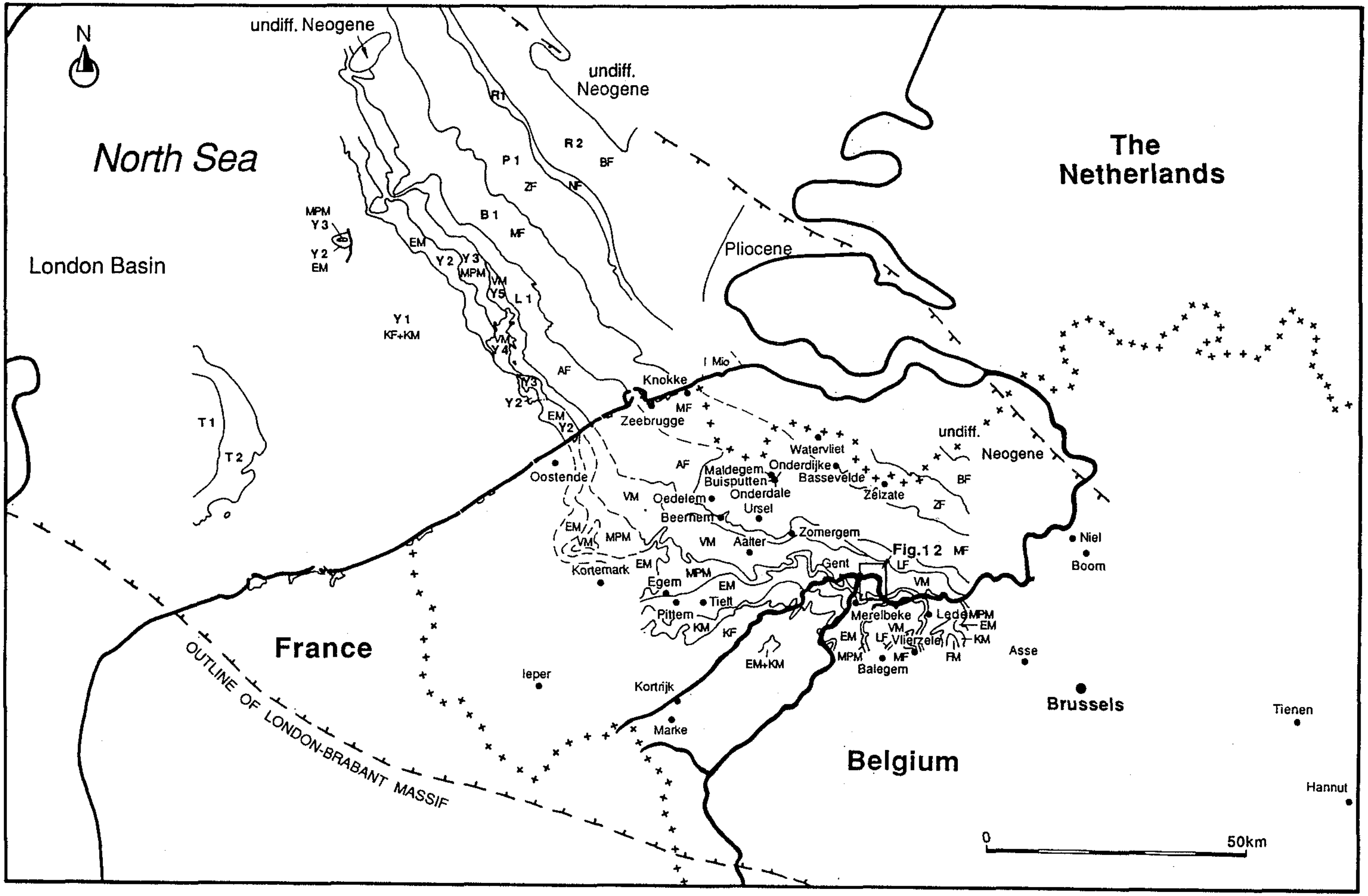


**Fig. 1.** Location of the study area in the southern North Sea Basin, and simplified geological map of the Belgian Basin showing the subcrop pattern of the Palaeogene offshore seismic-stratigraphical units and the onshore lithostratigraphical units beneath the Quaternary cover. All localities and type localities of lithostratigraphical units used in the text and the location of study area of Fig. 12 are indicated. KF: Kortrijk Formation; KM: Kortemark Member; EM: Egem Member; MPM: Merelbeke and Pittem Members; VM: Vlierzele Member; AF: Aalter Formation; MF: Maldegem Formation.

Quaternary times, the area emerged repetitively in response to glacio-eustatic sea-level falls. The Holocene flooded shelf has remained essentially sediment starved.

In the Belgian Basin, the Palaeogene strata onlap the Late Cretaceous chalk and dip less than 0.5% to the NNE. Offshore (Fig. 1), they crop out locally on the sea bed between the discontinuous sediment cover of the Quaternary 'Flemish Banks'. Onshore in northern Belgium (Fig. 1), numerous well-known outcrops of the parallel WNW–ESE-oriented strata exemplify the classic Lower Cenozoic geology of the Belgian Basin.

## Available data and stratigraphical framework

### *Offshore seismic stratigraphy*

A high-resolution reflection seismic grid with a total length of about 16 000 km has been acquired in the Belgian sector of the continental shelf and adjacent parts of the Dutch, French and UK sectors (between 51°–52° N and 2°–3.5° E) with a variety of different seismic tools (Fig. 2). Detailed interpretation following Mitchum *et al.* (1977), allowed De Batist (1989) and De Batist & Henriet (1995) to identify 13 seismic-stratigraphical units and a number of subunits within the Palaeogene succession. They have been labelled with a character-digit symbol, indicating their most probable chronostratigraphical position: T1 and T2 (Thanetian), Y1 to Y5 (Ypresian), L1 and L2 (Lutetian), B1 (Bartonian), P1 (Priabonian) and R1 and R2 (Rupelian). The main seismic-stratigraphical characteristics of these units are listed in Table 1 (from De Batist & Henriet 1995), and are illustrated on a synoptic seismic and schematic type section, constructed as a composite or 'collage' of several seismogram sections acquired with comparable source signatures (Fig. 3).

Unit boundaries are surfaces of consistent reflector termination. Downlap is frequently observed on the basal surfaces, whereas coastal onlap occurs only sporadically. Erosional truncation and valley incisions are common features at the top of the units, but the seismic data do not always provide sufficient arguments to characterize all of them as unconformities *sensu* Van Wagoner *et al.* (1988), i.e. surfaces of subaerial exposure and erosion and their correlative submarine surfaces of erosion. Most of the units have a pronounced sheet-like shape, with planar dipping boundaries at their base and top, and show only minor thickness variations. Each unit is also characterized by a distinct seismic facies and/or by typical facies variations, indicative for the depositional environment and its evolution.

The subcrop pattern of these units at the base of the Quaternary cover, where present, is shown on Fig. 1. The stratal relationships and geometries are illustrated by means of a number of interpreted line-drawings of seismic sections through the Belgian Basin (Fig. 4).

### *Offshore lithostratigraphy*

Four shallow cored boreholes were drilled in front of the Belgian coast, through the Quaternary drift into the Tertiary substratum: the GR1, SWB, SEWB and VR1 wells (Fig. 2). These boreholes provide the lithological and micropalaeontological data required to complement the geometrical information obtained from interpretation of the extensive seismic data base. The boreholes cut through a composite, 200 m thick, marine sediment series of Eocene age, roughly forming a SW–NE/S–N dip section from Oostende to north of Zeebrugge, and have been described in detail by Jacobs & Sevens (1993*a*), and Jacobs (1995*b*). Grain-size and sedimentary facies analyses, completed with sediment-genetic interpretations, were performed on these cores, which allowed the complete section to be correlated lithostratigraphically with equivalent sediment series onshore (Fig. 5). Biostratigraphy was established from samples from all four wells, and compared to the biostratigraphy encountered in nearby onshore wells 22W-276 and 11E-138 (King 1990; Steurbaut 1990). Calcareous microfossil conservation was poor because of secondary oxidation and reworking, but palynomorphs (Fig. 5) provided valuable indications on age (following reference zonations of Costa & Manum (1988), and Powell (1988)), and diatoms on palaeobathymetry and depositional environment.

### *Onshore lithostratigraphy*

The Palaeogene stratigraphy of onshore northwestern Belgium was established by Rutot (1882, 1883), Mourlon (1888), Vandenbroeck (1893) and Leriche (1912, 1922), and also by Gulinck (1965, 1969*a*; *b*). In more recent years, detailed outcrop and borehole studies added to the knowledge of the classic Palaeogene stratigraphy of Belgium: the stratigraphy of the Lower Eocene was revised by Steurbaut & Nolf (1986), the transitional layers between the

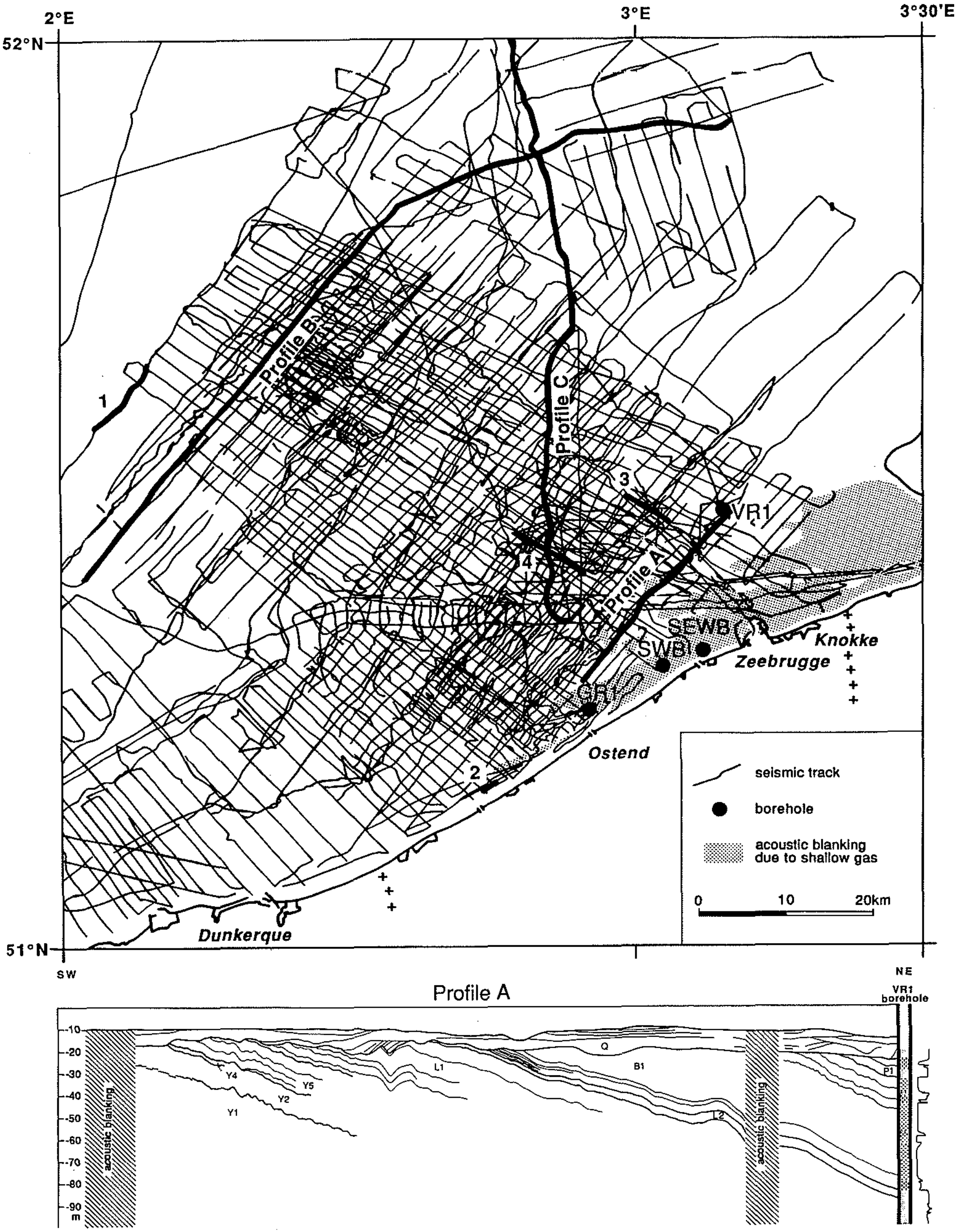


**Fig. 2.** Location of the available high-resolution reflection seismic grid and of the four cored boreholes GR1, SWB, SEWB and VR1. Also indicated are the locations of the interpreted line-drawings of profiles B and C (Fig. 4) and of the seismic profiles shown in the text: 1 = Fig. 7; 2 = Fig. 9; 3 = Fig. 11 and 4 = Fig. 14. Interpreted line-drawing of profile A through borehole VR1, showing the correlation of the seismic-stratigraphical units with the litho-units encountered in the core.

**Table 1.** *Seismic-stratigraphical characteristics of the Palaeogene in the offshore Belgian Basin (from De Batist & Henriet 1995)*

| Unit | Nature of base | Nature of top | Seismic facies | Geometry |
|---|---|---|---|---|
| R2 | Conformity | Erosional truncation channel incision | Regular pattern of continuous, parallel, high- to medium-amplitude reflectors | Planar dipping base; strongly incised & channelized top<br>Thickness: 0–60 m ($v = 1650\,\mathrm{m\,s^{-1}}$) |
| R1 | Discrete downlap | Discrete truncation | Discontinuous, subparallel to wavy reflectors with variable amplitude | Planar dipping base; planar dipping top<br>Thickness: ±35 m ($v = 1700\,\mathrm{m\,s^{-1}}$) |
| P1 | Discrete onlap | Discrete truncation | Vertical succession of two seismic facies units:<br>(2) homogeneous pattern of continuous, parallel, low- to middle-amplitude reflectors<br>(1) continuous, parallel, draping reflectors of variable amplitude | Planar dipping base; planar dipping top; divergent to NE<br>Thickness: 40–90 m ($v = 1700\,\mathrm{m\,s^{-1}}$) |
| B1 | Conformity | Conformity | Vertical succession of seven seismic facies units:<br>(7) reflection-free with a low-amplitude, discontinuous, draping reflector<br>(6) medium-amplitude, draping reflectors<br>(5) reflection-free<br>(4) convex mounds of medium-amplitude, prograding, hummocky reflectors<br>(3) reflection-free<br>(2) subparallel reflectors with shingled reflector on top<br>(1) regular set of continuous, parallel, high-frequent reflectors | Planar dipping base;<br>Planar dipping top;<br>Thickening to N and NE<br>Thickness: 45–60 m ($v = 1580\,\mathrm{m\,s^{-1}}$) |
| L2 | ? | ? | ? | Local distribution, very thin |
| L1 | Conformity | Tectonically influenced truncation | Vertical succession of two seismic facies units<br>(2) discontinuous, parallel to subparallel reflectors of variable amplitude; towards the top 2 or 3 discontinuous, subparallel, very high-amplitude reflectors<br>(1) 2 continuous, high-amplitude parallel reflectors, in the S and 3rd discontinuous, low-amplitude reflector | Planar dipping base:<br>Planar dipping top:<br>Thickness: 25–30 m ($v = 1700\,\mathrm{m\,s^{-1}}$) |
| Y5 | Downlap | Truncation and toplap | Three seismic facies units of local areal extent<br>(3) low-amplitude, parallel reflectors<br>(2) parallel-oblique clinoforms<br>(1) reflection-free | Planar dipping base; planar dipping top;<br>Wedge shape, pinching out towards N<br>Thickness: 0–17 m ($v = 1700\,\mathrm{m\,s^{-1}}$) |
| Y4 | Downlap | Truncation | Three SE prograding subunits with sigmoidal to parallel-oblique clinoforms of variable amplitude | Linear channelized base; planar dipping top; channel-fill shape (10 km wide, N70° E orientation) |
| Y3 | Discrete downlap | Truncation | Low-amplitude, discontinuous, parallel reflectors or parallel-oblique clinoforms | Planar dipping base; planar dipping top, locally channelized<br>Thickness: 0–25 m ($v = 1600\,\mathrm{m\,s^{-1}}$) |

**Table 1.** *Continued*

| Unit | Nature of base | Nature of top | Seismic facies | Geometry |
|---|---|---|---|---|
| Y2 | Downlap | Truncation | Reflection free or very low-amplitude, parallel-oblique, prograding clinoforms | Planar dipping base; planar dipping top<br>Thickness: ±30 m ($v = 1750\,\mathrm{m\,s^{-1}}$) |
| Y1 | Conformity | Discrete truncation | Low-amplitude, discontinuous, parallel reflectors, affected by intraformational deformations:<br>top part: undisplaced, faulted blocks with alternately tilting and downwarping bedding terminations<br>central part: major tilted blocks, convolute structures with broad synclines and cusp anticlines, diapirs<br>lower part: block-faulting, tilted and bent blocks, randomly dipping fault planes | Planar dipping base; planar dipping top; thickening to NE<br>Thickness: 150–180 m ($v = 1620\,\mathrm{m\,s^{-1}}$) |
| T2 | Downlap | Truncation | Oblique or shingled clinoforms and low-amplitude, discontinuous, subparallel or hummocky reflectors; incised channels at base and at some metres above base | Planar dipping base, locally channelized: planar dipping top<br>Thickness: 15–20 m ($v = 1800\,\mathrm{m\,s^{-1}}$) |
| T1 | Onlap | Truncation | Few parallel reflectors of variable amplitude, separated by reflection-free intervals | Irregular base (erosional surface): planar dipping top<br>Thickness: 15–30 m ($v = 1800\,\mathrm{m\,s^{-1}}$) |

Eocene and the Oligocene by Jacobs (1975, 1978) and the Oligocene by Vandenberghe (1978) and by Vandenberghe & Van Echelpoel (1987). The present knowledge of the Palaeogene lithostratigraphy (Fig. 6) was summarized by Maréchal & Laga (1988) with contributions from various authors.

## Palaeocene

In the following sections, the geometry and stratigraphy of the Palaeogene in the Belgian Basin based on offshore and onshore seismic, core and outcrop data are discussed. A summary of the seismic data and lithostratigraphy is given in Fig. 6.

### *Thanetian*

Offshore, the oldest stratigraphical unit of Palaeogene age is the shallow-marine Hannut Formation, equivalent to seismic-stratigraphical Unit T1 of De Batist & Henriet (1995). It is separated from the underlying Late Cretaceous chalk by a pronounced regional onlap surface. Seismic profiles show this erosional surface to be smooth and nearly parallel to the reflectors in the underlying chalk in most of the Belgian Basin. In the extreme west, however, in the prolongation of a major SW–NE-trending structural lineament (the 'North Hinder Deformation Zone' of De Batist 1989), Thanetian palaeohighs delineated by onlap terminations correspond to anticlinal structures (Fig. 7) trending N70° E to N95° E. Unit T1's seismic facies consists of few parallel reflectors of variable amplitude, separated by reflection-free intervals. These are interpreted as the alternations between clay layers and glauconitic fine sands that characterize the Hannut Formation.

It is overlain by the Tienen Formation (seismic-stratigraphical Unit T2 of De Batist & Henriet (1995)), which is known to consist onshore of a variety of continental, fluvial and lagoonal facies (Leriche 1928; De Geyter 1981; Laga & Vandenberghe 1990). On some offshore seismic sections distinct channel cut-and-fill structures can be observed at the base of the unit (Fig. 8; see also De Batist & Henriet (1995, Fig. 9)) and sometimes also at some metres above the base, thus locally defining two erosional surfaces. A tectonic origin for these

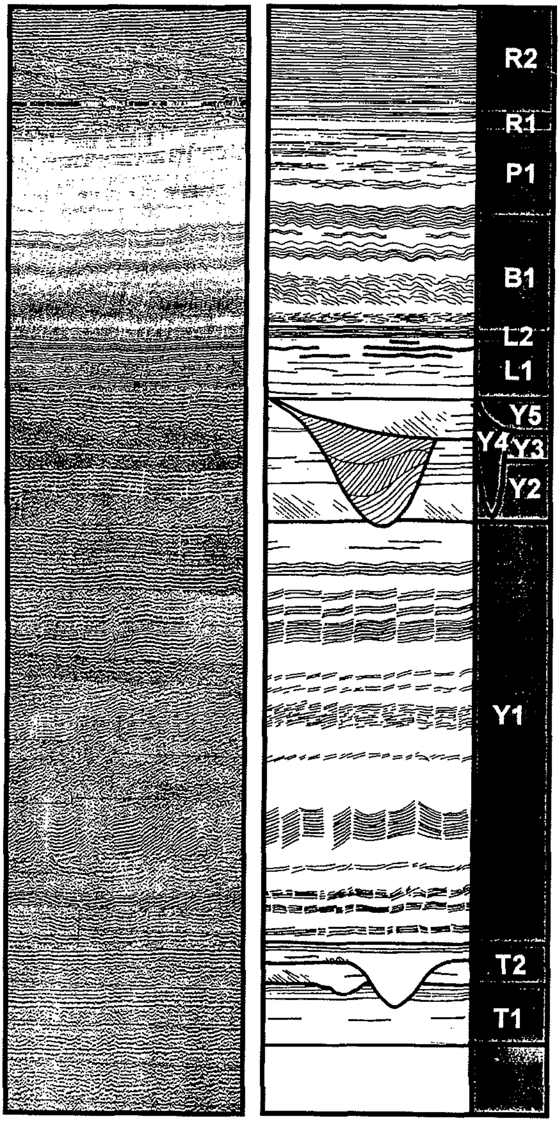


**Fig. 3.** Synoptic seismic type section, constructed as a composite or 'collage' of several seismogram sections acquired with comparable source signatures, and a synoptic line-drawing illustrating the most important seismic-stratigraphical characteristics of the Palaeogene in the offshore Belgian Basin.

incisions, possibly related to a first phase of updoming of the Weald–Artois High southwest of the study area, is very likely. Unit T2's seismic facies is characterized by oblique or shingled clinoforms and low-amplitude, discontinuous, subparallel or hummocky reflectors. All seismic characteristics suggest that the Tienen Formation is present offshore in its fluvial facies.

## Eocene

### *Ypresian*

The oldest stratigraphical unit of Eocene age in the Belgian Basin consists of the 'Ieper clay', which includes the Kortrijk Formation and the Kortemark Member of the Tielt Formation. It is

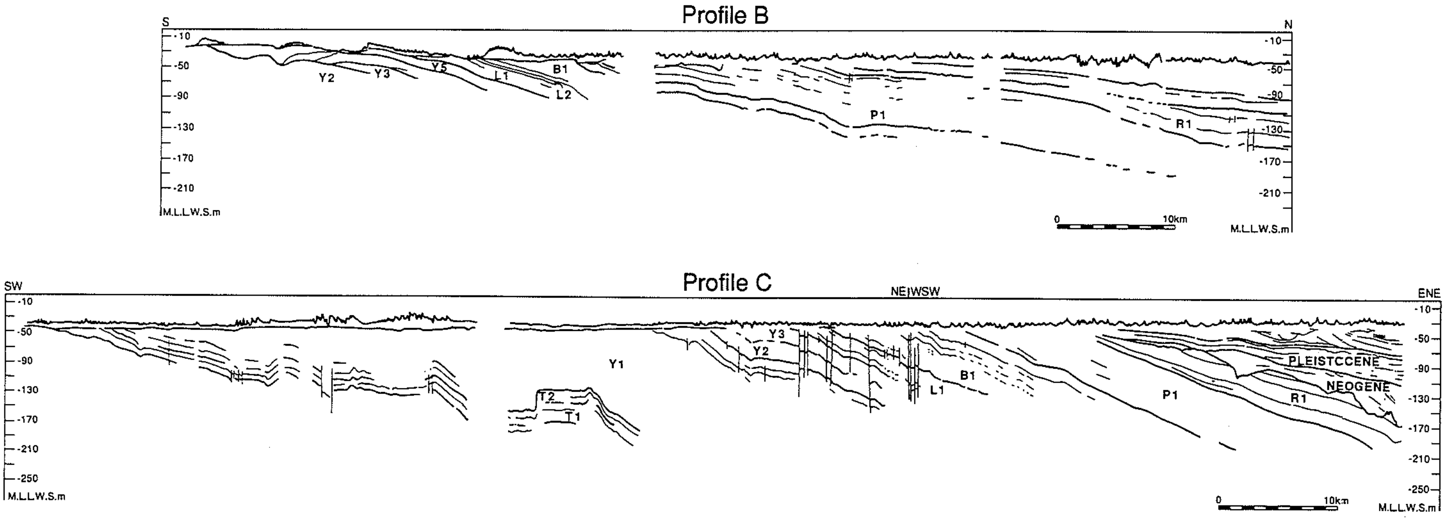


**Fig. 4.** Interpreted line-drawings of selected seismic sparker profiles through the offshore Belgian Basin illustrating some of the stratal relationships and geometries. Note the limited depth information (max. 100 m), which is due to the type of seismic source and receiver used during acquisition and to the occurrence of a strong sea-floor multiple. See Fig. 2 for location.

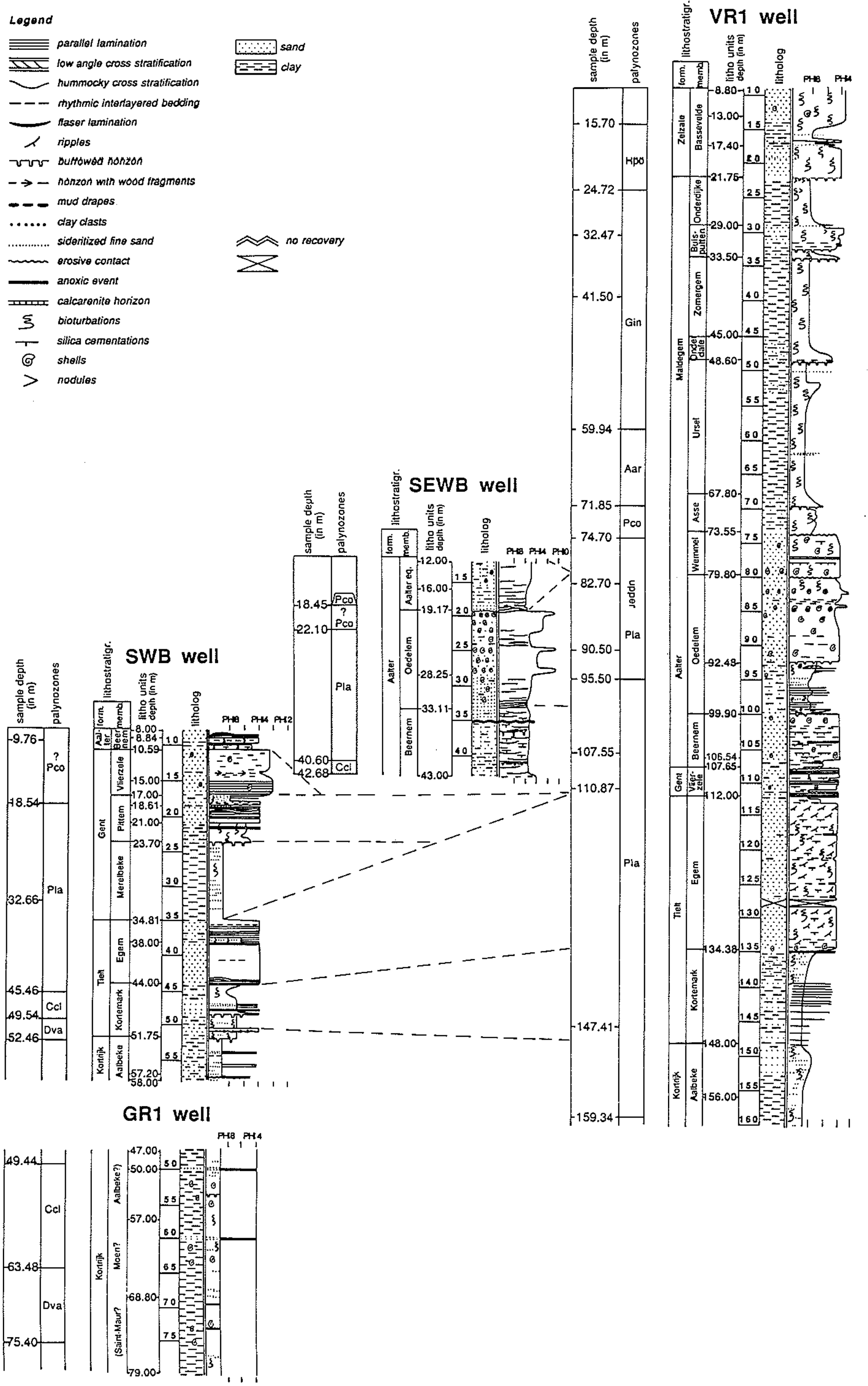


**Fig. 5.** Composite litholog of the offshore boreholes GR1, SWB, SEWB and VR1, with correlation of identified litho-units. See Fig. 2 for location.

equivalent to seismic-stratigraphical Unit Y1 of De Batist & Henriet (1995) and largely correlates with the London Clay Formation of southern England. Owing to its thickness of more than 150 m its outcrop dominates the geological map, both offshore and onshore. Seismic-stratigraphical Unit Y1 is characterized by a homogeneous seismic facies of low-amplitude, discontinuous,

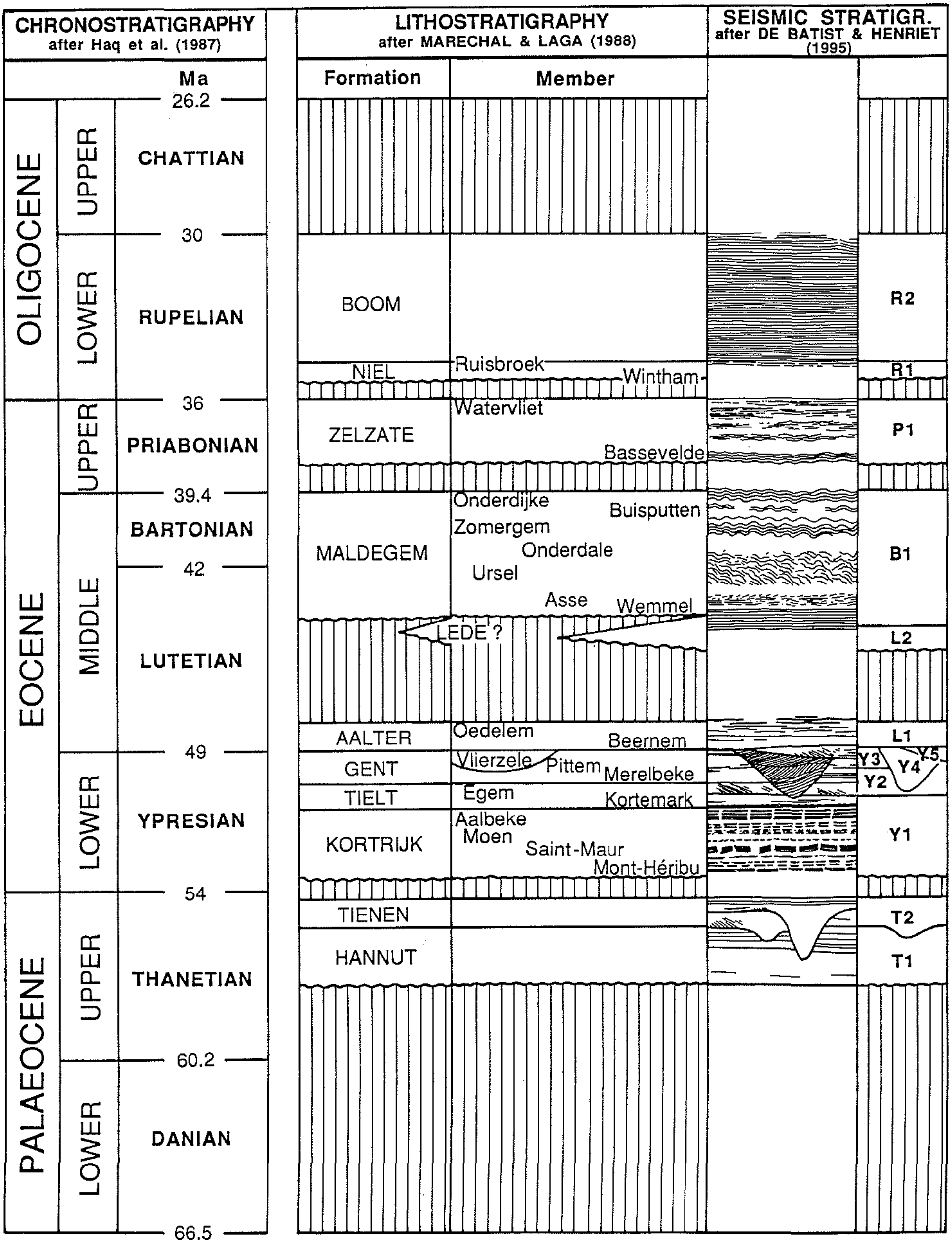


**Fig. 6.** Synoptic chrono-litho-seismic-stratigraphical correlation diagram for the offshore and onshore Belgian Basin.

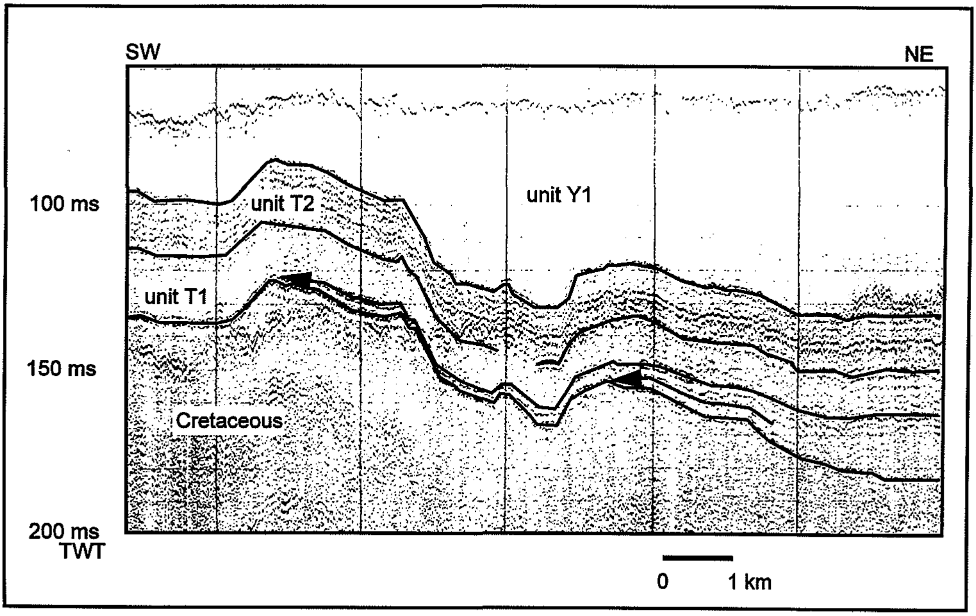


**Fig. 7.** Interpreted sparker profile showing the characteristic basal onlap on seismic-stratigraphical Unit T1 (Hannut Formation) against the structurally controlled palaeomorphology at the top of the Cretaceous chalk. See Fig. 2 for location.

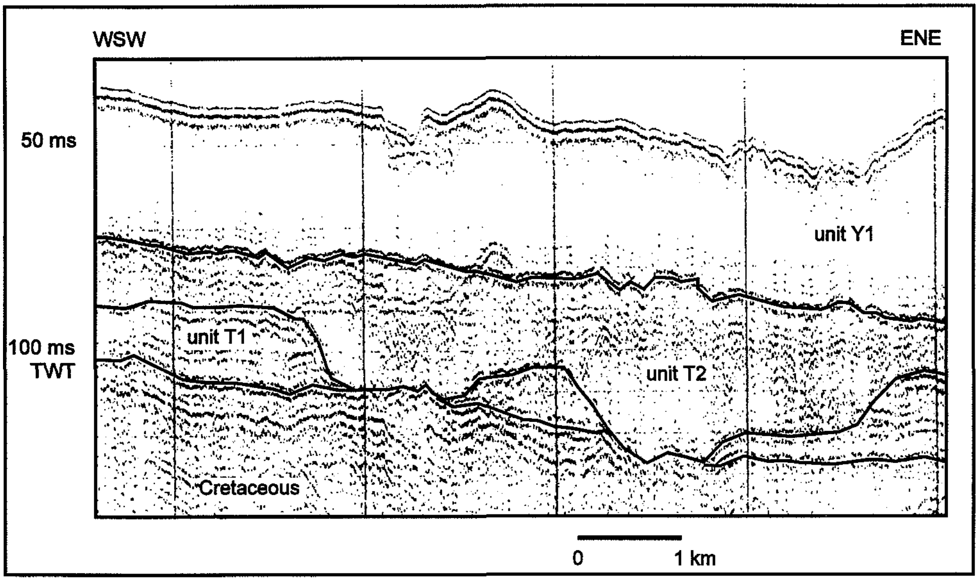


**Fig. 8.** Interpreted sparker profile showing the channel cut-and-fill structures at the base of seismic-stratigraphical Unit T1 (Tienen Formation). Location is at about 51°47′ N–01°46′ E, just outside Fig. 2.

parallel reflectors, suggesting a relatively long period of stable, low-energy depositional environments. In cores, the massive green-grey clay that makes up most of the Kortrijk Formation is interpreted to be deposited in a mud-shelf environment below storm-wave base, characterized by very low sediment accumulation rates of about 1.5 cm ka$^{-1}$ (Jacobs & Sevens 1988).

In the 'homogeneous' clay section of the GR1 well, submicroscopical clay-particle orientations indicate transgressive and regressive trends (Van Bavinchove, pers. comm.). During a transgressive phase the depositional environment deepens, causing a migration of the anaerobic environment towards the coast. This results in a progressive transition from an aerobic over a dysaerobic towards an anaerobic environment, accompanying a vertical change in clay texture from a disturbed (through bioturbation) and random orientation of the clay particles, over an undisturbed but preferential orientation towards a laminated and preferential orientation. The colour of the clay gradually becomes darker. This process reverses during a regression (O'Brien & Slatt 1990).

A dark, organic-rich clay layer in the GR1 well marks an anoxic event representing a condensed section. This is also documented by the submicroscopical texture that reveals the clay particles to be very well parallel-oriented, which is due to very low sedimentation rates and absence of bioturbation with reduced detrital sediment supply but high organic material deposition (Van Bavinchove, pers. comm.). Organic-rich laminae present in the GR1 well are most probably related to peak discharge of rivers. Bioturbated horizons indicate short periods of non-deposition or sediment reworking (hiatus).

In the upper part of the 'Ieper clay' section in the VR1 well, stratigraphically equivalent with the Kortemark Member, centimetric, fining upward, yellowish, silty sand laminae with sharp lower and upper boundaries point to increasing storm influence. They consist almost entirely of early-diagenetic authigenic botryoidal and framboidal siderite in a poor clay matrix (Van Bavinchove, pers. comm.), formed shortly after burial and before compaction, just beneath the zone of bacterial sulphate reduction. The

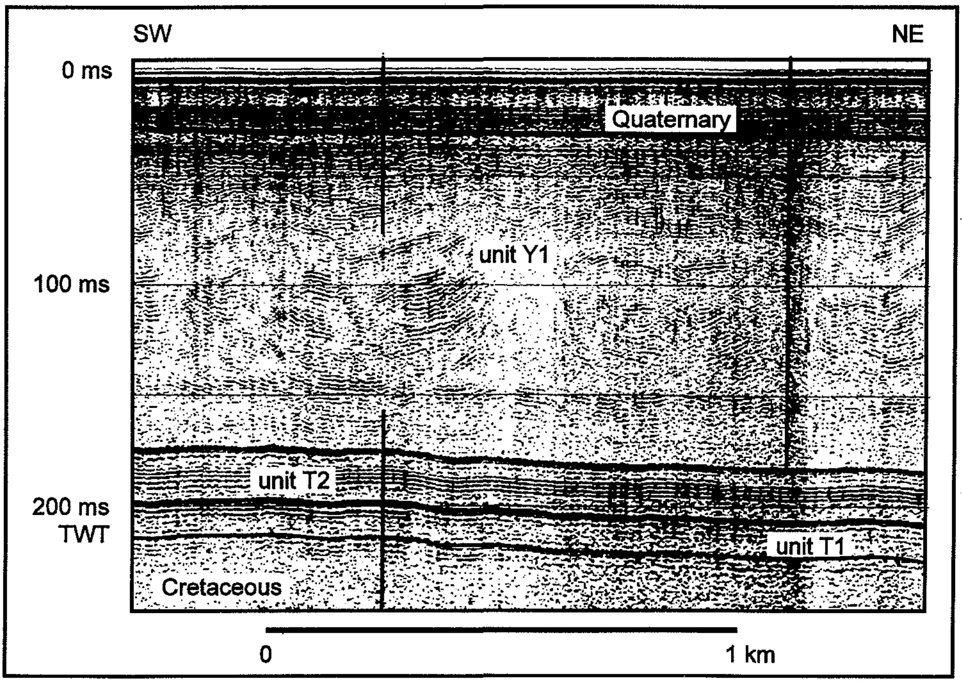


**Fig. 9.** Interpreted sparker profile off the Belgian coast showing the disturbed seismic facies of seismic-stratigraphical Unit Y1 (Kortrijk Formation) due to the presence of intraformational 'sediment tectonic' deformations. See Fig. 2 for location.

occurrence of slightly higher-amplitude reflectors at the top of Unit Y1 could be the seismic expression of this.

Palaeowater depths of the 'Ieper clay', based on palynomorph Dva to Ccl zones, range from 20–40 m at the base to 20 m at the top, while diatoms indicate that the depositional environment varies from oxygen-depleted central shelf through inner shelf with less salinity to coastal and inner shelf.

In the Kortrijk Formation section present in the GR1 and SWB wells, a stacked pattern can be discerned in a total of four fining upward clayey litho-units of overall transgressive nature. They are capped by one coarsening upward regressive litho-unit, consisting of sandy clay with burrows at the top, and by a sharp-based bioturbated silty to fine-sandy clay unit with centimetric silty sand lenses (Jacobs *et al.* 1990; Jacobs & Sevens 1993*a*; Jacobs 1995*b*). These litho-units cannot be identified on the seismic sections of Unit Y1, because the internal reflection pattern is strongly disturbed by a wide range of post-depositional, compaction-related intraformational 'sediment tectonic' deformations (Fig. 9), including faulting, clay diapirism, etc. (Henriet *et al.* 1988, 1991). Some of these structures can also be observed in onshore clay quarries (Verschuren 1992).

The 'Ieper clay' is overlain by the Egem Member of the Tielt Formation. This Egem Member is equivalent to the seismic-stratigraphical Unit Y2 of De Batist & Henriet (1995). The boundary between Y1 and Y2 is a laterally continuous, very high-amplitude reflector (see Fig. 3) throughout the Belgian Basin (De Batist *et al.* 1989). Based on its seismic characteristics it is interpreted as a sequence boundary overlain by downlapping lowstand deposits with reflection-free or very low-amplitude, parallel-oblique, prograding clinoforms. In the offshore boreholes, the Egem Member consists of sharp-based, glauconitic, bioturbated fine sands with low-angle cross-bedding and fine laminations, ripples and flaser lamination (mud drapes) indicative of a deltaic origin with a southern sediment supply (Jacobs *et al.* 1990; Jacobs & Sevens 1993*a*; Jacobs 1995*a*, *b*). Figure 10 shows some aspects of the sedimentary facies of the Egem Member in its type locality. Here, a 20 cm thick silica-cemented clayey sand layer with shell ghosts occurring at the top of the Egem sands, displays at its surface polygonal desiccation cracks, filled in with clay and iron coatings. This surface is interpreted to

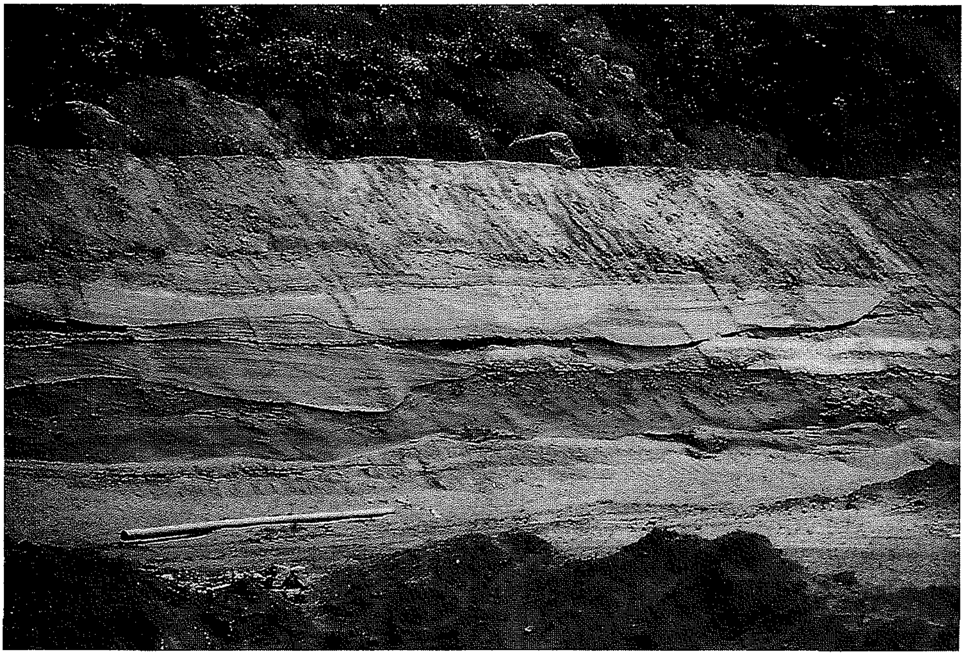


**Fig. 10.** Flat-bottomed erosion gullies of deltaic origin in the Egem Member (seismic-stratigraphical Unit Y2) visible in the Egem quarry.

indicate subaerial exposure (top lowstand deposits), as it is covered with abundant and coarse authigenic glauconite, probably representing a lateral time equivalent of the (transgressive) Merelbeke clay, that is absent in the Egem outcrop.

Seismic-stratigraphical Unit Y3 of De Batist & Henriet (1995) corresponds to the Merelbeke Member (at the base) and the Pittem Members (at the top), which are both part of the Gent Formation. Low-amplitude, discontinuous, parallel reflectors or parallel-oblique clinoforms characterize this Unit Y3. Facies and palaeobathymetry analyses performed on the offshore cores indicate that the sedimentary environment deepens up to a nearshore mudshelf (15 m palaeowater depth tending towards 20 to 30 m). In the SWB well, the strongly bioturbated transgressive Merelbeke silty clay with thin sand laminae is heavily burrowed at the top and truncated, suggesting delta-complex influence (Jacobs & Sevens 1993*a*; Jacobs 1995*b*). It is overlain by the bioturbated, sandy clay Pittem Member with mud drapes, rhythmic interlayered bedding, shell clasts and local silica cementations. The Pittem Member is interpreted to be deposited in a tidal environment during relative sea-level highstand, although palaeowater depths of palynomorph Pla zone seem to increase (reworking?), but salinity decreases and continental influx becomes prominent.

Seismic-stratigraphical Unit Y4 of De Batist & Henriet (1995) is confined to an erosional depression (channel or basin?), trending N70° E, some 20 km N off Oostende. It is locally more than 10 km wide and deeply incised in the underlying strata. On seismic sections, Unit Y4 displays three infilling stages by subunits composed of sigmoidal to parallel-oblique clinoforms of variable amplitude, prograding from NW to SE (Fig. 11). This seismic unit most likely correlates with a basal part of the Vlierzele Member, which is part of the Gent Formation. This interpretation is supported by comparable erosional features at the base of this Vlierzele Member onshore, as observed by Birchall (pers. comm.) (Fig. 12), who interpreted them as caused by valley incision in response to falling relative sea level.

Seismic-stratigraphical Unit Y5 (De Batist & Henriet 1995), separated from Unit Y4 by a sharp erosion surface, rapidly pinches out in the offshore direction (Fig. 11). A number of different facies subunits of local areal extent can be identified within this unit. Some consist of low-amplitude parallel reflections; others of eastward prograding parallel-oblique clinoforms; some are reflection-free. Unit Y5 probably correlates with the cross-bedded sands of the Vlierzele Member, which have been described onshore in several outcrops and that have been interpreted as a tidal ridge system (Houthuys 1990).

In the offshore borehole SWB, the Vlierzele Member is present in its typical facies, as green glauconitic fine sands with low-angle parallel lamination and belonging to palynomorph Pla or ?Pco zone. Wave-influenced sand shoals characterized by thin brown sand laminae and a brown clayey matrix in the top zone are indicative of an intertidal depositional environment transitioning into a supratidal environment. Organic debris and wood fragments are probably remnants of reworked soils and

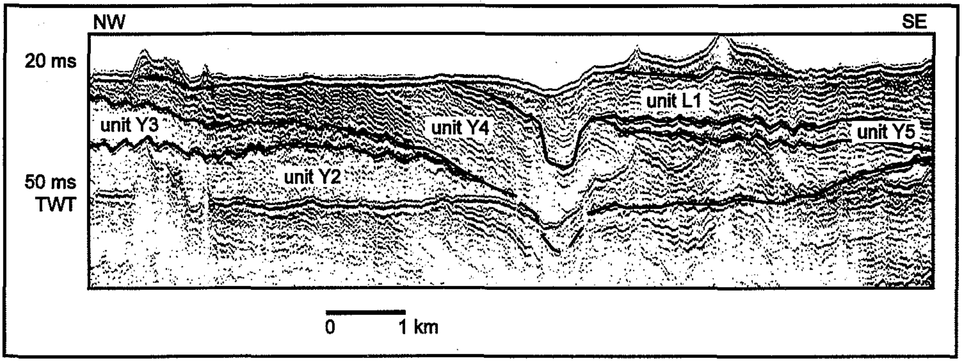
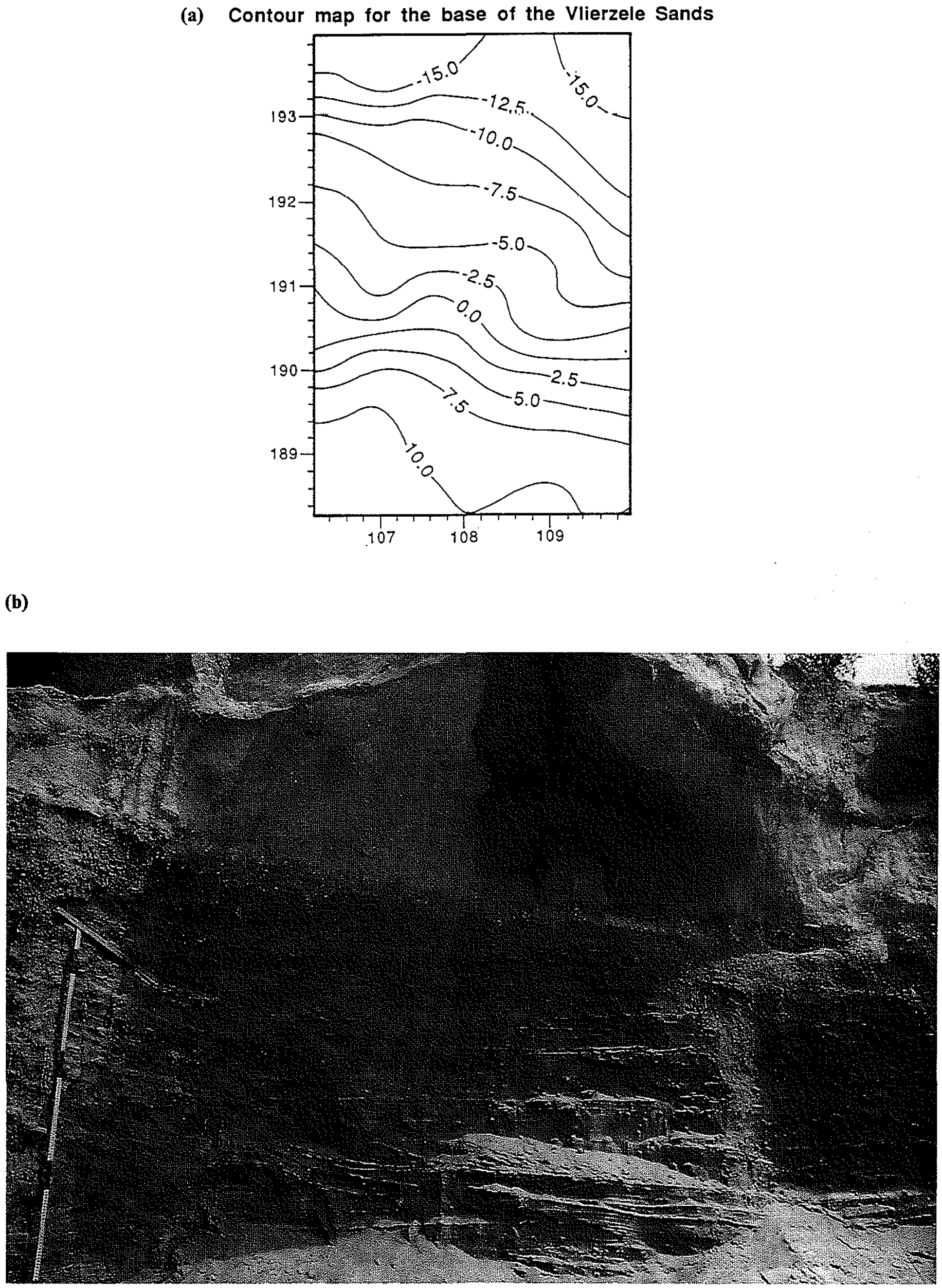


**Fig. 11.** Interpreted sparker profile showing the truncation associated with the erosional bases of seismic-stratigraphical Units Y4 and Y5 (Vlierzele Formation) and the progradational seismic facies of these units. Note that the shape of the erosional basin or channel of Unit Y4 is obliterated on this profile by a synclinal fold affecting these strata. See Fig. 2 for location.



(a) Contour map for the base of the Vlierzele Sands

(b)

**Fig. 12.** (**a**) Isohypses of the erosional base of the Vlierzele Member suggest local valley incision in response to falling relative sea level (after R. Birchall, pers. comm.). For location of study area, see Fig. 1. Lambert coordinates are indicated. (**b**) In the Balegem quarry, valley infilling is documented by green glauconitic fine sands with low-angle parallel lamination of the Vlierzele sands Member litho-unit (seismic-stratigraphical Unit Y4).

vegetation in the vicinity, suggesting emersion. The time-equivalent facies in the VR1 well is more clayey and deposited on the central (to outer?) shelf with an oxygenated bottom under 40 m palaeowater depth. The three coarsening upward cycles suggest transition from a lagoonal environment towards a minor mouthbar or crevasse splay deposition in a deltaic (delta plain) environment. At present, it remains unclear which seismic-stratigraphical unit (Y4 or Y5?) is represented as the Vlierzele Member in these wells. Due to its very restricted occurrence, it is likely that Unit Y4 is not encountered in either of the wells, and that both lithofacies are to be attributed to Unit Y5.

The erosion surface at the base of Unit Y4 is clearly a sequence boundary, while the channel infill and the overlying Unit Y5 could represent the lowstand and the transgressive (parallel facies) to highstand (prograding facies) deposits respectively, separated by a ravinement surface. Conversely, the erosion surface at the base of Unit Y5 could also be interpreted as a separate sequence boundary. In any case, the seismic data seem to suggest that the offshore Vlierzele Member is rather more complex than previously believed, and may contain a basal facies that is not known onshore.

### *Lutetian*

The Vlierzele Member is overlain by the Aalter Formation, largely correlative with seismic-stratigraphical Unit L1 (De Batist & Henriet 1995) and consisting of a variety of very shallow marine deposits with great vertical and lateral facies diversity, reflecting strongly varying depositional environments. In the SEWB well the succession starts with the Beernem Member, consisting of slightly coarsening upward grey-green bioturbated glauconitic clayey fine sands with local silica cementations, shell fragments (and large specimens of *Cardita planicosta* bivalves in the VR1 well). Vertical burrows of *Callianassa* extend from erosion surfaces and penetrate into parallel-laminated fine sands. Deposition took place in subtidal gullies and mixed intertidal flats with high-energy conditions caused by repeated channel incision and infill with lateral migration high on the shelf. Palaeowater depths decrease from 40 m (central to ?outer shelf, with oxygenated bottom) to 30 and 20 m (inner shelf).

Flaser lamination in the SEWB well, obliterated by bioturbation and parallel lamination, points to tidal influence during the deposition of the grey-green glauconitic fine sands to clayey sands of the overlying, highly fossiliferous Oedelem Member, which is characterized by an irregular but sharp lower boundary with clay clasts and burrows backfilled with sand. Coquinas exclusively composed of *Turritella* gastropods form barriers (Fig. 13), which in a later stage are reworked in a lagoonal facies as indicated by the deposition of sandy clays with reworked shells (Jacobs & Sevens 1993*a*; Jacobs 1995*b*). Slow sedimentation in an inner (to ?central) shelf environment with oxygenated bottom under 30 to 20 m palaeowater depth

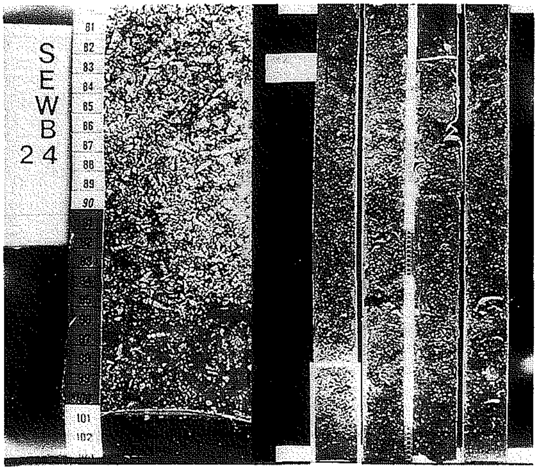


**Fig. 13.** In the SEWB cored borehole, the Oedelem Member litho-unit (seismic-stratigraphical Unit L1) contains coquinas composed of *Turritella* gastropods, that form barriers protecting a lagoon open to the sea.

evolves towards sedimentation on an inner and coastal shelf with decreasing salinity, under 20 to 10 m palaeowater depth.

The seismic facies succession within Unit L1 is in agreement with these types of deposits: (1) two continuous, high-amplitude parallel reflectors and a third discontinuous, low-amplitude reflector at the base; (2) discontinuous, parallel to subparallel reflectors of variable amplitude. A number of discontinuous, subparallel, very high-amplitude reflectors at the top of L1 correlate with calcareous sandstone beds that have been reported in the top section of the Oedelem Member in the Zeebrugge area (Depret 1983). They are indicative of the upward shallowing of the Aalter Formation (palynomorph Pco zone), the upper part of which has been interpreted as a stacked pattern of highstand systems tract (HST) parasequences.

Off Zeebrugge, the strata are offset by normal faults and deformed by asymmetrical folds. Here, the characteristic strong reflectors of the upper part of Unit L1 are truncated at the crests of the folds (Fig. 14). Two folding phases can be recognized from the seismic data (De Batist 1989). As the main folding phase clearly took place after the Bartonian, the observed truncation pattern indicates an initial deformation phase shortly before deposition of the overlying seismic-stratigraphical Unit L2 (De Batist & Henriet 1995). The upper boundary of Unit L1 therefore represents a tectonically enhanced unconformity. This seismically well-defined unconformity coincides with a considerable hiatus in the coastal area onshore, where the Brussel and Lede Formations of central-northern Belgium are generally absent. Seismic-stratigraphical Unit L2, overlying this unconformity, is a very thin and locally distributed, patchy deposit, which is most likely not present in the VR1 well. The seismic characteristics of Unit L2 suggest that it may represent a transgressive lag deposit, overlying a ravinement surface that coincides with the sequence boundary. Unit L2's exact nature and stratigraphical position remains uncertain, although it is most probably stratigraphically equivalent to the Lede Formation. Jacobs & Sevens (1993*b*) interpret this Lede Formation in onshore outcrops as a shallow marine, transgressive deposit, consisting of slightly fining upward, yellowish-grey, fine sands with numerous *Nummulites variolarius* and a sharp, erosive lower boundary with weathered *Cardita planicosta* specimens, silicified *Nummulites laevigatus*, well-rounded but corroded Brussel Formation sandstone pebbles, and ray and shark teeth. Apparent stratification is absent, but coarse-grained sand layers represent storm deposits, and (normally three) calcarenite horizons show great lateral continuity, and their gradual

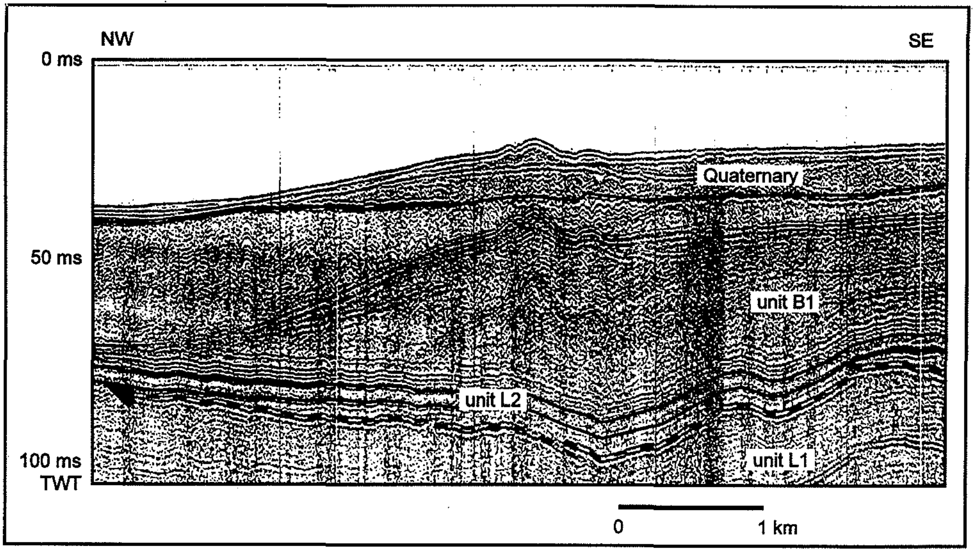


**Fig. 14.** Interpreted sparker profile showing the tectonically enhanced unconformity at the top of seismic-stratigraphical Unit L1 (Aalter Formation), the thin overlying Unit L2, and Unit B1 (Maldegem Formation) affected by folding. See Fig. 2 for location.

transition can sometimes be traced into coarse-grained sand layers that acted as local aquifers. The calcarenite build-up, characterized by a dense and well-cemented internal zone with shell ghosts sandwiched between two crumbly and poorly cemented outer rims with friable shells, suggests progressive formation by calcite precipitation, as meteoric water is pumped through local aquifers in these shallow marine deposits during the ensuing relative sea-level fluctuations (Tucker 1993).

### *Lutetian–Bartonian*

Onshore, the Lede Formation is overlain by the Maldegem Formation, which is also encountered in the VR1 well offshore. The formation is characterized by a regular succession of seven distinct litho-units showing typical alternations of sands and clays: the Wemmel sands Member at the base, the Asse clay Member, the Ursel clay Member, the Onderdale sands Member, the Zomergem clay Member, the Buisputten sands Member and the Onderdijke clay Member. The Maldegem Formation, with a total thickness of about 60 m correlates well with seismic-stratigraphical Unit B1 of De Batist & Henriet (1995). On seismic profiles throughout the Belgian Basin, Unit B1 is characterized by a very distinctive and laterally very continuous succession of seven seismic facies units (Fig. 15): from bottom to top (1) a regular set of continuous, parallel, high-frequency reflectors, (2) subparallel reflectors with shingled reflector on top, (3) a reflection-free interval,

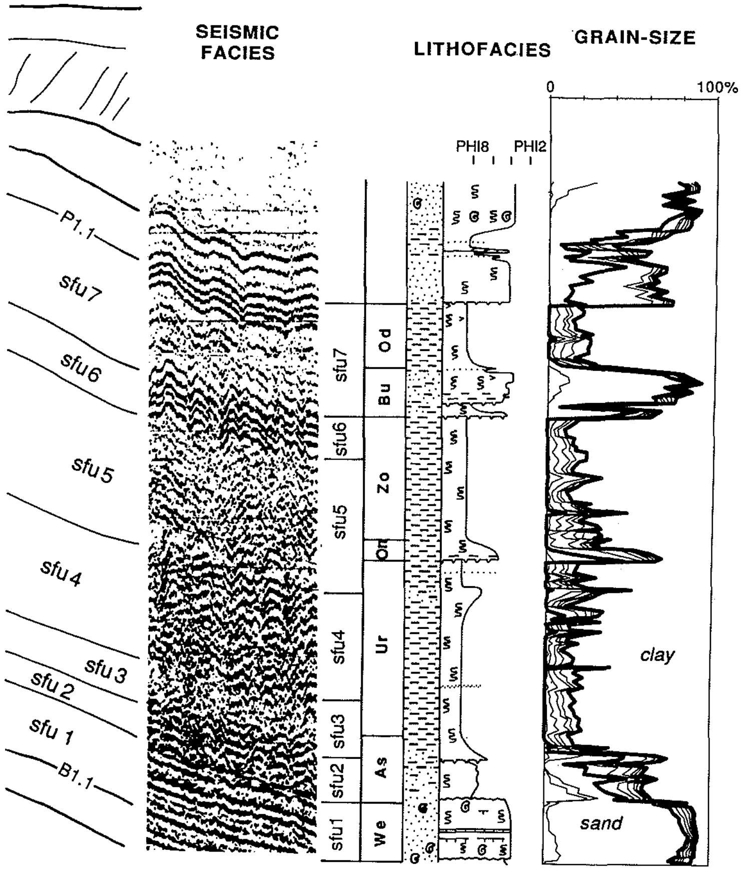


**Fig. 15.** The very distinctive and laterally continuous succession of seven seismic facies units (sfu) comprising seismic-stratigraphical Unit B1 (Maldegem Formation), correlates with grain-size and/or lithological changes in the VR1 cored borehole. However, comparable seismic facies do not always correlate with comparable lithological facies.

(4) convex mounds of medium-amplitude, prograding, hummocky reflectors, (5) a reflection-free interval, (6) medium-amplitude, draping reflectors, and (7) a reflection-free interval with a low-amplitude, discontinuous, draping reflector (see also De Batist & Henriet 1995, Fig. 11). Quite surprisingly and contrary to what has been suggested previously by De Batist & Henriet (1995), this succession of seismic facies does not simply mimic the succession of lithofacies that typifies these deposits. Figure 15 illustrates that seismic facies boundaries sometimes, although not always, coincide with the major lithofacies or grain-size boundaries, and that comparable seismic facies do not always correlate with comparable lithofacies.

In the VR1 well, the Wemmel sands Member at the base of the Maldegem Formation consists of grey glauconitic, slightly clayey fine sands, slightly fining upwards, with two discontinuous thin calcarenite horizons, weathered shell fragments and a sharp but irregular top. These seem to be slowly deposited in a central (to ?inner) shelf environment with an oxygenated bottom under 30 to 20 m palaeowater depth. They are characterized by palynomorph Pco (and ?reworked Pla) associations.

In the VR1 well (Fig. 15), the remainder of the Maldegem Formation can be described as composed of three stacked fining upward cycles of decametric thickness departing from erosion surfaces with sand-filled burrows. The lowermost cycle starts with highly glauconitic clayey sands with glauconite concentrations in burrows ('bande noire' of authors). They are covered by an alternation of bioturbated (mostly *Chondrites*) clayey sands and sandy clays of the Asse Member. They have been deposited in an outer shelf environment under 30–40 m palaeowater depth, with palynomorph Pco associations indicating the presence of a condensed section. These sandy clays grade into a blue-grey bioturbated massive clay – the Ursel clay Member – with pyrite concretions of prodeltaic origin (central to ?outer shelf with 40–50 m palaeowater depth; palynomorph Aar zonation). The second cycle also departs from a burrowed lower surface and consists of moderately clayey sands – the Onderdale sands Member – sometimes showing coarse interlayered bedding and flaser lamination typical of tidal flat sedimentation. It fines upward into a strongly bioturbated blue-green clay – the Zomergem clay Member – of prodeltaic origin, deposited in outer shelf (to ?slope) conditions (more than 50 m palaeowater depth). It belongs to the palynomorph Gin zone. The third cycle is similar in nature and is characterized in its lower part by slow sedimentation in a central (to ?outer) shelf environment, under 40 m palaeowater depth. It shows towards its top a shallowing tendency towards an inner shelf environment of about 15–20 m depth, while further onshore even thin detrital peat layers have been recorded in its burrowed and truncated top (Gulinck 1969*a*; Jacobs 1975).

On the basis of the aforementioned characteristics and of well-log signatures, the Maldegem Formation can be subdivided into three depositional sequences, each composed of transgressive and highstand deposits.

### *Priabonian*

In the VR1 well, the Maldegem Formation is separated from the overlying Zelzate Formation – of Priabonian age – by a burrowed erosional surface. It is equivalent to seismic-stratigraphical Unit P1 of De Batist & Henriet (1995) and thickens considerably in a basinward direction. In the VR1 well, it consists of strongly bioturbated clayey fine sands – the Bassevelde sands Member – with a mottled texture, locally containing carbonised plant remains. A bioturbated (*Chondrites*) intercalated sandy clay layer coarsens upward into glauconitic, bioturbated and mottled, slightly clayey fine sands, containing some shell grit (palynomorph Rpo zone). These units are interpreted as shallow marine (inner shelf environment under 20 m water conditions) and barrier-protected lagoonal, washover and tidal flat deposits (Jacobs & Sevens 1993*a*; Jacobs 1995*b*). Unit P1's seismic facies of (1) continuous, parallel, draping reflectors of varying amplitude, and (2) homogeneous pattern of continuous, parallel, low- to medium-amplitude reflectors, is consistent with this type of environment. Seismic-stratigraphically, the base of Unit P1 stands out as a low-angle coastal onlap surface and can therefore be characterized as a sequence boundary.

In the NE prolongation of the North Hinder Deformation Zone (De Batist 1989), the upper boundary of Unit P1 shows erosional truncation. Here, structurally undisturbed Oligocene strata rest unconformably on folded strata of Unit P1, of Eocene age. The boundary between Units P1 and R1 therefore represents a tectonically enhanced unconformity.

## Oligocene

### *Rupelian*

Seismic-stratigraphical Unit R1 of De Batist & Henriet (1995) probably correlates with most of

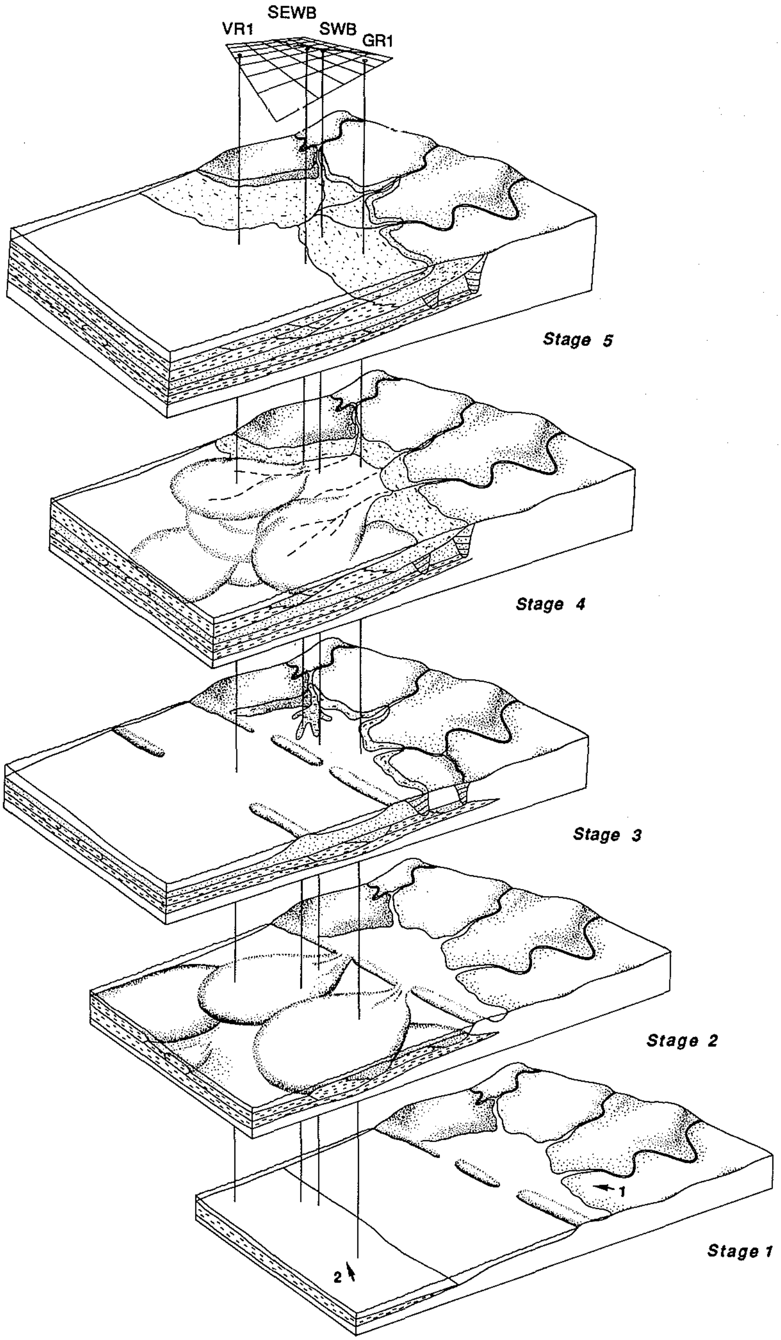


**Fig. 16.** Evolution of the siliciclastic sedimentary system in the southern North Sea Basin during the Eocene in time and space. Stage 1: early Early Eocene; Stage 2: middle to late Early Eocene; Stage 3: Middle Eocene; Stage 4: Late Eocene; Stage 5: late Late Eocene. Arrows indicate (1) north and (2) main longshore current direction.

the Niel Formation of northwestern Belgium (Steurbaut 1992), consisting of shallow-marine to deltaic/estuarine sands and clays (Jacobs & De Coninck 1977; Steurbaut 1986). The irregular and laterally discontinuous seismic facies of Unit R1, composed of subparallel to wavy reflectors with variable amplitude, is in agreement with these types of deposits. Unfortunately, this unit is not encountered in the VR1 well. Onshore, large 'Big Mac' concretions with a diameter of more than 1 m and a hamburger-like shape characterize the base of the Niel Formation. Macro- and submicroscopical growth patterns supported by geochemical and petrographical evidence suggest that they were formed during relative sea-level highstand when meteoric water was pumped through the sediment aquifers active in these shallow marine deposits (Olivier, pers. comm.).

Offshore, it is overlain by Unit R2, the youngest seismic-stratigraphical unit in the area that was assigned a Palaeogene age by De Batist & Henriet (1995). It has a maximum thickness of about 60 m. It forms the offshore equivalent of the Boom clay Formation of northern Belgium, but possibly also includes the uppermost part of the underlying Niel Formation. The seismic facies of the Boom clay is very characteristic and consists of a very regularly banded pattern of continuous, parallel, high- to medium-amplitude reflectors (see De Batist & Henriet 1995, Fig. 13). On very high-resolution seismic data, these parallel reflections consist of alignments of diffraction hyperbolae, generated by the well-known bands of Boom clay concretions or 'septaria'.

## Sedimentation model

On basis of the sedimentary facies, architecture and sequence-stratigraphical characteristics of the sediment series observed in the offshore seismic and borehole data sets, the depositional palaeoenvironments in the Southern Bight of the North Sea Basin during the Eocene (Palaeocene and Oligocene strata were not present in the offshore boreholes) could be reconstructed (Fig. 16).

### *Stage 1: early Early Eocene (Ypresian)*

During early Early Eocene times (Ypresian), distal Kortrijk Formation sediments were deposited on an open offshore mud shelf during a period when the uplift of the Weald–Artois High was initiated causing the separation of the Southern Bight of the North Sea Basin from the opening North Atlantic Ocean. The Kortrijk Formation litho-units form stacked parasequences indicating a constantly rising relative sea level (transgressive systems tract, TST).

### *Stage 2: middle to late Early Eocene (Ypresian)*

In middle to late Early Eocene times, relative sea level fell and a delta complex started to prograde onto the shelf. Heavy minerals indicate that this delta complex was fed by a fluvial drainage system with a southern sediment supply (Jacobs 1995*a*). The Kortemark Member of the Tielt Formation probably forms a complete lowstand systems tract (LST)–TST–HST cycle. The ensuing sea-level fall must have been considerable as indicated by the 'blocky' geophysical log response of the sharp-based LST of the Egem sands Member (Tielt Formation) in the following cycle. After a temporal reinstallation of an offshore mud shelf during a limited period of locally greater water depths, delta sedimentation with lagoonal mud flats and sand shoals is restored in the top portion of the Merelbeke and Pittem clay Members (Gent Formation), with deposition of regressive facies of HST as relative sea level starts to fall again. At the end of Early Eocene times (Vlierzele sands Member of the Gent Formation) tidal influence became prominent with deposition of wave-influenced subtidal sand shoals.

### *Stage 3: Middle Eocene (Lutetian)*

Because of the constant lowering of relative sea level during Middle Eocene times, the sedimentation system shifted landwards towards its most proximal position. High wave energy, longshore currents and large supply of coarse sediment force the delta to retreat. Wave-influenced subtidal and intertidal environments with subtidal gullies and mixed tidal flats (Beernem Member of the Aalter Formation) and submarine coastal barriers protecting a lagoon open to the sea (with storm deposits of the Oedelem Member) give rise to stacked HST parasequences, indicating constant shoreline regression and shallowing of the basin.

### *Stage 4: Late Eocene (Lutetian–Bartonian)*

In Late Eocene times, after a major hiatus, prominent but stepwise overall relative sea-level rise induces cyclic sedimentation from a tidal sand flat environment (sandy deposits of the Maldegem Formation) towards a prodelta environment (predominantly clayey Maldegem Formation deposits). Distal muddy delta fans alternate with proximal sandy sediments, displaying the progradational pulses of the delta lobes. Aggradation produces (at least three) stacked plurimetric sedimentary (para)sequences of TST–HST nature. They display a very simple, parallel layered (planar) geometry throughout the basin, indicating the almost total absence of intrabasinal relief. Each sequence appears to depart from a basal erosion surface, which indicates a repetition of transgressive pulses.

### *Stage 5: late Late Eocene (Priabonian)*

After a new but minor relative sea-level drop, responsible for the development of thin detrital

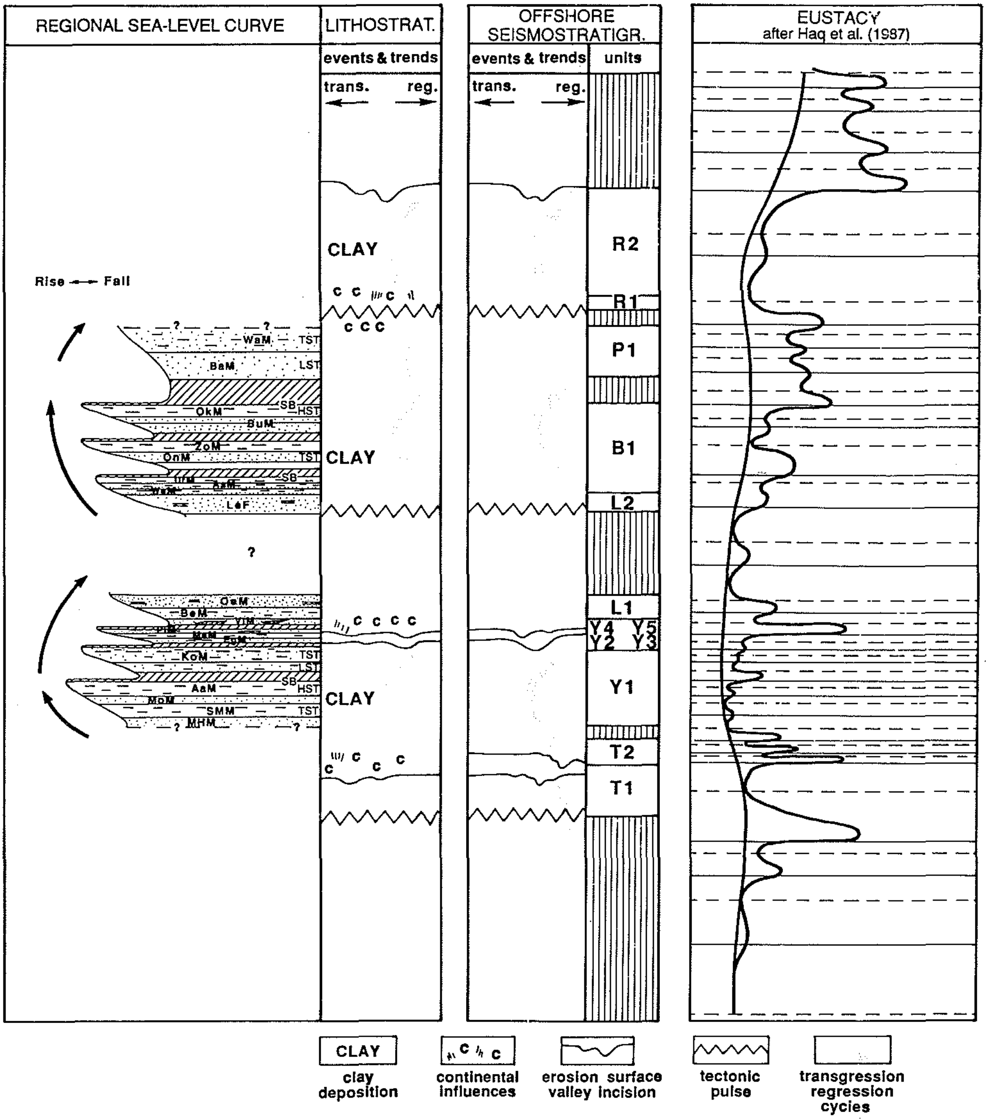


**Fig. 17.** Synoptic correlation diagram for the Belgian Basin. Seismic stratigraphy illustrates the major 'events and trends'. Eocene schematical regional relative sea-level curve displays two asymmetric second-order transgressive–regressive cycles with nine 'lithostratigraphical' third-order sequences.

peat layers and burrows backfilled with peaty sand in the top of the Maldegem Formation, stacked LST–TST (para)sequences develop that constitute the Uppermost Eocene Zelzate Formation. The sandy tidal flat and lagoonal sedimentation is reinstalled in slightly shallower-water conditions compared to Stage 4.

## Regional relative sea-level curve

A schematic relative sea-level curve has been constructed for the Eocene (Fig. 17) on the basis of the detailed lithofacies analysis of the offshore wells and of the geometrical data derived from the offshore seismic profiles, and using additional onshore outcrop data. It should be kept in mind that chronostratigraphical calibration should be made with caution as biostratigraphical control is still in progress and lacks precision.

In the Eocene, two asymmetric second-order transgressive–regressive cycles can be recognized, comprising nine 'lithostratigraphical' sequences of third-order. The lowest sequence of the lower cycle is characterized by a widespread relative sea-level rise (stacked TST) but followed by an overall fall: sediment texture in the four remaining lithosequences is gradually coarsening upward from massive, fine clays towards medium sands. Loss of accommodation space is shown by considerable shallowing of the basin and progradation, because of high supply of coarse sediment.

A major hiatus is interpreted as an important sea-level fall. It means that the ensuing pulsating relative sea-level rise must have been of comparable height (or even greater). This rise is responsible for a deepening of the basin, depositing three stacked fining upward sequences of overall transgressive nature and great lateral continuity. A similar sedimentary pattern, however, might be caused by pulsating variations in sediment flux and gradual rise, but this is highly unlikely because it would suppose the sediment flux variations to have the same amplitude over time. The last sequence of this upper cycle gradually coarsens and shallows upward due to relative sea-level lowering.

## Conclusions

Interpretation of an extensive high-resolution seismic grid has allowed 13 seismic-stratigraphical units to be identified within the Palaeogene section in the offshore Belgian Basin, their geometries to be defined on a regional scale and a well-documented seismic-stratigraphical model to be developed. Detailed analysis of four offshore cores has allowed these seismic-stratigraphical units to be correlated with the classical Palaeogene lithostratigraphy of northwestern Belgium.

When attempting to interpret the observed seismic-stratigraphical and lithostratigraphical units in a sequence-stratigraphical way, it should be kept in mind that the basic concepts of sequence stratigraphy have been developed for typical shelf-slope–basin sections along an Atlantic-type continental margin. Their application to margins in a 'ramp-type' setting, such as the Palaeogene southern North Sea shelf, is therefore not always straightforward. In this study, some important differences from the general sequence-stratigraphy model for passive margins could be observed, which impeded sequence-stratigraphical interpretation:

(i) geometries are not very obvious due to the low gradient and the distance from the shelf break; consequently, sequences, systems tracts and parasequences are stacked in a quasi-parallel and conformable way, separated by low-angle unconformities;

(ii) due to the low gradient, ravinement during transgression (even on a parasequence scale) can be quite severe and can completely erode underlying lowstand deposits and even large parts of previously deposited sequences, thus 'cannibalising' sequence boundaries;

(iii) sequences tend to be mainly composed of transgressive and highstand systems tracts, while lowstand deposits are mostly only preserved as incised channel fills;

(iv) because of the low gradient, discrete changes in sea level, sediment input or subsidence can create strong lithofacies shifts – this is particularly true for the entire Late Ypresian and Lutetian section in the Belgian Basin.

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# THE NEW GEOLOGICAL MAP OF NORTHWESTERN FLANDERS, SOUTHERN BIGHT NORTH SEA: PRESENTATION

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*KEY WORDS: Eocene, Northwestern Flanders - Belgium, siliciclastic shelf seas, geological mapping.*

The Belgian Geological Survey and the Administration of Natural Resources and Energy of the Flemish Ministry of Economic Affairs commissioned a new geological map on a scale of 1:50000. The map sheets Brugge (13), Lokeren (14), Tielt (21) and Gent (22) were drawn by the Geological Institute of the University of Gent. The archives of the Belgian Geological Survey served as basic information, and were completed with the archives of the Administration of Geotechnics of the Flemish Ministry of the Environment and Infrastructure and of the Geological Institute of the University of Gent. Additional information was provided by limited field observations, few hand drillings and two cored wells on the Lokeren sheet.

All data (identification, coordinates, characteristics, descriptions, interpretations, ...) are stored in dBase IV tables (PC environment). As a powerful geological database system is not operational yet (expected for 1996), data are treated with modest programs to draw the geological map of the Tertiary formations subcropping under the Quaternary cover. The contour maps of the base and thickness of the Quaternary and of the lower boundary planes of all occurring lithostratigraphical units were drawn in the same way. Profiles illustrate the geological settings described in explanatory text books.

To guarantee the maps' applicability and user friendliness, the option was taken to adopt lithostratigraphical units as basic subdivisions. Rather than of the same age, units of the same lithology are distinguished according to the proposals for the Paleogene lithostratigraphical scale of MARECHAL & LAGA (1988).

In general, all maps display Tertiary deposits of shallow marine character. They consist roughly of an alternation of Eocene and Oligocene clay and sand layers with a gentle slope to the NNE of less than 0.5%. Only in the outermost NE-corner of the study area, Neogene deposits occur.

On the Lokeren map sheet and partly on the Gent and Brugge map sheets, the geological contours are characterised by a parallel pattern, for which the Quaternary incision of the Flemish Valley together with the gentle NNE slope of the Tertiary layers is responsible. The lowermost lithostratigraphic unit in the southern part of the Tielt and Gent map sheets is the Kortrijk Formation, whereas the Vlierzele Member (upper part of the Gent Formation) has the largest extension due to its thickness of approximately 20 m. The Aalter Formation is in the west only represented by the Oedelem Member, disappearing a few kilometres east of Gent. The Lede Formation is only with certainty present in the eastern part of the study area. Additional field work would be necessary to determine the exact lateral extension of both Formations. The alternation of the sand and clay layers of the Maldegem and Zelzate Formations cover more than 50% of the Lokeren map.

In the southern part of the study area, the geological contour pattern reflects the accidented topography of the Tertiary substratum. Especially the southernmost part of the Gent map is characterised by a rapid succession of the different lithostratigraphical units. In a limited area, all deposits between the Kortemark and the Ursel Members are present.

The four geological map sheets give a clear overview of the occurrence of the Eocene and the Oligocene in the southern part of the North Sea basin. Vertical and lateral facies variations are governed by the ramp type margin setting of the basin, low subsidence rates and high sediment supply of southern origin.

| *LITHO* | | | **CHRONO** |
|---|---|---|---|
| **GROUPS** | *FORMATIONS* | Members | |
| **RUPEL** | *BOOM* | Putte<br>Terhagen<br>Belsele | **EARLY OLIGOCENE** |
| **TONGEREN** | *ZELZATE* | Ruisbroek<br>Watervliet<br>Bassevelde | **LATEST EOCENE** |
| | *MALDEGEM* | Onderdijke<br>Buisputten<br>Zomergem<br>Onderdale<br>Ursel<br>Asse<br>Wemmel | **LATE EOCENE** |
| **ZENNE** | *LEDE* | | **MIDDLE EOCENE** |
| | *AALTER* | Oedelem<br>Beernem | |
| **IEPER** | *GENT* | Vlierzele<br>Pittem<br>Merelbeke | **EARLY EOCENE** |
| | *TIELT* | Egem<br>Kortemark | |
| | *KORTRIJK* | Aalbeke<br>Moen | |

*Table 1 - Litho- and chronostratigraphy of the Eocene and Oligocene deposits occurring on the Brugge, Lokeren, Tielt and Gent map sheets.*

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