8 Stratigraphic analysis of the Ypresian off the Belgian coast

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ABSTRACT

The Ypresian depositional sequences defined by high-resolution reflection seismic investigations off the Belgian coast are correlated with the main Ypresian lithostratigraphic units known along the Belgian shore line and further inland. Particular attention is paid to the detailed seismic-stratigraphic features of the Ypresian, including the seismic facies related to the deposition and compaction history of these sediments.

INTRODUCTION

The interpretation of the numerous high-resolution reflection seismic profiles shot in recent years over the Belgian continental shelf has resulted in a detailed seismic-stratigraphic description and subdivision of the Palaeogene sequences of the offshore extension of the Tertiary Belgian Basin (HENRIET *et al.*, this volume). A mere glance on the seismic-stratigraphic subcrop map of the top of the Tertiary (figure 3 in HENRIET *et al.*, this volume) reveals that the direct substratum of the larger part of the Belgian continental shelf consists of Ypresian deposits. These deposits are also known on land, where they have been the subject of detailed lithostratigraphic and chronostratigraphic studies : e.g. the revision by STEURBAUT and NOLF (1986).

Both areas of observation are only separated by a narrow gap corresponding with the nearshore zone, where seismic observations are impeded by shallow waters and gassy surficial sediments absorbing all acoustic energy. There are consequently obvious reasons for attempting to bridge this gap, keeping however in mind the fundamental differences in stratigraphic approach applied in both domains.

GEOLOGICAL SETTING

The Belgian Ypresian sequence was deposited in the so-called Belgian Basin, a bightlike extension of the Early Eocene North Sea Basin. These deposits cover most of North Belgium, including the continental shelf. In the southern and western parts of this area, Ypresian deposits are directly outcropping or but slightly concealed by a discontinuous Quaternary cover. Further north and west, they are covered by younger Tertiary sediments (figure 1).

The total thickness of this sequence increases from a few metres in the far south of the land area up to some 180 m more north, in the Knokke boring (BGD 11E-138).

In the coastal area and offshore, the strata are gently dipping towards the northeast. This regional dip is probably the combined effect of the subsidence of the North Sea Basin, the tectonic activity of the Weald-Artois Anticline and the relative uplift of the London-Brabant Massif. As a consequence, progressively younger Ypresian deposits are met at the surface from southwest to northeast.

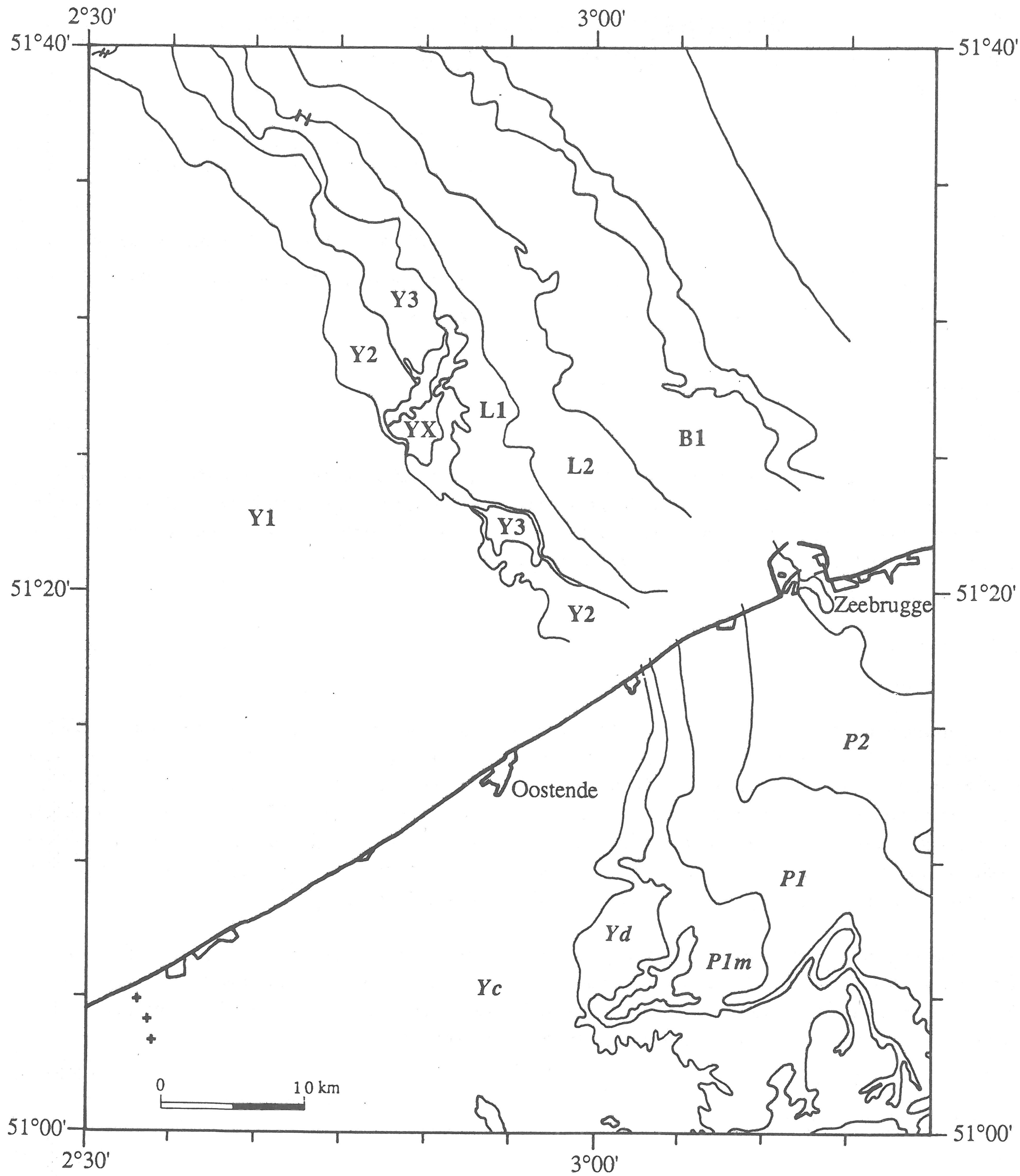


Figure 1 Combined solid map of the Eocene deposits in the Belgian Basin, illustrating the extension of offshore seismic-stratigraphic units (after HENRIET *et al.*, this volume) and onshore lithostratigraphic units. *Yc* = Ieper Clay. *Yd* = Kortemark Silt - Egem Sand. *P1m* = Merelbeke Clay. *P1* = Vlierzele Formation. *P2* = Oedelem Formation.

YPRESIAN LITHOSTRATIGRAPHY

According to STEURBAUT and NOLF (1986), two formations can be defined in the Ypresian deposits in Belgium : a lower Ieper Formation and an upper Vlierzele Formation. Both can be divided, vertically as well as laterally, into several lithostratigraphic units (figure 2). Lateral variations in lithological composition are common along the basin

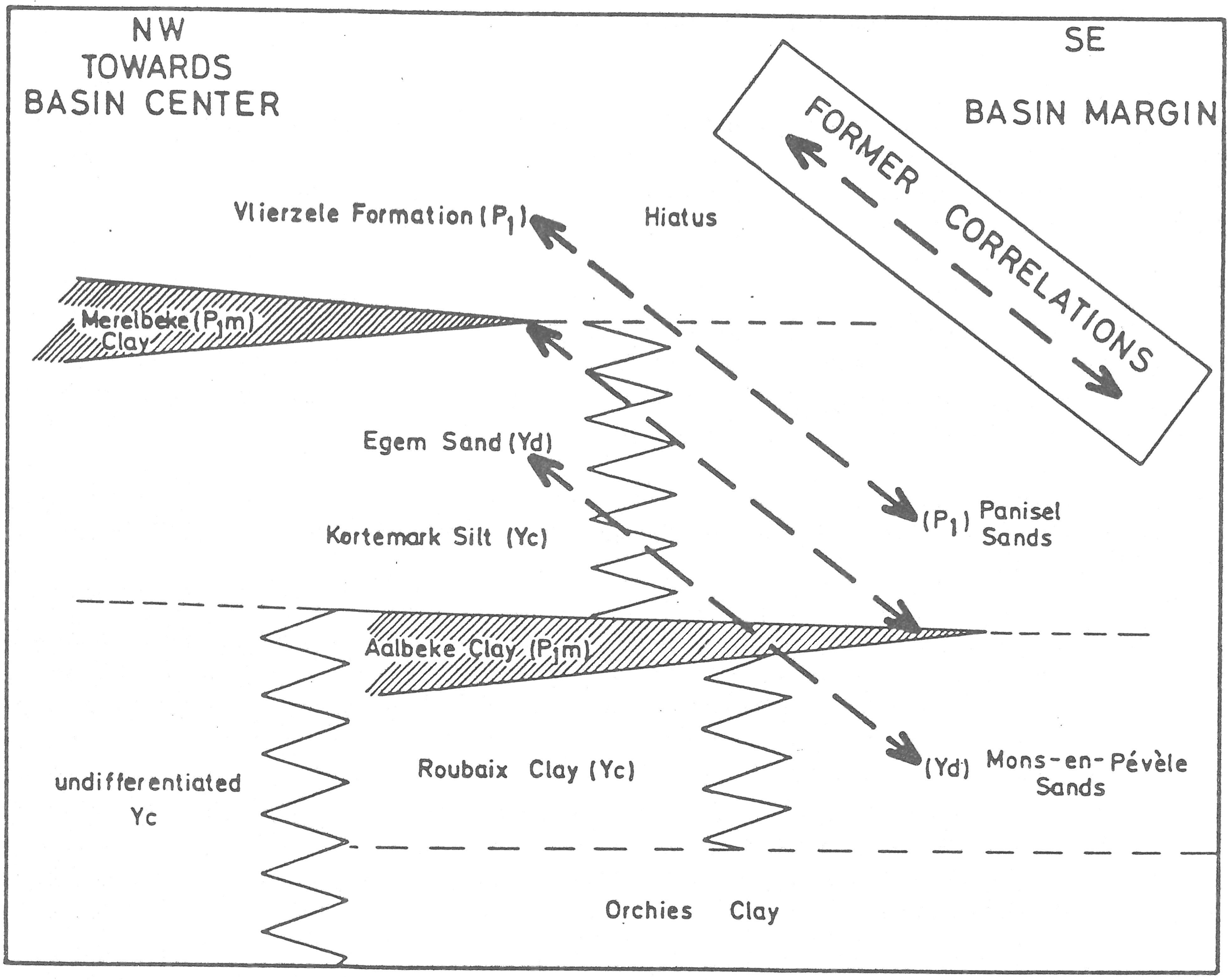


Figure 2 Correlation chart of lithostratigraphic units of the Ypresian in the Belgian Basin (after STEURBAUT and NOLF, 1986).

margins in central and southern Flanders but tend to become less explicit towards the northeast, further offshore in the palaeobasin.

In the coastal area, the Ypresian starts with a major undifferentiated clayey sequence : the Ieper Clay, grouping the lateral equivalents of the Orchies, Roubaix and Aalbeke Clay Members. Further south, the homogeneous heavy clay may become progressively more silty, locally containing silt or sand intercalations. The Ieper Clay is subcropping at the Quaternary coastal plain deposits along the west coast from De Panne to De Haan. Below the east coast, north of De Haan, its total thickness amounts to some 150 m (borings BGD 10E-30 and BGD 11E-138).

It is covered by the sandy, lateral equivalent of the Kortemark Silt Member and the Egem Sand Member, consisting of very fine sand with clay intercalations. Their maximum recorded thickness is 23 m (only 9 m in the Knokke boring BGD 11E-138).

The Ieper Formation terminates with a characteristic heavy clay layer of variable thickness (5-10 m) : the Merelbeke Clay Member. It is separated from the overlying Vlierzele Formation by a significant unconformity.

The Vlierzele Formation is quite heterogeneous and consists mainly of medium-grained cross-bedded sands. The Pittem Clay Member is a lower interval of local extension, built up of an alternation of clayey sands and sandy clays, with locally sandstone beds (boring BGD 11W-88).

CHARACTERISTICS USED IN CORRELATION

In developing a tentative correlation between offshore seismic stratigraphy and onshore lithostratigraphy all available evidence should be taken into consideration : the number of identified depositional sequences, the characteristics of their boundaries, their thickness and geometry, the seismic facies and the relative position in relation to possible onshore equivalents.

The subdivision of the offshore sequences into depositional sequences - the basic seismostratigraphic building stones - has been carried out in accordance with the principles of seismic stratigraphy (VAIL *et al.*, 1977) and the specific interpretative approach, as described elsewhere (HENRIET *et al.*, this volume). Four depositional sequences of supposed Ypresian age have thus been identified : Y1, Y2, Y3 and YX, separated by unconformities or hiatuses.

Reliable sequence thicknesses have been calculated with a generalized velocity model, compiled from a number of scattered velocity measurements carried out with various techniques (CHERLET, 1978 ; HELDENS, 1983 ; VERCOUTERE, 1987).

The seismic facies of the intervals between prominent reflectors could in some instances yield a clue for the interpretation of the depositional environment and of the early compaction history. It is also a potential lithological indicator, which however requires due borehole control. It should be noted here that the highest resolution can only be obtained in the upper 50 to 70 m below seabed, due to fundamental properties of seismic wave propagation and attenuation. As the strata dip towards the northeast, successive depth intervals can be investigated with optimum resolution for facies studies, but these are systematically shifted towards the northeast as their age decreases. This implies that a composite vertical section of seismic facies descriptions for successively younger depositional sequences (such as in figure 2, HENRIET *et al.*, this volume) always contains a certain lateral, basin-inward component.

A major criterion for offshore-onshore correlation has also been the purely geometrical fit of units on either side of the nearshore gap, using isobath maps of the base of the Quaternary (MOSTAERT *et al.*, this volume) and calculations of the local strike as guide-lines.

In correlating seismostratigraphic and lithostratigraphic units, a few considerations ought to be made about the fundamental validity of this approach. In accordance with the general principles of seismic stratigraphy as defined by VAIL *et al.* (1977), seismic reflectors do have a chronostratigraphic significance, as they generally represent bedding planes considered as isochronous surfaces. Although still point of debate, this statement seems to have proved its validity at the level of the analysis of major sedimentary basins. It has also been retained in the present approach (HENRIET *et al.*, this volume) of the Belgian continental shelf sequences. Correlating such "chronostratigraphic" boundaries with lithostratigraphic breaks might thus sound like a curse in stratigraphic practise. Two statements should be made in this respect.

First, the problem stated here is one of short-range correlation between two areas which have intensively been investigated with different techniques. Bridging a relatively narrow gap irremediably involves the best possible projection of one set of boundaries into the other one. In this way it might be better to speak of a "best fit" between two sequences rather then of a correlation, in the full significance of this word. Hence this bridging operation carried out on a very local scale does not automatically imply a recognition of a long-range identity of lithological boundaries and seismic reflectors. The problem of evaluating the true nature of a seismic reflection in this regional stratigraphic domain can only be solved with adequate borehole control in the offshore environment. The alternative of applying high-resolution reflection seismics of similar standards on land does not seem to be a short-range perspective, both for fundamental reasons of wave propagation in unsaturated media (a particular aspect of the more general problem of so-called "static" corrections on land) and for economical reasons.

A second remark is that the seismic-stratigraphic analysis of deep hydrocarbon-bearing basins (VAIL *et al.*'s original approach) automatically involves the use of waves with a dominant wavelength (and hence resolution) of a couple of tens of metres. In high-resolution reflection seismics, the dominant wavelength is in the metre range, thus providing a much finer tool possibly offering a higher potential for imaging lithological contrasts. This emerging idea deserves further attention.

THE Y1 DEPOSITIONAL SEQUENCE

The boundary between the Ypresian sequences and the underlying Thanetian (Palaeocene) deposits is locally marked by a weak but clearly defined unconformity.

Above this unconformity, the whole of the Y1 sequence is characterized by a lack of true reflecting horizons. Only at the base, about 6 to 7 m above the unconformity, a relatively consistent reflector can be identified, which can be traced all over the Southern Bight and which correlates in the Thames estuary with a hard horizon of volcanic ash, the so-called Harwich stone band. This ash marker is known as a prominent reflector also further north in the North Sea Basin.

The relative absence of true reflecting horizons, which can be identified with any seismic source and configuration, does not mean the absence of any possibility of imaging the structure of the Y1 sequence, which can be identified with the Ieper Clay. Indeed when high-resolution seismic sources are properly tuned, in other words when the right energy is delivered in the right frequency band and due attention is paid to pulse shaping, a remarkable interference composite emerges from this homogeneous clay unit . Such a composite represents the sum of all weak reflection responses from the many, subtle interfaces and laminations within the clay sequence (HENRIET *et al.*, 1982 ; HENRIET *et al.*, 1988). Such interference patterns closely mould

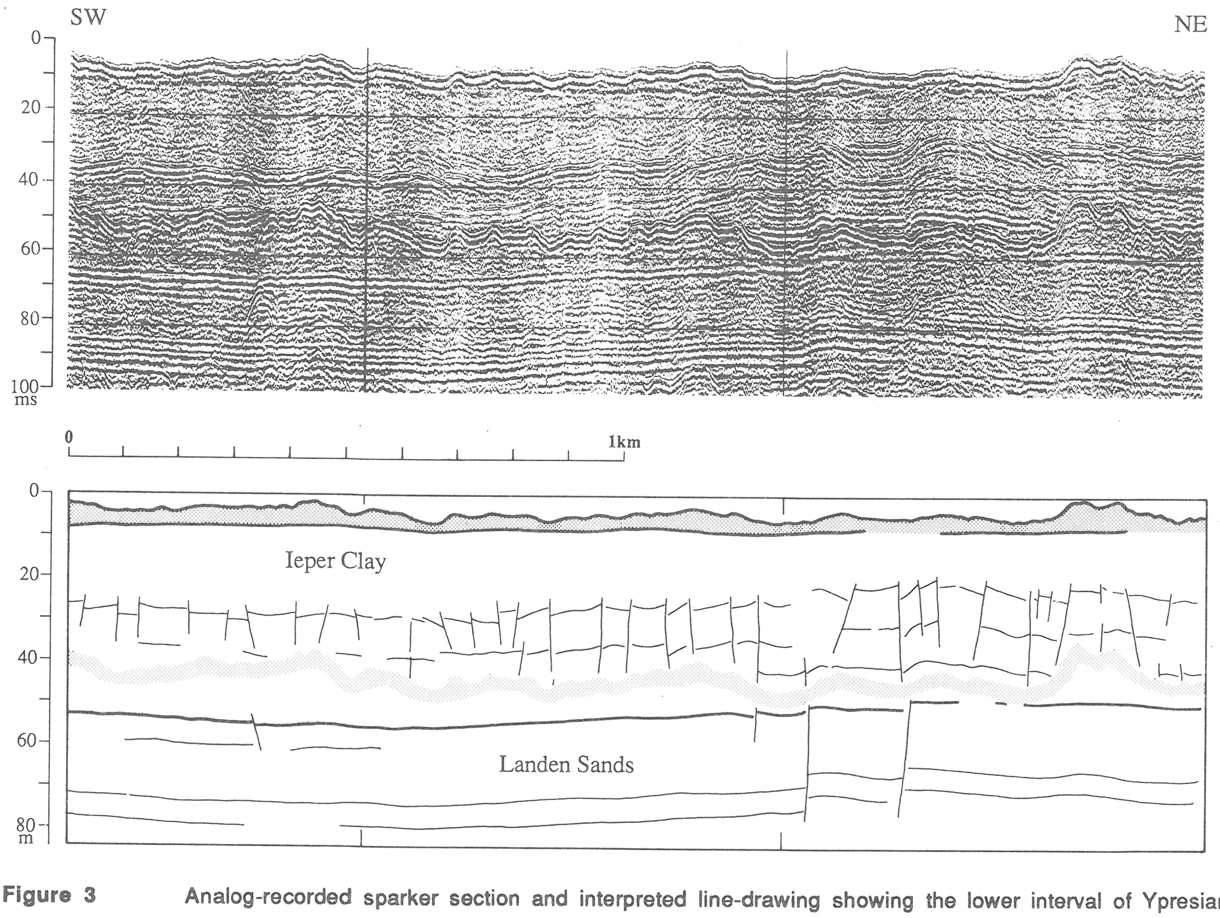


Figure 3 Analog-recorded sparker section and interpreted line-drawing showing the lower interval of Ypresian clay-tectonic deformations. Approximate localization : N 51°09.50', E 02°15.00'.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an interval velocity of 1620 m/s.

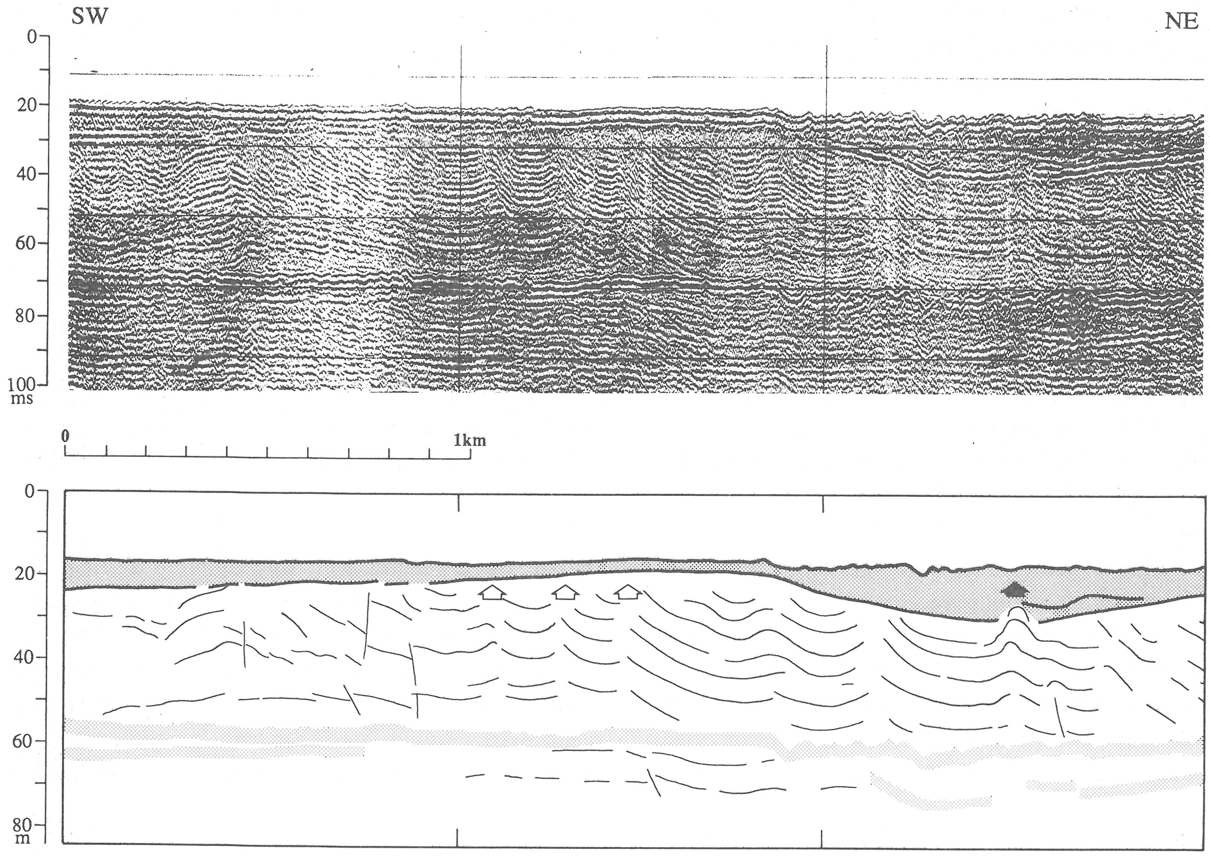


Figure 4 Analog-recorded sparker section and interpreted line-drawing showing the second interval of Ypresian clay-tectonic deformations. Approximate localization : N 51°16.00', E 02°24.00'.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an interval velocity of 1620 m/s.

the structure of the clay beds and allowed the discovery of a most intriguing and extensive set of internal deformations of these clays.

The style of these deformations may vary from place to place, being more chaotic in some areas and regular in others, but a remarkable observation is a distinct kind of vertical zonation, with a superposition of intervals with different but related deformations.

In a lower interval, up to some 25 m above the undisturbed basal reflector, intense block-faulting may be observed, with tilted and bended blocks and apparently randomly dipping fault planes (figure 3). The average throw amounts to a couple of metres.

In a second interval, stretching from about 25 metres up to at least 70 metres above the clay base, the movement initiated in the lower interval amplifies and develops into a convoluted pattern, consisting of a festoonlike alternation of broad, rounded synclines and narrow, cuspate anticlines (figure 4). These anticlines often develop into diapyrlike features. The apparent wave-length of the convoluted structure varies between 200 and 300 metres and the amplitude of the clay waves ranges from 2 to 10 metres.

Further upward in the stratigraphic sequence, the convoluted structure becomes increasingly disturbed, giving way to a pattern of faulted blocks, sometimes with a dominant tilt direction (figure 5). Such patterns of faulted blocks with dipping fault planes have also been observed on land, e.g. in the "Koekelberg" quarry in Marke (figure 6).

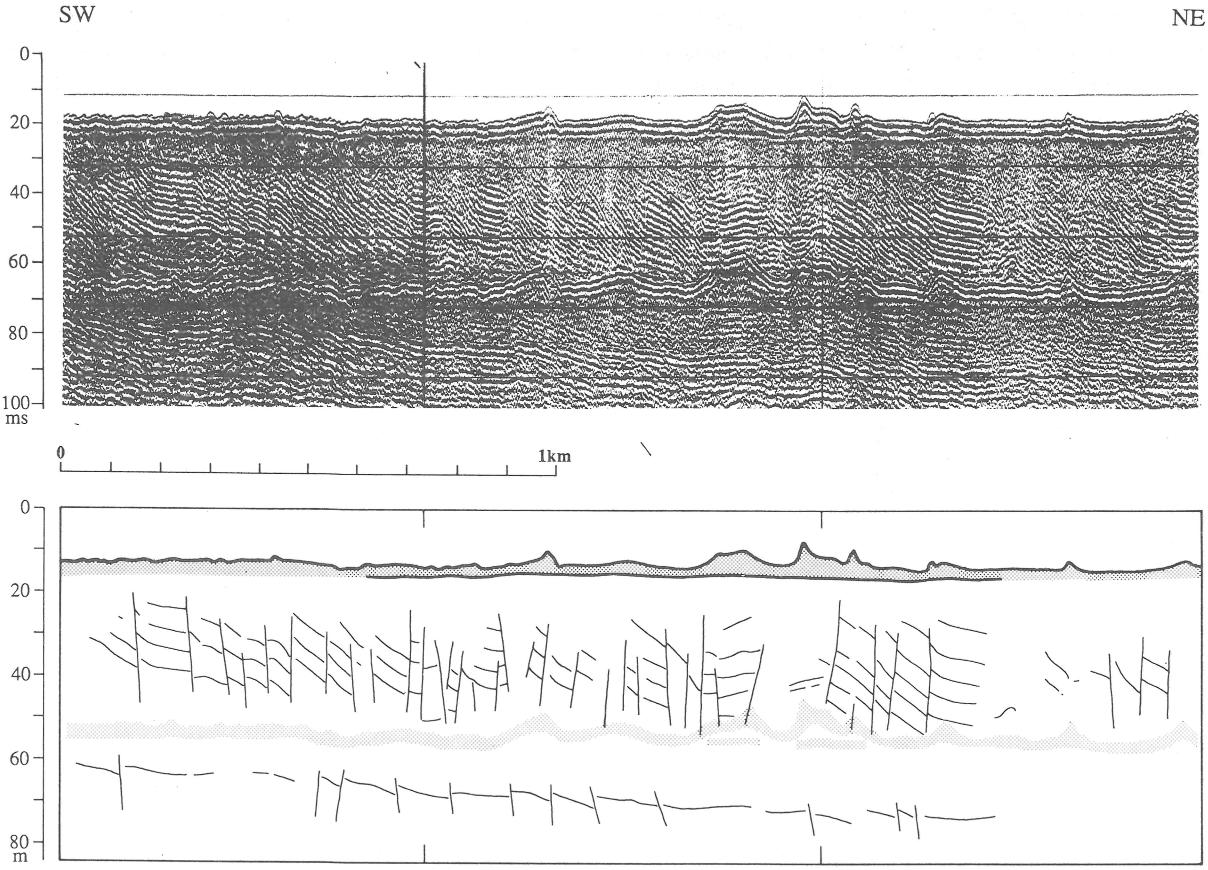


Figure 5 Analog-recorded sparker section and interpreted line-drawing showing the third interval of Ypresian clay-tectonic deformations. Approximate localization : N 51°18.00', E 02°26.00'.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an interval velocity of 1620 m/s.

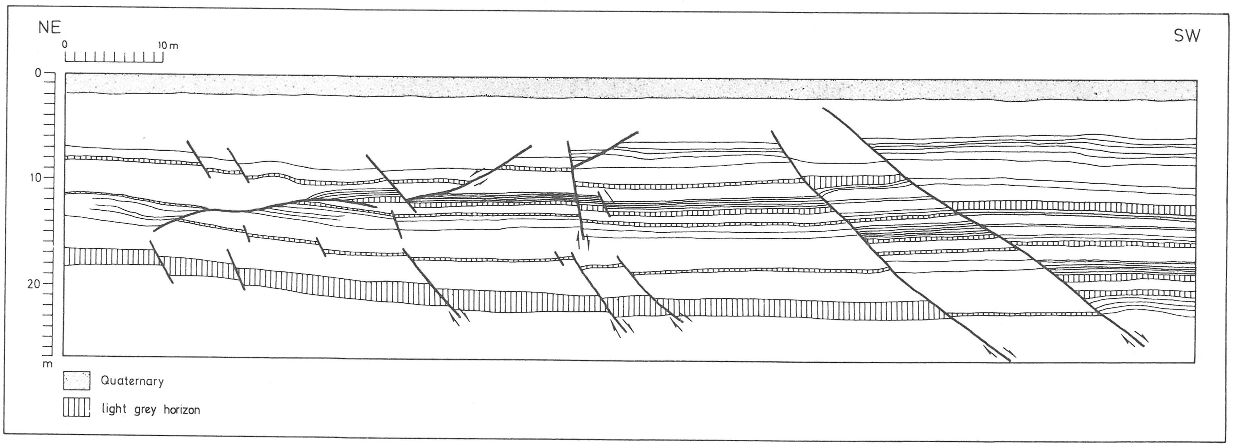


Figure 6 Faults in the "Koekelberg" quarry, Marke (Belgium) (VAN VAERENBERGH, 1987).

Approximatively at the level where the Ypresian clay should grade into the Ypresian sands, another peculiar deformation pattern is observed (figure 7). Here some well defined reflectors are again affected by faults, but the deformation consists of alternately tilting and down-warping bedding terminations, without significant tilting or displacement of the blocks themselves, between the faults. Tilting and down-warping segments associated with each fault point away from each other, in opposition with bedding deformations caused by normal drag associated with block-faulting.

A genetic model for these features has been proposed (HENRIET *et al.*, 1988), implying a build-up of undercompaction and density inversion due to a self-sealing mechanism of the compacting clay body, the subsequent development of a central clay wave fitting a Rayleigh-Taylor-type instability as well as of brittle deformations in the more compacted base and top intervals and finally a relaxation of the pore water overpressure, freezing the deformations in the shape nowadays observed. This whole process was probably completed short after the deposition of the Ieper Clay unit and of the covering Egem Member, as shown by the amplitude of the deformations, fading progressively away in the overlying sand layers.

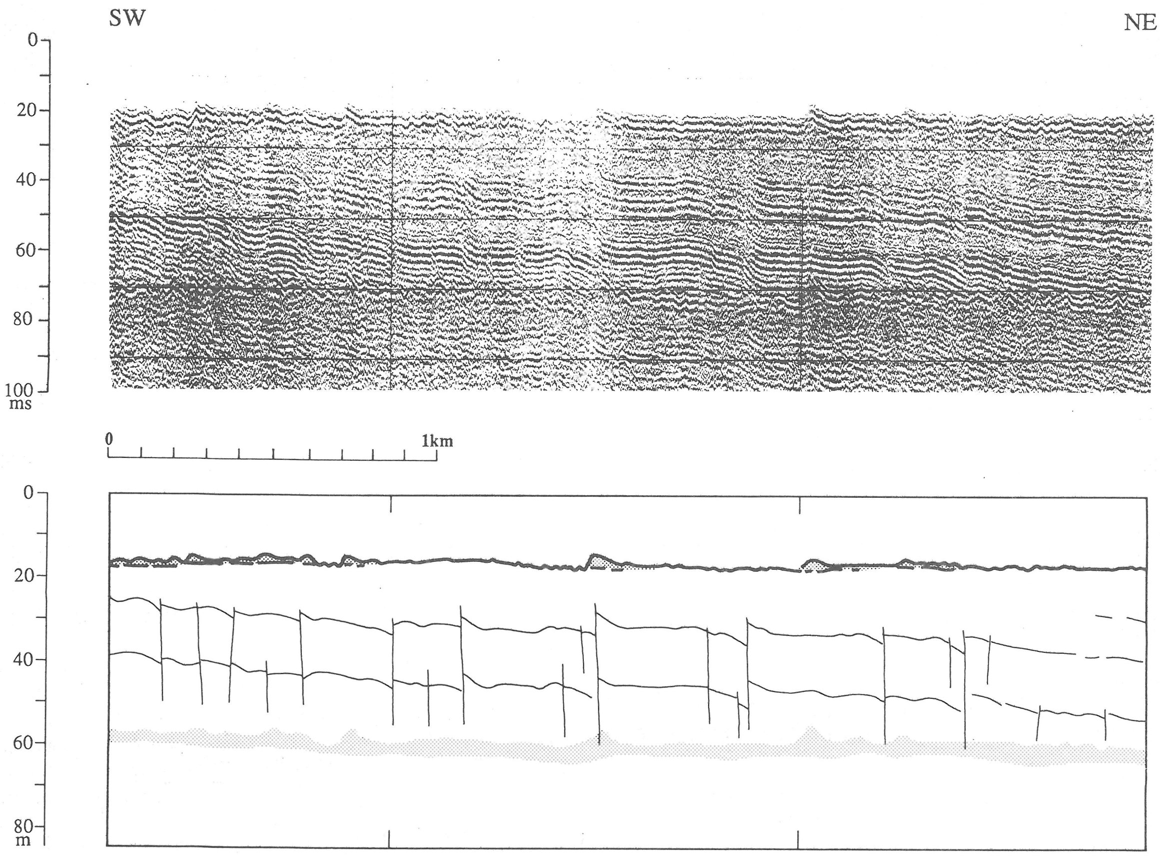


Figure 7 Analog-recorded sparker section and interpreted line-drawing showing the upper interval of Ypresian clay-tectonic deformations. Approximate localization : N 51°31.50', E 02°39.50'.
Vertical scales in ms are two-way time. Vertical scales in m are calculated with an interval velocity of 1620 m/s.

THE Y2 DEPOSITIONAL SEQUENCE

The boundary between the Ieper Clay and the following depositional sequence, Y2, can only be identified close to the coast, where a very discrete downlap can be observed on the distinct base reflector Y2.1. This weak unconformity disappears towards the basin centre, where the transition becomes gradual, but the reflector itself remains one of the strongest, most characteristic seismic-stratigraphic markers of the entire Palaeogene off the Belgian coast.

The total observed stratigraphical thickness of Y2 ranges from some 30 m in the north to an average of 15 m closer to the coast, where the sequence clearly has been truncated. Deep scouring can locally be observed (figures 8 and 9).

In general, two seismic facies units can be identified within Y2. A lower one, some 18 m thick, may consist of very weak, sometimes prograding reflector elements, but is usually completely reflection-free. Further to the north it is overlain by a second seismic facies unit, composed of a set of parallel reflectors of changing amplitude.

In accordance with its seismic facies characteristics the entire sequence can be correlated with the Egem Member : a lower interval of homogeneous, fine sands and an upper one, containing *Nummulites*-enriched horizons and calcareous sandstone banks.

Both units can also geometrically be connected, despite the strong northeasterly deflection in the outcrop pattern observed when the offshore seismic-stratigraphic map is compared with the onshore lithostratigraphic map (figure 1). This deflection is caused by a local depression in the erosion surface at the top of the Tertiary (MOSTAERT *et al.*, this volume ; DE VOS, 1984).

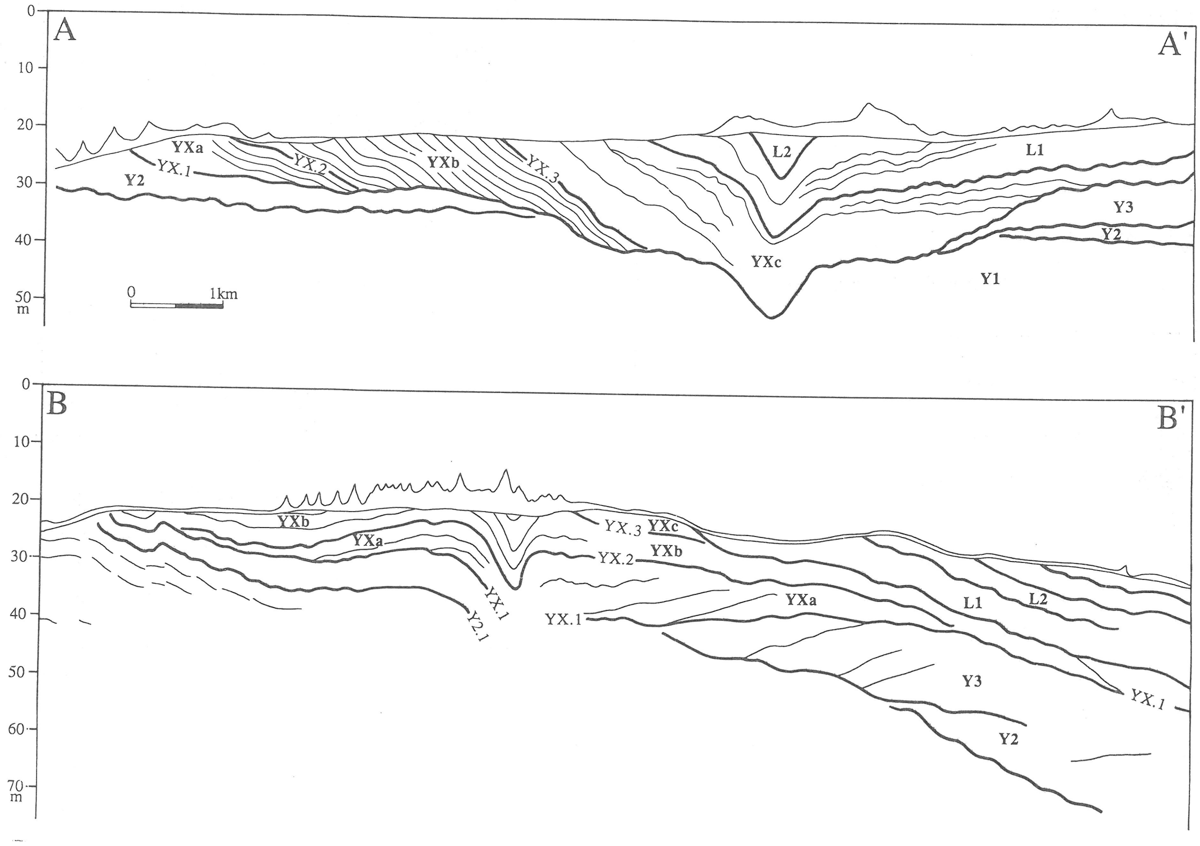
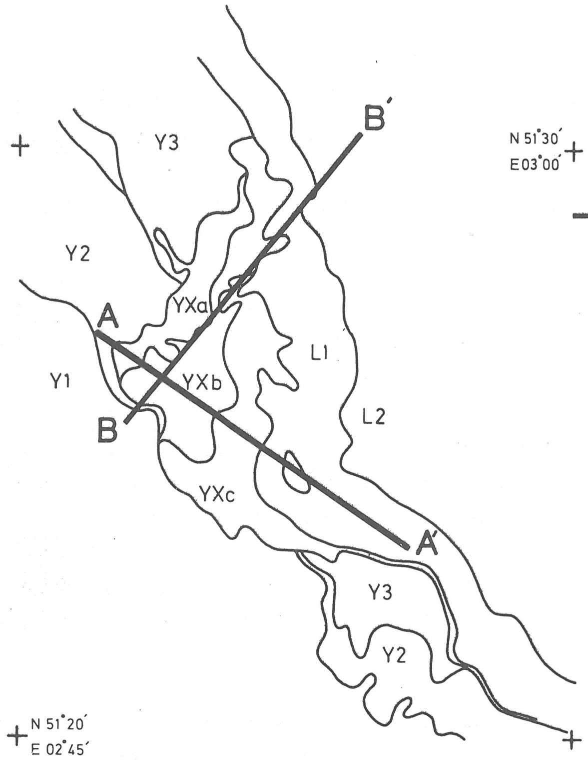


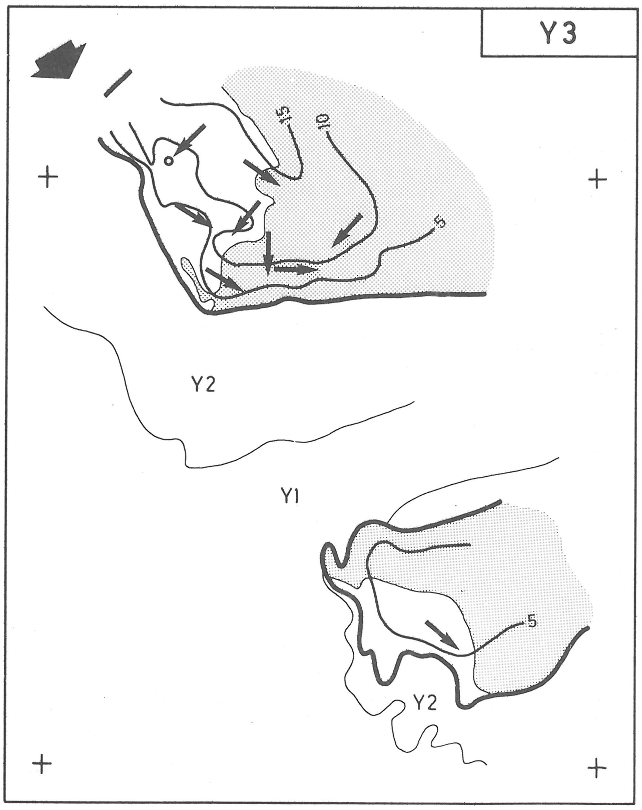
Figure 8 Type sections AA' and BB', illustrating successive erosive phases and the configuration of the basin-fill subsequences north of Ostend. For approximate localization see figure 9.
Vertical scales in m are calculated with an interval velocity of 1700 m/s.



YPRESIAN
BASIN-FILL SEQUENCES

SUBCROP MAPS OF
Y3, YXa, YXb, YXc TO L1;
LAPOUT PATTERNS AND ISOPACHS

0 5 10 km



SYMBOLS:

- 5 — isopach contour line
- subcrop extension
- covered by overlying Tertiary units
- apparent downlap
- apparent onlap
- apparent concordance
- direction of progradation

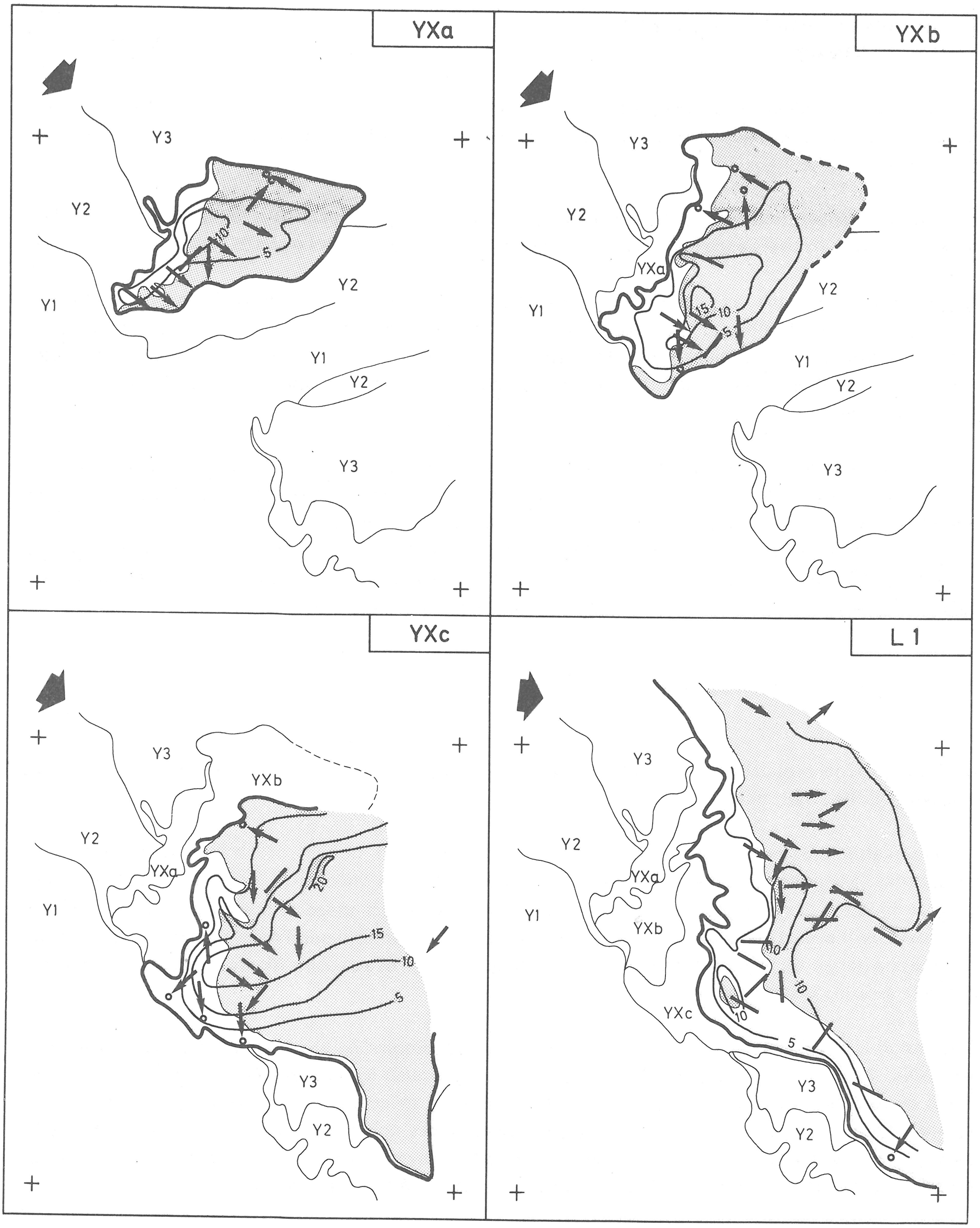


Figure 9 Successive subcrop and isopach (on base of an interval velocity of 1700 m/s) maps of Y3, the YX basin-fill subsequences and L1, illustrating seismic facies and lapout patterns.

THE Y3 DEPOSITIONAL SEQUENCE

The following depositional sequence, Y3, is separated from the underlying Y2-unit by a distinct erosion surface, which is best developed in the southern part of the area, where locally also some subtle baselaps can be observed in Y3.

The observed thickness reaches about 15 m in the north, but is usually less than 10 m further to the coast, where even in some areas this sequence has been entirely removed by erosion (figures 8 and 9).

In the southern part of the area (figure 9), the seismic facies is characterized by weak, roughly southwards prograding reflectors. Further to the north however, it shows some analogy with the underlying unit with parallel reflectors of variable amplitude. In this area the transition of Y1 into Y2 and Y3, and even into the overlying L1-unit (cf. HENRIET *et al.*, this volume), is very gradual, without noticeable unconformity or abrupt change in seismic facies.

On land, the previously mentioned Egem Member is overlain by the massive, homogeneous clay of the Merelbeke Member. Such a lithology could account for the fact that on the offshore isobath map of the base of the Quaternary (MOSTAERT *et al.*, this volume) the Y3-outcrop often appears as a significant positive feature. Furthermore, the boundary between the Ieper Formation and the Vlierzele Formation is known as an important unconformity (STEURBAUT and NOLF, 1986) ; a similar consideration can be made for the top of the Y3-sequence. Therefore a correlation of Y3 with the Merelbeke Member is suggested.

THE YX DEPOSITIONAL SEQUENCE

The last depositional sequence of supposed Ypresian age, YX, occurs only locally, as a complex fill of an erosive depression (DE BRUYNE, 1984).

This remarkable erosion feature is located about 20 km north of Ostend. It has a predominantly westsouthwest-eastnortheast orientation and it was scoured into the underlying units Y3, Y2 and even into the top of the Ieper Clay, over a width of more then 10 km. The exact shape of this erosive structure and its extent towards the east remains uncertain, due to its burial under younger Tertiary deposits, which leave it beyond the range of high-resolution seismic probing. Isopach evaluations (figure 9) suggest a circular, rather than an elongated shape.

YX can be divided into three subsequences in a southeasterly prograding basin-fill configuration, respectively named YXa, YXb and YXc (figure 8). Their seismic facies (see also figure 6 in HENRIET *et al.*, this volume) consists of abundant, tangential or parallel obliquely prograding reflectors. A detailed analysis of the internal structure and lapout patterns of Y3, the three YX-subsequences and the overlying L1-sequence (figure 9), shows a progradation, swinging from a southsoutheasterly over a southeasterly to an almost easterly direction. This rotation is associated with a southeasterly migration of the depocentres.

Due to be isolated character of this depositional sequence, it is not easy to link it with any onshore lithostratigraphic unit. However, there are some striking analogies between these deposits of limited areal extent and typical seismic facies, with the abundantly cross-bedded, ravinating Vlierzele Formation in the coastal plain (MOSTAERT, 1985). The typical stratigraphical configuration also recalls some parallelism with the Brusselian event in central Belgium, although on another scale and in an apparently different stratigraphical position.

CONCLUSION

On base of a detailed analysis of the offshore seismic data off the Belgian coast and a comparison with the onshore geology, it has been possible to establish a tentative correlation of the identified seismic-stratigraphic depositional sequences and the recently revised Ypresian lithostratigraphical units.

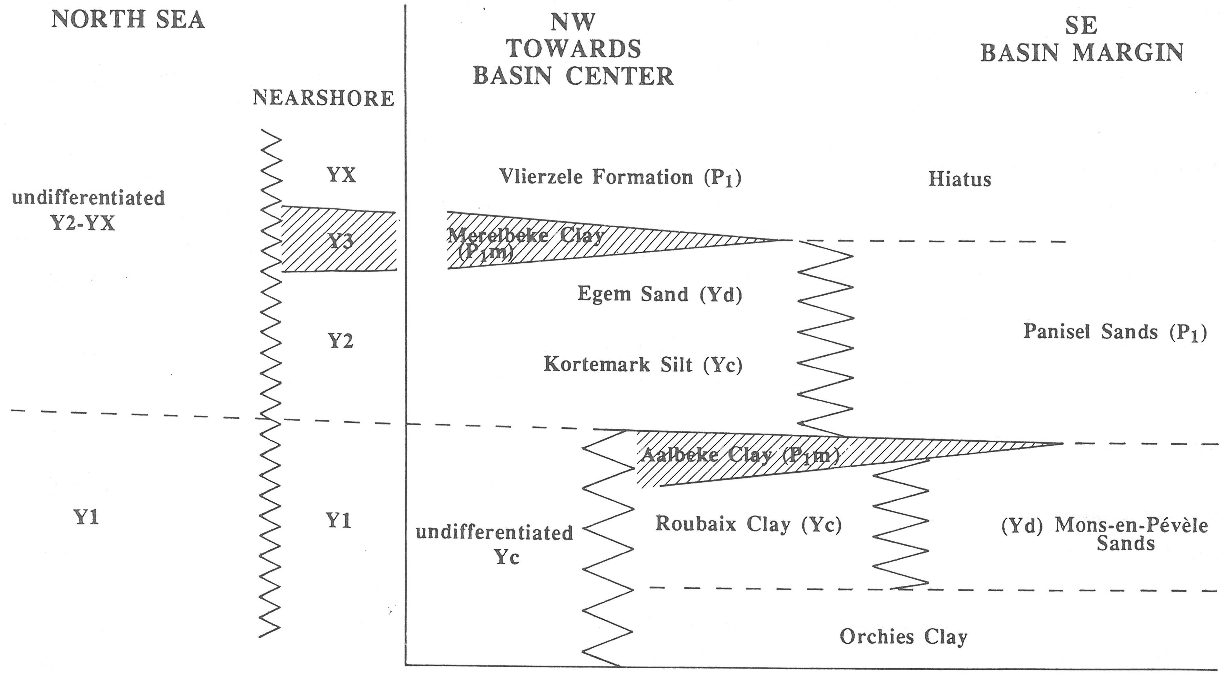


Figure 10 Stratigraphic correlation chart of the Ypresian in the Belgian Basin, ofshore and onshore.

This correlation is presented on a litho-, chrono- and seismic-stratigraphic correlation chart (figure 10). Although all observations indicate that for instance the short-range lateral and vertical changes in lithofacies frequently observed in the Flanders area and offshore close to the coast tend to become less explicit towards the palaeobasin's centre, future borehole control will still be necessary for ascertaining the exact sedimentological composition as well as geologic age of all identified seismic-stratigraphic units.

ACKNOWLEDGEMENTS

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