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Subsurface structural analysis of the late-Dinantian carbonate shelf at the northern flank of the Brabant Massif (Campine Basin, N-Belgium).

by

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R. DREESEN [1], J. BOUCKAERT [2], M. DUSAR [2], J. SOILLE [3] & N. VANDENBERGHE [4]

INTRODUCTION

1.1.- SEISMIC SURVEYS IN THE ANTWERP CAMPINE AREA

In table A (p. 36) a list is given of all the seismic surveys carried out in the area investigated. In particular the recent campaigns 4, 5, 6 and more especially 7 were used in our study.

The different acquisition and processing parameters of the recent campaigns are listed in table B (p. 37). The well seismic velocity surveys available are indicated in table C (p. 37).

1.2.- GEOLOGICAL - STRATIGRAPHICAL SETTING

The studied area represents the southernmost part of the Campine - Brabant Basin at the northeastern edge of the London - Brabant Massif (fig. 1). The geological framework of the area is made up of a sequence of slightly north-dipping Cenozoic and Mesozoic strata, which unconformably overly steeper but also north-dipping Devono - Carboniferous strata, which in their turn cover a structurally more complex Cambro - Silurian basement (LEGRAND, 1968).

The Cenozoic deposits reach a thickness of about 600 m and comprise the following lithostratigraphical suite (from top to bottom) : Pleistocene Campine clays and sands, the Neogene glauconitic Sands, the Boom Clay, the Kallo Clays and fine Sands complex, the Lede - Brussel - Panisel Sands, the Ieper Clay and the Landen - Heers Clays and Marls.

The Mesozoic is essentially composed of Upper-Cretaceous (Campanian - Maestrichtian) chalky limestone and marl deposits (about 200 m thick).

The Paleozoic (Pre-Permian) subcrop has been reached by several drillholes in the Campine area, East of Antwerpen, of which the Heibaart and Turnhout boreholes are the best documented (BLESS *et al.*, 1976; 1981) (fig. 2).

The Heibaart - Loenhout borehole (He 1 and 1 bis) has been drilled in 1962 by PETROFINA. Coring was discontinuous. Lower Namurian strata underlying the basal Cretaceous unconformity were reached at 1052 m and the Dinantian at 1138 m. The Upper Devonian sandstones and marine shales sequence was reached at 1461 m. The borehole penetrated the Silurian subcrop at 1627 m. Between 1977 and 1980 several boreholes (DZ H1 - DZ H6) were drilled on top of the Heibaart structure on behalf of DISTRIGAZ, in order to test the possible reservoir qualities of the uppermost karstic zone in the Dinantian carbonates for subsurface gas storage. For a detailed description of the cored intervals of these boreholes (microfacies - microfauna - depositional environments) the reader is referred to BLESS *et al.* (1981). The cored intervals located at the top of the karstified Dinantian limestone have been attributed to the basal Warnantian (V3b). Microfacies analysis of the cores of boreholes DZ H2 and DZ H4 (S-flank of the Heibaart dome) pointed out a deposition in an open marine shelf lagoon under shallow water conditions, whereas the cores of the other boreholes (all located on the N-flank) indicated deposition on tidal flats in very shallow lagoons with restricted water circulation and hypersaline waters. The Turnhout borehole (drilled between 1953 and 1955 for the Institut National de l'Industrie Charbonnière and the Belgian Geological Survey) reached the Upper Carboniferous at 1002 m and the top of the Dinantian at 2162 m. Lithological descriptions, especially of the Silesian, have been published by DELMER (1962, 1963). The reader is referred to BLESS *et al.* (1976) for a review

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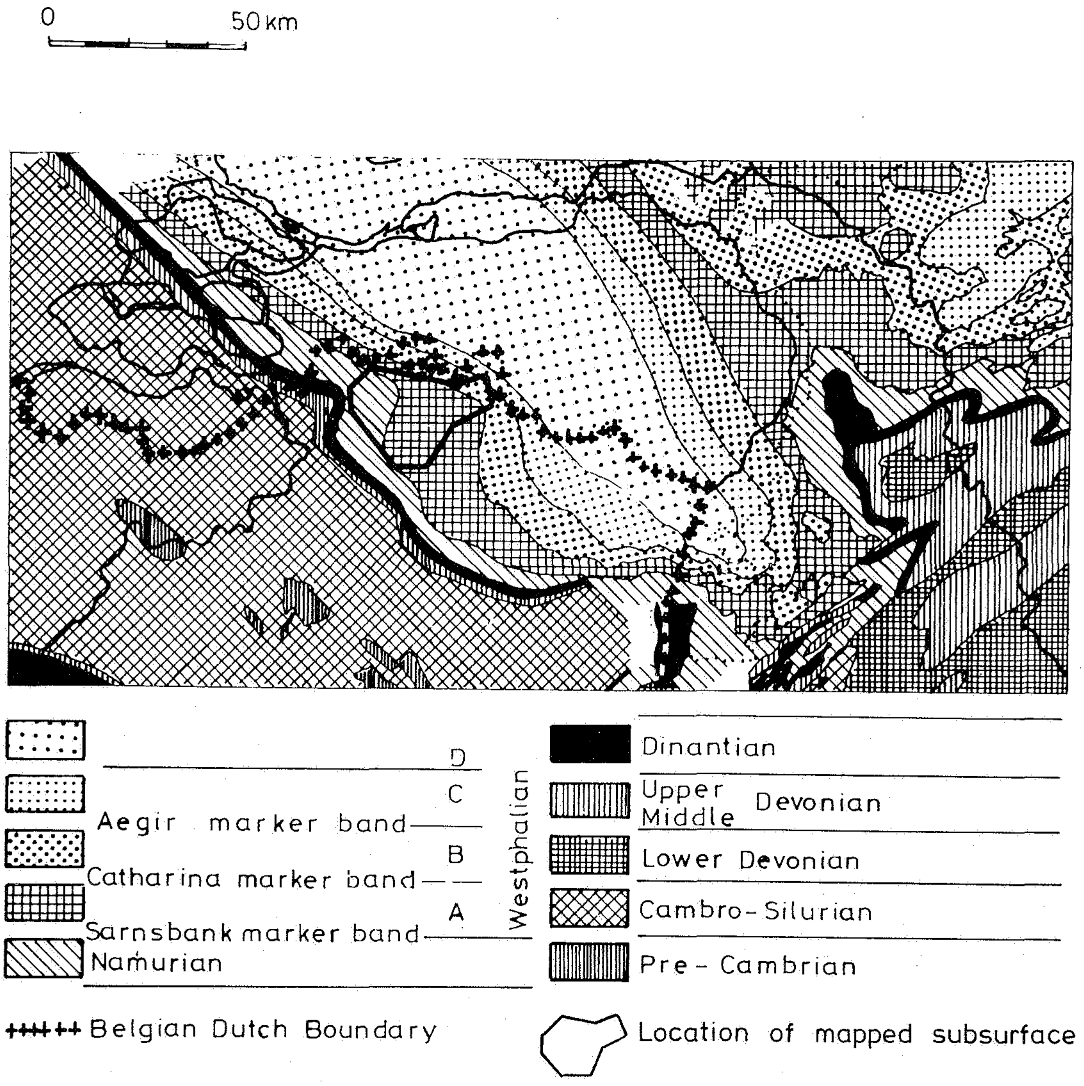


from Van Staalduinen et. al. (1979): The Geology of the Netherlands

Figure 1. - General geological situation map.

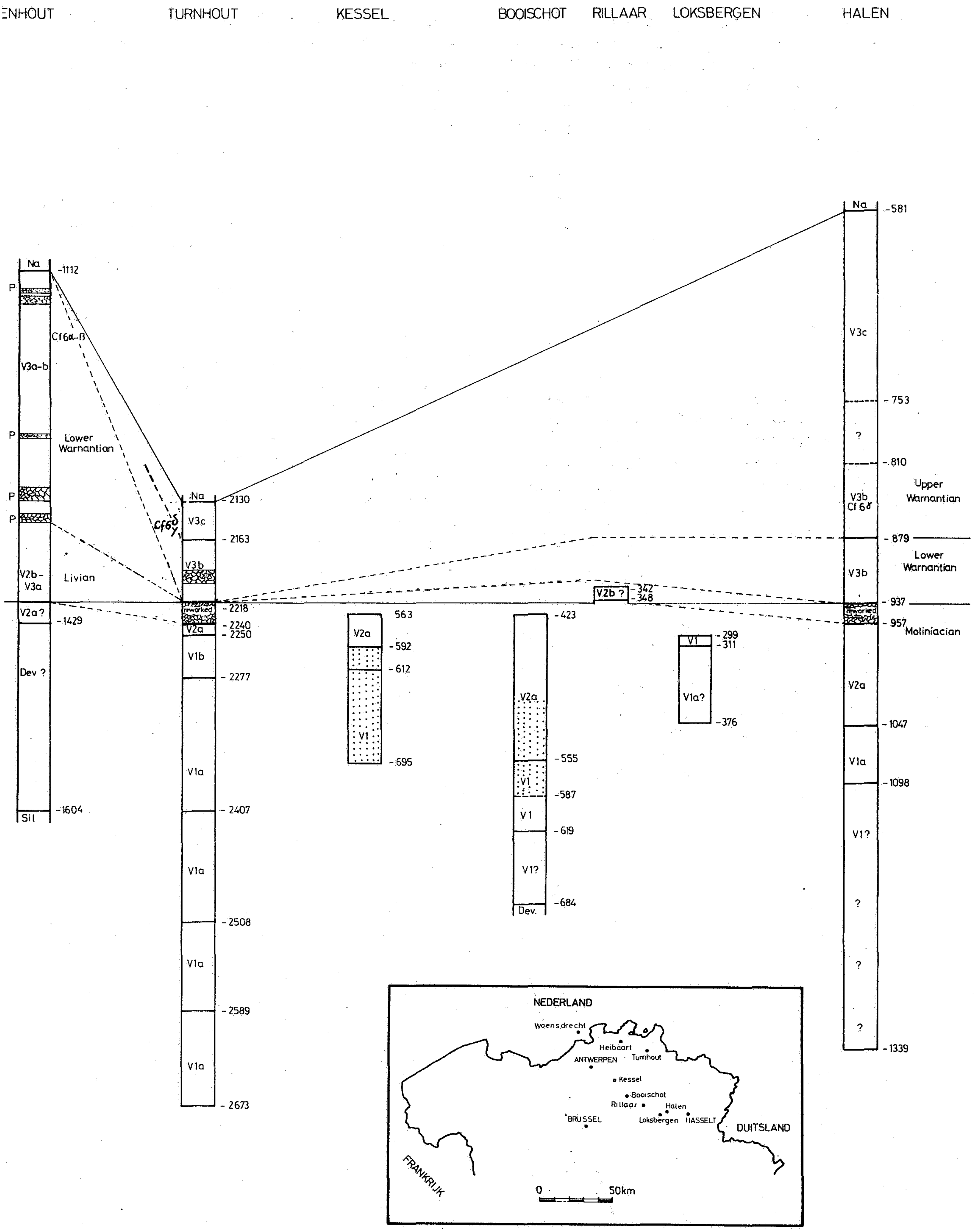


Figure 2. - Stratigraphic correlation of the Dinantian well sections in the Campine area.

of the microfaunal content and biostratigraphic conclusions on the Dinantian. Microfaunal assemblages (Foraminifera) indicated an V1a through V3c (Moliniacian - Warnacian) age for the penetrated carbonates. None of the boreholes in the studied area has yielded a stratigraphically continuous sequence of Dinantian rocks thus far.
From the frequent occurrence of stratigraphic gaps, unconformities, hardgrounds, breccias and reworked microfossil assemblages in the studied boreholes N of the Brabant Massif, it is clear that several epeirogenic movements have influenced the sedimentation pattern during late Dinantian times (BLESS *et al.* 1976, 1981). Continental facies have even been recorded from the Booischot borehole : conglomerates, sandstones, cornstones, paleosoils, all dated V2a (LEGRAND, 1964; BLESS *et al.*, 1976).

The Namurian is incomplete in the Campine Basin since the Pendleian and basal Arnsbergian strata are missing (BOUCKAERT, 1967). This stratigraphic hiatus is the result of a widespread regression coinciding with orogenic movements of the sudetic phase (GRAULICH, 1962). This regression affected essentially the nearshore and inner shelf areas of the southern borders of the Brabant - Campine Basin.

The subsequent transgression gradually spread out across the shoals but was only completed in Kinderscoutian times (BOUCKAERT, 1967; BLESS *et al.*, 1980). The age of the oldest Namurian strata in the Turnhout borehole is Upper Arnsbergian (E2c) whereas the stratigraphical gap between Dinantian and Namurian extends into the Kinderscoutian most probably, in the Heibaart boreholes (BLESS *et al.*, 1980, 1981).
Thickness variation along the northern border of the Brabant Massif is relatively small (500-680 m over a distance of more than 100 km).
However the preserved thickness of the Namurian has been reduced to less than 70 m over the particular Heibaart antiform structure due to post-Westphalian pre-Cretaceous erosion. The Namurian succession becomes significantly thicker towards the central parts of the basin as can be deduced from the more than 1800 m thick sequence in the Rijsbergen-1 NAM-borehole (BLESS *et al.*, 1976). The more precise nature of this deep Namurian basin, north of the Heibaart area, has been described by VANDENBERGHE, 1982 (N flank Brabant Massif - 1980 seismic survey). This deep basin which mainly consists of silty mudstones with some important sandstone levels, at least towards the top (VANDENBERGHE, 1982) is bordered to the south by an important north-dipping and roughly east - west striking listric-shaped fault, hereafter called the Hoogstraten fault, which runs south of Hoogstraten, Wortel and Weelde (VANDENBERGHE, 1984). This listric fault, accompanied by adjacent " roll-over" structures is interpreted as a growth fault, which developed during Westphalian times and probably already from the late Namurian onwards. The Dinantian - Namurian unconformity might have acted as a flat-lying sliding plane for the displacement and the stretching of the Namurian strata. This growth fault may represent the northernmost limit of the shallow Dinantian carbonate shelf : farther to the North, Kulm-type Dinantian deposits might explain the disappearance of the outspoken Dinantian limestone reflector.

The preserved thickness of the Westphalian does not exceed 575 m in the Turnhout borehole (DELMER, 1962) whereas it is completely lacking on top of the Heibaart structure. Obviously these thickness figures are determined by the structural dip of the Upper Carboniferous and the post-Westphalian to pre-Upper Cretaceous erosion.

An overlap-sequence on top of one of the more continuous sandstone reflectors might indicate a Namurian-Westphalian unconformable contact (VANDENBERGHE, 1982).

The major and also the youngest tectonic features in the studied area finally are the NNW-SSE directed tensional faults which affect the Carboniferous strata as well as the overlying Meso-Cenozoic deposits. These important faults are related to the Roer Valley Graben boundary faults of the Netherlands Central Basin. They have been active at least since the late Paleozoic. During most of the Meso-Cenozoic they have been reactivated, sometimes in opposite senses, resulting in thickness variations of several Cenozoic formations in the NE-part of Belgium (VAN STAALDUINEN *et al.*, 1979).

1.3.- MAIN RESULTS

The compilation of subsurface structural data from several reflection seismic surveys, carried out between 1974 and 1982, resulted in a series of structural isochron maps covering a surface of about 400 km^2 in the North Campine area, south of the Dutch-Belgian border. The isochron map of the top of the Dinantian reflects the structural complexity of the Late Visean regressive carbonate shelf.
The surprising topography of the base of the Cretaceous otherwise illustrates the erosional unconformity at the beginning of the Upper-Cretaceous transgression influenced by the underlying Paleozoic strata.
The most striking structural element observed on the top Dinantian structural map, is the alternation of flattened, wide, positive areas and narrow, relatively deep, synform belts with some more localized collapse structures (western part of the studied area). Farther to east, the structural picture becomes very complex, due to the interaction of several fault systems. The central, transitional area seems to be affected by extensive, but narrow, NS directed graben-like deformations.
The structural influence of the Paleozoic subcrop upon the covering Mesozoic deposits is well illustrated in the

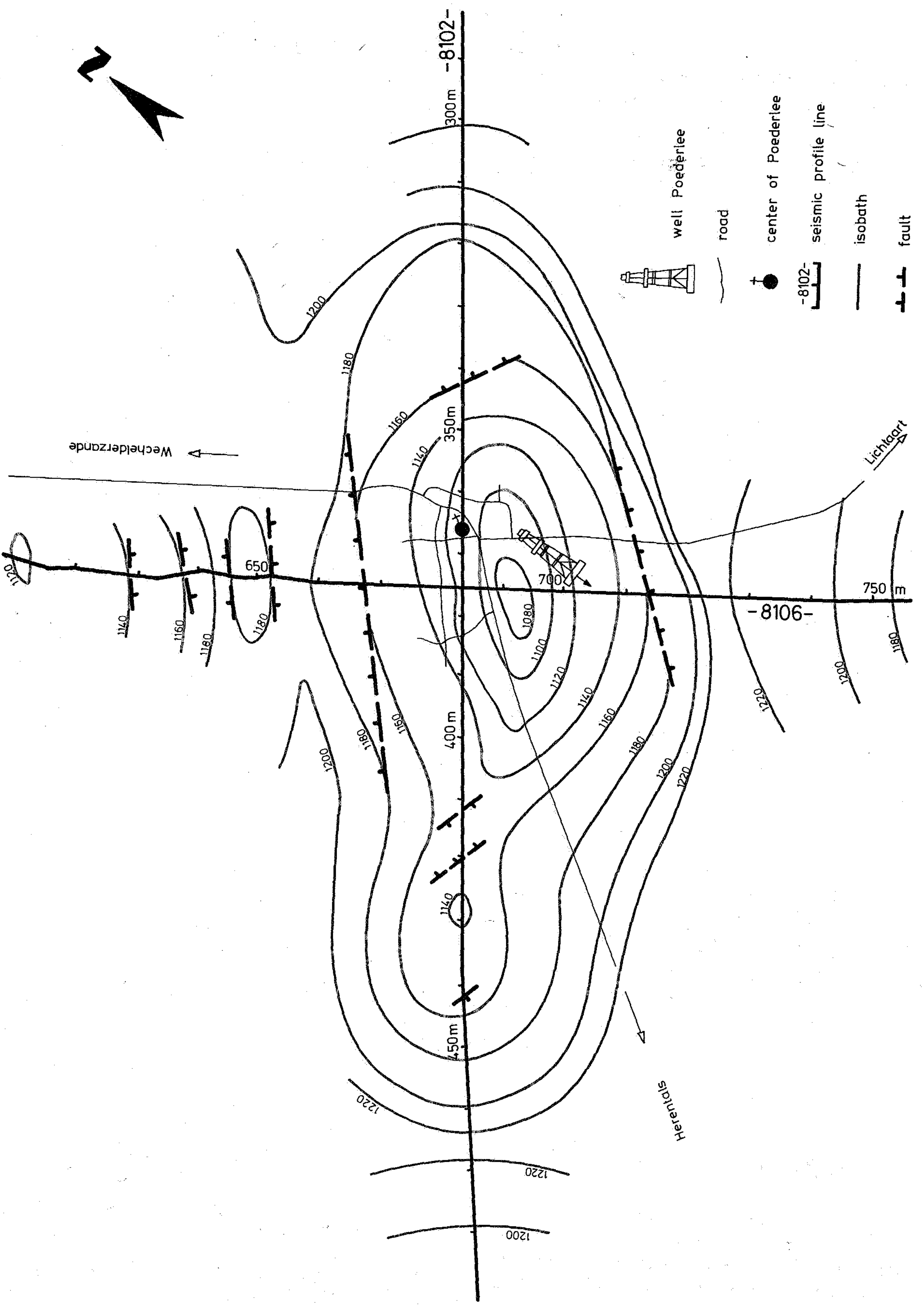


Figure 3. - Isobaths of the top Dinantian at Poederlee (from Finite Difference Migration, FDM, seismic profiles).

enclosure IV, by the presence of sinkholes as well as by the occurrence of NS trends deviating from the general EW strike of the basal Cretaceous topography.

From the structural relationships between Dinantian-Silesian and Paleozoic-Meso-Cenozoic, a working model can be derived for the paleogeographical and structural evolution of the investigated area.

2. THE DINANTIAN CARBONATE SUBCROP

2.1.- SEISMIC CHARACTER

South of the listric fault, the top of the Dinantian limestones is expressed as a pronounced, slightly dipping seismic reflector. By its high amplitude and lower frequency this reflector can in general easily be distinguished from Upper Carboniferous reflectors.

North of the Hoogstraten fault, the pronounced character of the top Dinantian is lost, except for some short dipping intervals near the fault.
Although the top of the Dinantian limestones is expressed as a reflector of good quality, some zones are not and the top Dinantian reflector then becomes discontinuous and in some cases even hard to recognize. These zones are in general restricted to narrow depression belts. Their origin is discussed in the next paragraphs.

An intriguing feature, observed in all the seismic surveys, is the almost complete absence of good reflectors, if any, below the strong Dinantian reflector, with the exception of one particular deep reflector, west of Westmalle (see further).

This could result from the important increase in acoustic impedance at the contact of Namurian shales and Dinantian carbonates, reflecting almost all the seismic wave energy.

Furthermore a strong karstification and brecciation occuring within the Dinantian, as seen in the different boreholes, might have contributed to scatter the energy.

2.2.- GENERAL STRUCTURAL TRENDS AND ANOMALIES

The Dinantian subcrop (enclosure III : Isochron map of the top of the Dinantian) can be structurally subdivided into two main zones : a western zone in which the strike grades from WNW-ESE in the north to NNW-SSE in the south, and an eastern zone with a dominant NNW-SSE strike. An important NNW-SSE oriented fault system characterizes the transition between both structural areas.

2.2.1.- Western zone

The most striking feature of the western zone is the alternation of broad antiform and narrow depression belts, bordered by parallel longitudinal faults. The most obvious longitudinal depression belt is the one running NW to SE, between the St-Antonius - Zoersel-Grobbendonk antiform and the Westmalle-Vlimmeren-Lille antiform belt. The strike changes abruptly from WNW-SSE to NNW-SSE near Zoersel where the Dinantian subcrop displays a pronounce kink or "nose".

This depression belt has a lenght of more than 18 km and a width ranging from 250 to 1000 m. Within the depression belt several minima occur, with maximum depths between 250 to 300 m (the depth time conversion is based on well seismic data in the Heibaart and Turnhout boreholes (table C).

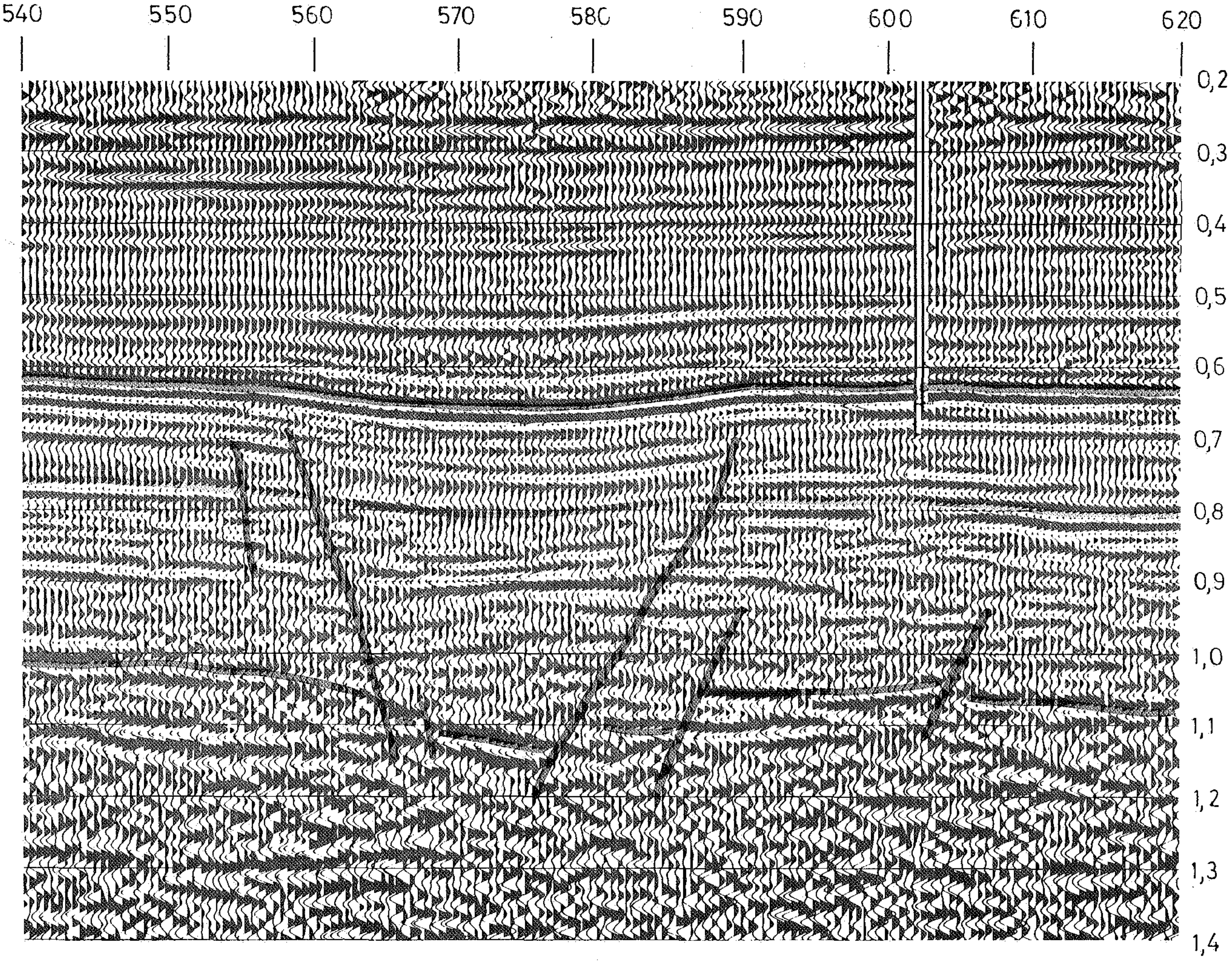
The Westmalle-Vlimmeren-Lille antiform belt (width 1 to 3 km, maximum heigth of about 200 m) is subdivided by transversal depressions into several elongated antiform units; the southernmost limb of this antiform belt, the Wechelderzande-Lille-Poederlee antiform complex, is separated from the adjacent Vorselaar antiform unit, by a (sub)transversal depression. Both units most probably have been former parts of a same NW-SE elongated antiform flat.

The Poederlee antiform, in the southernmost part of the latter antiform complex, has recently been selected as a potential subsurface gas storage target. An exploration borehole on top of this Poederlee structure will be drilled for DISTRIGAZ and the BELGIAN GEOLOGICAL SURVEY (fig. 3).

The Westmalle and Vlimmeren antiform structures are separated by a SW-directed extension of a birdfoot-like lobated depression, right under the centre of Oostmalle. This depression belt extends from Vlimmeren to the W over more than 7 km, and reaches a maximum depth of about 200-250 m near Oostmalle. Since the transversal fault bordered depressions do not substantially differ seismically from the longitudinal ones, these depressions in fact cut a rectangular pattern into the top of the Dinantian limestone.

An EW directed antiform belt separates the Oostmalle depression from the next one, the St-Lenaarts depression belt, the minimum of which is situated SE of St-Lenaarts (maximum depth of about 200-250 m).

The main axis of this belt runs NW-SE whereas its numerous lobes or extensions have a dominant EW orientation,just as their bordering longitudinal faults. The NW-extensions of the St-Lenaarts trough are the western limit of the next and most important antiform complex of the western zone, the Loenhout - Heibaart - Rijkevorsel dome structure.



yellow : base of Cretaceous
blue : top of Dinantian
orange : base of Tertiary
red : faults

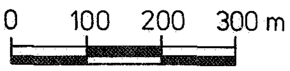


Figure 4. - Collapsed nature of the Dinantian top with accompanying subsidence till the Tertiary (8107 FDM).

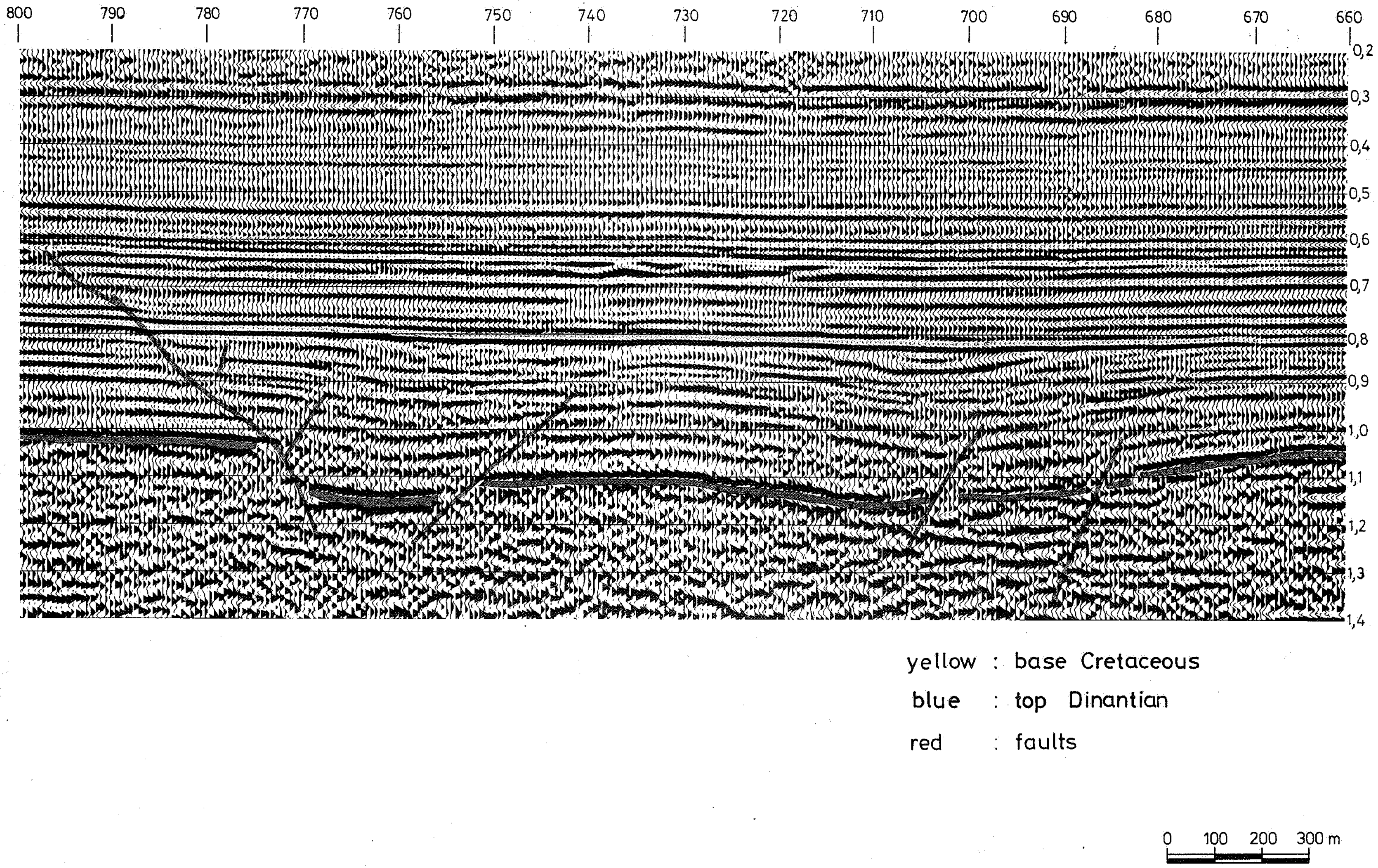


Figure 5. Two adjacent subsidence zones in the Dinantian (8111-EDM)

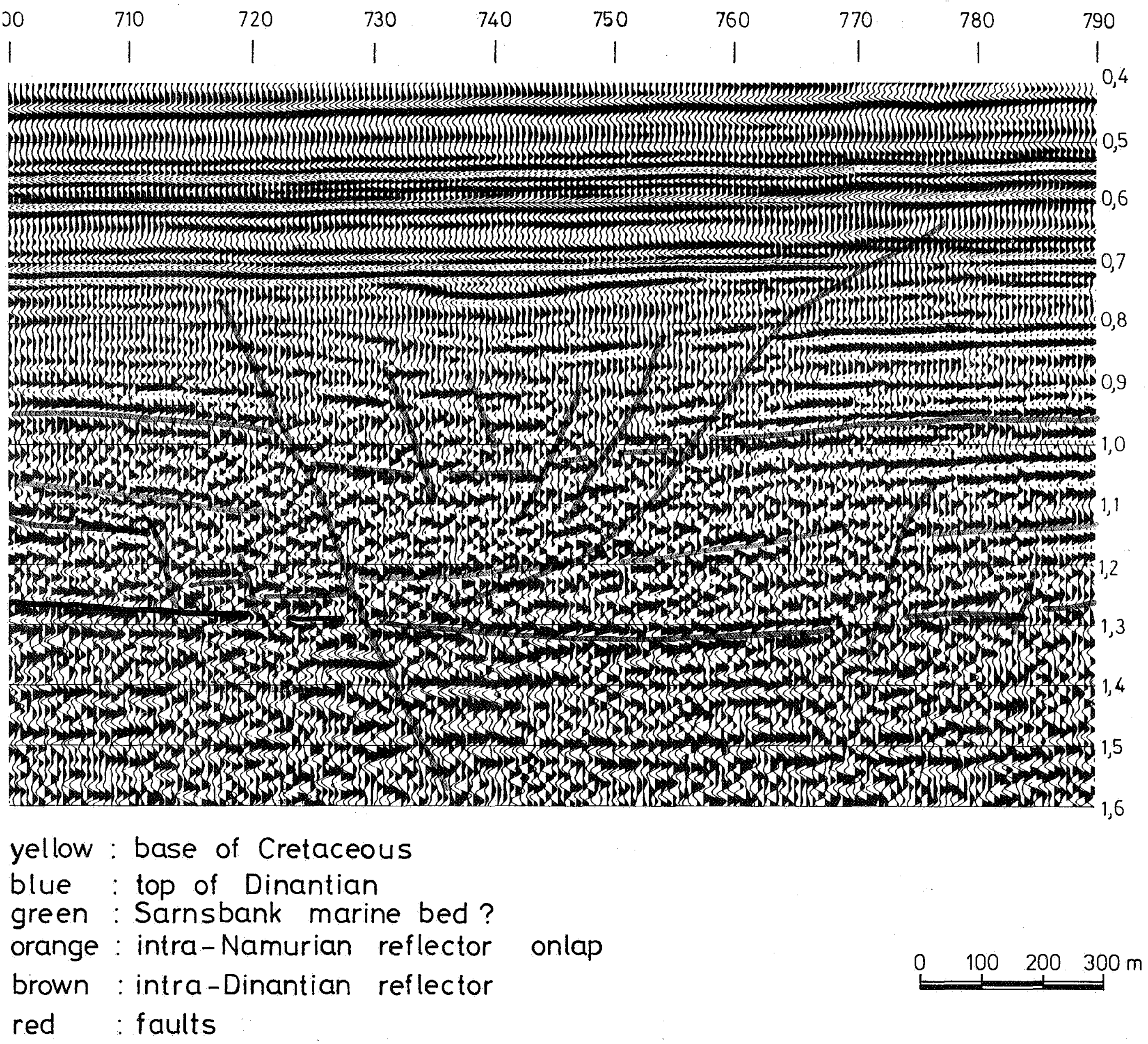


Figure 6. - Influence of the top Dinantian subsidence on the sedimentation during the Westphanian and the occurrence of an internal structure in the Dinantian underlying the Poederlee antiform (8106 FDM).

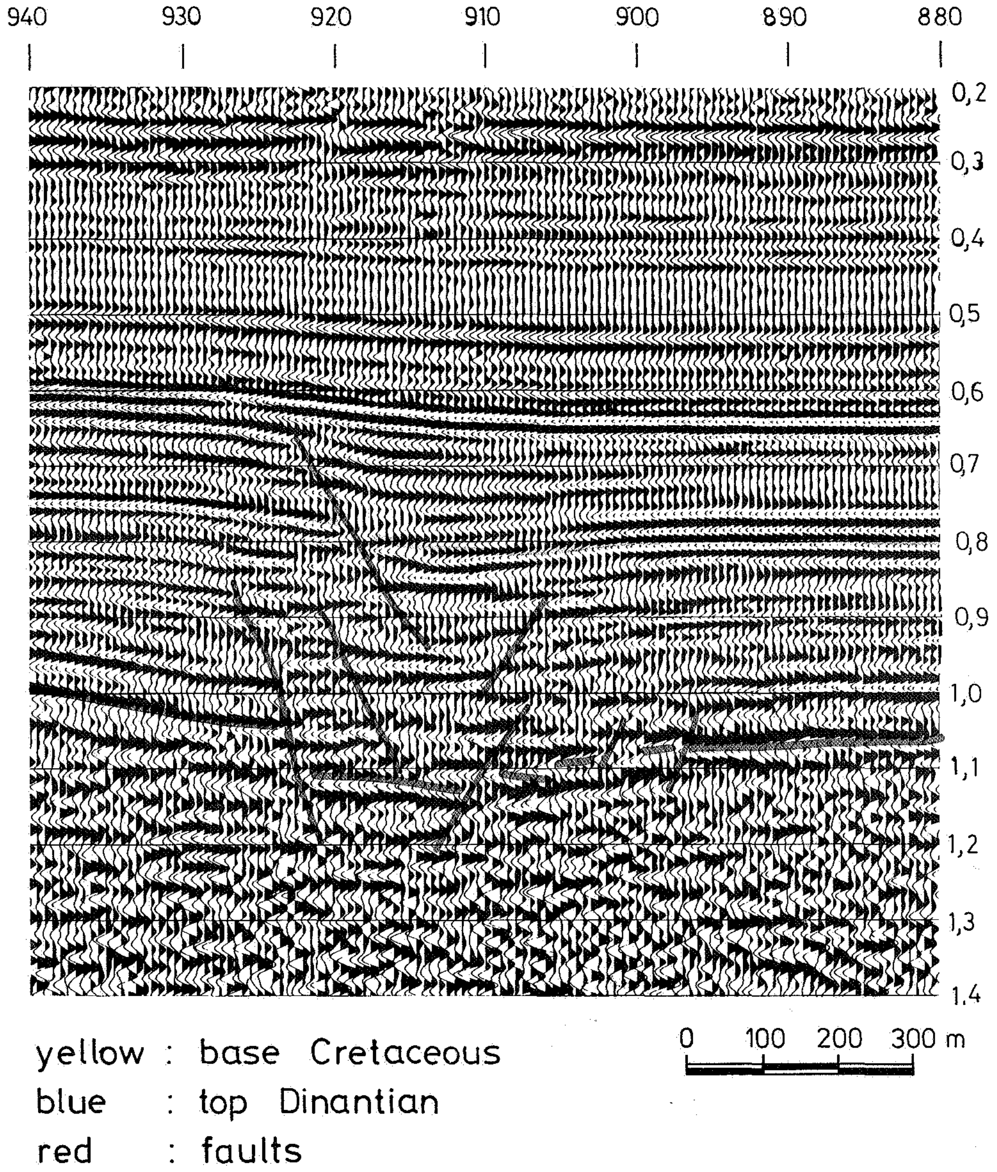
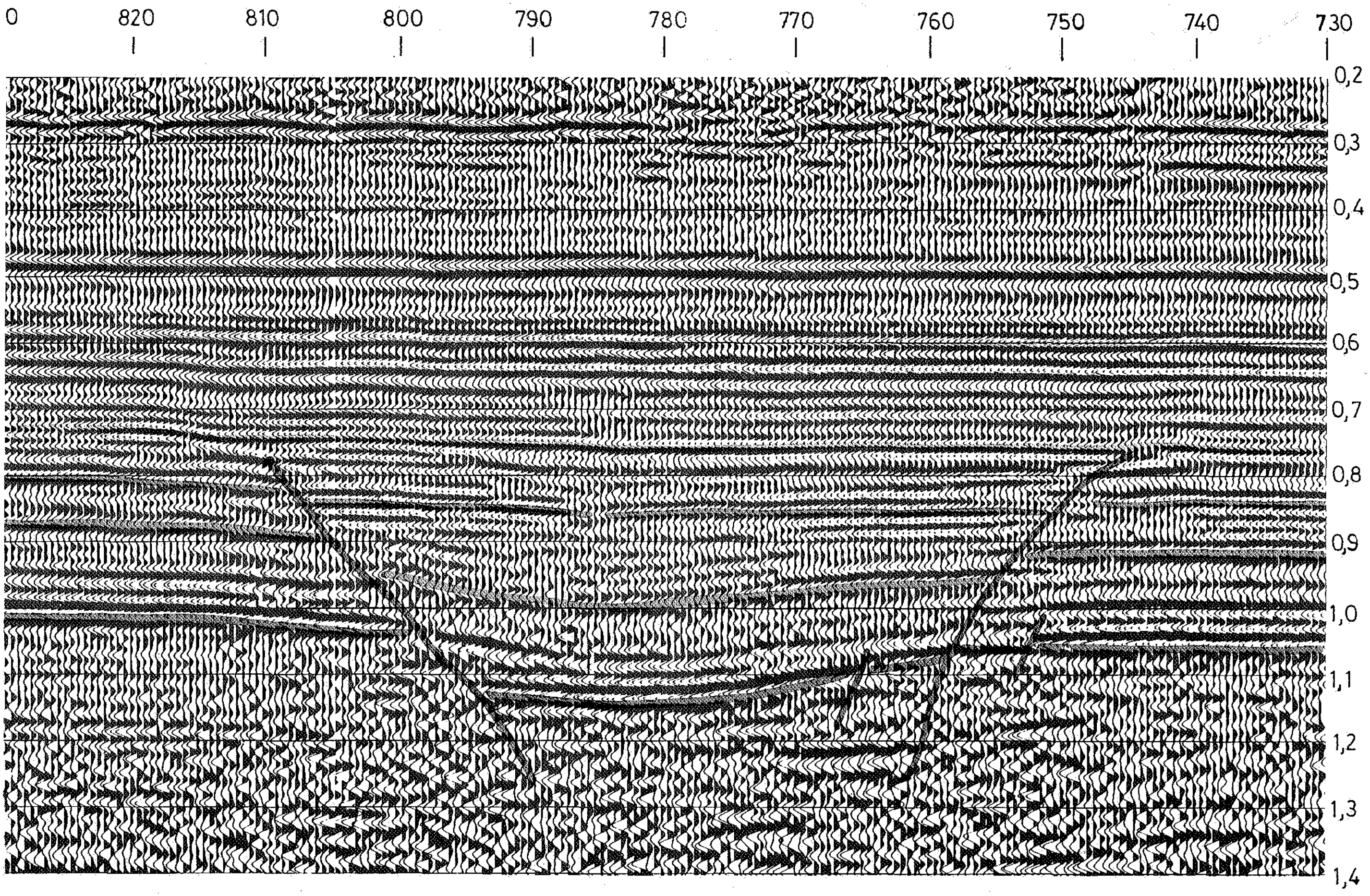


Figure 7. – Faults in the post-Dinantian sediment sequence induced by the subsiding Dinantian (8111 FDM).



yellow : base Cretaceous
blue : top Dinantian
green : Sarnsbank marine bed ?
orange : intra-Westphalian reflector
red : faults

Figure 8. - Infill of the subsiding zone as shown by the thickness increases in different Upper Carboniferous intervals (8109 FDM

This complex comprises a main EW oriented dome with an extension to the SE. It is separated from its southeastmost limb, the Rijkevorsel antiform flat, by a narrow NE-SW directed depression, bordered also by longitudinal parallel faults.

The latter flat also forms a connection to the south with the Westmalle-Vlimmeren antiform complex. Further to the north and the northeast otherwise the carbonate shelf is steeply dipping in the same direction and hits the EW directed listric faults near Hoogstraten, where the Dinantian reflector disappears beneath or coincides with the flat-lying plane. The Heibaart-Loenhout dome is the most pronounced antiform structure in the studied area, and has been thoroughly investigated by several seismic surveys and exploration drilling campaigns (see introduction). Its culmination point reaches about 300 m near Heibaart.

2.2.2.- Eastern zone

The dominant structural features of the eastern zone are the NNW-SSE to NS strike of the subcrop, and the eastward dip. In the northeastern area the tectonic framework becomes more complex.

The area west and northwest of Turnhout is characterized by the presence of NNW-SSE elongated flat antiforms (e.g. Gierle high, Merksplas high, Beerse high) bordered or subdivided by very narrow, faulted and parallel synform structures (e.g. west of Gierle, west of Beerse, Vosselaar). These flat antiforms have a length of about 10 km, a width of about 2 km and a maximum heigth of about 150 m.

The depression belts are 150 to 500 m wide and they reach a maximum depth of about 200 m (e.g. west of Beerse).

To the northeast of Turnhout the structural picture becomes very complex, due to the presence of several mutually intersecting fault systems (see further). As a result of these tectonic deformations the Dinantian subcrop has been subdivided into several structural blocks with different dip and dip direction.

The last obvious antiform structure and adjacent elongated narrow depression, are located north-northeast of Turnhout. East of these structures, a real structural trend of the Dinantian subcrop is no longer discernible.

2.2.3.- Transitional zone

An extensive - at least 17 km long - faulted depression belt, runs from the North, near Hoogstraten, to the southeast of Poederlee, and marks the transition between the two main structural areas mentioned above.

This graben-like depression is the narrowest in the south (about 500 m, NE of Poederlee) but widens towards the northwest, where it reaches a maximum width of about 3 km near Hoogstraten.

The longitudinal bordering faults are not continuous but they are made up of several successive fault steps. Within this faulted depression belt, some internal structures are still visible, such as a 4 km long, NS directed antiform structure (between Vlimmeren and Beerse). This depression belt widens northeast of Rijkevorsel but the seismic interpretation of this area is very preliminary because of the insufficient seismic coverage.

2.3.- DEFORMATIONS

The faults affecting the top of the Dinantian carbonates can roughly be grouped into three main deformation mechanisms :

1. growth fault
2. collapse structures
3. tectonics.

2.3.1.- Growth fault

This major EW directed and N to NW - dipping listric fault runs at a distance of about 2 km to the north of the Loenhout-Heibaart dome, in an eastward direction, south of Hoogstraten, Wortel and Weelde.

For a detailed description of this growth fault and of its bearing on the structural evolution of the Campine Basin during Silesian times, the reader is referred to VANDENBERGHE (1984).

The growth fault affects essentially the Upper Carboniferous strata (a steep fault plane in the upper part, gradually flattening towards the base). The flat-lying, slightly NE-dipping Dinantian-Namurian unconformity has been used most probably as a sliding plane to displace the Silesian strata towards their depocenter in the north.

A series of E-W or WNW-ESE directed faults between Turnhout and the Belgian-Dutch border, are interpreted as satellite faults of the main growth fault and developed probably simultaneously with the major growth fault from Late Namurian on and mainly in the Westphalian. These faults have been transversally cut by the younger graben-related faults.

2.3.2.- Collapse structures

The most conspicious structural element in the western zone of the investigated area is the presence of longitudinal, transversal and lobate depression belts, partially with closed contours on the isochronmap (enclosure III).

In all these cases these depressions are bordered by relatively steep and parallel normal faults, along which the Dinantian limestone reflector has been gra-

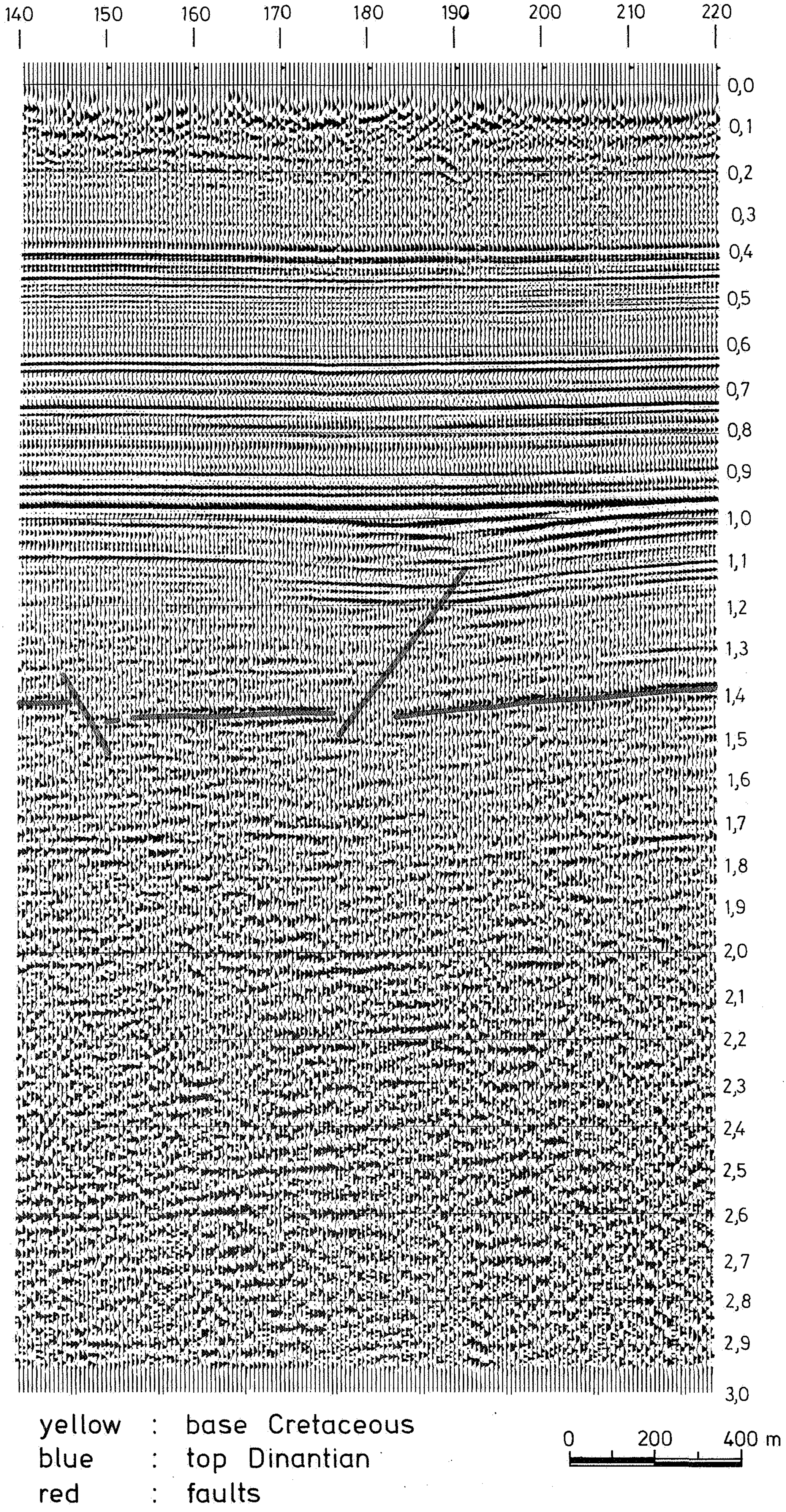


Figure 9. - Influence of the subsiding Dinantian on the overlying Upper Carboniferous and Cretaceous (8012).

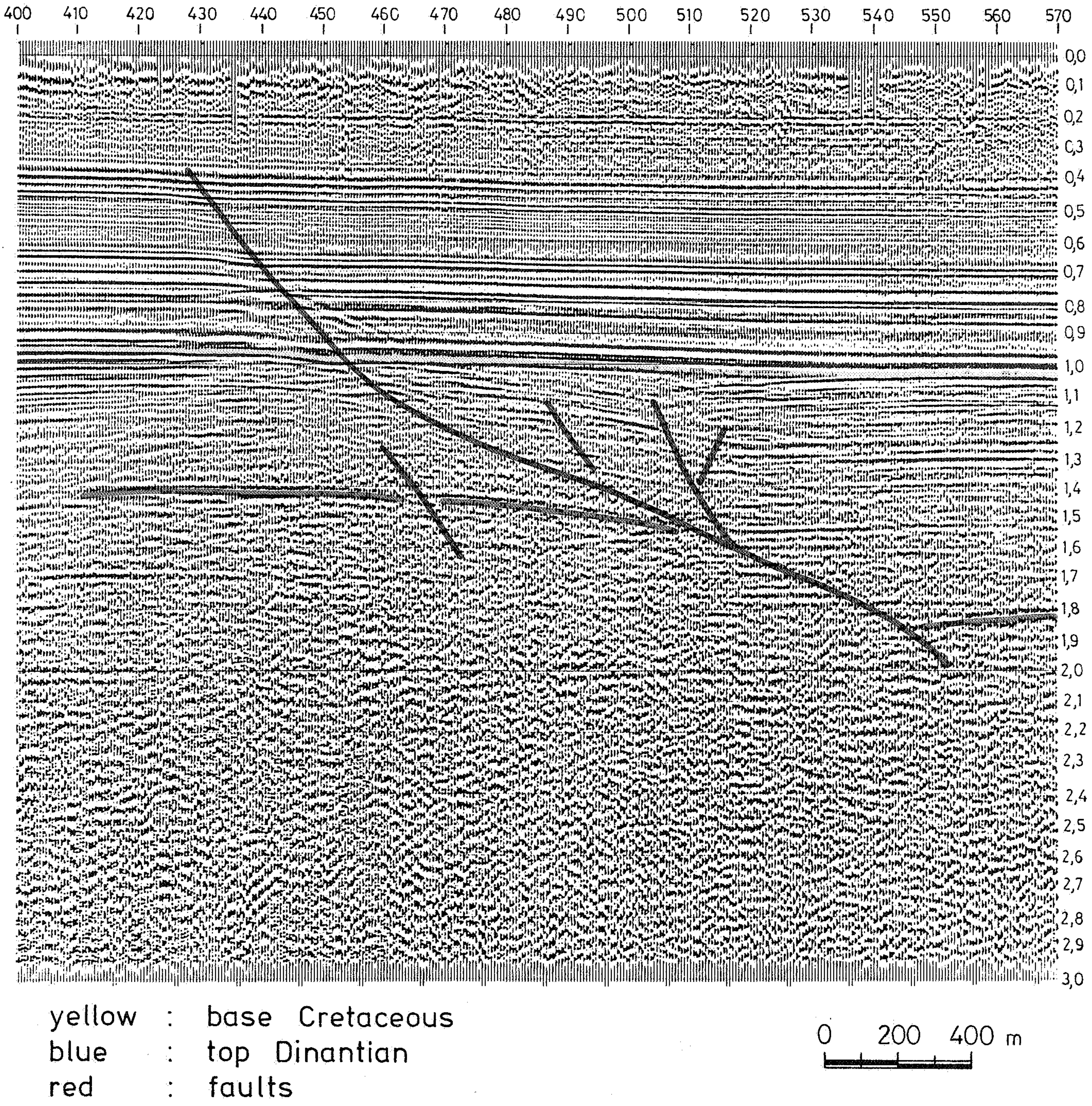
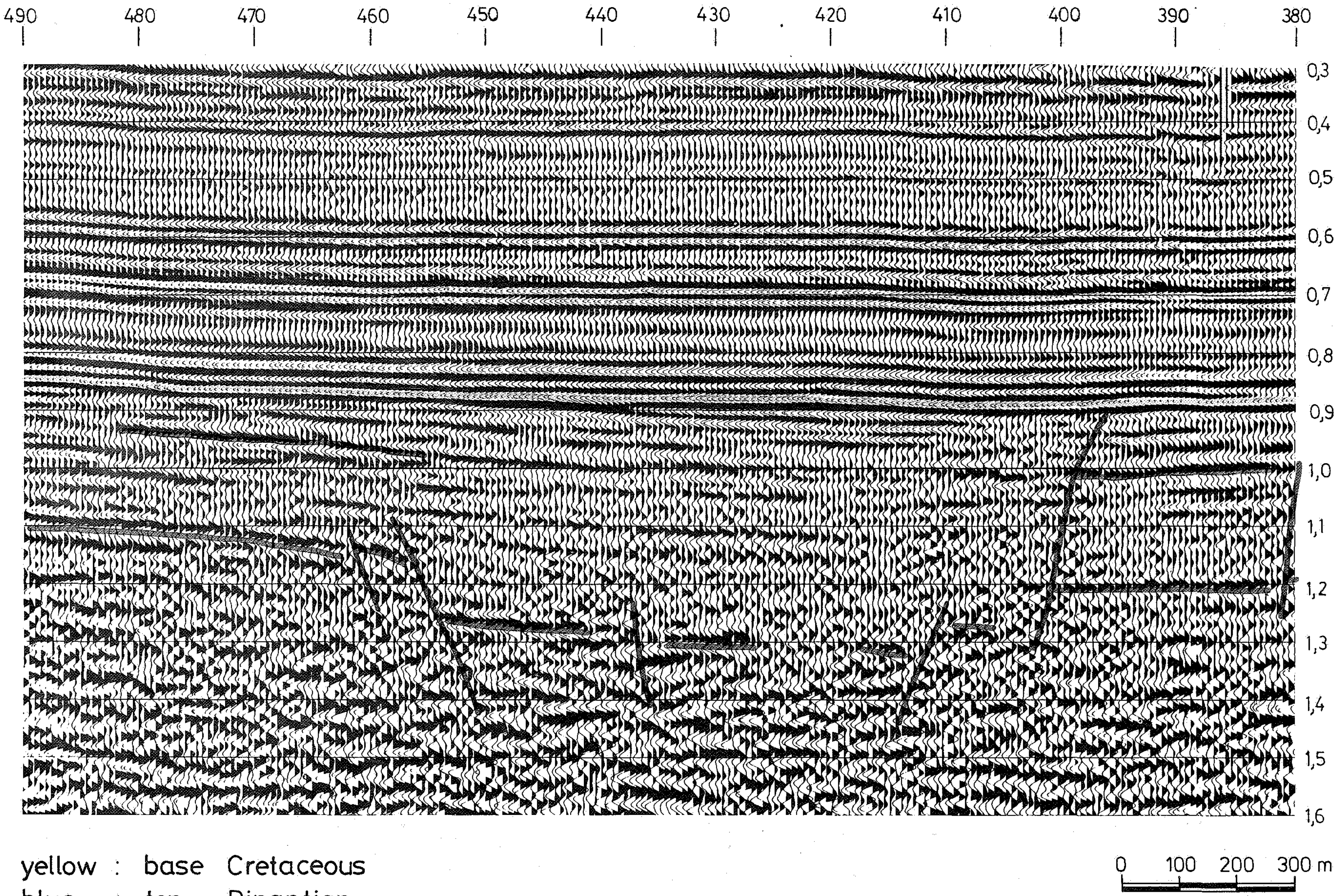


Figure 10. – Nature of the Graben boundary fault (8004).



yellow : base Cretaceous
blue : top Dinantian
green : sarnsbank
red : faults

Figure 11. – Nature of the central belt subsidence (8111 FDM).

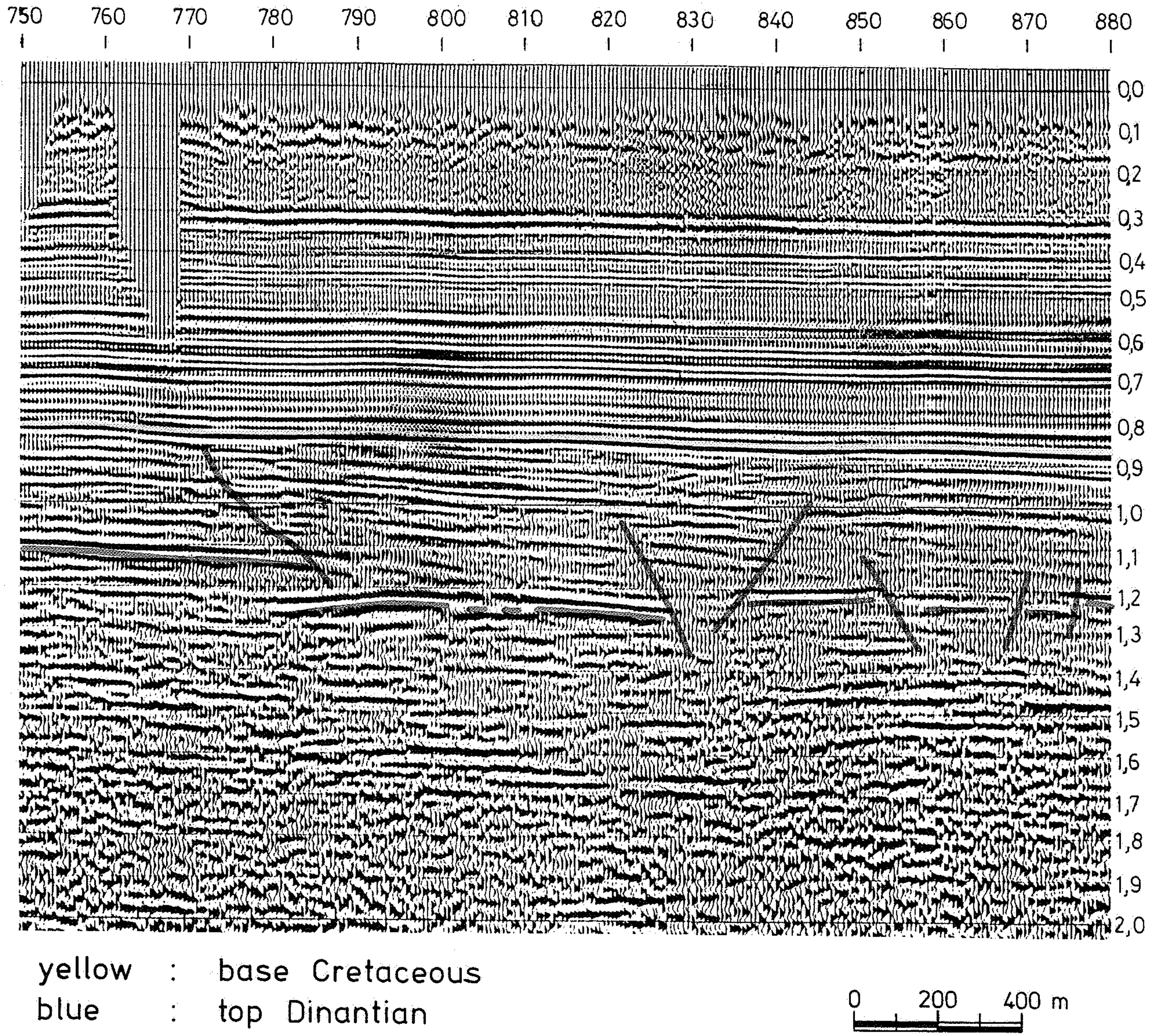


Figure 12. - Nature of the central belt subsidence (8110).

dually or stepwise displaced downwards.

These bordering faults not only affect the Dinantian limestone and the Silesian but generally also the Cretaceous and the basal Cenozoic formations as well (fig. 4).

The deformation intensity inside the fault-bordered depressions shows lateral as well as vertical variations : in many cases the Dinantian limestone reflector only, has been broken and/or displaced, whereas the overlying strata have been moderately to strongly bent (fig. 5). But often also the younger Silesian strata have been dislocated : the overlying Cretaceous and Cenozoic strata are strongly bent, with decreasing concavity towards the younger formations (fig. 4). The youngest formations affected, as can be detected from seismic lines, are of Late Eocene age.

Inside the fault-bordered depressions it is often difficult to trace a particular Silesian reflector from one end to another. In some cases this is obviously due to a difference in seismic character related to facies changes during the deposition of that particular reflector (fig. 6). Another reason for this indistinctness is the apparant chaotic character of the deformed Silesian strata above dislocated Dinantian limestone, suggesting broken or brecciated formations (fig. 7).

Broken and brecciated basal Namurian siliciclastics have also been observed in a cored section through the Namurian-Visean contact in well DZH-1 on the Heibaart - Rijkevorsel dome.

On the other hand one may observe the presence of contemporaneous infill, evidenced by the increased thickness of some upper Namurian or basal Westphalian reflector intervals, just above the depression center (fig. 8).

These observations favour the idea of a synsedimentary deformation mechanism during the Silesian. This deformation continued into more recent times, as shown for example by the unexpected topography of the base of the Cretaceous unconformity in the western part of the survey area (enclosure IV). Indeed the roughly E-W striking basal unconformity plane displays a particular morphology of elongated depressions (e.g. around the "nose" of Zoersel) and more isolated, elleptical to lobate subsidence areas resembling sinkholes (e.g. Westmalle, Oostmalle, St Lenaarts), the axes of which are located exactly above the faulted Carboniferous depression minima (enclosure III).

From their general morphology and especially from their structural relationship with the overlying strata, we may conclude that these particular deformations are not tectonic in origin but developed rather continuously over a long period, albeit with different intensity, suggesting collapse mechanisms.

These collapse structures are most probably the result of the dissolution of underlying carbonates and/or evaporites (see further).

From the differences in deformation intensity (different numbers of stratigraphic levels affected) we may presume that the dissolution has been active during different time intervals since the end of the Visean : first under vadose water conditions (during the final Visean-early Namurian emersion) and later by subsurface groundwater circulation.

No typical collapse structures have been observed within the eastern structural unit, with the exception of one NNW-SSE running depression belt, right north of Turnhout, wherein the Upper Carboniferous strata are strongly bent and the base of the Cretaceous shows a gentle concavity above the underlying deformed Dinantian limestones (e.g. at the crossing of lines 8004 and 8012). At most a gentle inclination is observed of some Silesian reflectors. The basal Cretaceous remains almost unaffected except for some N-S directed kinking in its general E-W strike (enclosure III).

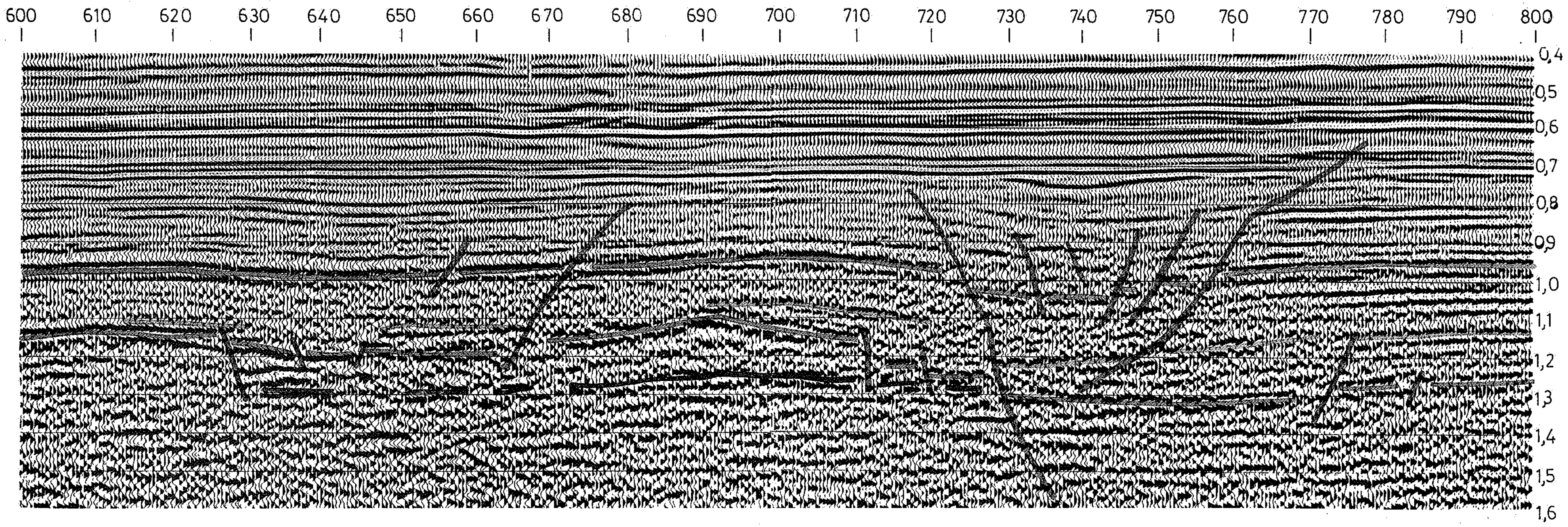
The lack of collapse features affecting the post-Silesian in the eastern zone might also be explained by an increase in thickness of the Silesian overlying the collapsing Dinantian.

2.3.3.- Tectonics

2.3.3.1.- The Roer Valley Graben boundary faults

The presence of important NNW-SSE directed normal faults, northeast of Turnhout, adds considerably to the complexity of the eastern structural zone (LEGRAND, 1968). These faults are the westernmost representatives of an extensive NW-SE tending network of longitudinal tensional faults in NE-Belgium, which constitute Roer Valley Graben boundary faults, prolongating the Netherlands Central Graben towards the southeast. Two of these graben faults have been observed in the investigated area, northeast of Turnhout; the first west of Ravels, the second east of Weelde. The latter has been related to the so-called Reijen Storing (BOUCKAERT & VANDENBERGHE, 1980). They can be followed to the north furthermore, across the E-W striking Hoogstraten fault. These graben faults not only affect the Carboniferous, but also the Cretaceous and the younger Cenozoic formations. Consequently they represent the youngest tectonic deformation in the studied area. Their fault plane is often sigmoidal (fig. 10). The Carboniferous strata have been more displaced (greater offset) than the overlying formations, suggesting a rejuvenation of older fault planes. The graben-related fault, west of Ravels, consists of a series of normal step faults (with increasing offset to the east) rather than of an single fault place (enclosure III and IV).

Thickness and facies variations of the Meso-Cenozoic strata have been recorded from shallow boreholes on both sides of the different graben-faults (north-Campine area, LAGA, 1973; PAULISSEN, 1973) as well as from recent seismic surveys in the Campine coal



yellow : base of Cretaceous
blue : top of Dinantian
green : Sarnsbank marine bed ?
orange : intra-Namurian reflector → onlap
brown : intra-Dinantian reflector
red : faults

Figure 13. – Internal structure of the Dinantian and the onlap contact of the Namurian (8106 FDM).

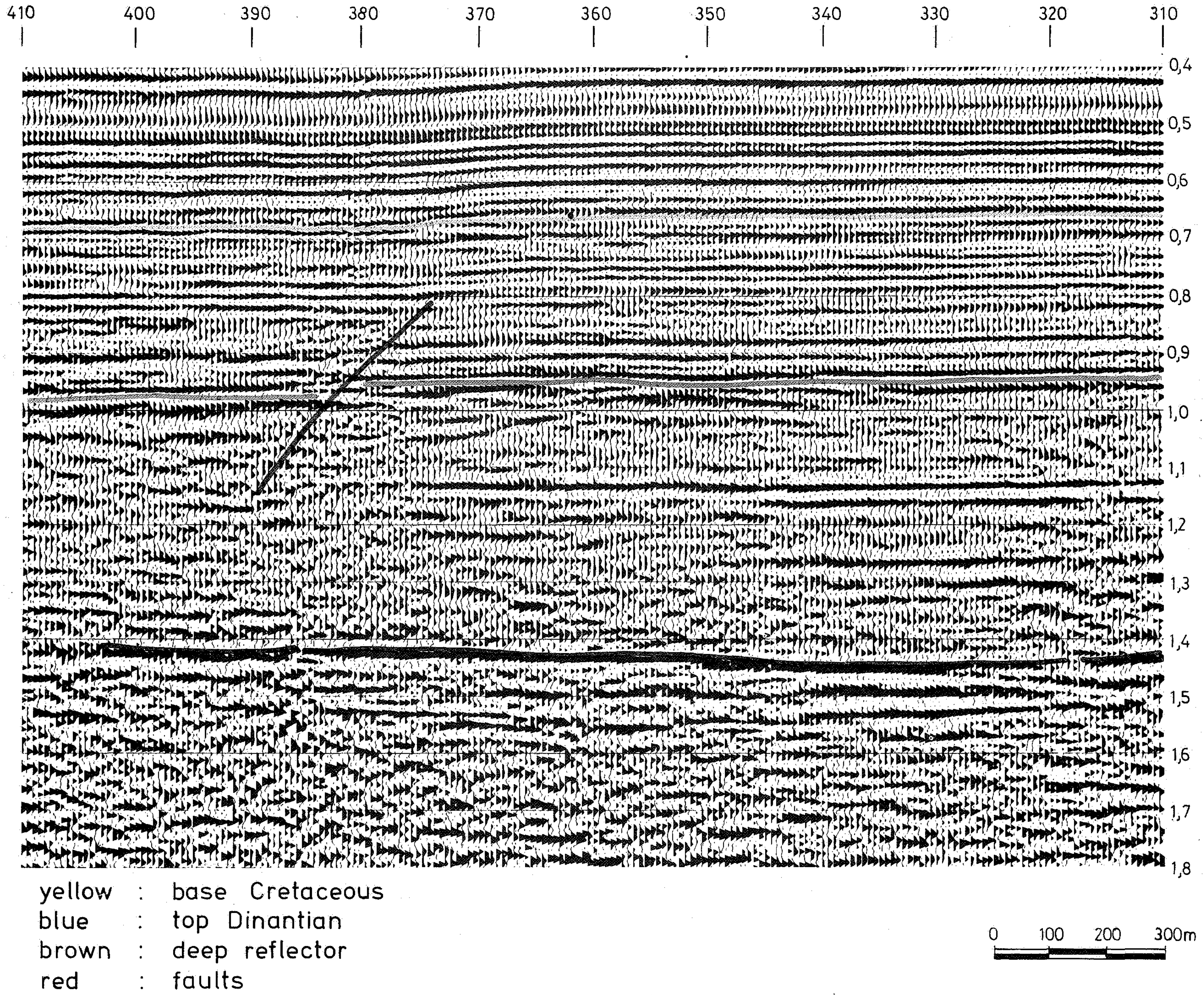
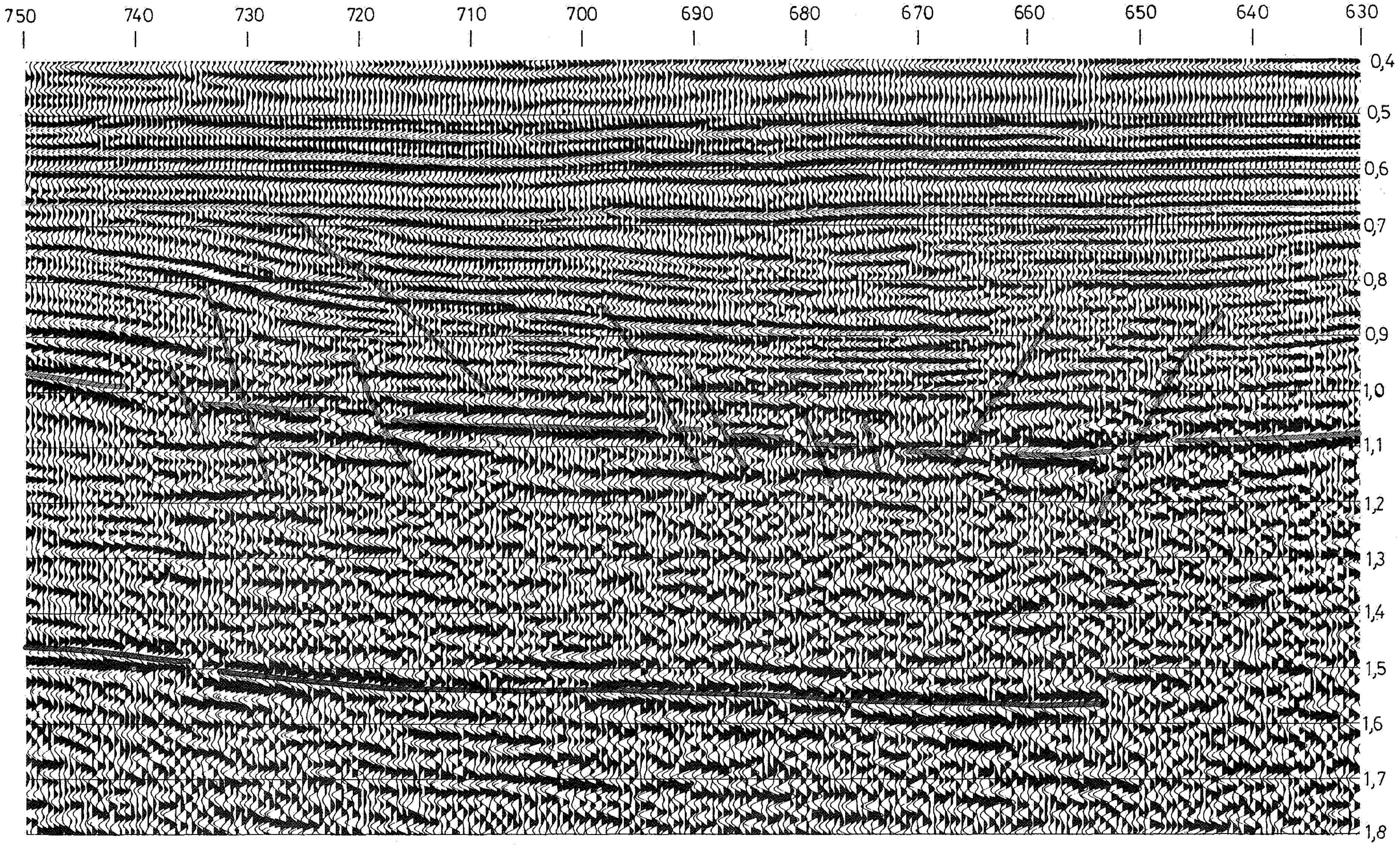


Figure 14. – Deep reflector at 1.4 sec. (8108).



yellow : base Cretaceous
blue : top Dinantian
brown : underlying deep reflector
red : faults

field (BOUCKAERT, DUSAR & VAN DE VELDE, 1981), suggesting reactivation of these graben-faults during different stratigraphical intervals occasionally in opposite senses.

2.3.3.2.- The central belt

A particular graben-like deformation affects the Dinantian and Silesian formations in the central, transitional zone of the survey area. This deformation belt can be traced over more than 17 km, shallowing gradually to the South, where it probable disappears to the east of Poederlee. It apparently widens towards the northwest (northeast of Rijkevorsel) and seems to terminate at the EW-running Hoogstraten fault although the limited seismic coverage there makes any interpretation inconclusive.

This extensive NNW-SSE running fault-bordered depression belt is shown in profile by the seismic lines 8111-8110-8109-8101.

The bordering faults consist of several longitudinal fault steps tapering off into one another (e.g. east of Vlimmeren, enclosure II).

This graben-like deformation is characterized by an. important offset of the Dinantian limestone along relatively steep, normal faults (especially important in the north) which traverse the Silesian without affecting the basal Cretaceous unconformity. The latter displays mostly a gentle kinking just above the underlying faults (enclosure III).

The asymmetrical base of this "graben" is apparently composed of several Dinantian limestone blocks, dipping in opposite directions. These internal structures (synantiformal) are visible for instance west of Beerse-Merksplas (enclosure II, IV).

The overlying Silesian is almost unaffected by this internal blockfaulting but displays some subsidence and/or infill phenomena (thickness variations of some reflector intervals) (fig. 11, 12), which would suggest at least a partially synsedimentary origin and an early (Upper Carboniferous) age for this deformation.

A post-Paleozoic reactivation of the faults is probable, as deduced from the kinks in the basal Cretaceous unconformity strike. Anyhow, this central deformation belt differs essentially from the western structural zone by the more important offset of the Dinantian reflector, by its asymmetric outline and by the less pronounced subsidence of the overlying strata.

2.4.- INTERNAL AND UNDERLYING STRUCTURES

2.4.1.- Internal structures of the Dinantian limestone

Because of the important acoustic impedance contrast and the loss of energy through scattering at the irregular (karstified) contact between Dinantian and Namurian, internal structures of the Dinantian carbonate mass are either not visible or hardly indicated on the seismic profiles. One exception is the apparent internal reflector right under the antiform of Poederlee, about 125 m/sec (approx. 250 m), under the top of the Dinantian (fig. 6). This internal reflection is not a multiple. This particular reflector is essentially subhorizontal, with a very slight dip to the E and looks like the apparent prolongation underneath the antiform of the Dinantian reflector. Of special interest is the presence of a distinct uplift of the reflector right under the culmination point of the Poederlee high limit.

In the Heibaart dome some internal structures have also been observed, which directly underly the top of the Dinantian. These reflections are not as clear as in the Poederlee area : they are rather discontinuous and show a wavy seismic character, with variable dip; laterally they stop at the flanks of the antiform Dinantian reflectors (fig. 13).

These reflectors might be interpreted as discontinuous internal stratification, although the indistinctness of these reflectors makes an interpretation very difficult. The dip, measured in the cores on top of the Heibaart antiform structure reached 10^o at maximum.

2.4.2.- Underlying deep reflectors

Most of the apparent deeper reflectors under the top of the Dinantian reflector, are related to multiple reflections from overlying strong Meso-Cenozoic reflectors.

A particular genuine deep reflector nevertheless has been observed at a distance of about 450 to 600 m/sec below the top of the Dinantian limestone (fig. 14, 15). Although this reflector has not systematically been mapped, it is visible throughout most of the seismic lines in the extreme west and south of the investigated area, where it runs apparently subparallel to the overlying top of the Dinantian.

The exact origin and the stratigraphical position of this deep reflector is unknown.

3. RELATIONSHIP WITH OVERLYING STRATA

3.1.- UPPER-CARBONIFEROUS

3.1.1.- Namurian

The contact between the top of the Dinantian carbonates and the overlying Namurian mudstones is a well-defined limit on the geophysical logs (BLESS *et al.*, 1981).

Cored samples of boreholes DZH-1 and DZH-3 consist of dark-grey silty mudstones with silty laminae.

Dips of 4^o to 8^o have been measured. Similar lithologies have been described from the Turnhout borehole.

The Namurian generally displays a rather wavy seismic character with weak and discontinuous reflectors, as compared to the more pronounced and more continuous reflectors of the overlying Westphalian.

The onlap of the basal Namurian strata upon the Dinantian relief illustrates the stratigraphical gap between both stages. This angular unconformity is particularly obvious on the flanks of both the Heibaart and Poederlee antiform structures (fig. 13, 14).

Outside these particular areas the onlap is less clear : here the Namurian apparently conformably overlies the Dinantian and only a very weak unconformity may locally be detected.

The Namurian sediments have also intensively been deformed inside the faulted depression belts of the underlying Dinantian : strongly bent or even broken reflectors characterize the Namurian above the Dinantian depression minima; very locally one may observe also some infill phenomena.

These deformations are indicative of a synsedimentary mechanism during or shortly after the deposition of the strata corresponding to these particular Namurian reflectors.

The Namurian strata wedge out to the west and are completely absent in the extreme west-part of the studied area (e.g. profiles 8108-8113) : here a direct contact is observable between top Dinantian and basal Cretaceous (enclosure IV).

Above the Heibaart and Loenhout type highs, the youngest Namurian (and especially the Westphalian) strata tend to be remarkably parallel to the top of the Dinantian. Hence a gentle reactivation of these domal structures at the end of the Namurian base of the Westphalian cannot be ruled out.

In the northern part of the survey area, an important sedimentary basin developed from Namurian times onwards. The southern border of this deep Namurian basin coincides with the E-W tending listric fault (2.3.). The axis of its depocenter runs approximatively perpendicular to the general strike of the Dinantian shelf, except for the northwestern most part of the studied area (Heibaart-Loenhout region) where both run parallel.

3.1.2.- Westphalian

The contact between the Namurian and the Westphalian formations is characterized on the seismic profiles by a strong reflector which can easily be traced throughout most of the investigated area. This reflector has been correlated with the Sarnsbank marine band and an underlying sandstone unit, as compared to borehole data from Turnhout (DELMER, 1962) and Meer (VANDENBERGHE, 1984).

The Westphalian is characterized by the presence of strong continuous reflectors of rather high frequency, characteristic of alternating mudstones, sandstones and thin coal-seams.

The thickness of the Westphalian is varying according to the underlying Dinantian-Namurian topography; it also wedges out towards the west and the south. No Westphalian strata have been encountered in the boreholes on top of the Heibaart structure.

Just as the underlying Namurian, the Westphalian strata have been affected by collapse deformation inside the fault-bordered Dinantian depression belts. The deformation intensity decreases from the base to the top, varying from broken reflectors (e.g. the Sarnsbank reflector) to only gently bent reflectors (fig. 8, 16).

In the latter case it is not uncommon to observe a different seismic character as well as thickness differences inside and outside the faulted depression belt, related there to facies changes and infill phenomena during the deposition of the different Westphalian sediments (2.3.).

3.2.- MESOZOICUM

An isochron map of the base of the Mesozoic illustrates its structural relationship with the Carboniferous.

The general strike of the basal unconformity is E-W with a very slight dip to the NE. In the Loenhout-Heibaart area the basal Cretaceous unconformity plane gently dips at 1.20' to the NNE (BLESS *et al.,* 1981). In the western structural zone, longitudinal depression belts and more isolated depression minima occur just above the faulted depression belts affecting the top of the Lower Carboniferous. Particularly obvious is the presence of extensive NW-SE running depression minima, with closed contours, such as near Westmalle, Oostmalle and St Lenaarts.

Normal faults, discontinuous and with small offset, delimit these basal Cretaceous depression belts and minima. They are clearly related to, if not coinciding with, the bordering faults of the underlying faulted Carboniferous synforms (enclosure IV).

It is noteworthy furthermore that neither the Heibaart dome nor the Poederlee high have influenced, in any way, the general morphology of the overlying basal Cretaceous unconformity plane. All of the other antiform structures shown on the basal Cretaceous isochron map otherwise (such as the Vorselaar-Wechelderzande high, the Westmalle-Vlimmeren high, the Rijkevorsel high, etc.) are clearly influenced by the presence of the underlying antiform structures in the Dinantian (compare both the enclosures II and III). These observations then would imply two different mechanisms for the origin of the antiform structures in the studied area. A non-tectonic, post-sedimentary

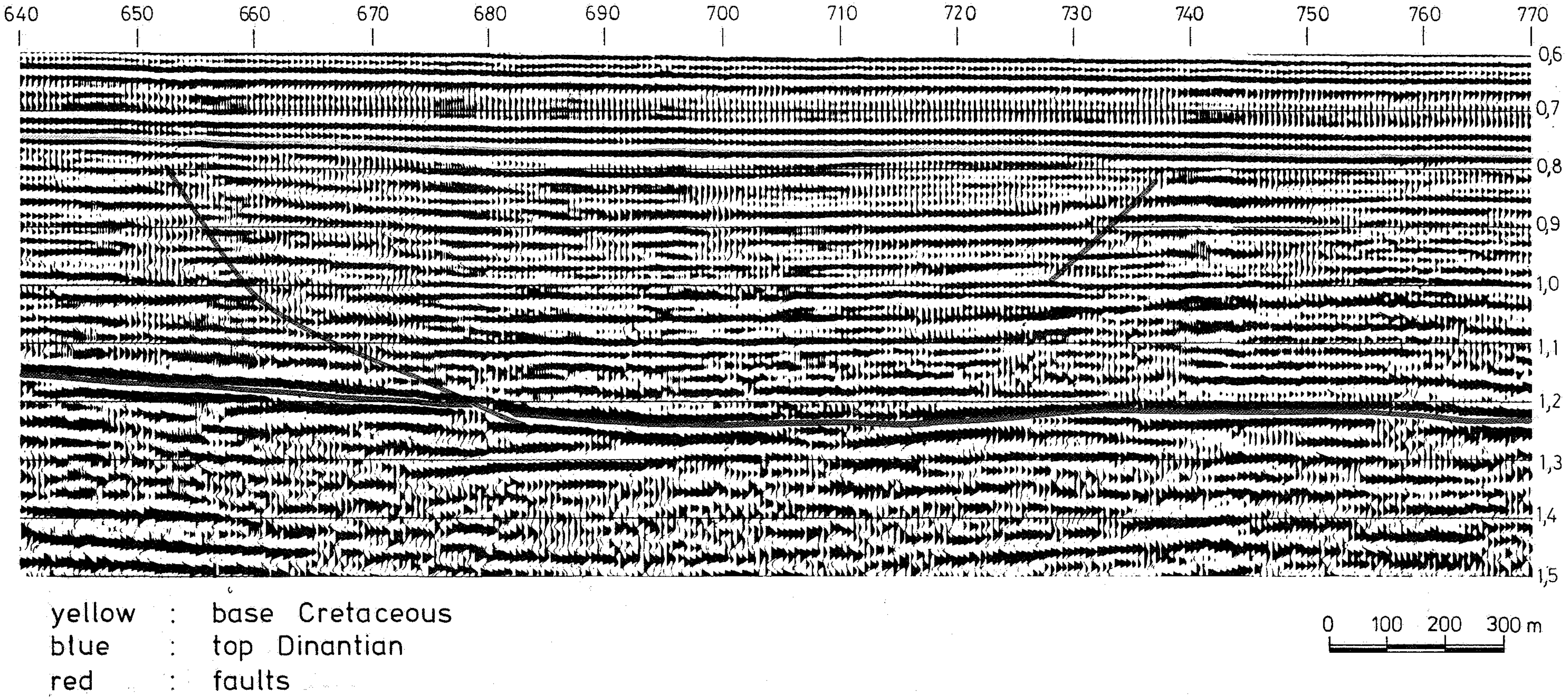


Figure 16. - Slightly bent Upper Carboniferous reflectors overlying a subsidence zone in the Dinantian (8101).

deformation mechanism such as the subsiding and/or collapsing of neighbouring carbonates (= the faulted depression belts) would be typical of the relatively broad and flat antiform structures bordered by small and relatively deep depression belts as discussed in part 2.

The particular Poederlee and Heibaart domes otherwise must have been positive areas (paleorelief), already before the deposition of the Upper Carboniferous. This latter idea is also supported by the visible onlap of the older Namurian strata upon both the Dinantian highs.

In the central and eastern structural zones of the investigated area, the basal Cretaceous unconformity displays pronounced N-S to NNW-SSE kinking of its general E-W strike. These kinks are especially well-developed east of Merksplas. They surmount or coincide with underlying NNW-SSE trending fault planes in the Dinantian and Silesian (bordering faults of depression belts), which would suggest a gentle post-Carboniferous reactivation of these structural lines. The major deformations affecting the basal Cretaceous, are the graben-related tensional faults which run northeast of Turnhout. The first one, west of Wortel is well-developed, whereas the second one, east of Weelde is only hardly indicated and cannot be traced further down to the south. A direct contact finally between the Dinantian and the basal Cretaceous is visible in the extreme west of the studied area, west of Westmalle (seismic profiles 8108 and 8113) : here the Silesian is completely removed by erosion along a roughly NNW-SSE-trending line.

In the uppermost part of the Booischot borehole, a paleokarst has been observed within V2a limestones, filled up with a breccious mixture of chalky limestone and black clay, the latter of possible Wealdian age.

This might represent the only evidence thus far for the presence of Lower Cretaceous in the Antwerp Campine (LEGRAND, 1964).

3.3.- CENOZOICUM

The relationships between the Dinantian structures and the Cenozoic sediments are restricted to relatively small local subsiding areas within the western structural zone.

A remarkable subsiding (bending) of some Cenozoic reflectors occurs just above the depression centers (with closed contour) of the basal Cretaceous unconformity, which in their turn overly the faulted Dinantian collapse centers. The deformation intensity is variable from one subsiding centre to another, as well as vertically : the concavity of the affected reflectors decreases towards the younger formations.

The youngest Cenozoic formations affected by underlying collapse phenomena, as shown by seismic sections, are dated as uppermost Eocene (fig. 4). These observations support the idea of a non-tectonic, continuous deformation mechanism, which has been active since the end of the Visean.

4. GEOLOGICAL WORKING MODEL

The combination of borehole data and subsurface structural elements (seismic interpretation) allows the proposition of a paleogeographical and structural working model for the Dinantian shelf in the Antwerp Campine area. This hypothetical model needs to be confirmed nevertheless by new borehole data and further seismic exploration.

4.1.- PALEOGEOGRAPHY

The boreholes which penetrated the Dinantian carbonates in the Campine revealed the presence of the following particularities :

- paleosoils and associated detrital sediments (Kessel, Booischot);
- silicifications (Halen, Turnhout, Kessel, Heibaart);
- breccias (Turnhout, Heibaart, Kessel, Booischot);
- internal angular unconformities (Loksbergen);
- paleokarst (Booischot, Heibaart);
- reworked microfossils (Turnhout, Halen);
- irregular contacts, erosional unconformities, hardgrounds (Heibaart).

Stratigraphic correlation moreover between these boreholes showed important variations in thickness of the different Visean stratigraphical units suggesting unstable sedimentary regimes.

Microfacies analysis furthermore of cored intervals on top of the Heibaart dome, demonstrated that restricted marine to sublagoonal depositional environments prevailed during late Visean times.

The abundant authigenic quartz crystals observed within Livian to Warnantian algal-stromatolithic limestones (e.g. in Heibaart and Turnhout) are related either to hypersaline conditions (BLESS *et al.,* 1981) or to vadose water circulation, acid fresh waters derived from adjacent emerged areas (Labofina report, 1976).

All of the former observations indicate thus a shallow to very shallow epicontinental sea, bordered to the S by relatively flat, deeply weathered non-carbonate hinterland on the Brabant Massif, which has been affected intermittently by epeirogenic movements.

Subtropical to semi-arid climatological conditions moreover allowed the development of soils on the hinterland, whereas vadose waters provoked synsedimentary silicification in the nearby unconsolidated carbonates, as well as karstification in the emerged lithified carbonates.

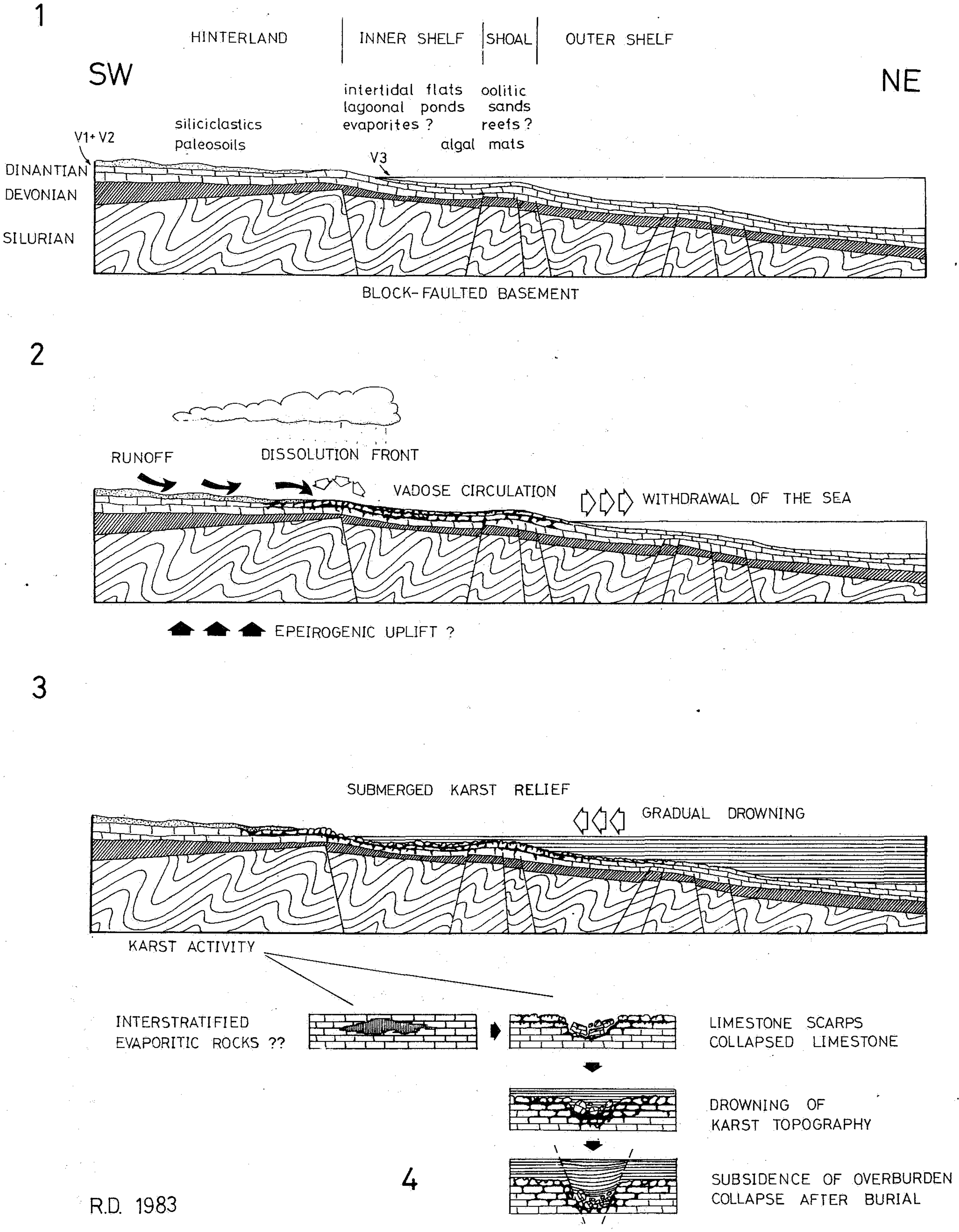
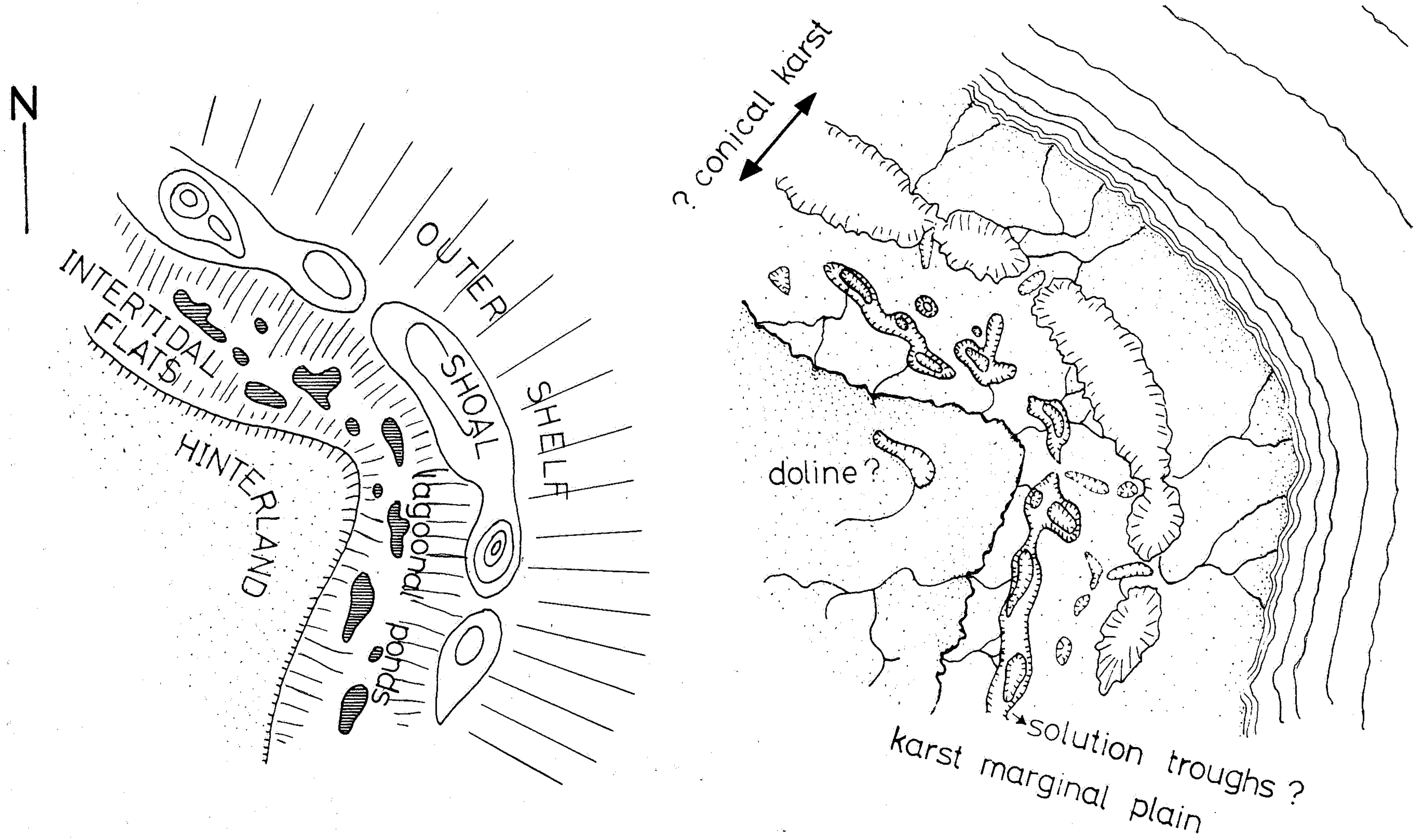


Figure 17. - The different stages in the paleogeographical evolution of the Dinantian shelf (working model).
1. Late Visean regressive shelf; 2. Early Namurian emersion - Subaerial exposure; 3. Namurian transgression invading a karst topography;
4. Subsidence and collapse phenomena by ongoing groundwater circulation
(SW-NE crossections trough paleogeographical sketch of fig. 18).



PRE - KARST

KARST

Figure 18. - Hypothetical paleogeographical sketch for the Dinantian subcrop.

It is suggested that the pre-Namurian topography consisted of a solution-etched limestone relief. This solution-topography developed shortly after a significant drop in sealevel, encompassing at least the Pendleian (corresponding to the stratigraphical gap observed in the boreholes Turnhout and Heibaart).

At that moment acid run-off from the non-carbonate hinterland in the southwest flooded into the emerged shelf lagoon carbonates in the east and northeast (fig. 18). Maximum solution therefore occured along the lithological contact of siliciclastics-carbonates. Subsequent collapse resulted further int the appearance of limestone scarps, as illustrated by the scarp along the "nose" of Zoersel.

Karst development closely followed the withdrawal of the sea to the east-northeast and preferentially affected highly soluble (inter-supratidal) carbonates or even evaporites. This could explain the remarkably parallel orientation of ridges and troughs indicating belts of similar lithology parallel to the paleo-coastline (= the Zoersel scarp).

The adjacent shelf lagoon was bordered to the east and northeast by a discontinuous belt of more or less isolated shoals (the Heibaart and Poederlee domes) which represent structurally-controlled positive areas : the Heibaart 1 borehole penetrated condensed Devonian and Carboniferous deposits, and a relatively shallow Silurian basement. A similar structurally-controlled high is supposed to occur in Poederlee.

This shoal-line represents most probably the inner shelf margin : beyond this line the dip of the shelf increases considerably (e.g. northeast of Loenhout). Farther to the east and northeast, the topography of the NE-dipping Dinantian outer shelf has strongly been affected by synsedimentary faults, which developed from the early Silesian on, as well as by post-Silesian graben-related faults. A solution morphology nevertheless developed most probably also upon this supposed outer shelf, as demonstrated by the presence of karst phenomena in the Turnhout borehole in the Upper Visean (Warnantian) carbonates.

From a morphological point of view, this hypothetical paleogeographical reconstruction of the Antwerp Campine area, shows some affinities with the Late Quaternary Yucatan shelf in the southern Gulf of Mexico (LOGAN *et al.,* 1969). The Yucatan Peninsula consists of a low undulating karst plain that has no surface drainage. Soil-filled depressions support dense rainforest. During Wisconsin glaciation times, the karst margin plain extended over the area which is now the inner shelf, with a solution rim and conical karst developing close to the present shelf margin. Much of the Yucatan plateau has been submerged by the post-Wisconsin marine transgressions to form a shallow open clastic-free continental shelf. A series of elongated rocky hills, forms a discontinuous raised rim around the inner shelf margin. These hills are capped or partly capped by biostromal deposits, submerged reef-banks and emergent reefs (pinnacle reefs and knolls).

Playa lagoons and swampy mudflats are present on the seaward margin of the karstic hinterland.

The post-Dinantian - pre-Silesian karst topography originated much in the same way as the karst-determined shelf relief in Southern British Honduras, as described and illustrated by PURDY (1974) (fig. 18), although a real guarding rim of reef barriers is not present in our recontructed model. Similar processes nevertheless must have been active an the emerged Dinantian carbonates during early Namurian times (fig. 17).

After the Pendleian-time interval, the karstified Dinantian shelf has gradually been drowned by the Namurian transgression, which invaded the emerged shelf from the east. Because of this gradual drowning, the westernmost areas of the emerged shelf have been longer exposed to solution activity than the eastern regions. This could perhaps also account for the apparent structural differences between both structural zones.

4.2.- STRUCTURAL EVOLUTION

Two important structural directions can be observed on the Isochron map of the Dinantian reflector (enclosure II) : first an E-W to NW-SE direction which abruptly takes a N-S orientation near Zoersel; secondly, directions perpendicular to the former, and which apparently radiate around the Zoersel high (western structural zone).

These structural lines subdivide the subcrop into a chess-board-like configuration of small highs and troughs. Some of these blocks were already structural highs before the Visean (e.g. Heibaart dome).

In our opinion those structural lines represent a fault-pattern related to a block-faulted basement.
The karstification of the emerged carbonate shelf has been guided most probably by joints along these fault paths, along which the vadose waters could easily penetrate the carbonate mass, and could have possibly reached underlying or interstratified evaporites. This would explain the presence of narrow collapsed depressions perpendicular to the normal parallel highs and depression belts (see the Poederlee high for instance). Interstratified collapse breccias have been observed in the Turnhout and Halen boreholes, especially at the Livian-Warnantian contact.

After drowning of the karst topography by the invading Namurian sea, the solution of carbonates was still proceeding due to continuous groundwater circulation. This mechanism provoked collapse and subsequent subsidence of the overlying strata. Dissolution and collapse breccias are therefore to be expected within these deformed depression belts.

A reactivation of these faults could also explain the uplift of some small blocks such as the Heibaart and Poederlee highs, during early Westphalian times most probably.

The presence of an important NNW-SSE-directed graben-like deformation (transitional zone) could also be interpreted as the result of tensional movements along some of these deep-seated lineaments. These tectonic movements, accompagnied by synsedimentary deformation, could characterize an early stage of the Asturian phase (early Westphalian ?).

The post-Westphalian continental phase eroded the Dinantian-Silesian subcrop down to the actual level before being covered again by Upper Cretaceous marine sediments.

The eastern structural zone became affected finally by graben-boundary faults, especially during Cenozoic times.

4.3.- COLLAPSE STRUCTURES AND SINKHOLES

Collapse structures have been seismically identified for the first time in the subsurface of the Antwerp Campine area.

The interpretation of these structures is compatible with the recent observation of paleokarst phenomena and associated solution collapse breccias in the Upper Devonian and Carboniferous around the Brabant Massif.

They have been described from different stratigraphic levels suggesting different periods of updoming or eustatic sealevel fluctuation, subaerial exposure and subsequent karstification.

Boreholes at Turnhout and the Heibaart dome already indicated that the Dinantian subcrop is karstified in the Antwerp Campine area (BOUCKAERT & VANDENBERGHE, 1980).

Important paleokarst and solution collapse breccias affect Frasnian limestones in the Visé area, along the eastern border of the Brabant Massif. They developed during Famennian times and have gradually been drowned by the Dinantian transgressions. The breccias originated most probably after the dissolution of Lower Frasnian evaporites (on top of the Givet Limestones) (POTY, 1981, 1982).

Dolostone breccias near the Tournaisian-Visean (Ivorian-Moliniacian) boundary in the eastern parts of the Namur and Dinant Synclinoria as well as in the Vesdre area, have been interpreted as evaporitic collapse breccias. They are often capped by columnar or palissade calcite which are interpreted as either a pseudomorphy after gypsum or speleothems. Dedolomitization zones on top of these collapse breccias are interpreted as paleosurfaces, suggesting temporary subaerial exposures (SWENNEN *et al.,* 1981, 1982; JACOBS *et al.,* 1982).

More than 100 subsidence pits (so-called "puits naturels" or subjacent karst collapse dolines) have been recorded in the Mons Basin (extreme west of the Namur Synclinorium) where they affect the Silesian and overlying formations (Cretaceous depression of the Haine Valley) (DELMER & VAN WICHELEN, 1980). Their extension is limited. They were known to the coal mining industry as "cylindrical accidents" or "circular faults").

These subsidence pits were only recently related to the dissolution of evaporitic rocks which were covered by Warnantian carbonates (DELMER, 1977); it was the discovery of an unexpected thick sequence of anhydrite (about 600 m) in the St Ghislain borehole (1976) which favoured this idea for the origin of these bizarre deformations in the Haine Basin. This nodular anhydrite is underlying V3b-V3c limestones in which slumping and brecciated levels frequently occur (DEJONGHE, DELMER & GROESSENS, 1976). In the nearby Douvrain borehole (1979) a dissolution breccia has been encountered at a stratigraphic level corresponding to the interval with anhydrite of the St Ghislain borehole (LECLERCQ, 1980).

The Ghlin borehole (1980) otherwise penetrated an abnormal thick sequence of Lower Turonian marls (over 350 m) and brecciated Silesian rocks, which represent the infill of a subsidence pit. This pit originated most probably after the dissolution of carbonates and evaporites on top of, or interstratified within, the Warnantian carbonates (DELMER *et al.,* 1982). The authors suggested that the subsiding rate inside the pit was irregular, and that the pit must have acted as a sediment trap during Cretaceous times.

DELMER (1977) noted the analogy finally between the Wealdian topography of the Haine Valley and the evaporite-buried karst of the Athabasca Carbonate in N-Canada or the "cenote" landscape of Yucatan (cenote : water-filled collapse doline).

Very dramatic furthermore has been the record of recent collapse phenomena in the Tournaisis region (1970-1977) where combined geological-hydrological particularities of the subsurface provoked numerous collapses of the overburden, resulting into the formation of "puits naturels" reaching the surface (De ROUBAIX & LEGRAND, 1977). The top of the Dinantian limestone lies here at a depth of less than 100 m. The numerous karst pits, which occur all over the solution-etched paleosurface have been filled with Wealdian, Cretaceous and Cenozoic deposits. After a drastic lowering of the groundwater level inside the karstified Dinantian limestone (more than 1 m per year) the aquifer collapsed and provoked a gradual subsiding and subsequent downfall of the overlying formations.

Some of the paleokarst phenomena at the Dinantian-Silesian contact are still visible in outcrop : in abandonned limestone quarries along the Meuse Valley, at Tramaka for instance. Here paleokarsts cavities on top of Warnantian carbonates are filled with Namurian shales, at the very base of which irregular beds of lead mineralizations have been observed (JACOBS *et al.,* 1982).

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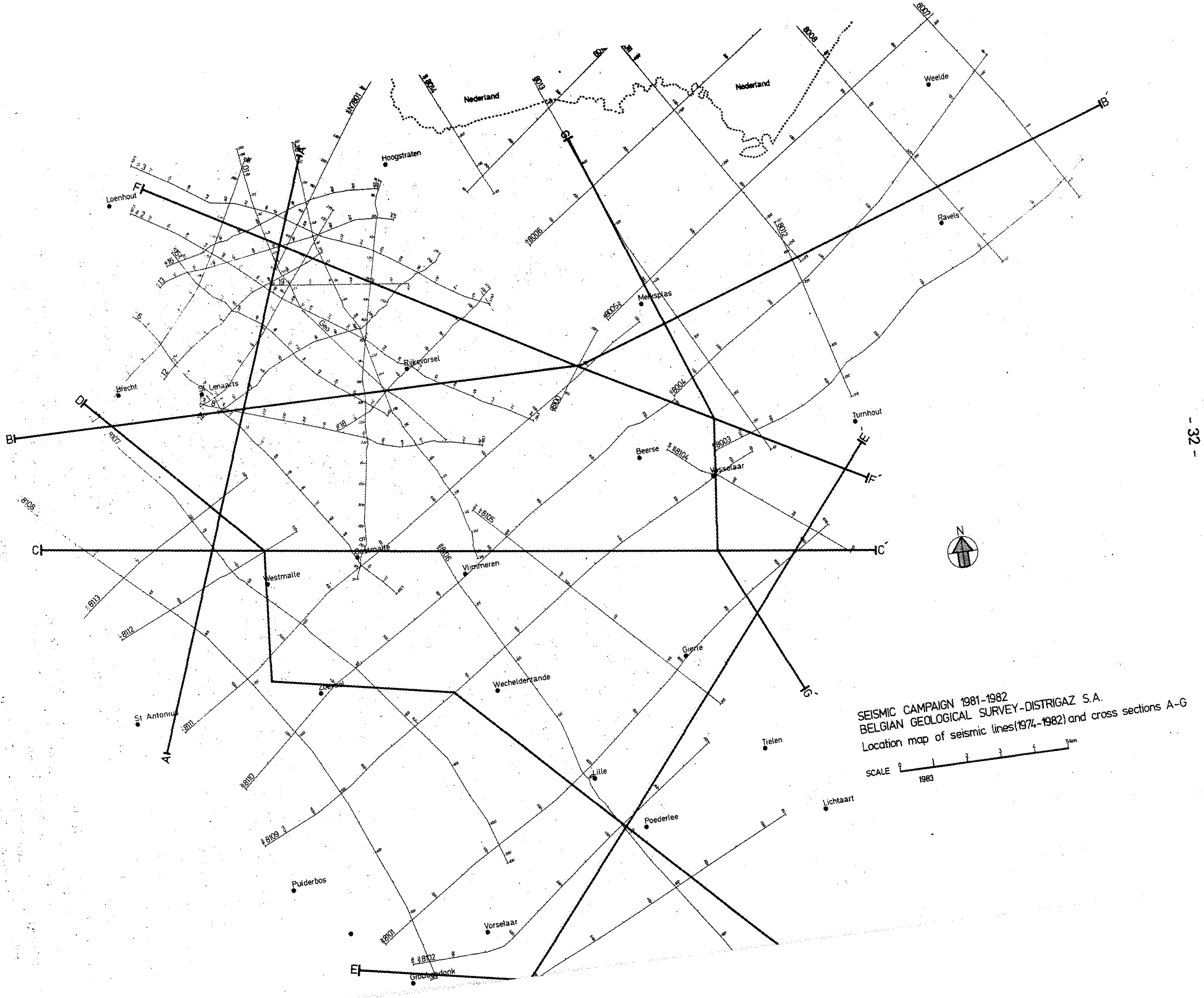
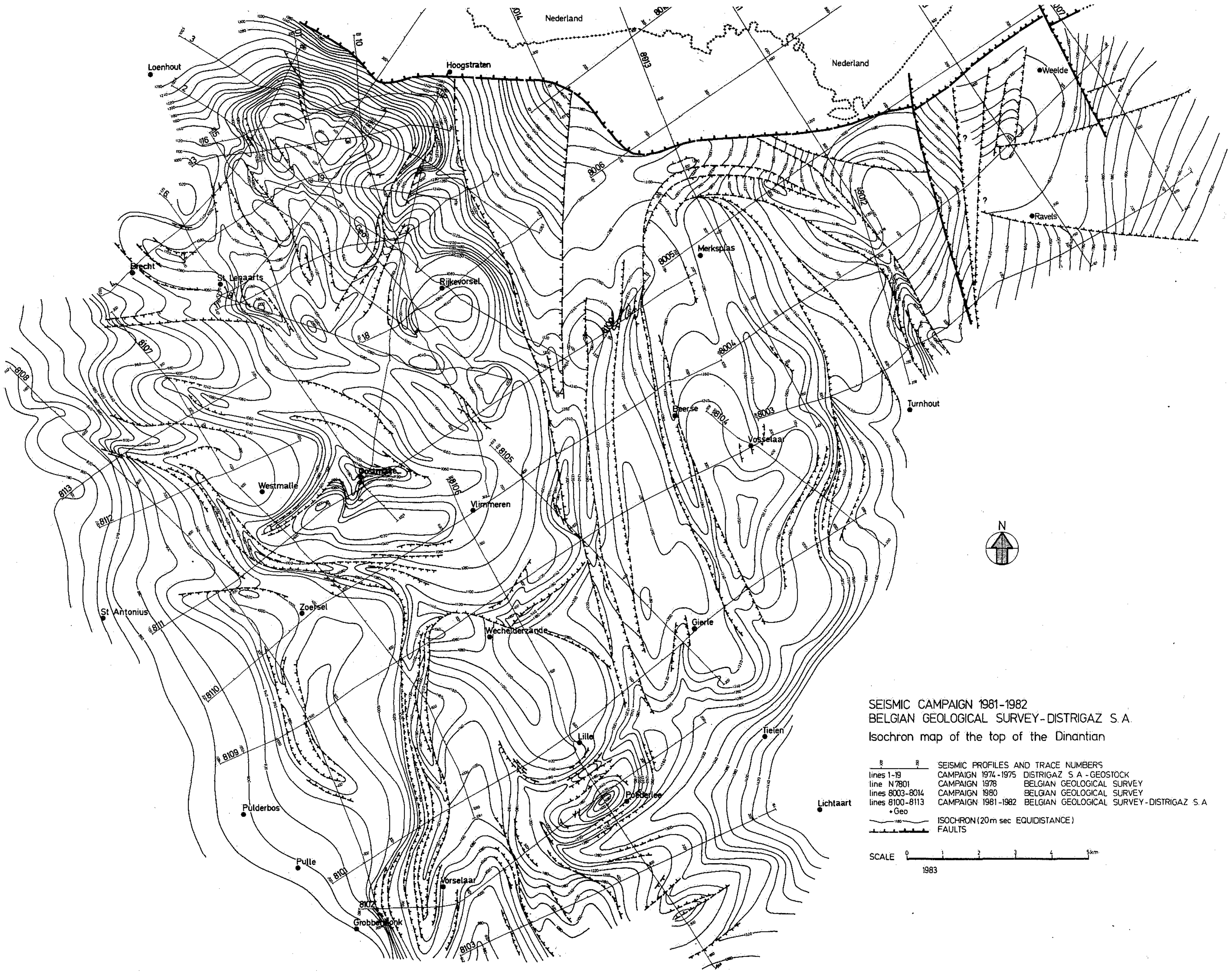
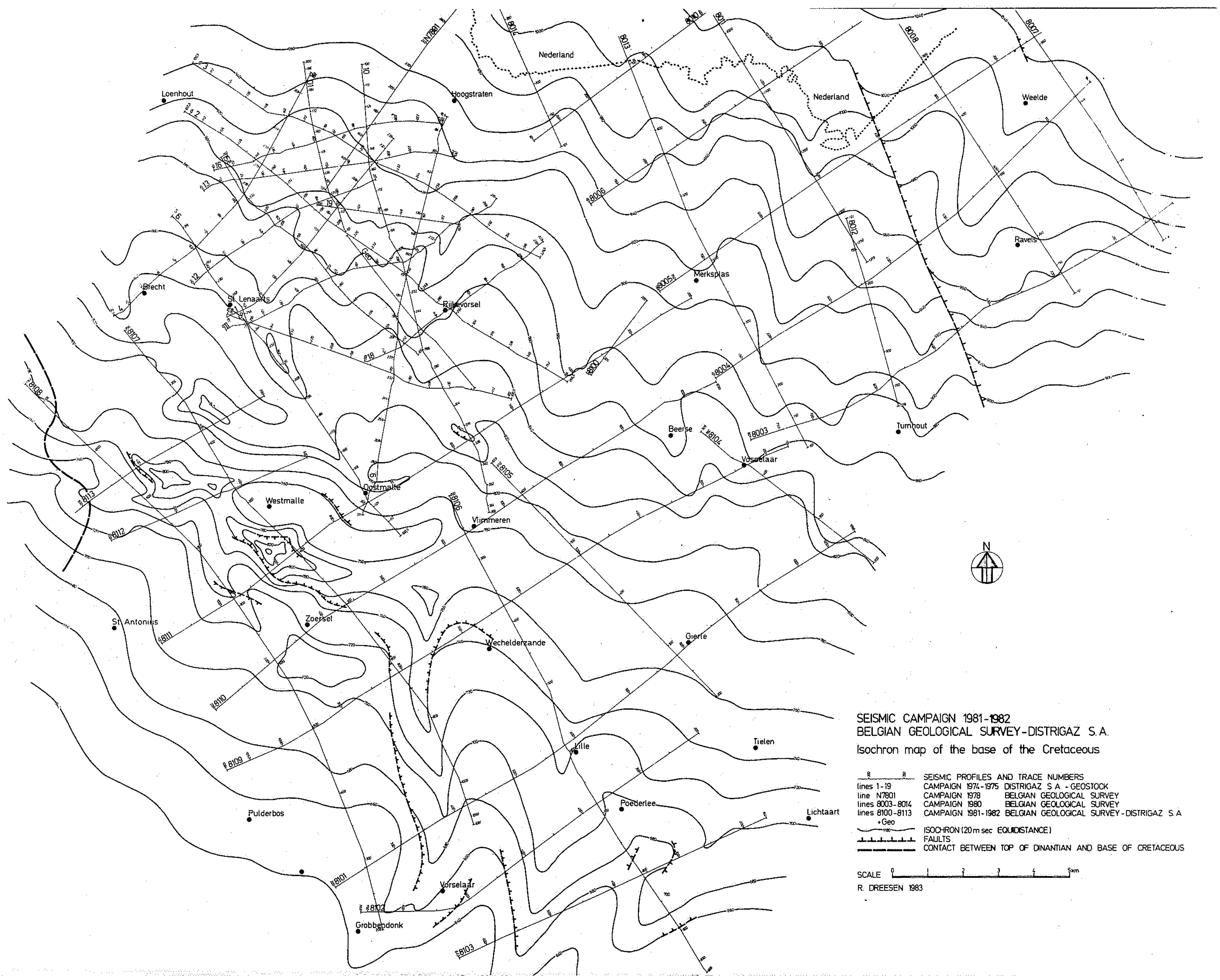


SEISMIC CAMPAIGN 1981-1982
BELGIAN GEOLOGICAL SURVEY-DISTRIGAZ S.A.
Location map of seismic lines (1974-1982) and cross sections A-G

Enclosure 1.- Location map of seismic profiles (1974-1982) and cross-sections A to G.

Enclosure II. - Isochron map of the top of the Dinantian.



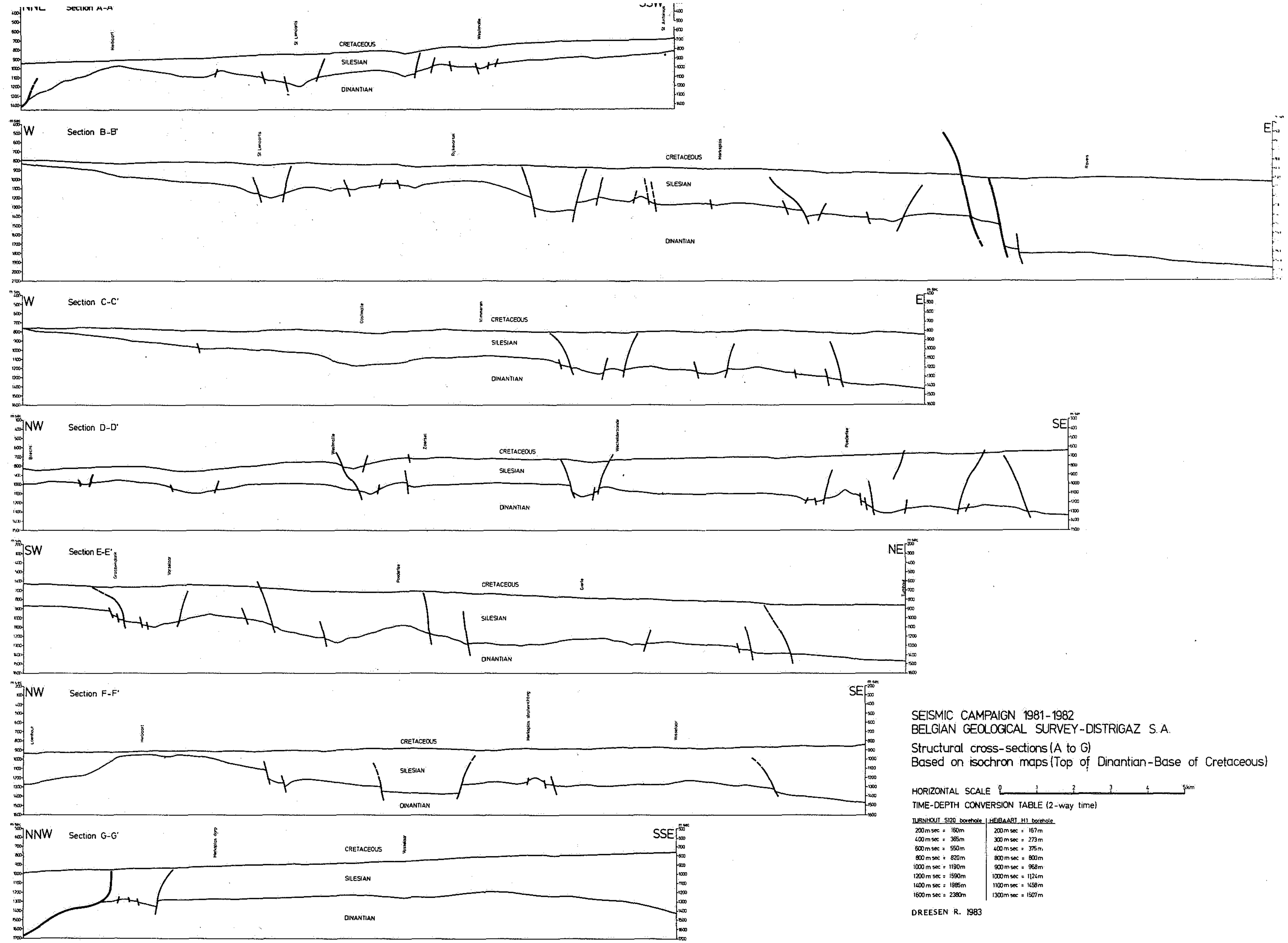


SEISMIC CAMPAIGN 1981-1982
BELGIAN GEOLOGICAL SURVEY-DISTRIGAZ S.A.
Isochron map of the base of the Cretaceous

R. DREESEN 1983

Enclosure III. - Isochron map of the base of the Cretaceous.

Enclosure IV. - Cross-sections A to G.



SEISMIC CAMPAIGN 1981-1982
BELGIAN GEOLOGICAL SURVEY-DISTRIGAZ S.A.

Structural cross-sections (A to G)
Based on isochron maps (Top of Dinantian-Base of Cretaceous)

HORIZONTAL SCALE 0 1 2 3 4 5km

TIME-DEPTH CONVERSION TABLE (2-way time)

TURNHOUT S120 borehole	HEIBAART H1 borehole
200 m sec = 160m	200 m sec = 167m
400 m sec = 365m	300 m sec = 273m
600 m sec = 550m	400 m sec = 375m
800 m sec = 820m	800 m sec = 800m
1000 m sec = 1190m	900 m sec = 968m
1200 m sec = 1590m	1000 m sec = 1124m
1400 m sec = 1985m	1100 m sec = 1458m
1600 m sec = 2380m	1300 m sec = 1507m

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Table A. - SEISMIC SURVEYS IN THE CAMPINE AREA E AND NE OF ANTWERP

CAMPAIGN	SURVEYORS + n^o^ OF SURVEY	COMMISSIONERS	PURPOSES / TARGET
1. Campine Belge 1953-1956	SEISMOS n° 881	Belg. Geol. Survey	- unconformity at the base of the Cretaceous - presence of Permo-Triassic - fault systems within the Cenozoic - delimit the S-border of coal bearing strata.
2. Campine Belge 1961-1962	SEISMOS n° 1367	Société Campinoise de Recherches et d'explorations Minérales (SCREM)	subsurface mapping of the Carboniferous limestone further elaborated in 3.
3. Bree-Kessenich-Heibaart 1963	Compagnie Générale de Géophysique	Société Campinoise de Recherches et d'Explorations Minérales (SCREM)	- the antiform trend of the Heibaart-Vlimmeren area, as shown by a gravimetric survey (1962, SCREM) (hydrocarbon exploration). - presence of deeper reflectors
4. Heibaart 1974-1975	PRAKLA-SEISMOS n° 741044	DISTRIGAZ S.A.	- delimit the Heibaart antiform (gas-storage project) - thickness of the covering Upper Carboniferous strata.
5. Heibaart 1978	PRAKLA-SEISMOS n° 781310	Belg. Geol. Survey	- investigation of karstified water-infilled limestones at the top of the Dinantian - investigation of the NE-slope of the Heibaart Loenhout antiform structrure (geothermal energy project)
6. N-flank Brabant Massif 1980	PRAKLA-SEISMOS n° 801311	Belg. Geol. Survey, Univ. of Utrecht, E.E.C.	- methodology study for distinguishing between karst-affected and compact limestone (Dinantian top) (geothermal energy project)
7. Oostmalle 1981-1982	PRAKLA-SEISMOS n° 811321	Belg. Geol. Survey, DISTRIGAZ, S.A.	- the detection of appropriate structures S and E of the Heibaart structure in the karstified Visean limestone (gas-storage project).

Table B. - ACQUISITION PARAMETERS OF RECENT SEISMIC CAMPAIGNS IN THE STUDIED AREA (VIBROSEIS-reflection surveys by PRAKLA-SEISMOS, Hannover)

CAMPAIGN	Heibaart 1974-1975	Heibaart 1978	N-flank Brabant 1980	Oostmalle 1981-1982
COMMISSIONER	DISTRIGAZ, SA, Brussels GEOSTOCK, Paris	Geol. Survey Belgium	Geol. Survey Belgium University Utrecht, EEC	Geol. Survey Belgium DISTRIGAZ
SOURCE Parameters				
Sweep	18-65 HZ, 10 s	20-100 Hz, 7 s	18-98 Hz, 11 s	15-90 HZ, 20 s
N° of vibrators	3	3	3	3
Vibrator spacing	20 m	7,5 m	10 m	10,44 m
Vibrator step width	7 m	0 m	0 m	2,61 m
Length vibrator pattern	89 m	15 m	20 m	28,71 m
vertical stacking	8-fold	8-fold	8-fold	4-fold
vibrator centres	50 m	30 m	40 m	40 m
RECEIVER Parameters				
N° of groups	48	24	120	120
Geophones per group	24 or 36	12	12	18
group length	55 m	11 m	20 m	22 m
geophone array	in 2 or 3 rows,equally spaced (50 m)	in 1 row, equally spaced (40 m)	in 1 row, equally spacel (20 m)	in tapered array (34m) (in 1 row, equally spaced (34)
geophone type				(lines 8100, 8103, 8105 only).
geophone type	SM4 - (10 Hz)	SM4 - 510 Hz)	SM4 - (10 Hz)	SM4 - (10 Hz)
RECORDING Parameters				
record length	13 s	9 s	14 s	24 s
sampling rate	4 ms	2 ms	2 ms	2 ms
50 Hz notch filter	in	not	not	not
Low-cut filter	12 Hz, 18 dB/oct	12 Hz, 18 dB/oct	12,5 Hz, 12 dB/oct	12,5 Hz, 12 dB/oct
High-cut filter	62 Hz, 72 dB/oct	124 Hz, 72 dB/oct	125 Hz, 72 dB/oct	125 Hz, 72 dB/oct
Gain constant	42 dB	42 dB	42 dB	42 dB
PROCESSING Parameters				
1. Routine processing (PRAKLA-SEISMOS) display	all lines (19)	all lines (3)	all lines (15)	all lines (15)
2. Coherency filter display	not	not	all lines (15)	all lines (15)
3. Wave equation migration	line 2	line 7801	8011 propate	lines 8102-8106-8107 8111-8112

Table C. - SEISMIC VELOCITY SURVEYS

1. Turnhout (17E/225, S120) (Rapport sur les mesures de vitesses sismiques dans les sondages 121-Meeuwen et 120-Turnhout 1953-54 SEISMOS n° 734).

2. Heibaart 1 (7E/178, S129) (Rapport de supervision et d'interprétation concernant l'étude sismique de Heibaart. Rapport n° 4 : Stockage souterrain de gaz en Belgique, DISTRIGAZ, GEOSTOCK, 1974/75).

3. Meer (7E/205, S149).