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FIRST RESULTS OF THE BELGIAN GEOTRAVERSE 1986 (BELCORP)

by

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(8 figures)

ABSTRACT.- In 1986 a reflection seismic crustal study (Belcorp), initiated and planned by the Belgian Geological Survey, was observed straight trough the Brabant Massif, as the Belgian contribution to the International Lithosphere Project, the European Geotraverse and the Belgian Drilling Program.

The 132 km long profile has been observed between the variscan front in the South and the southern rim of the Campine-Brabant Basin in the North.

This paper gives an overview of the measurements and data processing. A geological interpretation of the reflection data has been attempted : it is suggested that reflection segments represent large-scale shear zones, due to relative movement of the crust, down to the Moho depth of 12-14 sec. TWT. (between 40 and 50 km).

RESUME.- En 1986 à l'initiative du Service géologique de Belgique, une coupe sismique réflexion fut réalisée à travers le Massif du Brabant. Cette étude est une des contributions belges au Programme International pour l'Etude de la Lithosphère, à la Géotraverse Européenne ainsi qu'au programme de sondages belges.

Un profil de 132 km de longueur fut ainsi réalisé à partir du Front Varisque au Sud jusqu'au bord méridional du Bassin Campinois-Brabançon au Nord.

Ce papier donne un aperçu de l'acquisition et du traitement des données. Une interprétation géologique des réflecteurs est présentée sous toutes réserves : il est suggéré que des segments de réflecteurs représentent des zones de cisaillements, causés par des mouvements relatifs de la croute. Ceci s'étendrait jusqu'au Moho situé entre 12 et 14 sec. (TWT), soit entre 40 et 50 km de profondeur.

INTRODUCTION

History and international frame

BELCORP (= Belgian continental reflection seismic program) was initiated and planned by the Belgian Geological Survey in 1984, and is connected to the International Lithosphere Project, the European Geotraverse and the Belgian Drilling Program, which started in 1952.

BELCORP is conceived as a serie of vertical reflection seismic traverses crossing the major geotectonic units and is related to programs in Northern France (ECORS), in West-Germany (DEKORP) and even in cooperation with german oil-industry (BEB).

The main targets of BELCORP are :

- investigation of the Earth's crust in Belgium by seismic reflection measurements;
- combination in the future with other geophysical and geological studies to reveal deep tectonic structures;
- cooperation with neighbouring countries for better understanding of the development of the Variscids.

The traverse position was chosen as a function of the paleozoic geology and the position of deep research holes available (fig. 1).
The traverse has a length of 132 km (1585 single records) and crosses in its central part the caledonian anticlinal structure (Legrand, 1968) of the Brabant Massif, flanked on both its northern and southern side by moderately dipping Hercynian formations, starting with relatively thin Middle and Upper Devonian and thicker Lower and Upper

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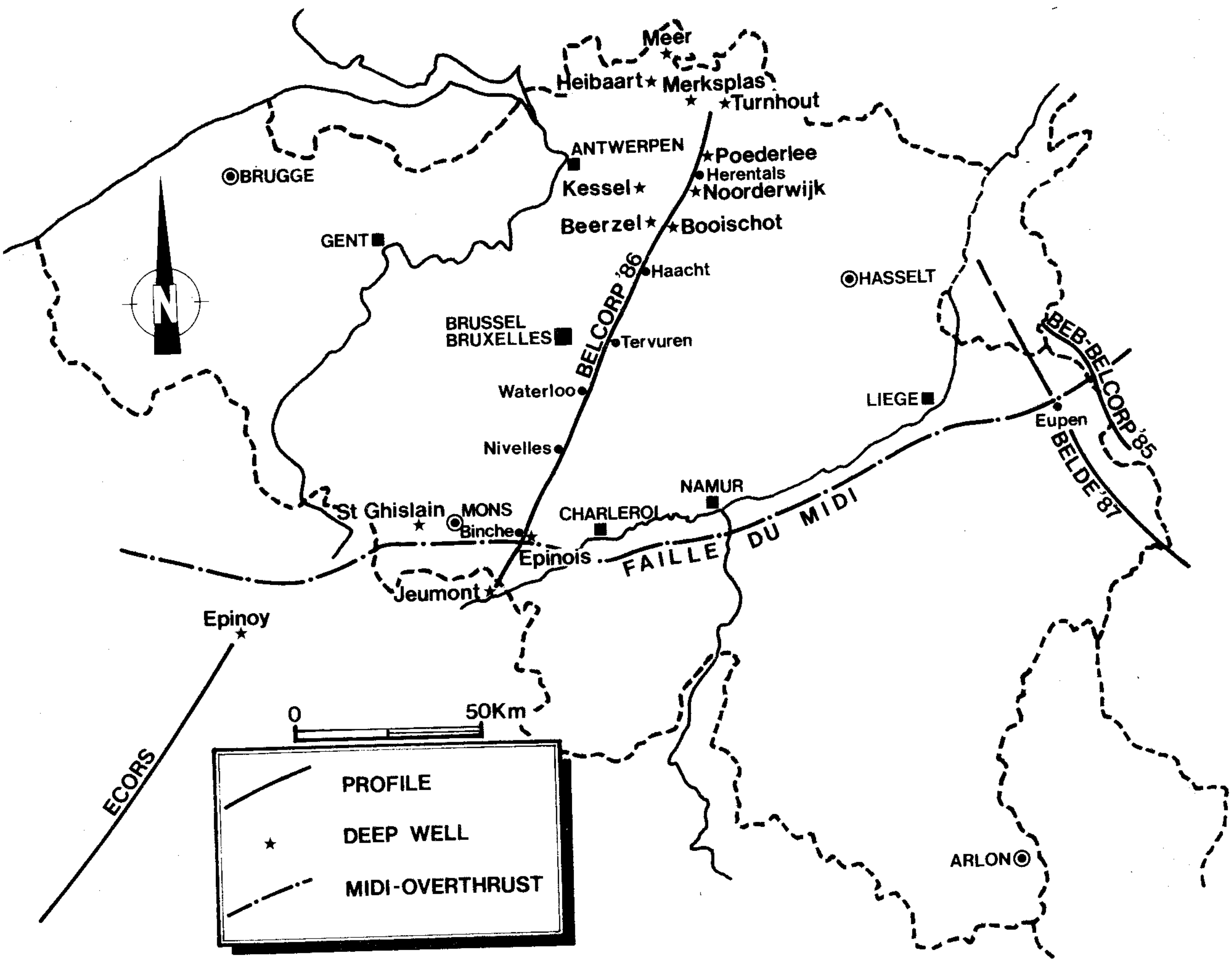


Figure 1.- Situation map with the position of different deep seismic surveys.

Carboniferous rocks. In northern Belgium about 1000 m of soft Upper Cretaceous chalks and Tertiary marls, clays and sands cover the Upper Carboniferous coal measures, whilst in southern Belgium the traverse crosses the Midi overthrust (fig. 2).

From SWAT (4) line over the Welsh Massif, the Ecors data in North France and DEKORP experiences in Germany (Dobinson A, 1985; Cazes M. *et al.*, 1985; Meissner R., 1987) it is expected that both the Variscan internides and externides will show good reflectors whilst the Caledonian Brabant Massif, the mechanically stable foreland bloc of the Variscan orogeny, will be seismically rather transparent and wedging southwards at low angle under the variscan fron overthrust.

I.- THE ACQUISITION AND PROCESSING OF THE BELCORP LINE, CARRIED OUT BY PRAKLA-SEISMOS, HANNOVER, BRD

1.- THE ACQUISITION

The source was provided by 4 vibrators, type VVCA; the vibrator pattern 79,6 m; VP spacing 80 m between PG stations. Geophones (type SM4 10 Hz) 24/trace.
Group spacing : 80. Subsurface coverage 50 fold. The field recording was executed by a 200-channel recording instrument type Sercel 348 (MTA 09). Line length 16.640 m. The field tapes were recorded in SEG-B format (9-track, 6250

bpi). The recording length of 32 sec comprises the combi-sweep (20 sec, 12-48 Hz) and the correlated seismic data (12 sec) (alternate 0-12 s, 4-16 s). The sampling rate was 4 ms. The instrument filters were set to 12,5 Hz (slope 12 dB/oct) lowcut, 125 Hz (slope 72 dB/oct) highcut and notch out, 42 dB gain was applied.

The average production reached, 4,100 km/ working day.

2.- THE PROCESSING

The first step of processing was the calculation of basic static corrections by automatic picking of first arrivals.

The routine processing contains the following processing steps in the order shown below :

1. Input of correlated survey data, demultiplexing and CDP-sorting
2. Gain removal
3. Spherical divergence corrections
4. Deconvolution before stack
5. Basic static corrections to datum level +/— Om
6. Dynamic corrections devided from velocity analyses
7. Automatic residual static corrections
8. Scaling
9. Muting
10. Horizontal stacking (nominal 30 fold)
11. Coherency filter
12. Frequency filter
13. Normalization
14. Output and display

Input were the correlated field tapes. After demultiplexing a meander sorting of the data was carried out followed by an output on tape, SEG-Y format.

Under consideration of the recording instrument gain a spherical divergence correction was executed. The velocity function used for this correction as taken from experience of previous surveys.

A pre-stack deconvolution with offset-dependent design gates was applied to the data.

Near trace offset :

1st gate :	250 ms -	4000 ms
2nd gate :	3600 ms -	6500 ms
3rd gate :	6100 ms -	11000 ms

Far trace offset :

1st gate :	2500 ms -	4000 ms
2nd gate :	3600 ms -	6500 ms
3rd gate :	6100 ms -	11000 ms

The basic static corrections were calculated by the method of «Automatic Picking of First Arrivals».

Constant velocity stacks (GENT), usually 1 per 10 km, were carried out after examination of a preliminary stack which was stacked with a velocity function from adjacent lines of a previous survey, taking into account the geological conditions. The stacking velocities, determined in this way, were utilized according to their subsurface locations. A linear interpolation was performed between these reference points.

To improve the static correction, derived from «Automatic Picking of First Arrivals», the automatic residual static correction program ARSTAT was applied. The gate for the calculation of the residual statics was fixed between 800 ms and 2200 ms. After the computation, the residual statics determined for each trace were split into surface-consistent components and applied as additions shot and geophone corrections.

The horizontal stack was performed along the meander line. A suitable muting scheme for the stacking of single traces was determined from corrected single coverages.

Before output and display of the final stack the resulting traces were filtered. The chosen filter was as follows :

0.0 - 16.0 sec (travel time) : 12 tot 35 Hz

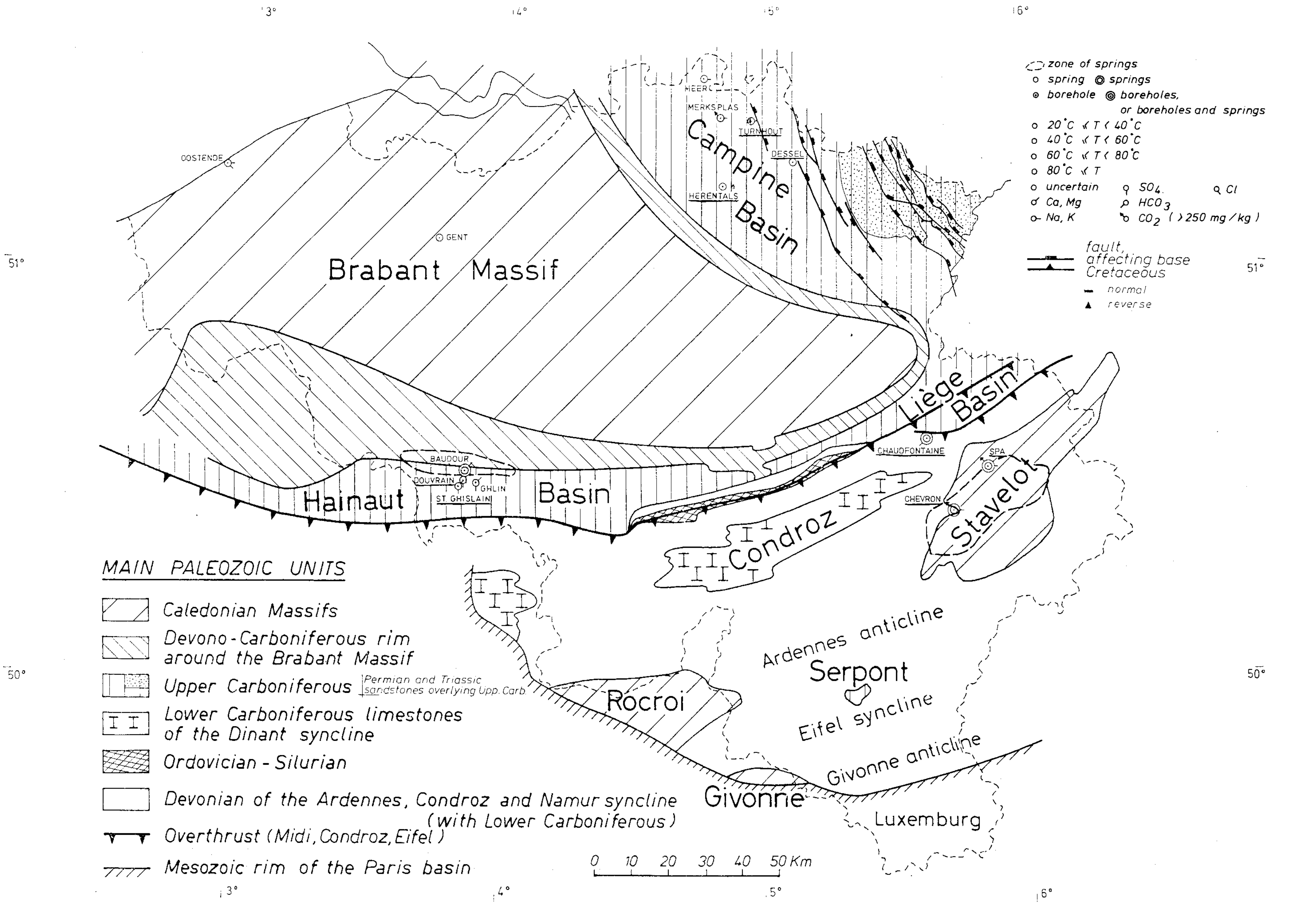
The filter boundary was linearly interpolated between these boundaries. The definition of the frequency limits relates to - 3 dB of the amplitude with a slope of 48 dB/Oct.

Normalization was applied two times during the processing. The first scaling was performed before stack with a gate length of 2000 ms.

A time-dependent normalization with overlapping gates of a length between 200 and 2000 ms was applied to the resulting stacked traces before display. The average amplitude value was determined in each gate and a multiplication factor derived. This factor was linearly interpolated between the gate centres.

The final sections are displayed on 1:25.000 and 6 cm/sec respectively horizontal and vertical scales and 1/66666 and 3 cm/sec.

The section processed under these conditions did not show much coherent energy and even


3°
4°
5°
6°
51°
50°
zone of springs
spring
springs
borehole
boreholes,
or boreholes and springs
20°C ≤ T < 40°C
40°C ≤ T < 60°C
60°C ≤ T < 80°C
80°C ≤ T
uncertain
SO4
Cl
Ca, Mg
HCO3
Na, K
CO2 (> 250 mg/kg)
fault, affecting base Cretaceous
normal
reverse
OOSTENDE
GENT
MEERLE
MERKSPLAS
TURNHOUT
DESSEL
HERENTALS
Campine Basin
Brabant Massif
Liège Basin
CHAUDFONTAINE
SPA
CHEVRON
Stavelot
BAUDOUR
DOUVRAIN
GHLIN
ST GHISLAIN
Hainaut Basin
Condroz
Ardennes anticline
Serpont
Eifel syncline
Rocroi
Givonne anticline
Givonne
Luxemburg
0 10 20 30 40 50 Km
MAIN PALEOZOIC UNITS
Caledonian Massifs
Devono-Carboniferous rim around the Brabant Massif
Upper Carboniferous
Permian and Triassic sandstones overlying Upp. Carb.
Lower Carboniferous limestones of the Dinant syncline
Ordovician - Silurian
Devonian of the Ardennes, Condroz and Namur syncline (with Lower Carboniferous)
Overthrust (Midi, Condroz, Eifel)
Mesozoic rim of the Paris basin

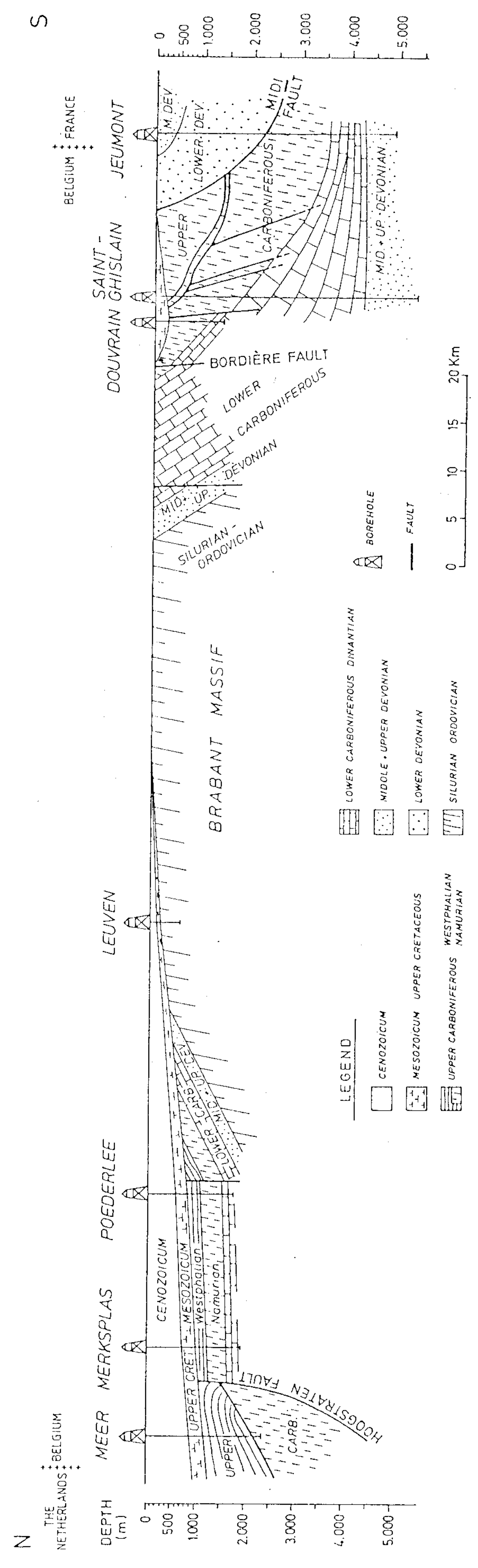


Figure 2.- Overview of the main paleozoic units and section along a line Meer-St-Ghislain-Jeumont (northern France).

short reflectors were almost absent.

In an attempt to improve the signal to noise ratio a coherency filter was applied to the data. Each trace was compared to neighbouring traces and only coherent responses were enhanced. The section produced in this way (fig. 3) now shows many very short reflector traces (shorter than 1 km) which slightly dip (25-30°); the dip directions are constant in zones of a few seconds thick and several tens of km long.

Obviously the question arises to what extent these reflector bits are genuine geological features and not the artefacts of a desperate processing geophysicist. The authors are convinced of the geological significance of the reflector traces for the following reasons : first of all, the dipping reflectors show patterns of distinguished zones distributed at different depth intervals and at different location. If the patterns were introduced by processing either systematic changes with depth or with location along the profile would be expected or a totally random distribution of similarly dipping reflector zones. Secondly, the change in emitter receiver configuration at VP 593 has no influence at all on the reflector pattern.

II.- THE LINE DRAWINGS

1.- THE CONTINUOUS REFLECTORS IN THE NORTHERN AND SOUTHERN TOPZONE OF THE PROFILE

As expected from deep seismic work in the neighbouring countries the Variscan strata do show good continuous reflectors.

In south Belgium the profile starts at the (fig. 4) approximate location of the Jeumont well (Clément, 1963). It allows the identification of the Midi overthrust bringing Lower Devonian clastics over the coal measures. The coal measures lose their seismic signature in the outcrop zone to the north of the Midi overthrust probably due to the former mining activities. The Midi overthrust can be identified at VP 80 at 0.6 sec.

The second strong, locally disrupted, reflector slightly less dipping than the Midi overthrust, at VP 40 identifiable at 1.4 sec., is the top Dinantian reflector.

The third and strongest reflector, identifiable at VP 40 at 1.7 sec. and parallel to the top Dinantian reflector is the P reflector at Jeumont representing the top of the Middle Devonian carbonates. It probably corresponds to the «2ième réflecteur profond» in northern France (Raoult &

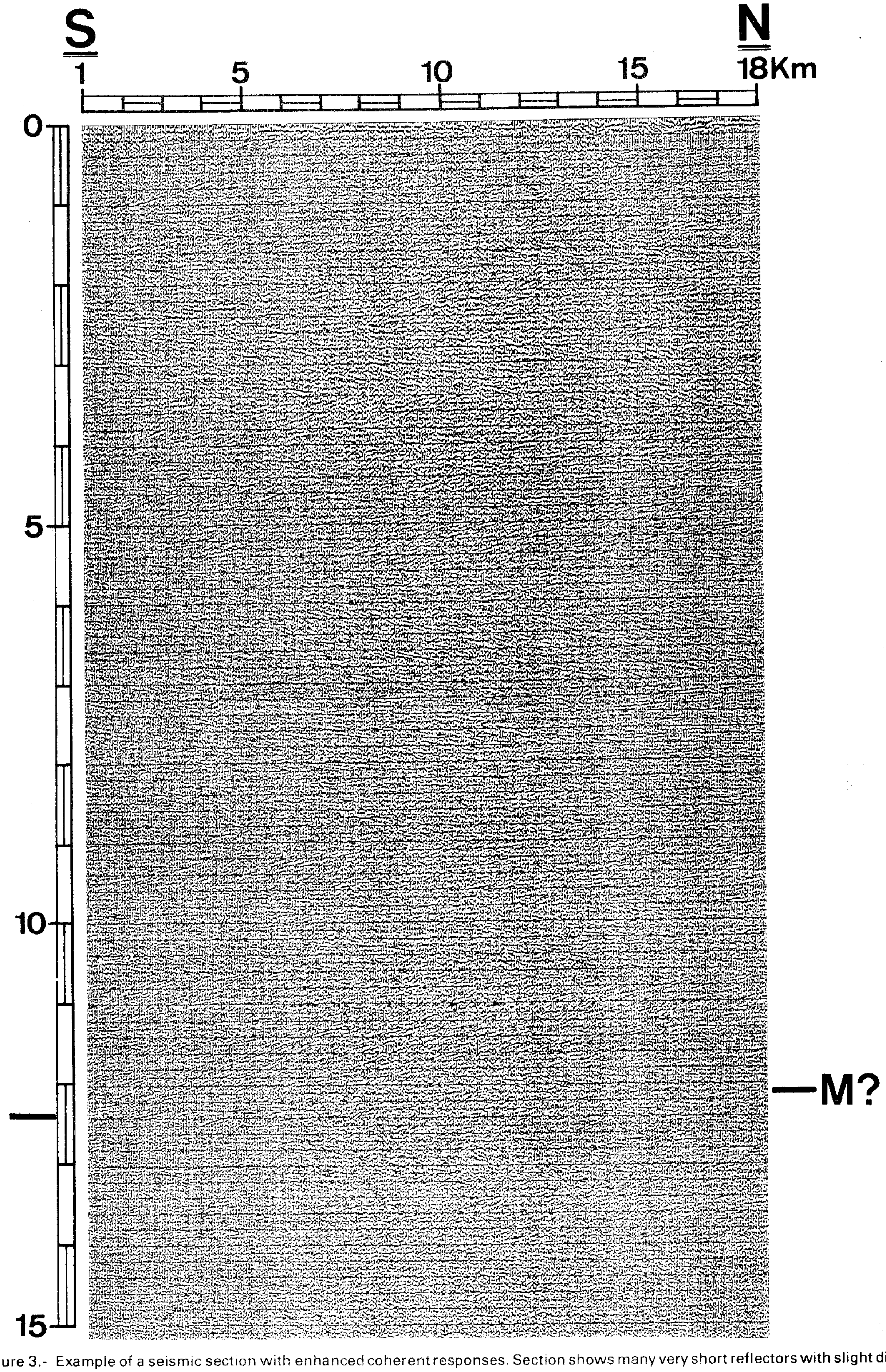


Figure 3.- Example of a seismic section with enhanced coherent responses. Section shows many very short reflectors with slight dip. Dip direction are constant in zones of several tens of km long. m ? = Moho.

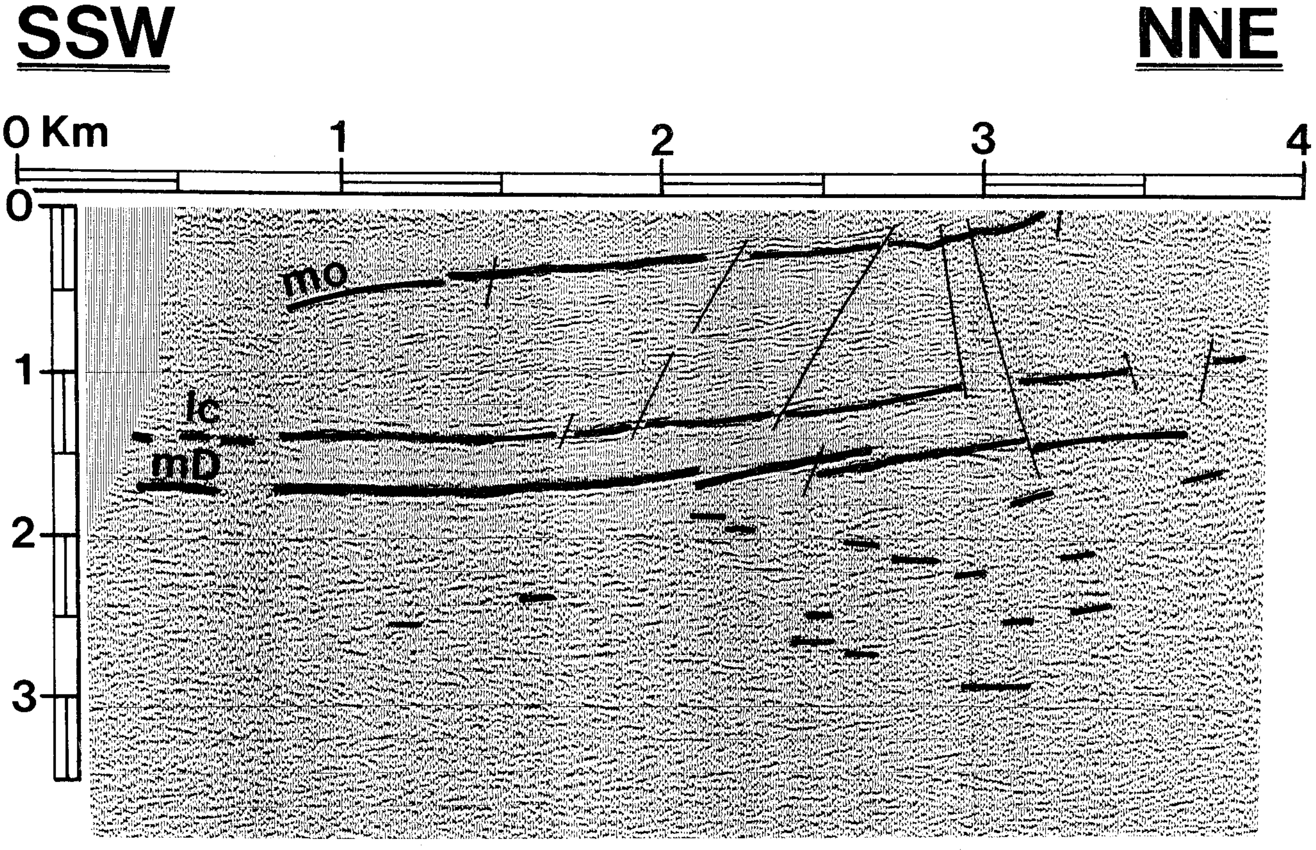


Figure 4.- Continuous reflectors in the southern part of the profile.
mo = midi overthrust; lC = Lower Carboniferous; mD = mid Devonian.

Meilliez, 1985) (at Epinoy Well, Northern France, at 2.2 sec.).

Unfortunately the northern continuation is disturbed under the mining area.

In northern Belgium the set of strong parallel (fig. 5) reflectors with a base at about 1 sec. in the very north of the profile represents the Upper Cretaceous and Tertiary sediments, overlying unconformably the Upper Carboniferous.

On conventional seismics till now, in Northern Belgium, the top of the Dinantian is the deepest reflector that might be observed.

2.- THE PRE VARISCAN PART OF THE PROFILE

In a first step, all the small coherent reflector strips are marked. It can be observed that the reflectors can be grouped into zones of similar dip (see fig. 3).

To entrance the visual effect of the similar dip of the several short reflectors, dip trend lines were constructed in an next step (fig. 6).

In a next step the boundaries between the different zones are drawn (fig. 7). These boundaries are not expressed by reflectors although dips sometimes tend to converge with the boundaries. More than 10 such zones might be distinguished.

III.- THE INTERPRETATION

1.- THE PROBLEM OF THE VELOCITY ANALYSIS

Any lithological interpretation of deep seismic needs at least reliable velocity data. However the short reflector strips, only made visible after coherency filtering was applied, obviously do not allow a good estimate of stacking velocities. Calculating interval velocities from the visually derived stacking velocities indeed leads to some impossible results.

Although for this reason the absolute values can not be used - and hence no lithological interpretations are possible - the qualitative picture, suggesting a layering of lower and higher velocities, is acceptable realistic.

Currently a new processing effort is done in trying a velocity analysis on CDP stacks on which a coherency filtering is applied before the velocity

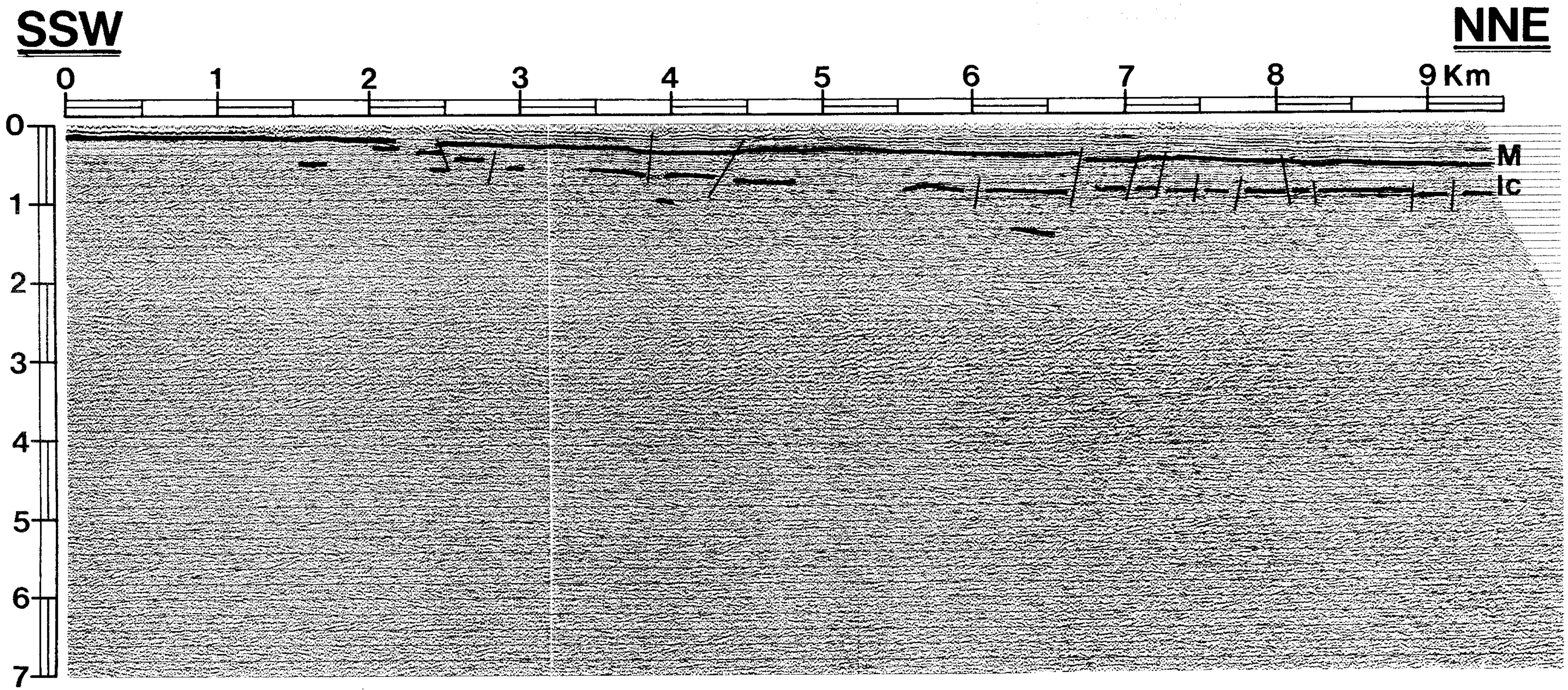


Figure 5.- Continuous reflectors in the northern part of the profile.
M = base of the Cretaceous; IC = Lower Carboniferous.

analysis.

2.- THE PRESENCE OF THE MOHO

As the Moho is defined as a velocity contrast and considering the lack of reliable velocity data, this definition criterium can not be used.

On reflection seismic sections the Moho appears at the base of a laminated zone (Hale & Thompson, 1982). Such a laminated zone is absent under the Brabant Massif. The only marked change in signal character is where the dipping short reflector strips are nog longer present; this is at about 12 sec. in the south and at 14 sec. in the north. Using about 7000 m/sec. stacking velocity, it means the Moho would be between 40 km and 50 km. This figure is in line with data form Babuska *et al.* (1984) estimating the Moho under the subvariscan fore deep and Rhenish Massif to be about 50 km (their fig. 10).

Souriau (1979) proposes a model with the Moho at 30 km in north Belgium and De Vuyst (1967) estimates the crust to be 20 km thick under the Brabant Massif.

The Moho in the northern part of Dekorp 2 is about 11 sec. (35 km) (Franke *et al.*, 1987) and a similar depth is derived from ECORS in northern France (Matte & Hirne, 1987).

Meissner *et al.* (1983) estimate the Moho under the Stavelot Massif at 10-11 sec.

It should be noticed that one observation of a badly defined Moho (if any Moho at all!) under a structural Old Massif is in accordance with other observations under old massifs (e.g. Matte & Hirn, 1987, under central Armorican zone) and the observation that topography in the Moho only shows very young features (Meissner, 1987).

3.- THE SIGNIFICANCE OF THE SHORT REFLECTORS

a) It has been demonstrated that the reflector strips represent genuine geologic features.

It is still expected to find diffractions at the deepest levels because of the rapid amplitude loss of diffractions with depth and certainly not to find only diffractions without true reflecting surfaces.

Therefore it is assume that the reflector strips represent effectively reflecting surfaces.

b) As the neighbouring reflector strips are lining up through their similar dips it is justified to think that they earlier were much longer continuous reflectors now degraded through the recrystallation of the rocks in equilibrium with their high P-T conditions. A comparison with other areas (Wever *et al.*, 1986; Meissner *et al.*, 1986; Meissner, 1987) shows that reflectors shorter than 1 km are (fig. 8) typical for old shield areas with low heat flow. Although no thermal conductivity values are available and no deep wells for thermal gradient measurement are penetrating the Brabant Massif. Temperature maps at several depths suggest the cold nature of the Brabant Massif.
As the trends of the reflector strips define long, parallel and oblique bands within the zones, it is improbable that they represent alternations of different lithologies. Rather they are probably structural features.

c) As the reflector dips are well aligned however it is improbable that they are caused by smaller faults or folds.
Therefore they represent the remnents of former larger structural planes, maybe analogous to the well observed imbricated thrust slices in Variscan belts.
Analogous oblique dipping features observed in deep seismics include the north flank of the London Platform where they are interpreted as shear faults in the middle crust (Reston & Blundell, 1987). Page *et al.* (1986) have published an interpretative geologic section under the terrains of the Alaska coast at the Canadian border where the Pacific Plate subducts. These authors have identified several thin rootless sheets (10 km) alternating with thin layers of ultramafic high velocity zones.

Within each thin sheet, faults are suggested dipping in the diretion of subduction and caused by shear. The sheets and layers are interpreted as phases of underplating by subduction.

A similar deep structural pattern is identified under Vancouver-Island where the Juan de Fuca plate subducts under Vancouver Island. Within the slobs of the modern subduction complex, traces of reflectors dipping in the subduction direction, are observed (Lewis, 1987).

4.- STRUCTURAL INTERPRETATION

It is believed that each zone represents an individual structural unit and that the interval dipping direction is due to shear while the unit was emplaced to its present position. Shear fault dip direction indicates the direction of movement.

This interpretation implies, because of the different dip directions that units were emplaced from both north and south (seismic record only in one direction!). At least five zones in each direction can be identified. Thicknesses are estimated between 5 and 15 km and the length of

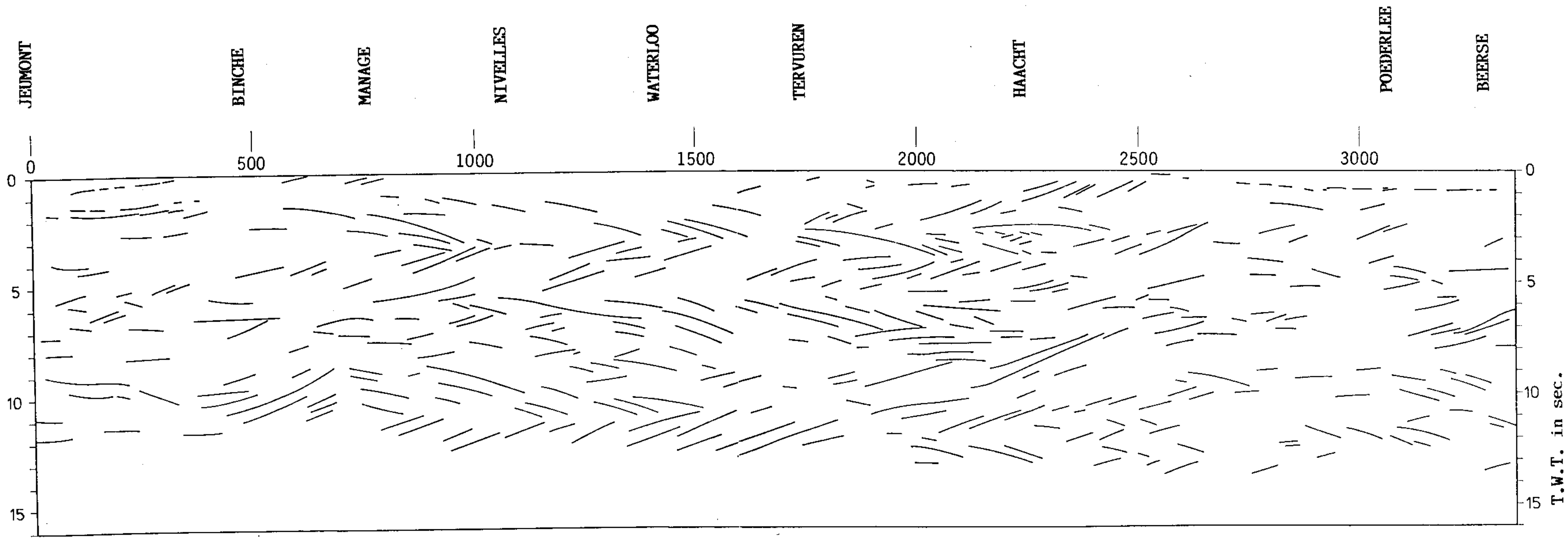


Figure 6.- Construction of dip-trend lines based on the short reflectors.

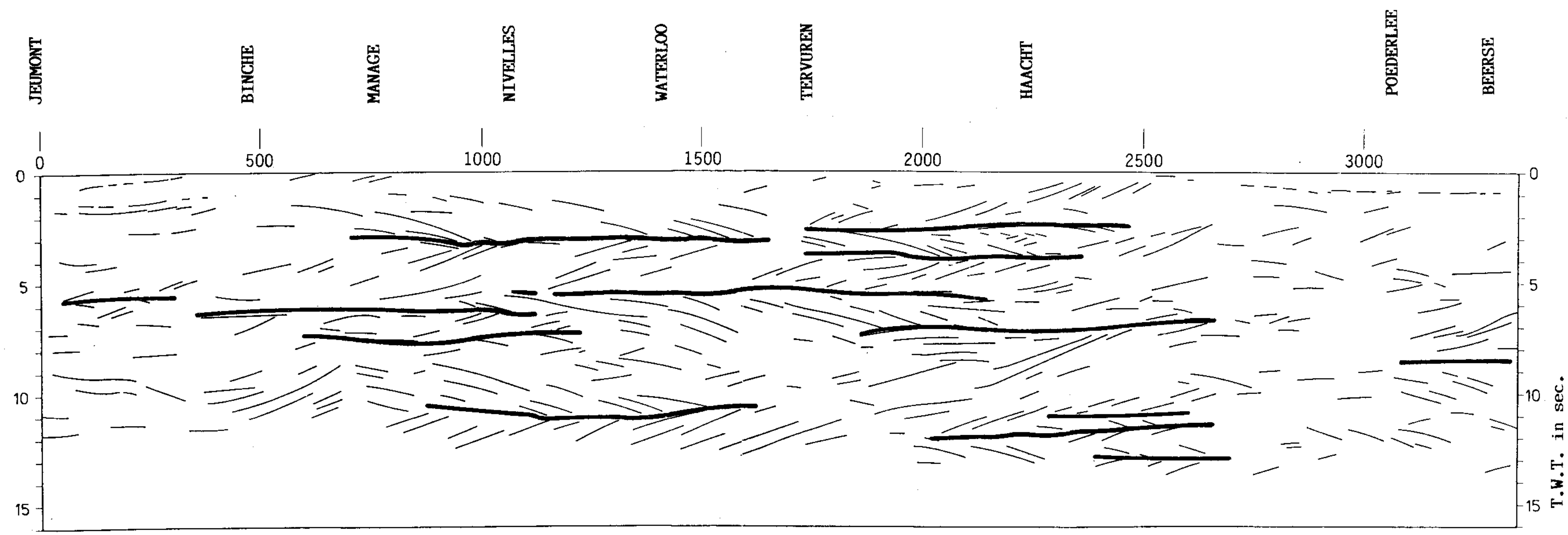


Figure 7.- Boundaries traced between the different dip trends.

the zones is several tens of kms and even over 100 km. The zones may represent the original sedimentary wedges of Caledonian and mainly Precambrium age deposited at the edges of former cratons which later collided. In the process of colliding with or subducting under the opposing wedge, major decollement surfaces or shear faults developped in the wedges. Such a simple model is represented by Raleigh (1986). The different dip directions suggest that both the northern and the southern craton were alternatively actively progressing through Precambrian and Caledonian time.

In this model the stacking of the several wedges of relatively less dense rocks on top of each other may have triggered an isostatic resound responsible for the uplift of the Brabant Massif since early hercynian times till now.

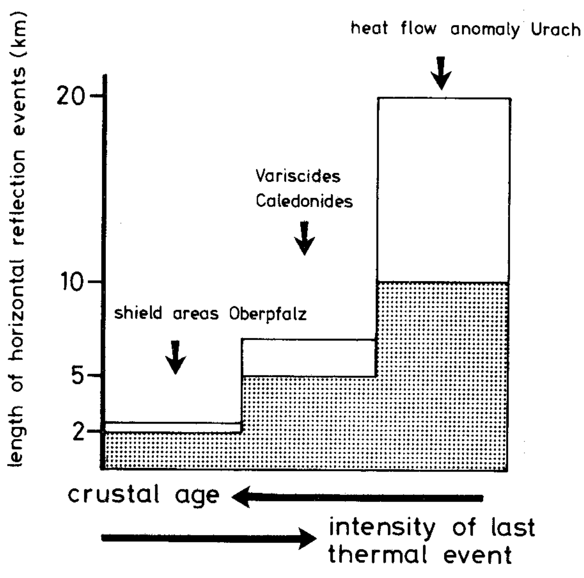


Figure 8
Figure after Wever *et al.*, 1986.
Short reflectors are typical for old shield areas.

IV.- OTHER GEOPHYSICAL DATA OVER THE BRABANT MASSIF

It is the purpose of this paragraph to review briefly other geophysical information available over the BELCORP line and relevant to the deep structure of the Brabant Massif.

1.- GRAVIMETRIC DATA

The gravimetric map of Belgium (Jones, 1948; Jones, 1950) with 5 mugal equidistance shows an outspoken negative anomaly crossing the geotraverse south of the central part, while north of the central part a positive anomaly is crossed.

The negative anomaly, better developed to the west, was investigated by De Meyer (1983, 1984). Modelling showed the maximal depth of the anomaly to be 8 to 10 km. Both a shallow batholithic body - the anomaly corresponds to the volcanic Asghill subcorp (Legrand, 1968) - and a sediment wedge of relatively less dense rocks could generate the observed anomaly.

The positive anomaly corresponds to a zone of delayed P-Wave arrivals from nuclear explosions. Souriau (1979) explains the anomaly by a rise of the Upper Mantle to 20 km in stead of the normal 30 km depth. The rise is laterally constrained but the anomaly could originate below 200 km depth. In the opinion of Souriau, a hot spot already responsible for Polish and Eifel vulcanism would cause the anomaly.

The negative anomaly crosses the profile at about 1400, the positive anomaly at about 2400.

Both anomalies go unnoticed on the seismic profile.

2.- SEISMOLOGY

The Brabant Massif is a stark block and earthquakes are seldom occurring and are of low intensity or magnitude (Van Gils & Zaczek, 1978). Isoseist maps of historic earthquakes (Van Gils, 1956; Van Gils & Zaczek, 1978) delineate the Brabant Massif as a structurally separate block. Hypocenters within the Brabant Massif are estimated around 25 km depth and even deeper than 30 km.
It was not been possible till now to define seismologically the Moho underneath the Brabant Massif (De Becker, pers. com.).

3.- MAGNETICS

Two magnetics maps are available (1934, 1963).

Generally speaking the Brabant Massif is a broad positively anomalous zone, whilst to the north, in the same area as the positive gravimetric anomaly, a negative magnetic anomaly occurs. Interpretation (De Vuyst, 1967) has never been very detailed.

As a conclusion it can be stated that geophysical data over the Brabant Massif are not very helpfull to interprete the BELCORP line.

Besides any modelling is muddled by the almost complete absence of basic petrophysical data such as rock densities, magnetic subceptibilities, and P. and S. rock velocities and thermal conductivities.

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