Interreg North-West Europe
DGE-ROLLOUT

Deliverable T2.1.13 – Interpretation of seismic data in NRW

Part 1 - Results of the reprocessed seismic line DEK87-1A

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Disclaimer

The purpose of the following report is to summarize the interpretation results of a reprocessed deep seismic reflection survey. It is not a peer-reviewed paper and therefore does not replace the own independent research on this topic.

The results presented herein are the authors' subjective opinions based on the research which has been done for this report. The report brings together the joint knowledge of the involved project partners of the DGE-ROLLOUT project.

We cannot guarantee the accuracy, reliability, correctness or completeness of the information and materials given in this report and accept no legal responsibility.

Contents

1. Introduction

The objective of this deliverable is to investigate the structure of the deep subsurface of NRW (and parts of Belgium) for carbonate rocks that are candidates for the development of deep geothermal energy. Within the framework of the DGE-ROLLOUT project, the seismic lines of the German Continental Seismic Reflection Programme (DEKORP) were reprocessed and reinterpreted, focussing on the Middle Devonian and Lower Carboniferous (Dinantian) carbonate rocks.

This report summarizes the results of a new interpretation of the reprocessed seismic line DEK87-1A with a total length of 93.3 km. The northwestern end of the line starts at the Dutch-Belgian border region (Limburg, Belgium), crosses the Belgian-German border near Monschau (North Rhine-Westphalia, Germany) and terminates in the southeast near Adenau (Rhineland-Palatinate, Germany). The reprocessing of this vintage seismic data was carried out by DMT. The interpretation of the seismic line was made with the state-of-the-art software Petrel 2017 (Schlumberger Information Solutions) in collaboration with the Royal Belgian Institute for Natural Sciences - Geological Survey of Belgium (GSB) and the Geological Survey of North Rhine-Westphalia (GD NRW).

The geology along the seismic line DEK87-1A can be divided into three major parts from northwest to southeast:

(I) The Brabant Parautochton and the Vesdre Nappe consist of a Devono-Carboniferous sedimentary succession that unconformably overlies the Lower Palaeozoic basement of the Brabant Massif. The allochthonous sediments were part of a shelf platform, which favoured the deposition of limestone and carbonate formations, such as the Middle Devonian 'Massenkalk' and the Lower Carboniferous Tournasian-Visean (Dinantian) series. During the Variscan Orogeny, the sedimentary succession was folded and thrusted northwestwards. The German counterparts of these units are the Wurm Syncline and Inde Syncline, respectively. They are separated by the Aachen Thrust, a northeast striking fault, which is considered to be the continuation of the Theux-Tunnel Fault and the Midi Fault of the Ardenne Allochthon further to the west (Anderle et al. 1991, Hance et al. 1999).

(II) The Stavelot-Venn Massif is a Cambro-Ordovician succession of quartzites and banded shales with a low-grade metamorphic overprint forming an anticlinorium. During late Variscan times, it was thrust in a northwest direction as an out-of-sequence thrust onto the younger Devono-Carboniferous sedimentary succession of the previous part. The respective fault is referred to as the Eupen Thrust in Belgium, respectively the Venn Thrust in Germany (Anderle et al. 1991, Fielitz 1992). In the deeper subsurface, it branches off the Theux-Tunnel Fault (Hance et al. 1999).

(III) The Eifel Syncline is a monotonous succession of Lower Devonian marine sandstones and shales with a southward-decreasing metamorphic overprint. Compared to the Lower Devonian succession northwest of the seismic line, the sediments are much thicker: 900 m in the northwest vs. 5,000 to 6,000 m in the southeast (Anderle et al. 1991). This is explained by a Lower Devonian syn-sedimentary fault, which has been reactivated and inverted during Variscan times. This fault can be connected to the Monschau shear zone that separates the southeastern limb of the Stavelot-Venn Massif from the Eifel Syncline (Fielitz 1992).

The overall Variscan shortening reaches about 50 % in the Devono-Carboniferous succession in the northwestern part of the seismic line DEK87-1A (Hance et al. 1999) and 50-60 % along the Monschau shear zone (Fielitz 1992).

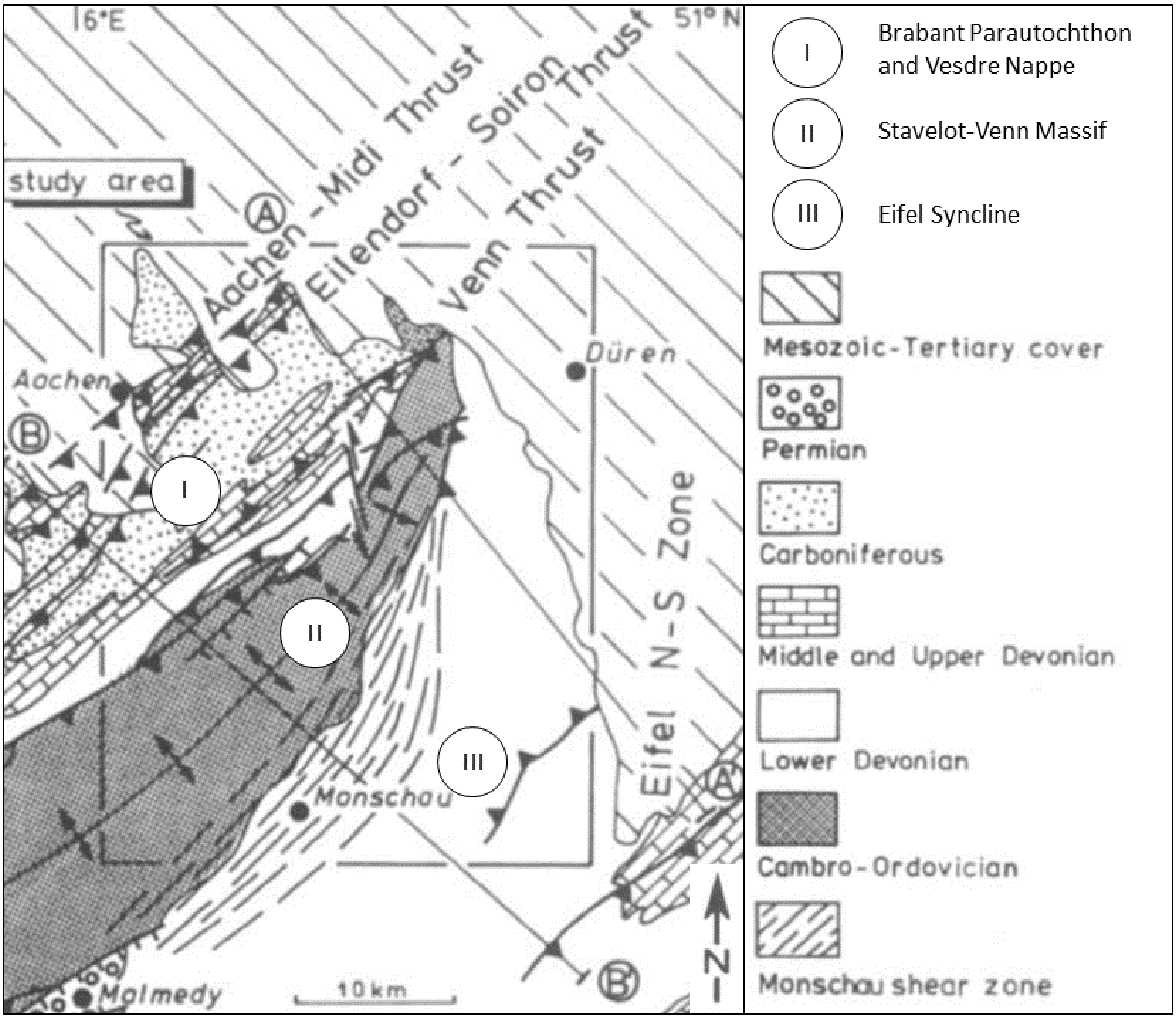

Figure 1: Geological map of the investigated area, modified after Fielitz (1992).

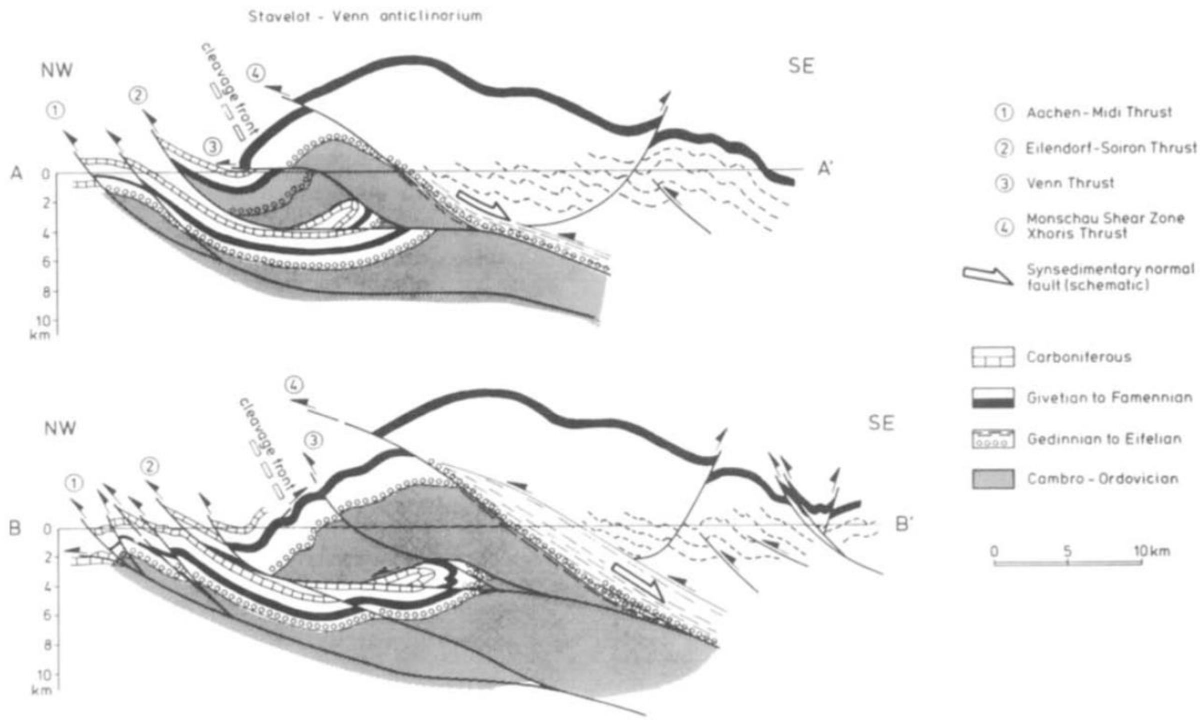

Figure 2: Geological cross sections within the investigated area (Fielitz 1992).

2. Methodology

The DEKORP seismic lines were acquired in the 1980's with the aim to investigate deep crustal structures and targets like the Mohorovičić Discontinuity and reached depths of approximately 50,000 to 60,000 m. The vintage seismic data were reprocessed by DMT GmbH & Co. KG (DMT) with the aim to improve the visibility of shallow targets in depths down to 6,000 m. Further details about the reprocessing can be found in Appendix 1. This report focusses on the methods of interpretation and presents the new results.

2.1 Basics of reflection seismic interpretation

Reflections in seismic images reveal distinctive changes of velocity and density at lithological interfaces. The acoustic impedance of a rock layer is defined as the product of bulk density ρ_B and P-wave velocity V_P: The normal incidence (vertical) reflection coefficient R between an upper layer *i* and a lower layer *i + 1* is given by:

- Acoustic impedance (I): $I = V_P * \rho_B$
- Reflection coefficient (R): $R = \frac{I_2 - I_1}{I_1 + I_2}$

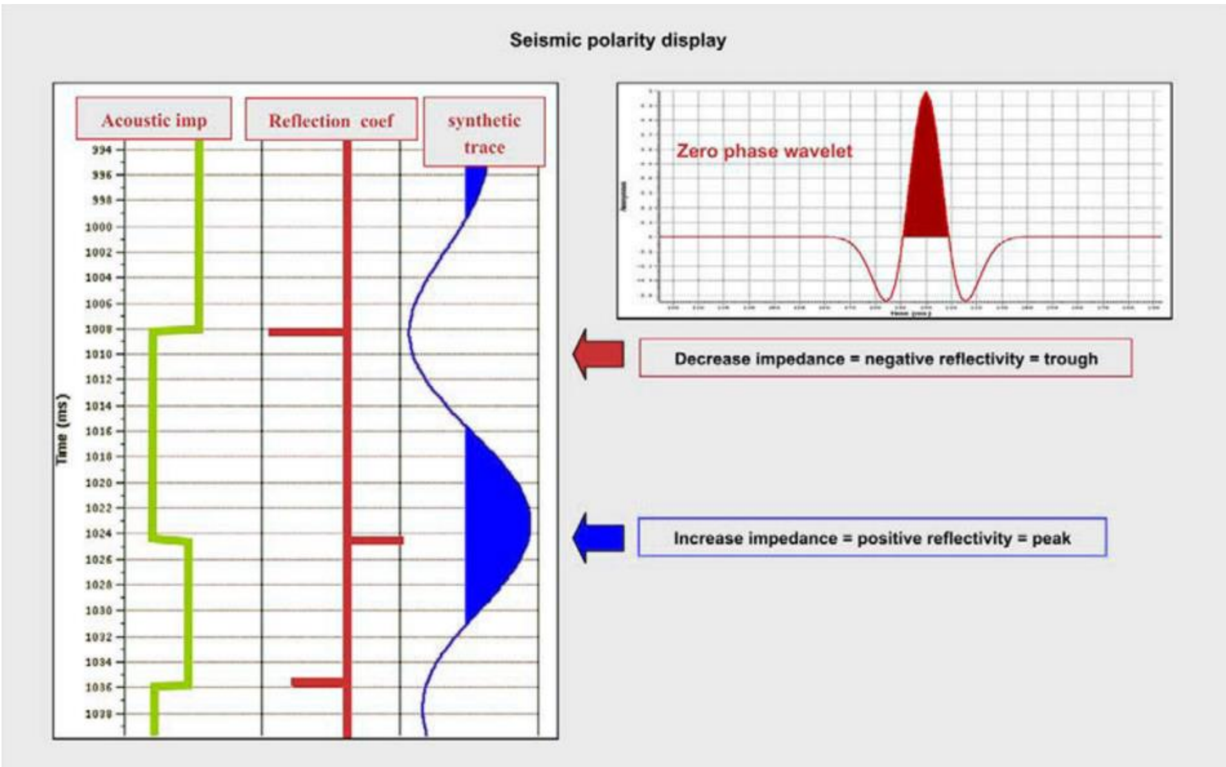

Figure 3: Positive polarity display, whereby an increase in acoustic impedance is represented by a peak in the synthetic trace (Veeken 2007).

The amplitude of an acoustic wave generated at layer interfaces in the subsurface and recorded by geophones at surface is dependent upon the reflection coefficient. Frequently, the reflection amplitudes coincide with lithostratigraphic boundaries. During the interpretation process characteristic reflections are marked and laterally followed (picking process). Vertical and sharp defined reflector offsets indicate faulting. Small scale faulting can often be identified by breaks in the reflector inclination rather than by clear offsets. Lateral changes in the seismic wave attributes (e.g. frequency, phase or amplitude force) may indicate 'weak zones' due to fractures, karstification or facies changes. Modern seismic interpretation programs facilitate the interpretation process by enhanced visualization and computation options. For this project the 3D interpretation and modelling software Petrel 2017 (Schlumberger Information Solutions) was used for the interpretation of the seismic data.

The polarity used for the seismic line DEK87-1A is SEG normal (polarity), which means an increase of impedance downwards is represented by a peak (positive). In the working Petrel project the peaks are displayed in red and the troughs in blue.

The interpretation workflow consisted of the following steps:

1. Import of available adjacent borehole data (drilling paths, formation tops, formation dips)
2. Import of seismic lines
3. Import of additional data, such as geological maps, surfaces etc.
4. Well top correlation
5. Assignment of seismic reflectors to geological boundaries by comparing the boundaries with the geological maps
6. Interpretation of reflectors and faults at the first iteration
7. Generation of seismic attributes for visibility improvement
8. Development of a geometric structural model (combination of in-sequence thrusting and out-of-sequence thrusting) in close collaboration with GSB in the second iteration
9. Establishment of horizons and faults related to the computer-based geometric structural model provided by GSB in the third iteration

2.2 Geological database

Apart from the formation tops of the seismic line DEK87-1A, data from 11 adjacent boreholes were available. None of them are directly connected to the 2D seismic line (Figure 4). Hence, the borehole RWTH 1 is the closest to the interpreted 2D line, however, the distance between this borehole and the seismic line is almost 12 km.

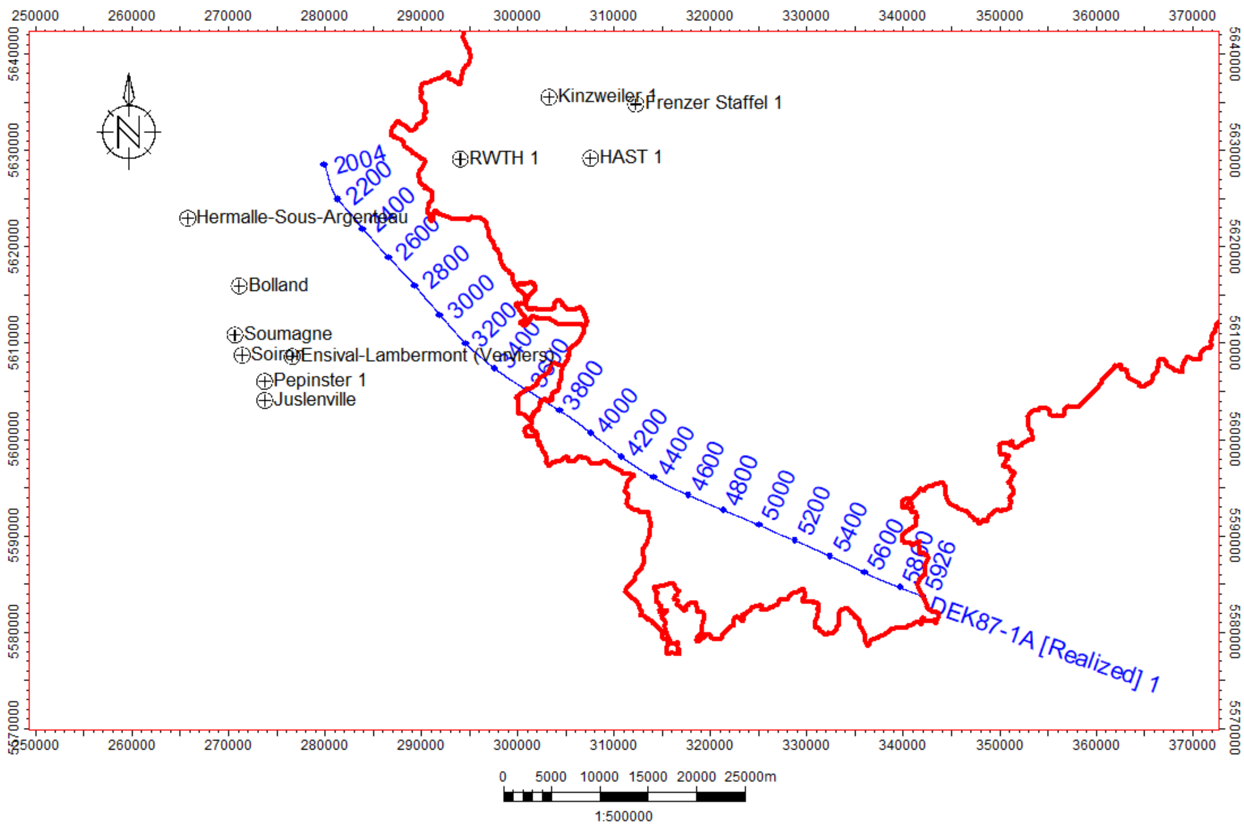

Figure 4: Basemap of the seismic line DEK87-1A (blue), adjacent wells (black) and border of North Rhine-Westphalia (red).

The boreholes Hermalle-Sous-Argenteau, Bolland, Soumagne, Soiron, Ensival-Lambermont (Verviers), Pepinster 1, Juslenville are located in Belgium (Wallonia) and the boreholes RWTH 1, HAST 1, Kinzweiler 1 and Frenzer Staffel 1 are located in Germany (North Rhine-Westphalia). All available drilling paths, formation tops and dip data have been imported into a Petrel project. The depth values of formation tops and dip data were taken from the drilling reports.

The formation tops for the seismic line DEK87-1A were interpreted using geological surface data from two geological maps:

- Geological map of North Rhine-Westphalia 1:100.000 – sheet C 5502 Aachen (Ribbert 1992)
- Geological map of Wallonia 1:25.000 – sheet 1 Henri-Chapelle – Raeren (Ghysel et al. 1990)

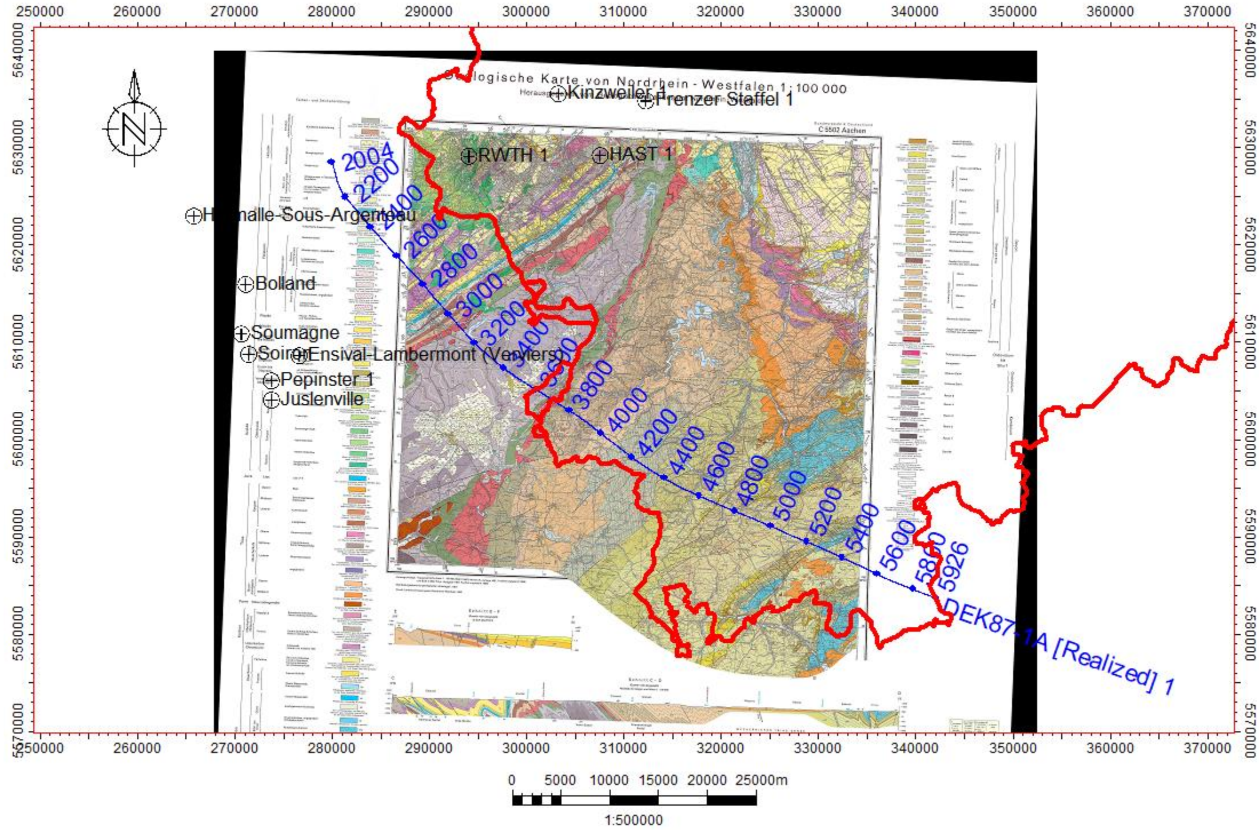

Figure 5: Basemap of the seismic line DEK87-1A (blue), the geological map of North Rhine-Westphalia 1:100.000 (Ribbert 1992), adjacent wells (black), and the border of North Rhine-Westphalia (red).

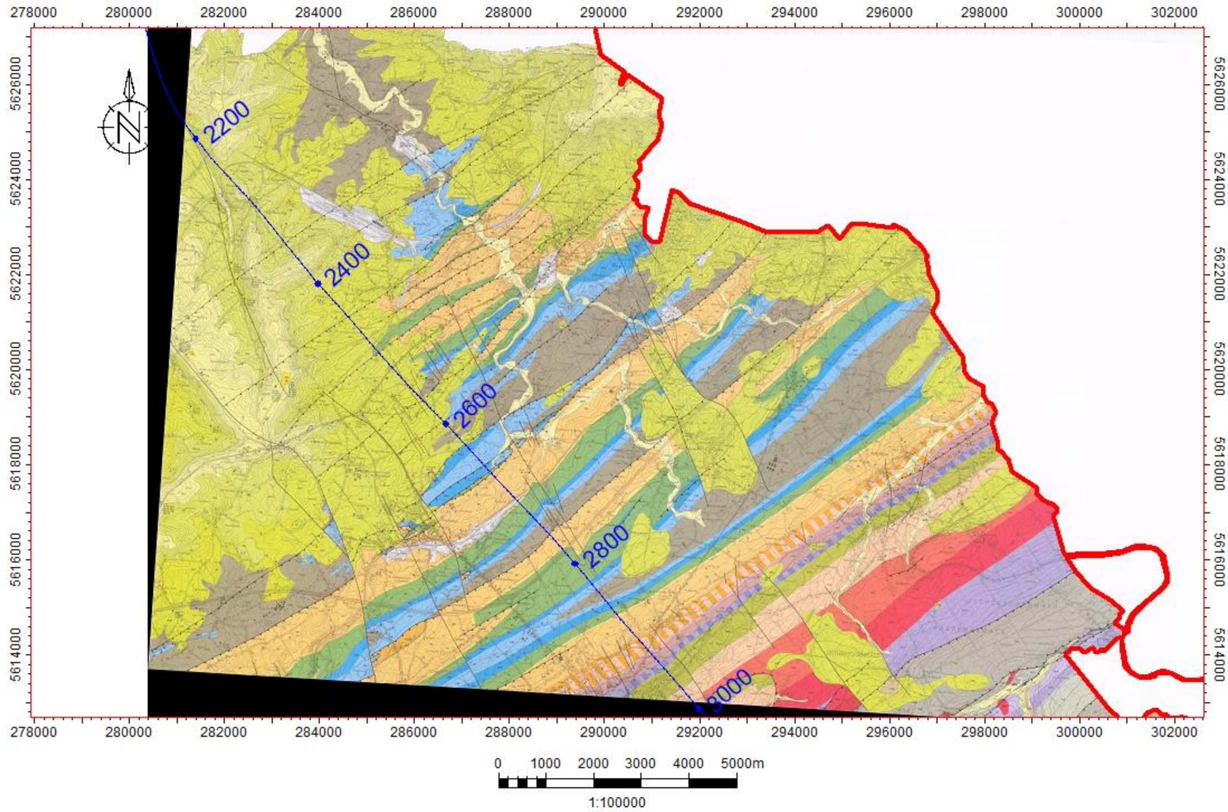

Figure 6: Close-up of the northwestern part of the seismic line DEK87-1A (blue), the geological map of Wallonia 1:25.000 (Ghysel et al. 1990) and the border of North Rhine-Westphalia (red).

2.3 Stratigraphy and well correlation

The main target horizons of the interpretation were the Carboniferous and Devonian limestone formations in the northwestern part of the seismic line DEK87-1A. Stratigraphically, the Carboniferous limestones belong to the Visean and Tournaisian stages (referred to as 'Dinantian carbonates'); Devonian limestones belong to the Frasnian and Givetian stages ('Massenkalk' in Germany, 'Lustin' in Belgium).

The geological maps available for the location of the seismic line comprize the stratigraphic sequences from Lower Cambrian to Upper Carboniferous (Namurian) (Figure 7).

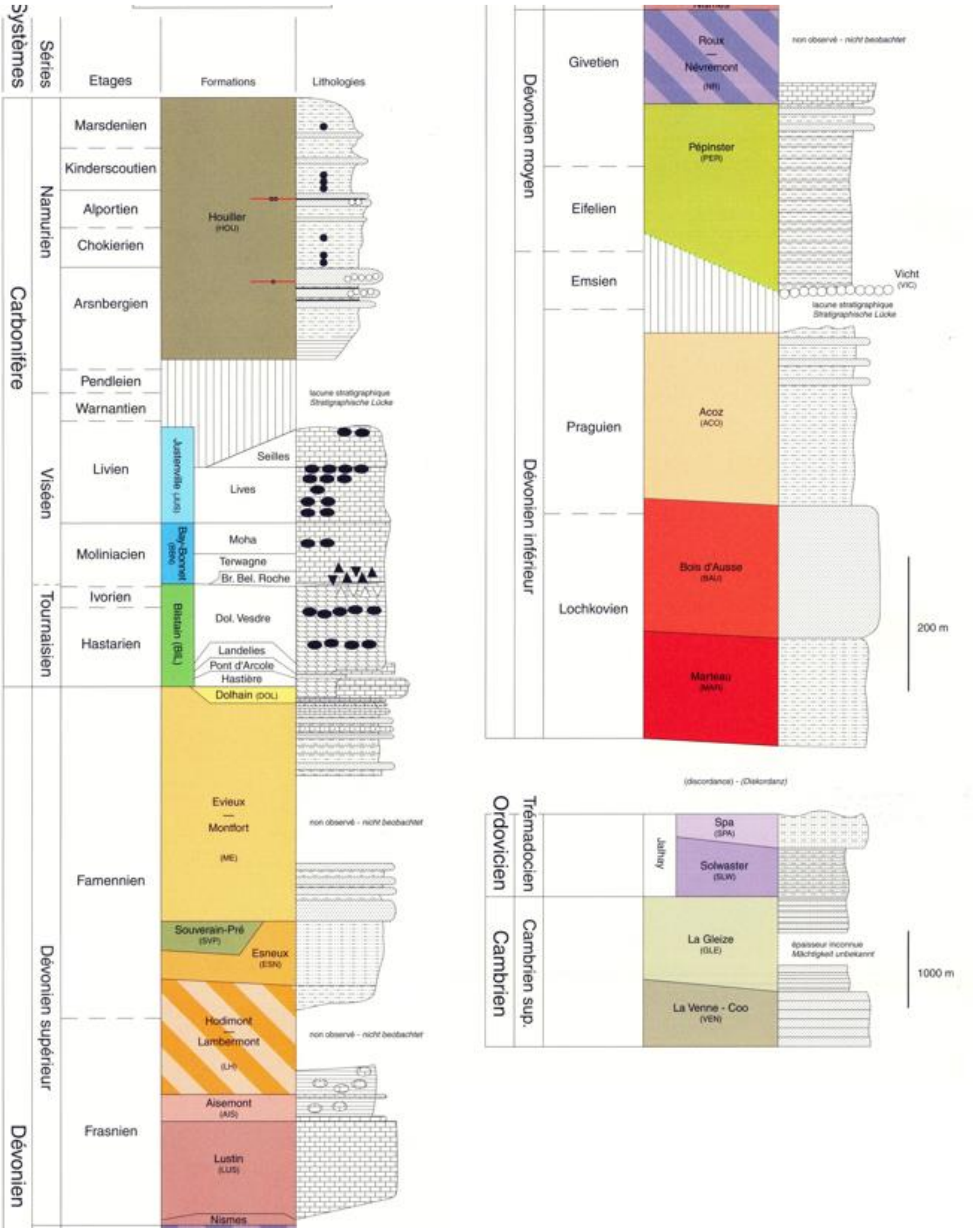

Figure 7: Stratigraphy of northeastern Belgium (Ghysel et al. 1990).

Although there are no boreholes near the seismic line DEK87-1A, the correlation with the formation tops of the adjacent boreholes helped to understand the complex structural setting of the study area with repeating sequences, overturned layers and complex thrust faulting and folding.

In addition to the formation tops, dip data of boreholes located in Belgium were taken from the drilling reports. These data are visualized in a borehole correlation section (Figures 8 and 9). If available, dip and azimuth data were included to distinguish between normal and overturned sequences. Downward-pointing tadpoles indicate normal layering, upward-pointing tadpoles indicate overturned sequences (Figure 10). This approach allowed to identify additional structural features like faults, overturned sequences and horizontally folded formations.

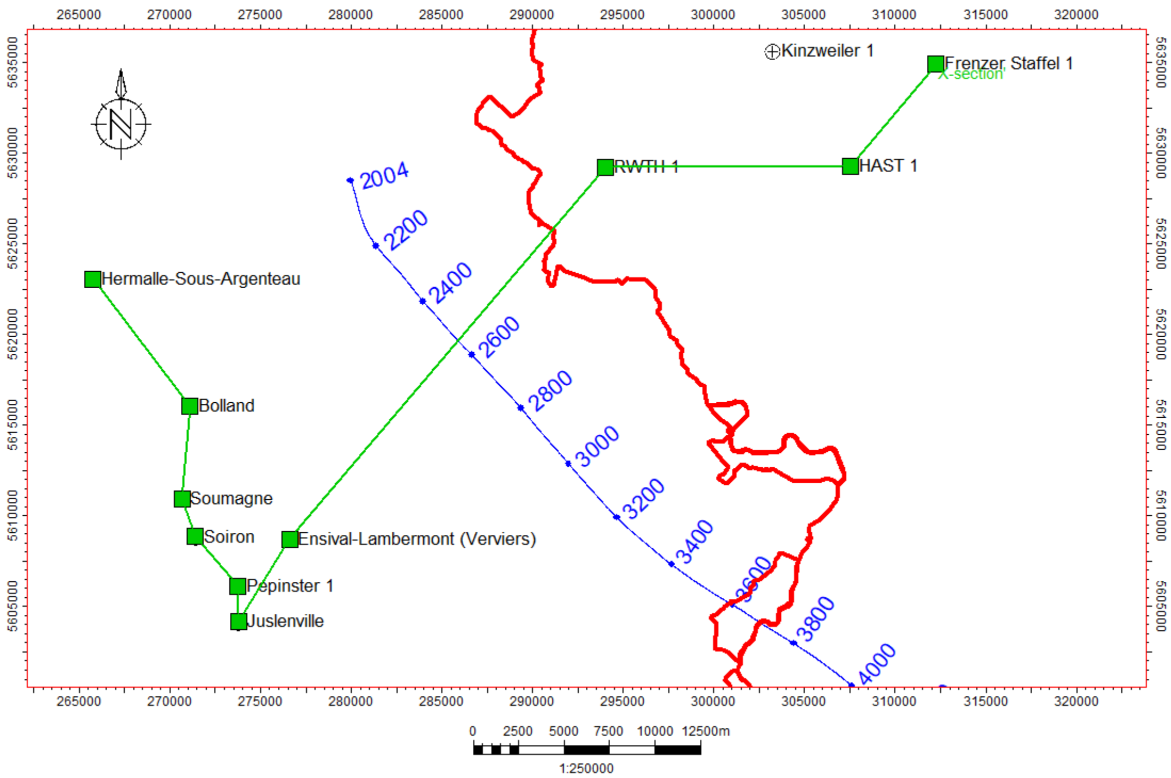

Figure 8: Close-up of the northwestern part of seismic line DEK87-1A (blue), borehole correlation section (green) and border of North Rhine-Westphalia (red).

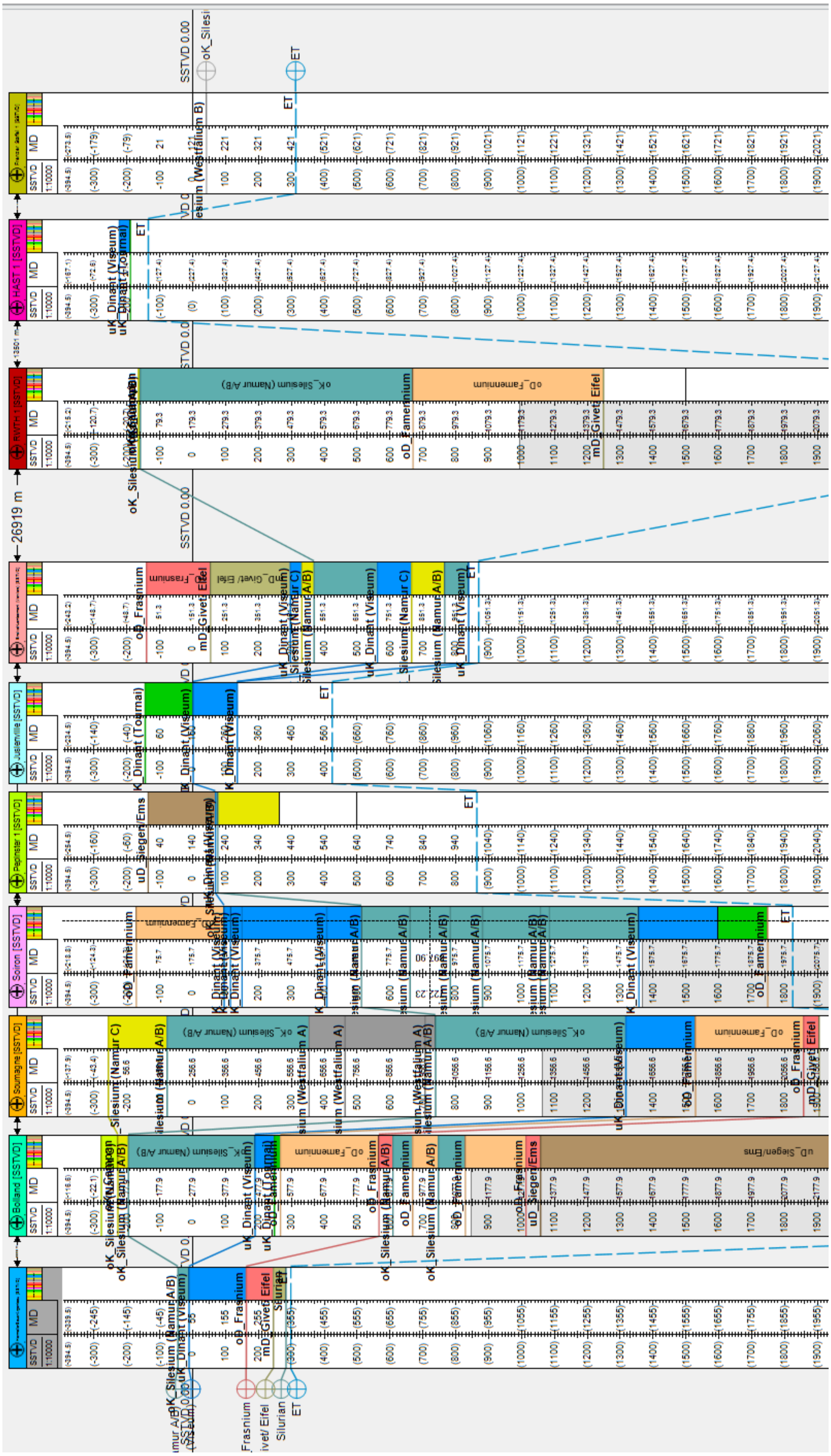

Figure 9: Borehole correlation section with relevant stratigraphic tops. See also Appendix 2.

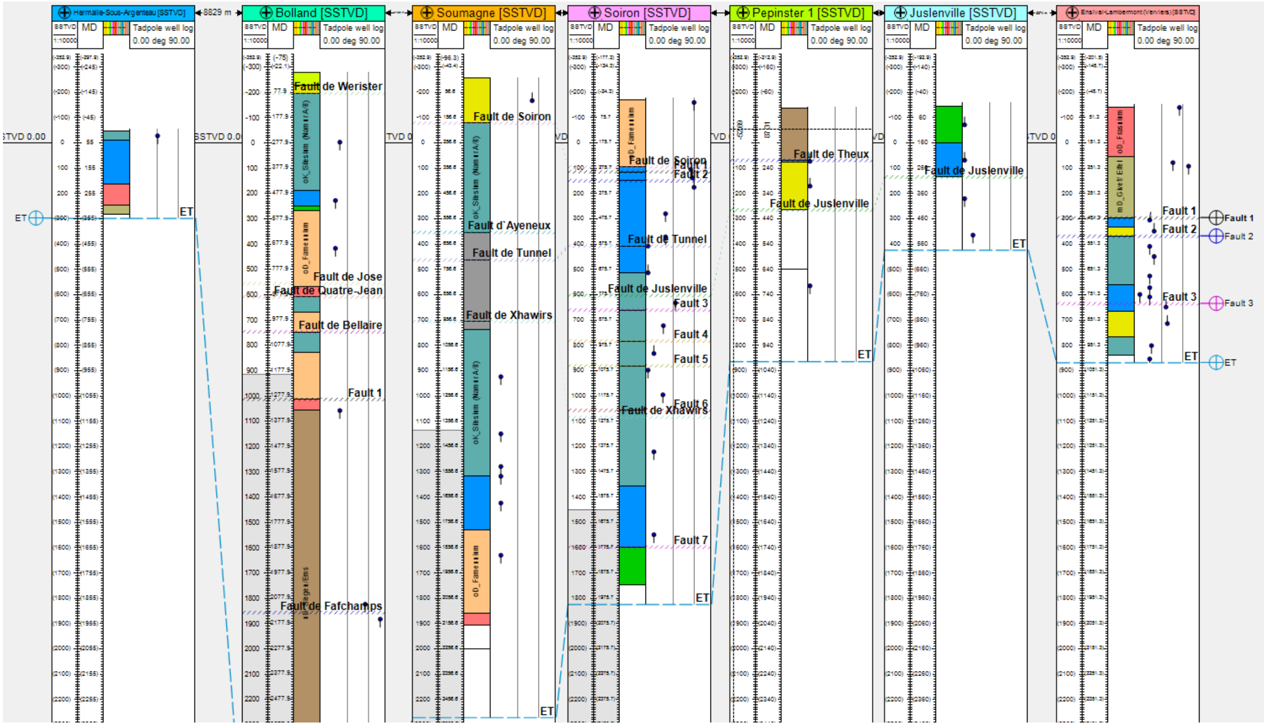

Figure 10: Borehole correlation section with faults and tadpoles indicating normal and overturned sequences (downward-pointing tadpole: normal layering, upward-pointing tadpole: overturned sequence).

The stratigraphic column in Figure 11 shows the location of several possible décollements after Hance et al. (1999). The most relevant of them for the interpretation are:

- the décollement in the Namurian on top of the Dinantian carbonates
- the décollement below the Frasnian-Givetian carbonates
- the deepest décollement below the Lochkovian quartzites (below the 'Bois d'Ausse' formation)

Almost all thrust structures in the seismic line DEK87-1A correspond to these décollements.

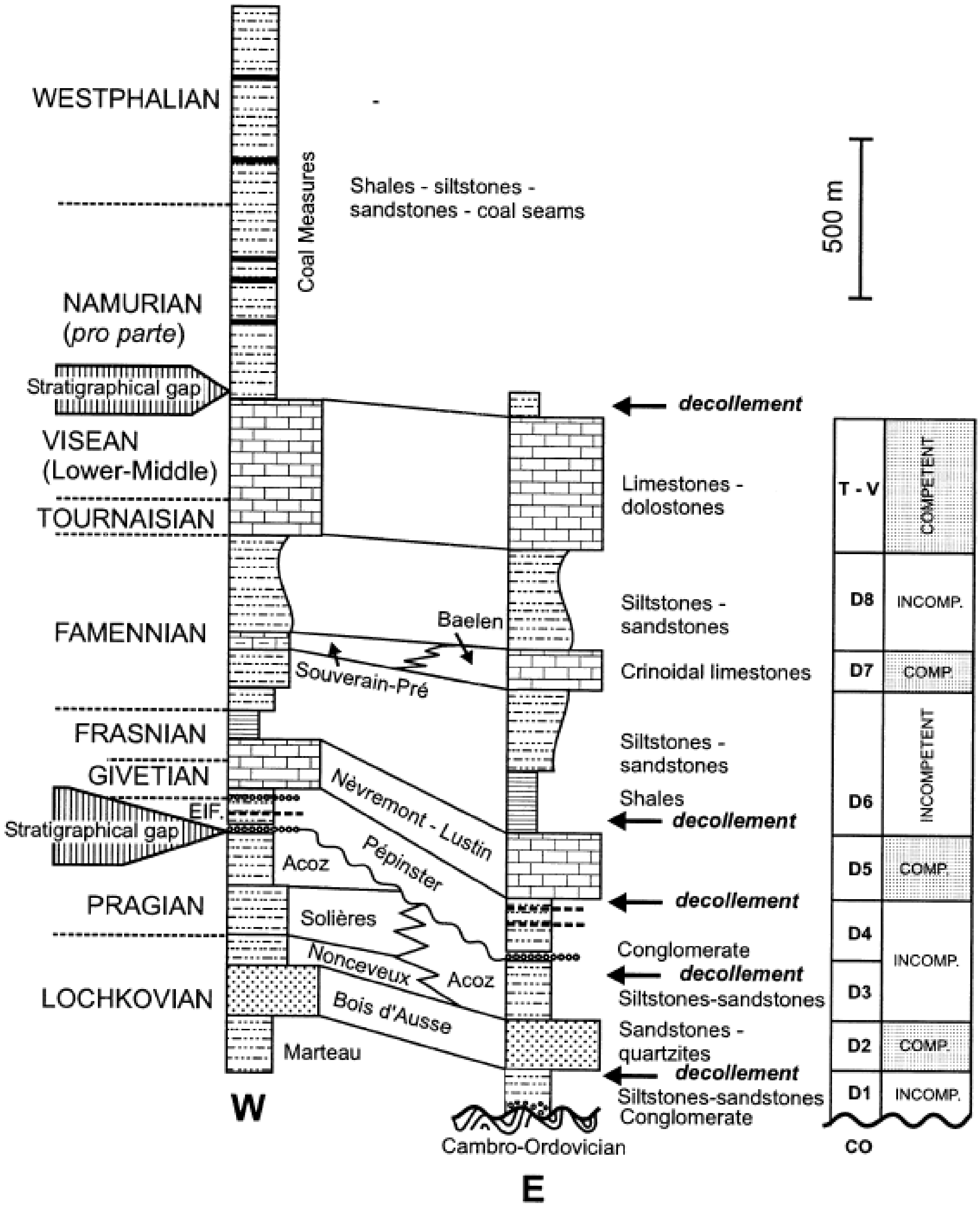

Figure 11: Lithostratigraphic columns of northeastern Belgium showing the main competent units and décollement levels (Hance et al. 1999).

2.4 Interpretation problems and limitations

Typical interpretation problems like noise, multiples, fault shadows, and surface and topography influences were identified. Additionally, the seismic line DEK87-1A is only suitable to a limited extent for the interpretation and mapping of shallow targets because of its original acquisition design, which was intended to image very deep crustal structures. Due to the absence of formation tops in shallower depths along the section, the geological maps were used for the interpretation. This approach, however, does not allow an accurate assignment of formation extensions to depth.

2.5 Seismic attribute analysis

Several seismic attributes have been generated and used for the interpretation to improve the visibility and understanding of the data. For more information, the reader is referred to Marfurt & Chopra (2006) and Chopra & Marfurt (2007). The following attributes were generated:

- Apparent polarity
- Local structural azimuth with different options
- Chaos with different options
- Cosine of phase
- Local structural dip with different options
- Dominant frequency
- Envelope with different options
- Local flatness with different options
- Generalized spectral decomposition
- Instantaneous frequency
- Instantaneous phase
- Instantaneous quality
- Original amplitude
- Reflection intensity
- Relative acoustic impedance
- RMS amplitude with different options
- Structural smoothing
- Sweetness
- Variance with different methods
- Second derivative

Among these attributes, the following were the most useful for interpretating the seismic line DEK87-1A:

- **RMS amplitude:** may directly map certain geologic features which are isolated from background features by amplitude response; it was used to distinguish the carbonates from background formations and the old Cambrian formations from the overlying Palaeozoic formations
- **Chaos**: by using this attribute, regions with low consistency typically correspond to regions with chaotic signal patterns and can be related to local geological features (e.g. faults/discontinuities, reef textures, channel infill, etc.); it was used to identify faults and locally undisturbed areas, like limestone blocks
- **Envelope**: this attribute is of importance for detecting major lithological changes that are caused by strong energy reflections and sequence boundaries; it clearly shows subtle lithological changes that may not be apparent on the seismic data and was useful to distinguish carbonates and quartzites from background formations
- **Local structural azimuth**: although this attribute has to be used very carefully on 2D seismic lines, it indicates the different projected compass directions and enhances distinguishing and visualizing tectonic structures
- **Local structural dip:** this attribute shows the angle of inclination of the seismic event as measured from a horizontal plane; it should be used very carefully on 2D seismic lines and was used to visualize complex tectonic features like duplex structures or flower structures
- **Second derivative**: the second derivative of the input seismic volume can be used to guide the picking by providing continuity in areas where reflections are poorly resolved on the raw amplitude; it was used to improve the visibility in poorly resolved areas

2.6 Geometric structural modelling

In order to explain the geometry of some structural features that are clearly visible on the seismic line DEK87-1A, the development of certain single thrusts had to be evaluated. Therefore, GSB developed and programmed a series of possible geometric structural models.

The geometric structural features are described below. The main focus of geometric modelling was concentrated on the northwestern and middle parts of the seismic line, below and northwest of the Eupen Thrust.

In-sequence thrusting in the northwestern part of the seismic line

A typical feature of in-sequence thrusting is a duplex structure. It develops in sedimentary successions when competent sedimentary layers (e.g. sandstone or carbonates) are separated by an incompetent layer (e.g. shales). With increasing tectonic shortening, the latter becomes a décollement on which the more competent sedimentary succession is pushed upwards and stacked upon itself several times forming a typical imbrication pattern (Figure 12). During in-sequence thrusting, the oldest horse is typically located more in the hinterland (to right in Figure 12), while the foreland (left) hosts the youngest horse.

This feature can be clearly recognized in the northwestern part of the seismic line DEK87-1A with décollements located between Devonian carbonates ('Massenkalk' or 'Lustin' formation) and Lochkovian sandstones and quartzites ('Bois d'Ausse' formation) (Figure 13).

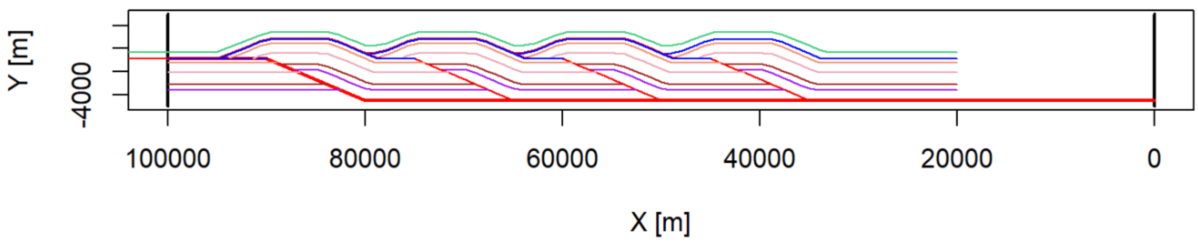

Figure 12: Model of a duplex structure with a typical imbrication pattern. This model includes four horses.

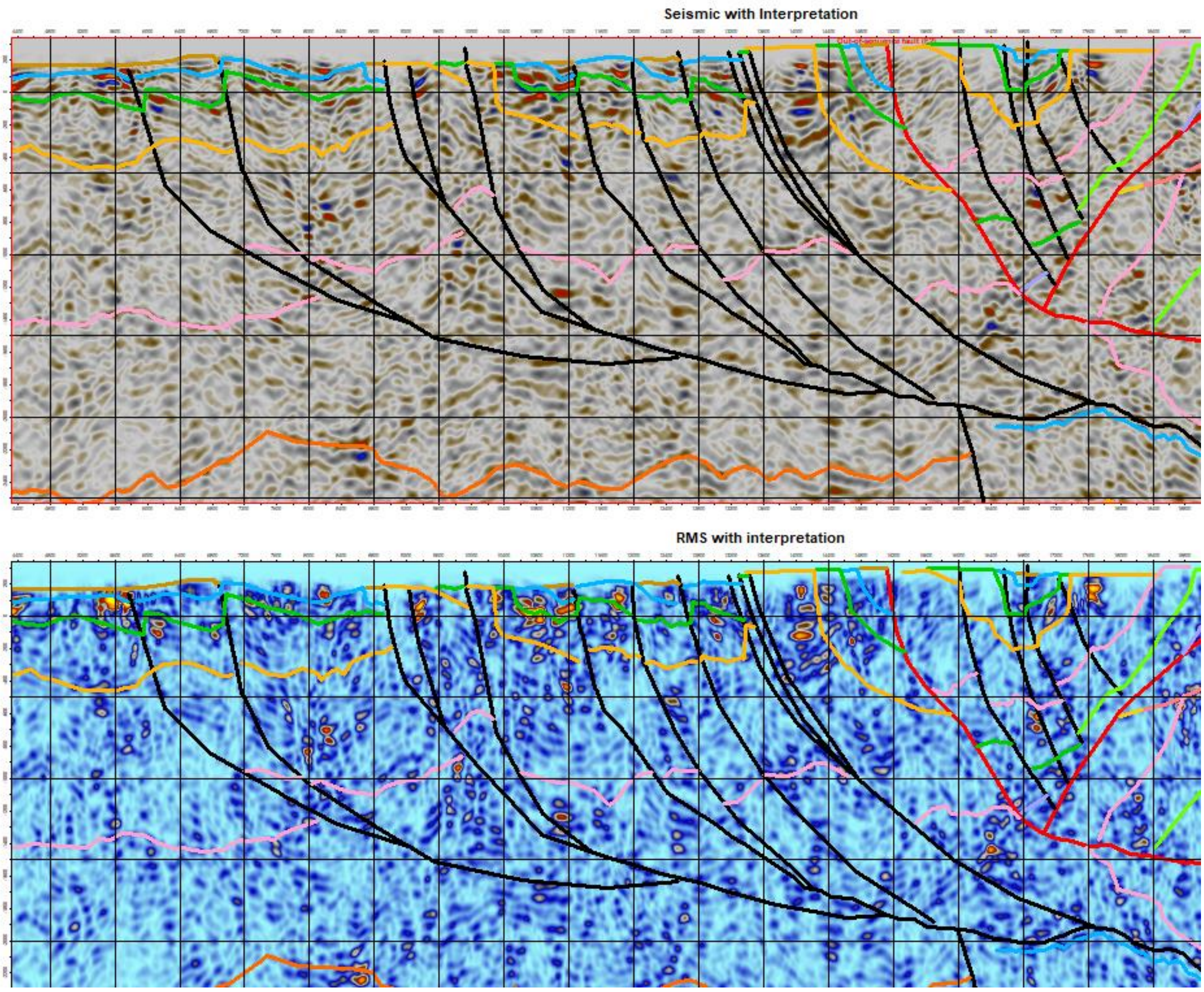

Figure 13: Northwestern part of the seismic line DEK87-1A showing imbrication patterns of in-sequence thrusting. See Table 1 for color legend.

Out-of-sequence thrusting in the middle part of the seismic line

Out-of-sequence thrusts typically occur as isolated faults or a sequence of faults that truncate existing fault and fold structures. They can be newly formed or reactivate older in-sequence thrusts, which can be discriminated by footwall observations (Hance et al. 1999). The modelling of out-of-sequence thrusting was performed in two approaches: (1) a simple out-of-sequence thrusting and (2) an out-of-sequence thrusting with a shear zone. Both models are shown in Figures 14 and 15, respectively. Elements of both models were also identified on the seismic line. Especially the middle part, below the Eupen Thrust, is extremely complex and has been interpreted as a stack of imbricated, partially tilted thrust sheets piled on top of each other (Figure 16). Due to the tectonic complexity and poor seismic quality, the exact fit between geometric modelling and interpretation was not completely possible. However, the modelling results have been successfully used to explain these structural features. The following figures represent a simple out-of-sequence thrusting with a shear zone and the corresponding part of the seismic line. The stacking thrust with tilted layers can be clearly correlated with different local décollements.

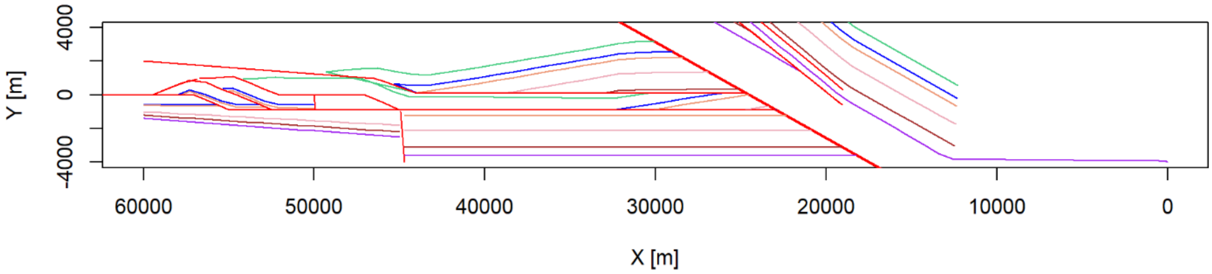

Figure 14: Structural modelling of simple out-of-sequence thrusting. The equivalent of the Eupen Thrust is located between position 18000 and 32000.

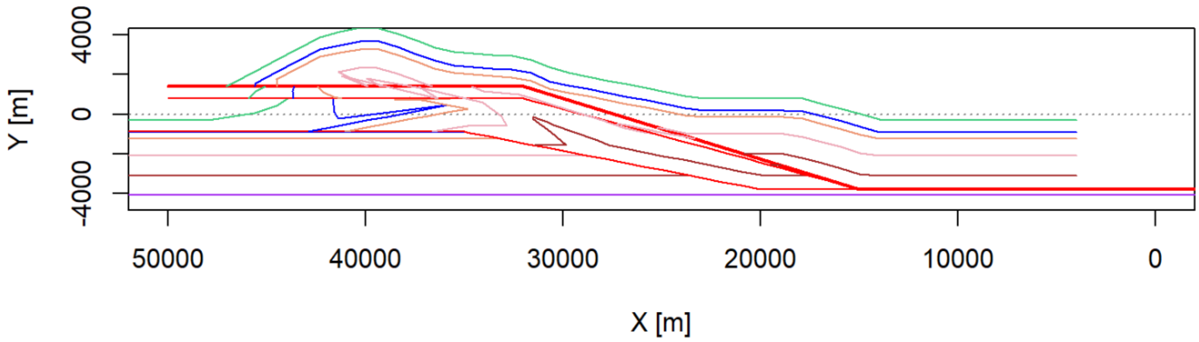

Figure 15: Structural modelling of out-of-sequence thrusting with a shear zone.

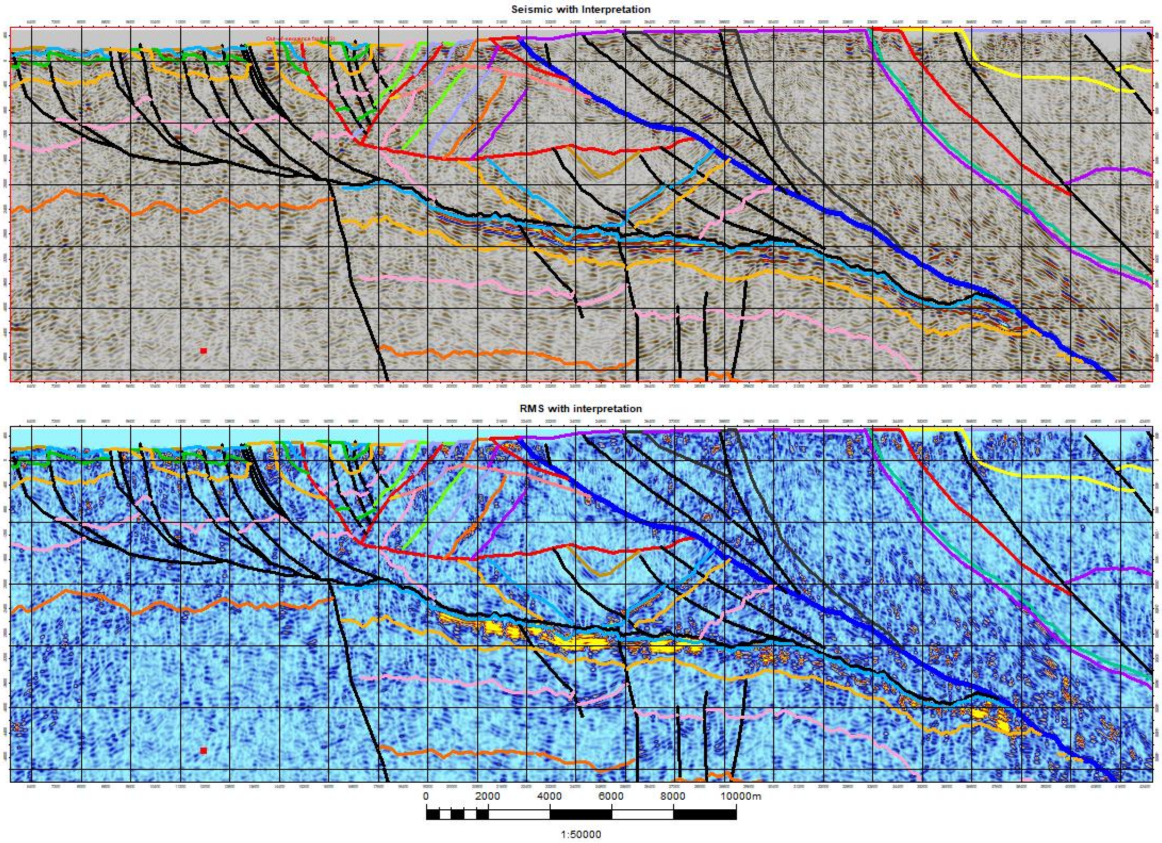

Figure 16: Middle section of the seismic line DEK87-1A with out-of-sequence thrusting (in red) below the Eupen Thrust (in dark blue).

Flower structure in the southeastern part of the seismic line

The transition zone between the Cambro-Ordovician succession of the Stavelot-Venn Massif and the Lower Devonian strata in the southeast is characterized by a diagenetic to low-grade metamorphic overprint, referred to as the Monschau shear zone (Fielitz 1992). The Lower Devonian strata following on top of the Stavelot-Venn Massif generally dip in a southeastern direction. They are disrupted by numerous faults first dipping southeast until km 68.5, and then dipping northwest until km 92 (Figure 17). In our interpretation, the series of faults has been interpreted as a large flower structure indicating a strike-slip movement. The reversal point is located at the border between the German federal states of North Rhine-Westphalia and Rhineland- Palatinate, near Blankenheim.

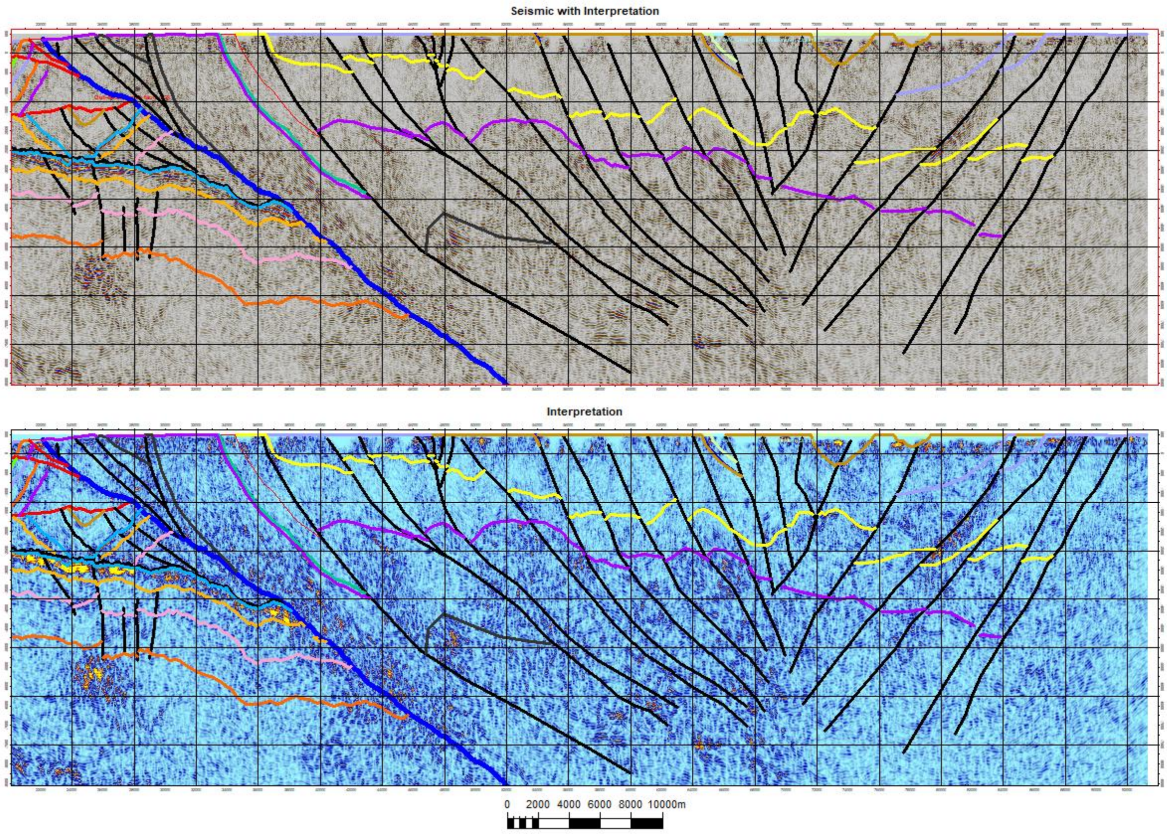

Figure 17: Southeastern section of the seismic line DEK87-1A with a large flower structure.

2.7 Seismic imaging of carbonates

Carbonates and anhydrites are supposed to have the highest impedance and likely show some areas with high amplitudes in the seismic image. Since anhydrites are not expected in the study area, the areas with prominent reflectors and high amplitudes are considered as carbonate formations. This assumption is supported by additional indirect carbonate indicators. Reef carbonates, for instance, typically show high impedances and high velocities (Figure 18). A characteristic feature is a strong reflection or a series of strong reflections at the top followed by a series of weak reflections (or even a transparent zone) below. The internal structures of carbonate formations may show cycles of progradation, retrogradation and aggradation. Other indirect indicators for carbonate formations are, for instance, prograding clinoforms, raised rims, low-stand build-ups and internal reflection architectures, such as back stepping, erosional truncations, canyon cuts, fill geometries, karst sinkholes and sub-horizontal layering.

Other geological settings may produce similar seismic images: water-filled carbonates, for instance, often indicate higher velocities or densities, and compacted sediments of old cratons generally show high impedances due high densities; interbedding with siliciclastics may also generate strong multiple reflections. Therefore, it is also important to include the indirect indicators into the interpretation.

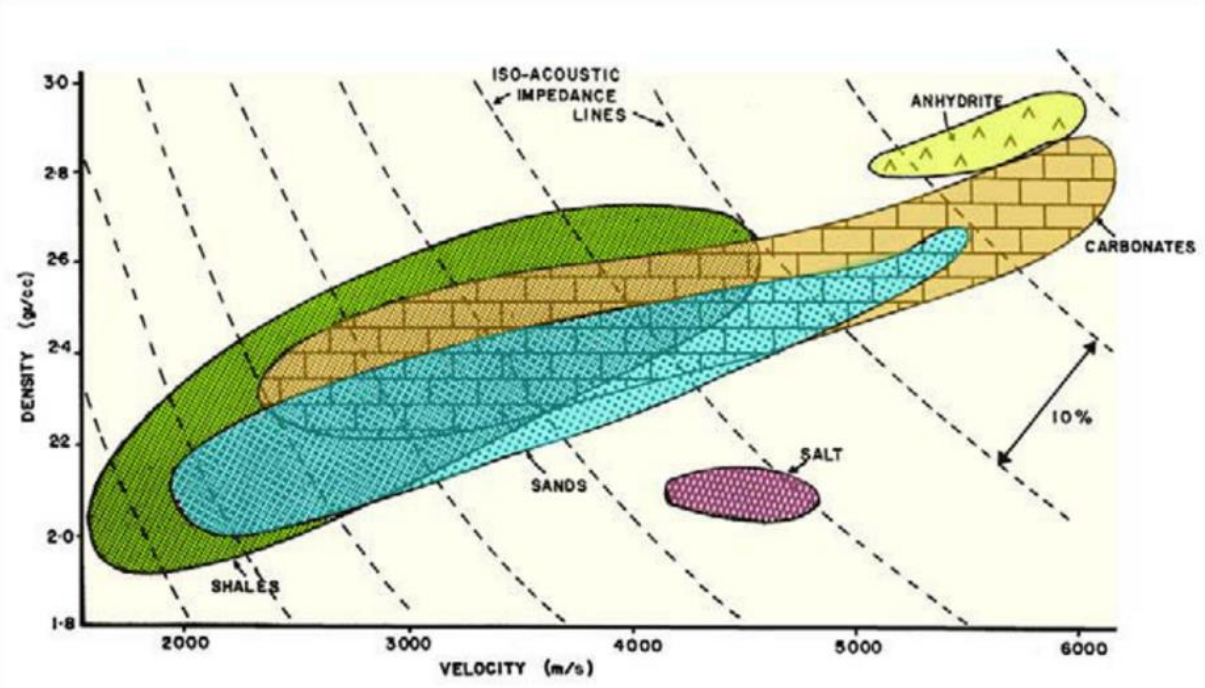

Figure 18: Interval velocity / density cross plot for different sedimentary rocks (Veeken 2007).

Some of the above-mentioned features, such as a series of strong reflections followed by a series of weak reflections below, prograding clinoforms, and karst sinkholes have been identified in the seismic line DEK87-1A, particularly in a prominent reflector below the Stavelot-Venn Massif. All of these features are indicative for carbonates, which have been interpreted as the top of the Dinantian carbonates (Figures 19 and 20). This southeast-dipping sub-horizontal reflector can be traced very clearly between km 19.4 and 38.4 in depths from 2,500 to 4,000 m. It was detected earlier by the DEKORP Research Group, who interpreted it as the detachment (décollement) of the Aachen Thrust (Anderle et al. 1991). In our interpretation, the Aachen Thrust is located directly on top of these carbonates using the Lower Namurian shales as décollement.

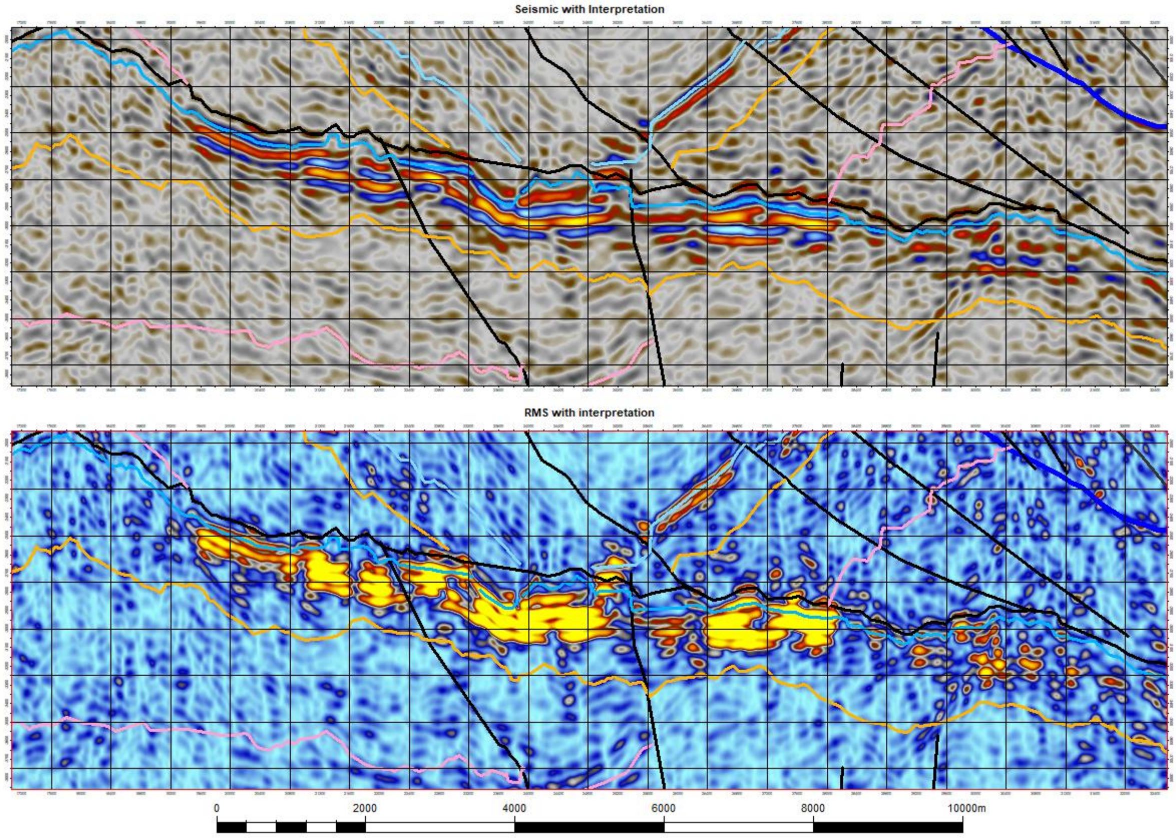

Figure 19: Close-up of a prominent reflector below the Stavelot-Venn Massif: the interpreted top of the Dinantian carbonates (light blue line) lies below the Aachen Thrust (black) and is marked by a series of strong reflections highlighted by the RMS attribute (vertical exaggeration: 2).

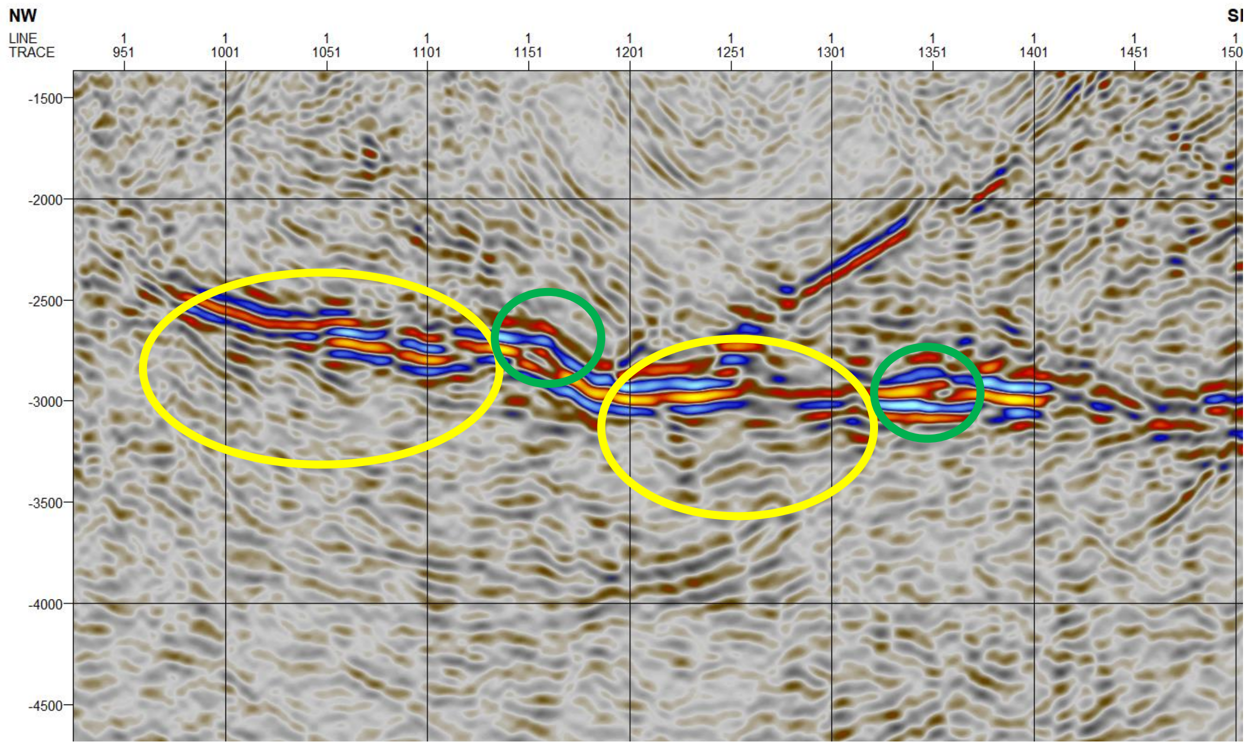

Figure 20: Typical carbonate features of the prominent reflector below the Stavelot-Venn Massif: prograding clinoforms with toplaps (in yellow circles) and karst sinkholes with chaotic features (in green circles).

3. Interpretation

The prominent reflector of the Dinantian carbonates below the Stavelot-Venn Massif could be followed with some certainty during the picking process, based on the indicators for carbonate formations (chapter 2.7). Depending on the lateral and vertical inconsistency of the Dinantian top reflector and its overlying sediments, it was not possible to stick to a typical picking interpretation on maximum/minimum amplitude of one single reflector.

The underlying formations were interpreted according to the trend of reflector inclination, the seismic reflection pattern and in consideration of the formation thicknesses. The formations from the geological maps were extended into depth following the trend of reflector inclination and general structural settings.

Due to the complex tectonic setting, the development of a geometric structural model was of crucial importance for the interpretation of the seismic line. The mapping of faults was supported by the application of the attributes ‘chaos’, ‘local structural azimuth’ and ‘local structural dip’ (Figures 21 and 22, chapter 2.5). Major regional faults could be tracked from the geological maps into depth (e.g. the Eupen Thrust); a similar approach was used for most of the faults in the flower structure in the southeastern part of the seismic line. In contrast to that, some other regional thrust faults (e.g. the Theux-Tunnel Fault) were interpreted based on the geometric structural model (see chapter 2.6). The interpreted features are typical of a compressional tectonic regime with fault-bend folds, fault propagation folds, duplex development, in-sequence thrusting, out-of-sequence trusting, back thrusting and flower structure development. The interpreted horizons are summarized in Table 1.

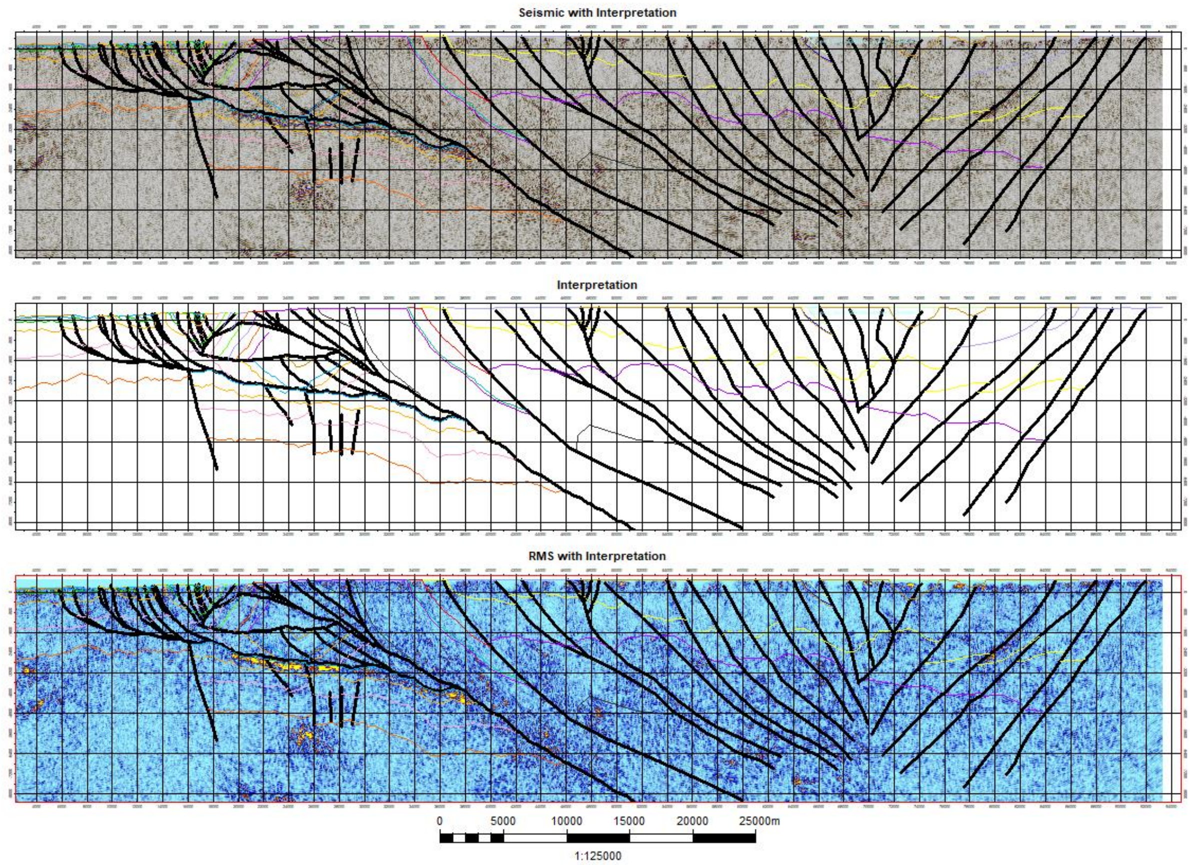

Figure 21: Final interpretation results of the seismic line DEK87-1A (seismic and RMS attribute): faults are depicted as bold black lines. See also Appendix 3.

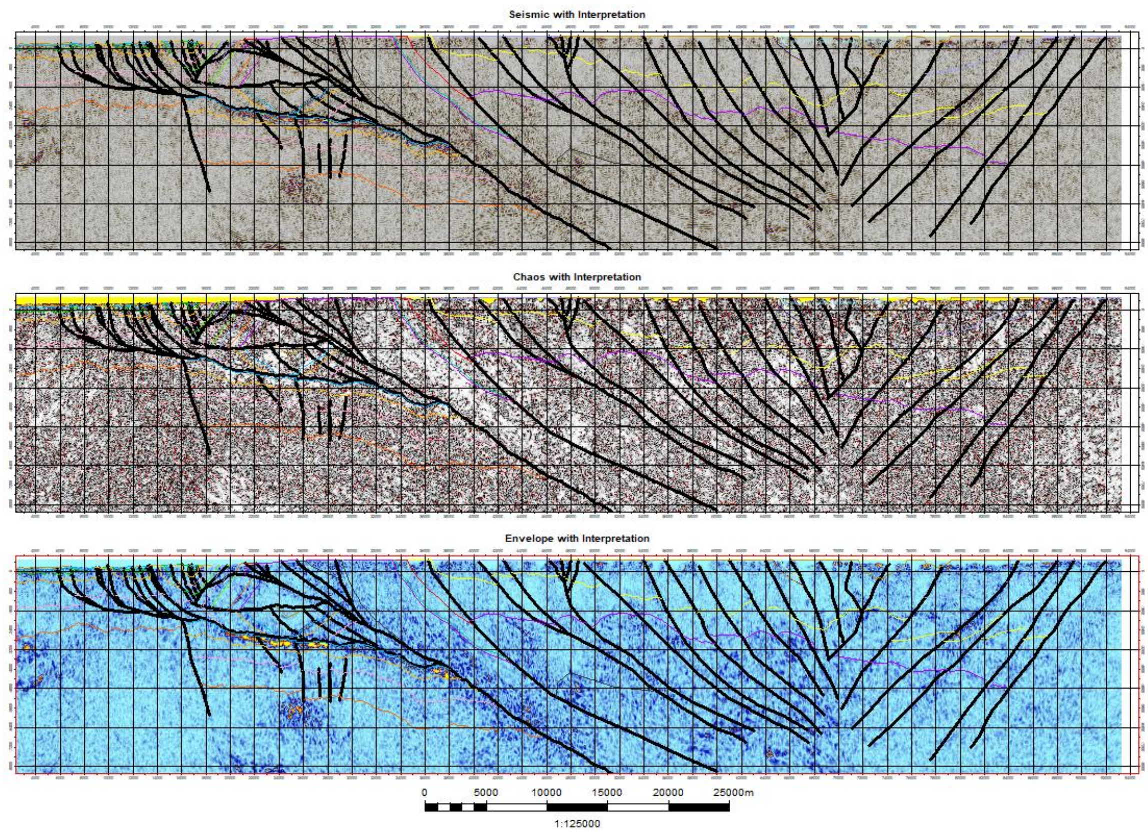

Figure 22: Final interpretation results of the seismic line DEK87-1A (seismic, chaos and envelope attributes): faults are depicted as bold black lines. See also Appendix 4.

Table 1: Color legend of the interpreted horizons of the seismic line DEK87-1A.

Interpreted Horizons

- uD_UnterEms (emS_emK_emG) 01: Dekorp_GD-NRW_Attributes
- uD_Ems_Siegen (eme): Dekorp_GD-NRW_Attributes
- uD_Ems_Siegen 04: Dekorp_GD-NRW_Attributes
- uD_UnterEms (emS_emK_emG) 05: Dekorp_GD-NRW_Attributes
- uD_ds_Siegen (Bois d'Ausse) 01: Dekorp_GD-NRW_Attributes
- uD_dg_Gedinne (Marteau) 01: Dekorp_GD-NRW_Attributes
- uD_ds_Siegen (Bois d'Ausse) 04: Dekorp_GD-NRW_Attributes
- uD_ds_Siegen (Bois d'Ausse) 03: Dekorp_GD-NRW_Attributes
- uD_ds_Siegen (Bois d'Ausse) 02: Dekorp_GD-NRW_Attributes
- oKarb_cn_Top_Namur 01: Dekorp_GD-NRW_Attributes
- oKarb_cn_Top_Namur 02: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Dinant_(Viseum) 01: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Dinant_(Viseum) 02: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Dinant_(Viseum) 03: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Dinant_(Viseum) 04: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Tournais 01: Dekorp_GD-NRW_Attributes
- uKarb_cdk_Top_Tournais 02: Dekorp_GD-NRW_Attributes
- oD_fa_Famennium 01: Dekorp_GD-NRW_Attributes
- oD_fa_Famennium 02: Dekorp_GD-NRW_Attributes
- oD_fa_Famennium 03: Dekorp_GD-NRW_Attributes
- oD_fa_Famennium 04: Dekorp_GD-NRW_Attributes
- oD_frk_Massenkalk (Frasnium) 01: Dekorp_GD-NRW_Attributes
- oD_frk_Massenkalk (Frasnium) 02: Dekorp_GD-NRW_Attributes
- oD_frk_Massenkalk (Frasnium) 03: Dekorp_GD-NRW_Attributes
- oD_frk_Massenkalk (Frasnium) 04: Dekorp_GD-NRW_Attributes
- oD_frk_Massenkalk (Frasnium) 05: Dekorp_GD-NRW_Attributes
- mD_evd_Givet_Eifel (Muldenkern_Dolomit) 01: Dekorp_GD-NRW_Attributes
- mD_evf_Eifel (Friesenrath-Sch Vicht Konglomerat) 01: Dekorp_GD-NRW_Attributes
- mD_evf_Eifel (Friesenrath-Sch Vicht Konglomerat) 02: Dekorp_GD-NRW_Attributes
- mD_evf_Eifel (Friesenrath-Sch Vicht Konglomerat) 03: Dekorp_GD-NRW_Attributes
- mD_Eifel_01: Dekorp_GD-NRW_Attributes
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- cbR3_Kambrium 01: Dekorp_GD-NRW_Attributes
- cbR3_Kambrium 02: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 01: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 02: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 03: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 04: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 05: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 06: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 07: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 08: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 09: Dekorp_GD-NRW_Attributes
- cbR4_Kambrium 10: Dekorp_GD-NRW_Attributes

4. Discussion

The investigated area has undergone a complex tectonic history, which includes at least two orogenic cycles: the Caledonian Orogeny that formed the Brabant Massif as a widespread basement and the Variscan Orogeny that caused complex in-sequence and out-of-sequence deformation structures. Reactivated deformations in the adjacent Lower Rhine Embayment of North Rhine-Westphalia and in the Eifel North-South Zone of Rhineland-Palatinate further shaped the region in post-Variscan times.

Many other studies and seismic surveys have been carried out, for instance, in northern France, western Germany and in the western, southern, and eastern parts of Belgium (Anderle et al. 1991, Hance et al. 1999, and references therein). Despite these seismic surveys and many studies, the interpretations diverge widely between the authors.

There are striking similarities between eastern Belgium, central Belgium and northern France indicating a major thrust (the Midi Fault) that has transported the Devono-Carboniferous succession onto the Brabant Massif during the Variscan Orogeny (Hance et al. 1999). The displacement along this overthrust reaches about 100 km in northern France (Anderle et al. 1991). Considering the prominent reflector of the seismic line DEK87-1A, a similar transport length could be assumed for the Devono-Carboniferous succession in the investigated area. It is tempting to assume that these carbonate deposits extend over the entire length of the Variscan thrust zone. The reflector is, for instance, also known from seismic surveys on the German side (Meissner et al. 1981, Durst 1985), where the reflection has also been interpreted as the Aachen Thrust, as was the case for the initial interpretation of the DEKORP Research Group (Anderle et al. 1991). However, this need not be the case everywhere. Recent results from the GEOCOND2022 seismic reflection survey in the framework of the DGE-ROLLOUT project in the central part of Wallonia have well imaged the Midi Thrust. However, in this case the presence of Dinantian limestone under this fault seems to be restricted to a narrow zone to the north. Such results should encourage to limit the extrapolations of 2D seismic lines to restricted lateral extensions. The results of one seismic line cannot simply be transposed to another. Therefore, thorough preliminary examinations and targeted exploration are imperative in the search for a deep geothermal carbonate reservoir. The involvement of surface geology is essential for good seismic interpretation.

5. Conclusion

The seismic line DEK87-1A was reprocessed and intensively re-interpreted based on surface geology, various attributes and geometric structural modelling. Due to poor seismic data quality the final interpretation was mainly carried out because of a conceptual approach. Different scenarios were considered with several iterations and intensive exchanges between the geological surveys of Belgium and North Rhine-Westphalia.

Previous interpretation scenarios (all are very different!) were also considered, but the interpretation is still fraught with uncertainties. However, thanks to the application of a variety of attributes, it was possible to locate the Dinantian carbonates in the seismic line making them a suitable target for deep geothermal exploitation. The actual potential of this possible reservoir may only be estimated by further exploration.

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Appendix 2 – Borehole correlation section DEK87-1A

Appendix 3 – Interpretation DEK87-1A (RMS)

Appendix 4 – Interpretation DEK87-1A (chaos, envelope)

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