# UPDATED TRANSNATIONAL HARMONIZED DEPTH AND THICKNESS MAP OF THE DINANTIAN IN NORTH-WEST EUROPE

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Date: 23 August 2023 (final version)

This report (D.T1.1.5) summarizes unpublished sub-deliverables of work package T1 (Mapping and Networking) of Interreg project DGE-ROLLOUT:

D.T1.1.1: Depth and thickness map of deep geothermal limestone reservoir in northern zone (BE: Flanders; DE: Lower Rhine, Ruhr Area; FR: Hauts-de-France; NL: Limburg, North Brabant, Gelderland).

D.T1.1.2: Depth and thickness map of deep geothermal limestone reservoir in southern zone (BE: Wallonia; BE/DE/NL: Euregio Rhine-Maas).

D.T1.1.3: Depth and thickness map of deep geothermal reservoir in Northern Upper Rhine Graben (DE: Darmstadt, Karlsruhe, Rheinhessen-Pfalz; FR: Alsace).

D.T1.1.4: Transnational harmonized depth and thickness map of deep geothermal potential in North-West Europe

## Content

## Summary

This report describes the construction of depth and thickness maps of the Dinantian limestones of lower Carboniferous age in the Netherlands, Belgium, North Rhine-Westphalia (Germany) and Hauts-de-France (France).

First an un-harmonized version of the maps was prepared by stitching together pre-existing national grids. This approach revealed multiple trans-border errors which were evaluated and finally solved during various workshops and discussions. Insights gained during the workshops and the interpretation of newly acquired seismic lines and well data made available during the project, the first versions of the maps were then significantly improved.

The result is a set of maps of the top depth and thickness of limestones of Dinantian age in the Interreg North-West Europe region. Although the maps show important improvements of previous maps, large uncertainties about the depth and especially the thickness of the reservoir still exist due to the limited availability and quality of the data in some areas of the study area.

## Introduction

Carbonate rocks dating from the Dinantian (Early Carboniferous) in the Interreg North-West Europe (NEW) region are known to have potential for geothermal energy production. Doublets in this area were drilled in Californië (Netherlands) and Mol (Belgium). Due to its deep burial at many locations, its geothermal potential, defined by factors as depth, thickness, temperature, porosity, permeability and rock type, is largely unknown. Various maps showing the depth of the top of the aquifer exist for all countries in the Interreg NWE region. However, they are often outdated or incomplete, and cross border inaccuracies and uncertainties are abundant.

In DGE-ROLLOUT, one of the goals was to update and extend the maps where they are incomplete or outdated, either by re-interpreting existing data or by new data acquisition, and to minimize cross border inaccuracies. Apart from constructing a top depth map of the Dinantian in the Interreg NWE region, the thickness of the Dinantian were mapped where possible.

The following sections briefly describe the mapping activities carried out in the partner countries. Appendices 1 and 2 show the resulting maps of the depth of the top and the thickness of the Dinantian. The map shown in Appendix 3 explains which areas were mapped, where the Dinantian was found to be present / absent due to erosion or non-deposition, etc.

## The Netherlands (compiled by TNO)

The 2019 mapping of the Dinantian limestone in the Netherlands consisted of an inventory, QC and existing interpretations and maps (in TWT) of the top and base of the Dinantian, (expected) intra-Dinantian boundaries (e.g. member level, platform-slope-basin boundaries), based on available 2D and 3D seismic and well data (Figure 1). This information was subsequently used to improve and refine the existing seismic interpretation of horizons and faults that resulted in a better perception on the lateral distribution of rocks of Dinantian age. The seismic interpretation also included mapping of deeper basement faults that may have determined the platform initiation and growth as well as faults that are considered to define the current platform-slope-basin boundaries. The latter faults, which may be younger extensions of the basement faults, may have been active during the platform formation and may also play a role in post-depositional diagenesis. Therefore, they are important for the prediction and mapping of lateral facies and reservoir quality changes. As faults are often less visible in deeper seismic sections, gravimetry and (aero)magnetics data was used for giving constraints on the deep structure of sedimentary basins and the underlying crust where possible. A full description of the mapping and time-depth conversion using the 'Velmod' velocity model can be found in Ten Veen et al. (2019) and on the NLOG website[1].

The results of the seismic interpretations are grouped into two data sets of the top and base of the Dinantian carbonate sequence, respectively.

The seismic interpretation results where first converted to point data followed by a time-depth conversion using the V0-k method. This sequence of seismic-interpretation data treatment was chosen to make sure that data density in the depth domain remains equal to that in the time domain i.e., the interpolation procedure does not affect the intermediate time-depth conversion results. After obtaining the points in depth (time versus depth), surfaces where generated using the convergent gridding algorithm in Petrel subsurface software. The surfaces are tied to the respective data at well location, using a 3 km influence radius, to produce well-tied maps. Gridding was initially only performed within maximum distance limits of the interpretation. For this purpose, separate polygons were created for the top and base of the Dinantian. For modelling purposes, a full map was also created (Figure 2). It should be noted that this map contains considerable uncertainty where seismic data coverage is scarce (Figure 4).

The interpretation of the top Dinantian is challenging in many locations, often owing to the deep burial (Figure 2). The coverage of the base Dinantian interpretation is even smaller. This is not only due to the limited data quality at depth but is also because in large parts of the study area, the thickness of the Dinantian is thought to be below the limit of separability i.e., the top and base are represented by a single reflector. Therefore the thickness of the Dinantian at those locations is unknown – at best a rough estimate of perhaps several tens of meters may be given.

The thickness, obviously, can only be calculated where the base Dinantian was interpreted. Consequently, the thickness map has the same coverage as the one of the Base Dinantian. Additional polygons were constructed that are based on the experience of the seismic interpreter and serve to indicate data-poor areas or areas where the image of the Dinantian is poor. These polygons were only

[1]https://www.nlog.nl/en/scan-2d-seismic-interpretation-and-depth-conversion-dinantian
https://www.nlog.nl/en/velmod-31

created for the top Dinantian, but also apply to deeper levels, and were used to blank the maps inside the interpretation polygons.

During the execution of DGE-ROLLOUT, roughly over 50 2D seismic lines were shot within the framework of the 'SCAN Aardwarmte' project (www.scanaardwarmte.nl; Figure 4) with the intention of improving the knowledge of the subsurface in data sparse areas that are potentially interesting for geothermal exploration. The Dinantian could be interpreted on a number of those lines. In addition, the existing SCAN interpretation of the Dinantian was revised in several locations. The resulting new and updated interpretations were used to generate updates of the Dinantian top and thickness maps.

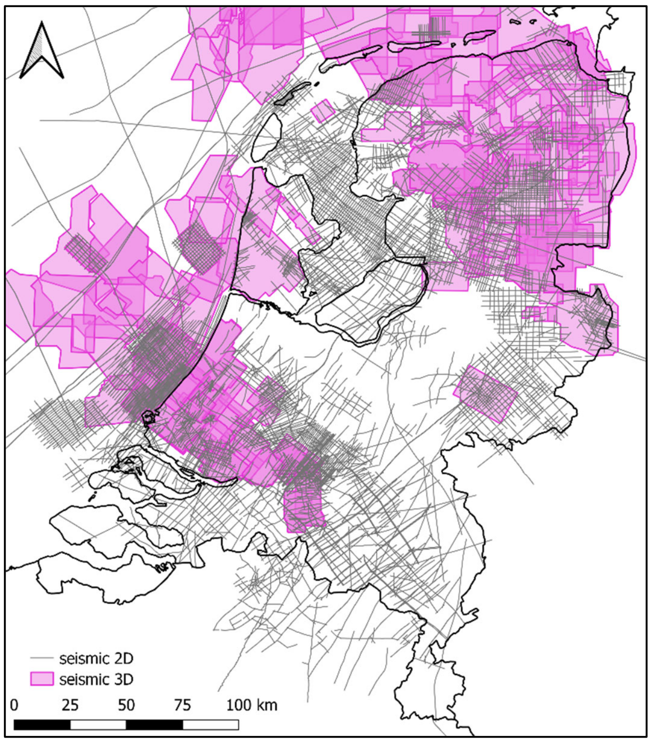


*Figure 1 Overview of all the available and consulted 2D (grey lines) and 3D (pink polygons) seismic data. Note that the Dinantian cannot be identified on all lines. Source: Ten Veen et al. (2019).*

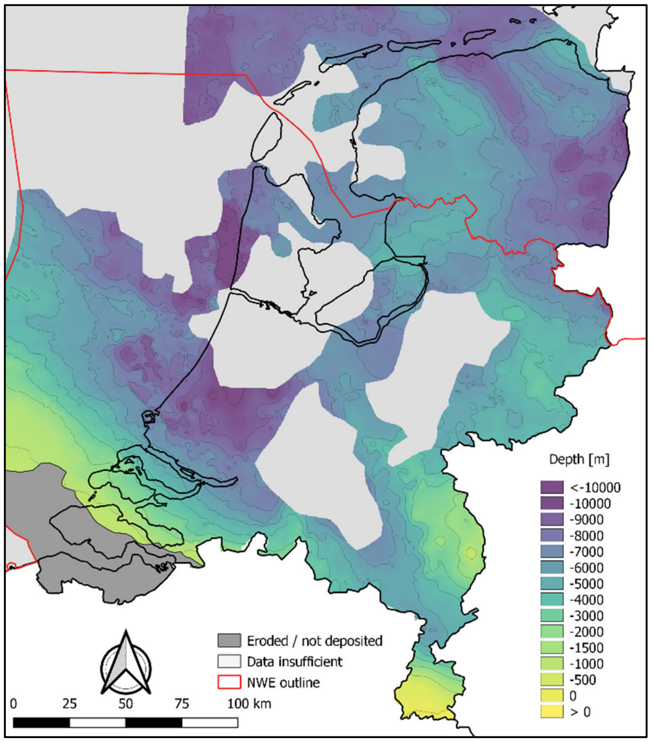


*Figure 2 SCAN (www.scanaardwarmte.nl) top depth of the Dinantian. Blanked areas have insufficient data for a reliable determination of the top depth. Modified after Ten Veen et al. (2019). For DGE-ROLLOUT, the onshore grey areas were interpolated.*

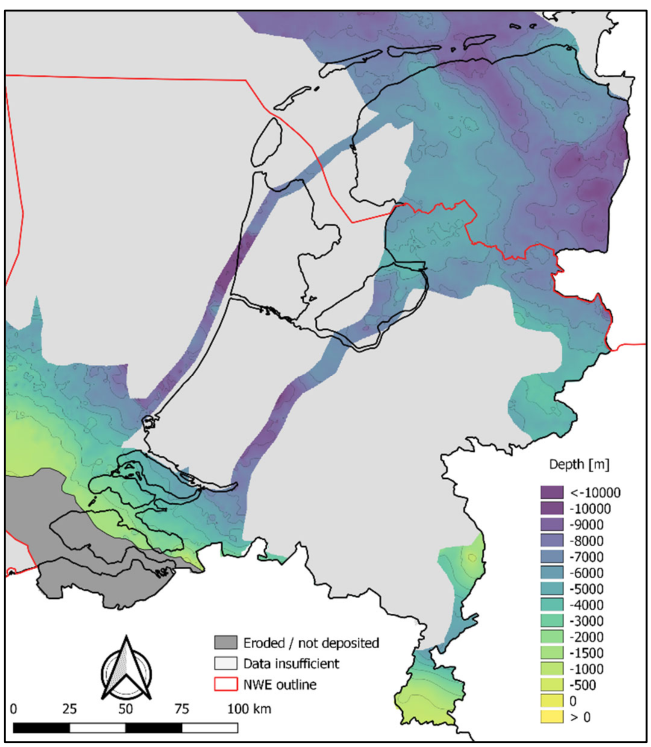


*Figure 3 Depth of the base of the Dinantian illustrating the limited control on the thickness. Modified after Ten Veen et al. (2019)*

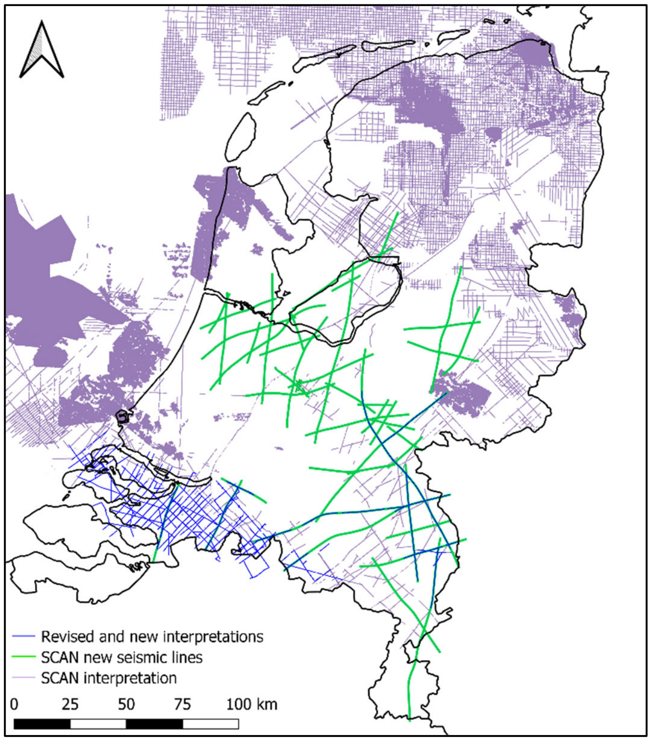


*Figure 4 SCAN Dinantian seismic interpretations, new SCAN seismic lines (www.scanaardwarmte.nl) and revised and new interpretations of the top Dinantian.*

## North Rhine-Westphalia (Germany, compiled by Geological Survey of North Rhine-Westphalia)

In the last decades, the Geological Survey of North Rhine-Westphalia (GD NRW) has created 3D models for the younger geological units reaching down to the Upper Carboniferous (Westphalian). Top and base of the Lower Carboniferous (Dinantian) have been constructed using the 3D-modelling software MOVE and SKUA/GOCAD. The construction was carried out in three steps:

1. Construction of the main faults
2. Construction of the Dinantian top
3. Construction of the Dinantian base.

Each of these work steps is described in detail in the following paragraphs.

### Construction of main faults

GD NRW already developed a GOCAD-based 3D model of the main faults, which is part of the "*Landesmodell*" that forms the base for the current constructions. All supra-regional faults, as well as some selected major regional faults, have been extended to a depth of 9,000 metres below sea-level [mNN]. After all extended faults had been created, they were cut along their intersection lines or extended towards their branched appendages, respectively. The faults of the Palaeozoic basement of the Ruhr Valley Graben were not included into the "*Landesmodell*". Therefore, these faults were additionally constructed by using the structural data of the KVB model ("***K**ohlen**v**orrats**b**erechnung*" = Coal Reserve Estimation); Figure 5).

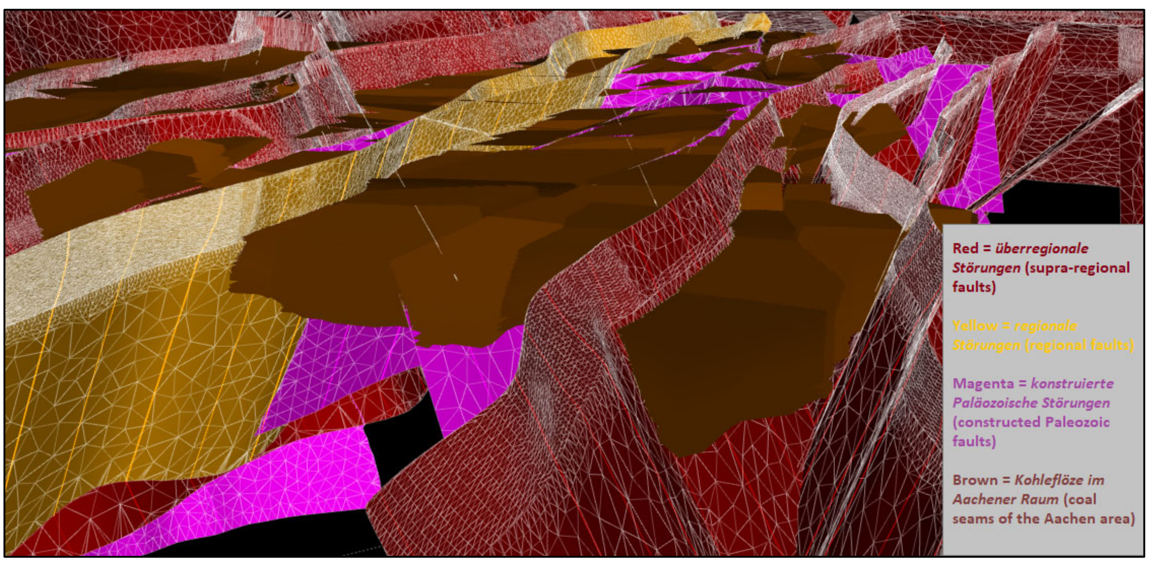


*Figure 5 The faults of the Palaeozoic basement in the Ruhr Valley Graben (illustrated in magenta) have been constructed using the structural information of the KVB model (illustrated in brown). The extended faults of the "Landesmodell" are coloured in red and yellow.*

### Construction of the Dinantian top

The Dinantian in North Rhine-Westphalia is mainly known from its outcrops in the Aachen region and along the northern edge of the Rhenish Massif on the eastern side of the river Rhine. In the subsurface to the north of these outcrops, only a few wells reach into the Dinantian (yellow symbols in Figure 6).

Seismic data were sparsely included due to the fact that limited digital information could be obtained from the archives, which are still in the process of digitisation. However, there has been a seismic survey, which specifically aimed to determine the location of the Dinantian top (red lines in Figure 6). Its depth was verified by the well Schwalmtal 1001.

Furthermore, important geological maps and cross sections have been digitised, georeferenced, and imported into the project. The outline of the Dinantian rocks has been digitised and projected onto the surface of the Palaeozoic top (light blue areas in Figure 6).

Besides this primary information, there are also regional 3D models of several areas in North Rhine-Westphalia, which had already been constructed. These include: the "*Informationssystem Tiefengeothermie*" (= Information System Deep Geothermal) for the Ruhr area, the DGE-ROLLOUT 3D subsurface model of the Weisweiler area, and the case study Kettwig. They mark important cornerstones that also provide useful structural information (green areas in Figure 6).

Another constituent to cover the remaining 'black spots' in the model, are the structural data contained in the KVB model. Some of the coal seams were used here as the equivalents of important marker horizons. Hence, these coal seams were used for the interpolation of the Dinantian top by using the marker horizons and an average thickness of the Namurian published by Drozdzewski (1992), (Figure 7).

All of the aforementioned data were used considering their quality and certainty following the order:

**wells > seismic lines > geological maps and sections > constructed 3D models > KVB model**

The 3D model for the Dinantian in the Netherlands has also been considered as a reference for the construction of the model surfaces. Finally, all these different constituents were connected, merged together, and cut at the contacts to the various fault surfaces.

Naturally, it has been necessary to use various sources of information for the construction of the Dinantian top in the subsurface. This implies that the completely merged surface of the Dinantian top is very heterogenic and thus contains various degrees of uncertainty.

This 3D model is, of course, preliminary. Much more data must be included in the future to improve its validity. Seismic data will be of specific interest in the next phase of the project in which the model will be adjusted and connected to its counterparts of the Netherlands and Belgium. Especially the DEKORP lines DEK-1A, DEK86-2N, and DEK86-2Q, which were obtained by the *GeoForschungsZentrum* (GFZ) in Potsdam, and which have been reprocessed recently by project partner DMT, will play a significant role in this process (Figure 8).

### Construction of the Dinantian base

The base of the Dinantian has been constructed using a hypothetical thickness map for the Dinantian, which is based on borehole data and the distribution of the Dinantian facies published in Arndt et al. (2020). To calculate the depth of the Dinantian base, the hypothetical thickness was subtracted from the constructed depth of the Dinantian top for each vertex point of the surface:

**depth base [mNN] = depth top [mNN] – hypothetical thickness [m]**

This work step was performed with SKUA/GOCAD, unlike the previous work steps, which were performed with MOVE.

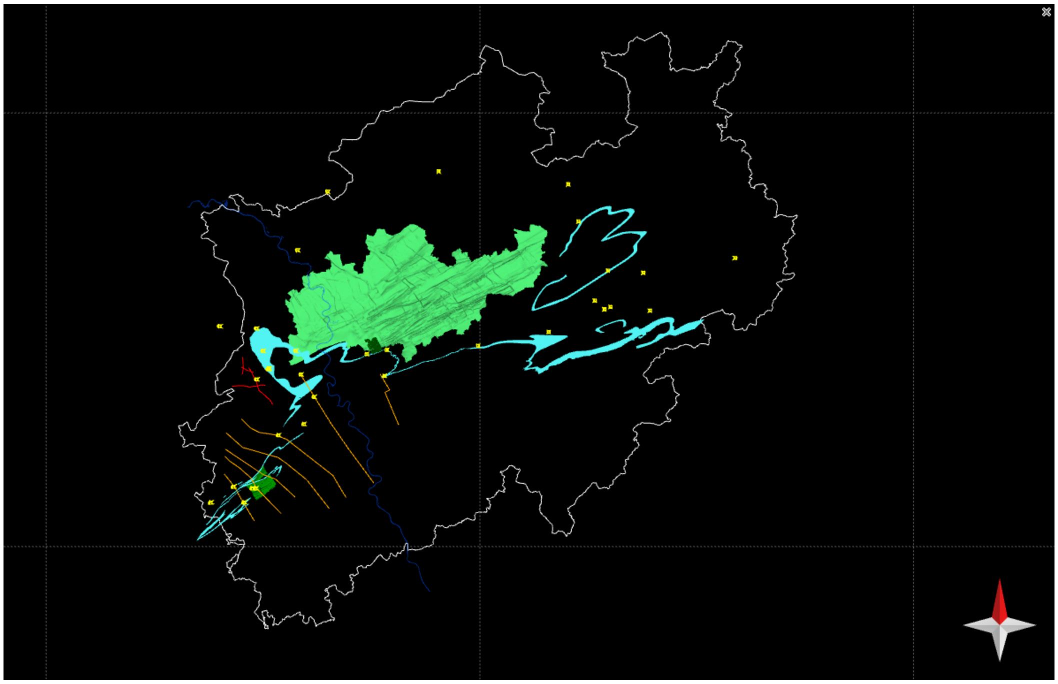

*Figure 6:* *Primary data of the Dinantian (yellow symbols = wells; red lines = relevant seismic sections; orange lines = relevant geological cross sections; light blue areas = Dinantian on the Palaeozoic surface) and previously constructed 3D models that contain information about the Dinantian (light green = "Informationssystem Tiefengeothermie"; green = Weisweiler; dark green = Kettwig); dark blue line = Rhine; white line = border of North Rhine-Westphalia.*

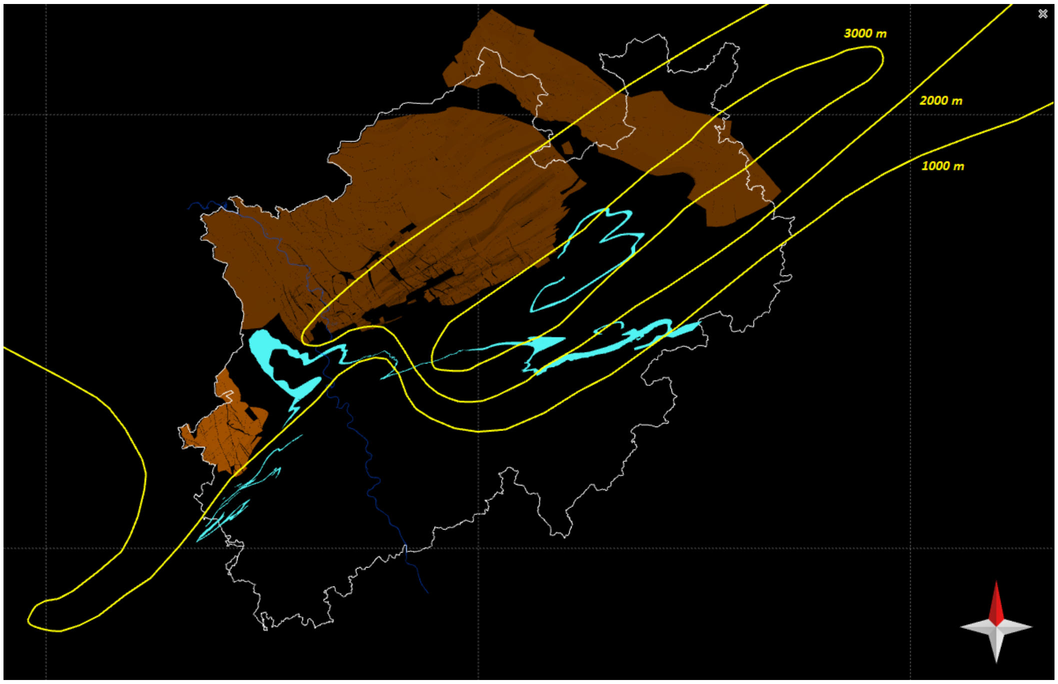


*Figure 7:* *Structural information of important coal seams from the KVB model: dark brown area = Sarnsbank; light brown area = Finefrau; yellow lines = isolines of the Namurian thickness after Drozdzewski (1992); light blue areas = Dinantian on the Palaeozoic surface; dark blue line = Rhine; white line = border of North Rhine-Westphalia.*

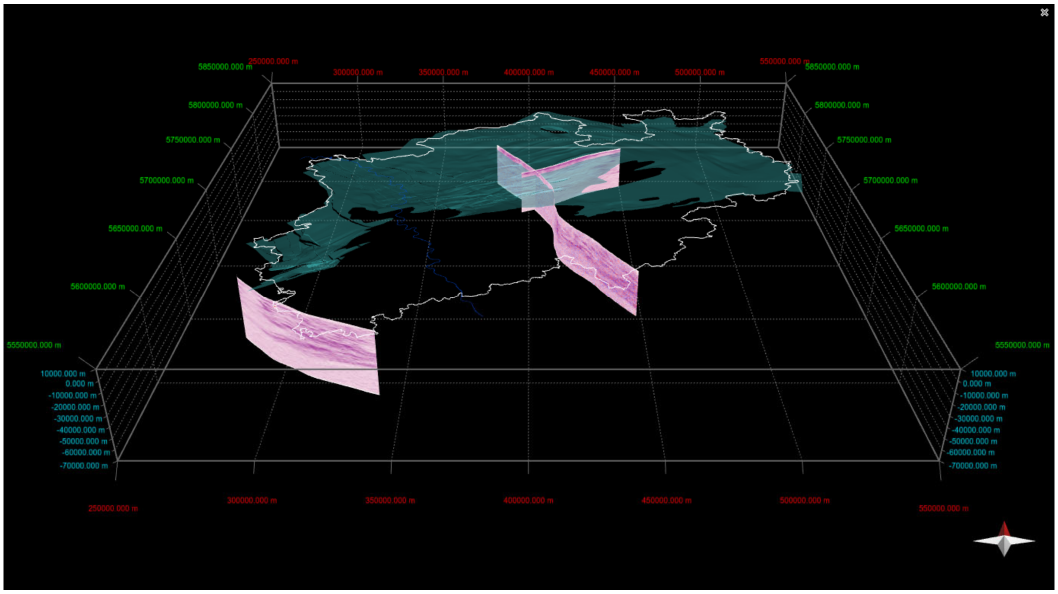


*Figure 8: Merged surface of the Dinantian top (light blue, transparent) and DEKORP lines; dark blue line = Rhine; white line = border of North Rhine-Westphalia.*

While a first unpublished version of the maps was created in 2021, a final updated version of the model has been constructed with a new version of the 3D modelling software MOVE (v2022; Petroleum Experts Ltd). For this version, data that became available during the project were used. In order to solve the remaining inconsistencies along the northwestern border of NRW to the Netherlands, the 3D model of the top of the Dinantian of NRW has been adapted to the Dutch subsurface model DGM-deep V5 (https://www.nlog.nl/en/details-dgm-deep-v5), which is based on the old seismic lines between Nijmegen / Kleef and Enschede / Gronau.

Furthermore, data from recently published regional models of the Rhine Valley and the Northern Rhenish Massif have been included (https://www.geothermie.nrw.de/tief), as well as the new 3D model of the Atlas Ruhr Area (D.T2.1.14 – Building up a geological atlas in the Ruhr Area) (Figure 1).

It was also planned to include newly acquired data resulting from the reprocessed DEKORP lines DEK87-1A, DEK86-2N, and DEK86-2Q for the updated maps. The seismic data has been interpreted and partly used for the updated version (see also D.T2.1.13 – Interpretation of seismic data in NRW).

DEK87-1A is located near the southwestern border of NRW to Wallonia (Belgium), trending NW-SE. The interpretation revealed a SE-dipping reflector in depths between 2.500 m and 4000 m, which has been interpreted as the Dinantian carbonate rocks. The interpreted line for the top of the Dinantian served as reference for the connection to the Walloon (Belgian) part of the in the deep subsurface. However, due to missing data on the German side, the extent of these carbonate rocks remains yet unconfirmed for NRW.

DEK86-2N and DEK86-2Q are located in the area of the Münsterland and the Rhenish Massif trending NW-SE (DEK86-2N) and SW-NE (DEK86-2Q). Although the seismic lines have been interpreted, the data was not included in the updated version of the 3D model of NRW because of two newly acquired seismic lines in the region of Münster (Figure 1), which are crossing the two DEKORP lines. The results of the new data lead to an overall new evaluation for the region, which is still in progress and beyond the scope of this project.

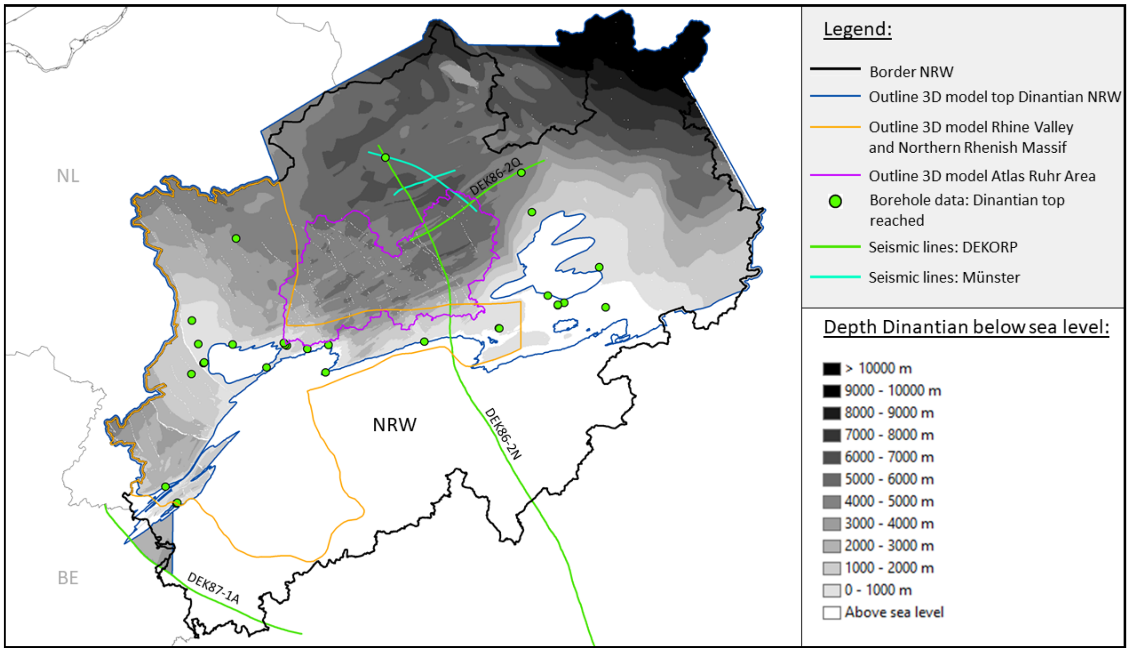


*Figure 9 Final depth map of the top Dinantian of North Rhine-Westphalia including the data used for the update.*

## Flanders (Belgium, compiled by VITO)

In the northern part of Flanders, the Dinantian strata are present in the Campine Basin, subcropping below Cretaceous sediments and the Upper Carboniferous Coal Measures (Figure 10). The basin extends North of the London-Brabant Massif.

In the past, several depth maps of the top of these Dinantian strata have been made by VITO. The latest version was completed as part of the mapping work VITO carries out for the Flemish Government. The project involves the construction of a 3D geological model of the subsurface of Flanders (G3Dv3, Deckers et al., 2019), from the surface to the top of the Cambrian to Silurian basement (London-Brabant Massif). The map of the top of the Dinantian sequence in G3Dv3 is based on seismic data, calibrated to deep well data (Figure 11). The thickness map of the sequence was mainly done on a conceptual basis, taking into account the subcrop areas and steered by the few wells where the entire sequence was drilled (Figure 12). The concept includes an overall increase in thickness from West to East (300 to 1000 m), and a decrease in thickness in the Roer Valley Graben down to 300 m.

Comparing the G3Dv3 map with the latest maps compiled by TNO in the Netherlands showed significant differences in depth along the Belgian-Dutch border. These are related to concepts used in the model where seismic data quality is unfortunately too poor (with increasing depth).

For now, it was decided to stick with the previous map of the top of the Dinantian strata for Flanders. This is the GEOHEAT APP map compiled in 2014 by VITO and TNO as part of an Interreg Flanders-the Netherlands project (VITO, Grontmij & TNO, 2014). This project aimed at cross-border mapping of possible geothermal reservoirs, analysis of their temperature and geothermal potential. The map encompasses four provinces, Antwerp and Limburg in Belgium, and Noord-Brabant and Limburg in the Netherlands.

The GEOHEAT APP map faced similar issues as DGE-ROLLOUT in connecting maps across the border: there were significant differences in depth. These were attributed to the use of different datasets, with mostly seismic data in the Netherlands and borehole data in Belgium. The differences in depth were increased by the uncertainty on seismic interpretations (and the decreasing image quality with depth) and by the fact that the Dinantian strata have only been drilled in a limited number of wells.

The GEOHEAT APP map addressed these issues in the border area by a joint effort in interpretation of available seismic lines both in the Netherlands and in Belgium. In Belgium in particular the 1953-1956 Campine area survey and the 1980 NFB survey in the Hoogstraten area were analysed. Interpretations were compared to well data in Belgium. Starting from the Velmod velocity model, a joint velocity model was built for the Carboniferous strata and used for the time-to-depth conversion. This approach succeeded in eliminating differences in the border zone, and more specifically differences related to the Hoogstraten fault structure. In the past, several depth maps of the top of these Dinantian strata have been made by VITO. The latest version was completed as part of the mapping work VITO carries out for the Flemish Government. The project involves the construction of a 3D geological model of the subsurface of Flanders (G3Dv3, Deckers et al., 2019), from the surface to the top of the Cambrian to Silurian basement (London-Brabant Massif). The map of the top of the Dinantian sequence in G3Dv3 is based on seismic data, calibrated to deep well data.

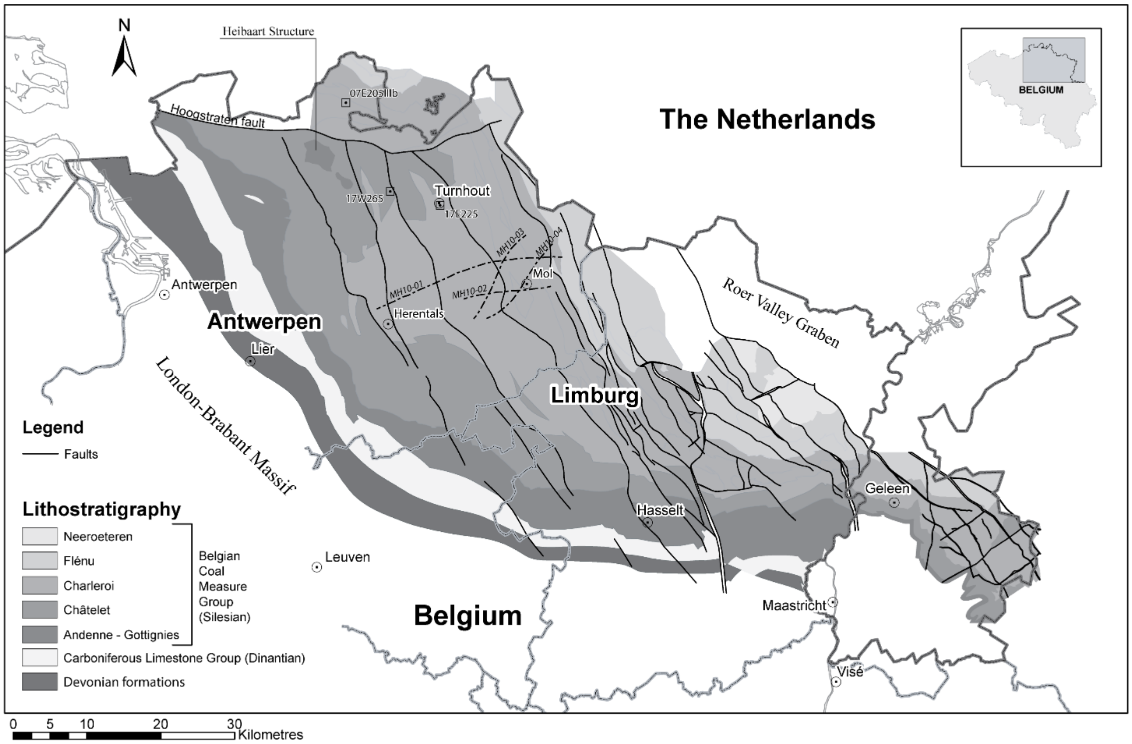


*Figure 10* *Pre-Permian subcrop map showing the presence of Devonian, Lower and Upper Carboniferous formations in the Campine Basin (compiled after Langenaeker, 2000, and Patijn & Kimpe, 1961).*

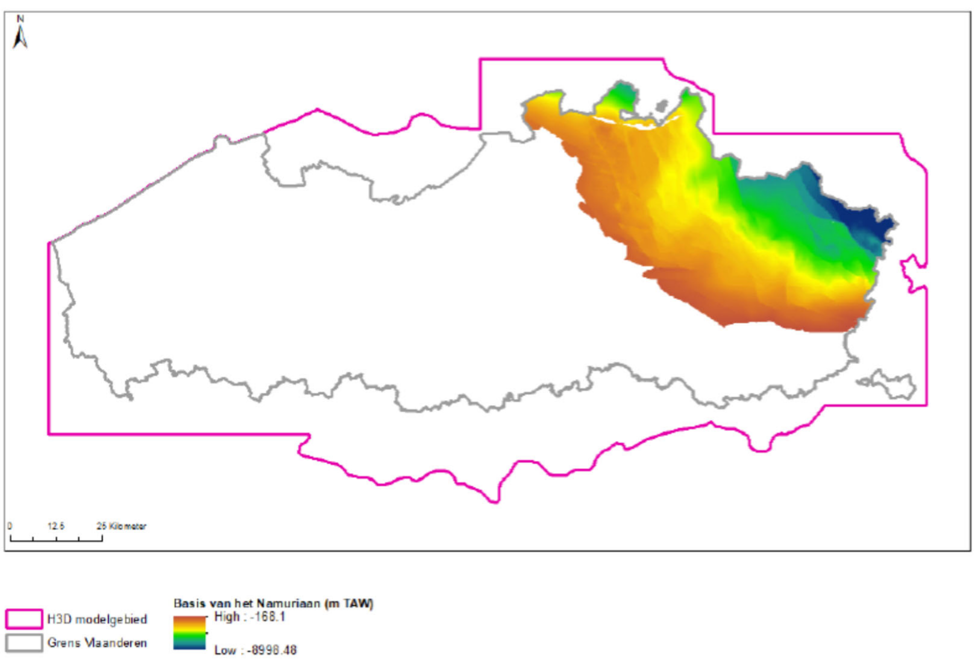


*Figure 11* *Map showing the depth of the top of the Dinantian (base Namurian) according to the latest G3Dv3 model for Flanders (Deckers et al., 2019).*

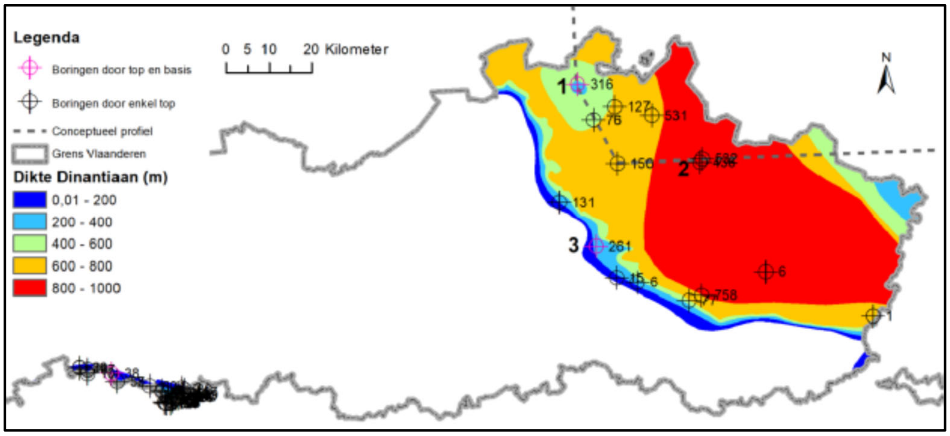


*Figure 12 Thickness of the Dinantian according to the latest G3Dv3 model for Flanders (Deckers et al., 2019).*

## Wallonia (Belgium, compiled by Geological Survey of Belgium)

The Dinantian limestone formations in Wallonia have since long been grouped into three main geological domains (Figure 13):

- the Ardenne Allochthon (Dinant Synclinorium),
- the Brabant Parautochthon
- under the south-dipping Midi-Eifelienne thrust fault ('Midi-fault').

The Dinantian limestone formations from the Dinant Synclinorium do not represent a target for the DGE-ROLLOUT project since these limestone units are outcropping and are therefore only a target for the development of shallow geothermal energy projects. In contrast, the Dinantian formations are deeply buried under the Midi-Eifelienne thrust fault (METF) and under the Upper Carboniferous Belgian Coal Measures along the central axis of the Brabant Parautochthon. The southern extension and the structure of the Dinantian formations under the METF is still poorly known and the subject of various and divergent models.

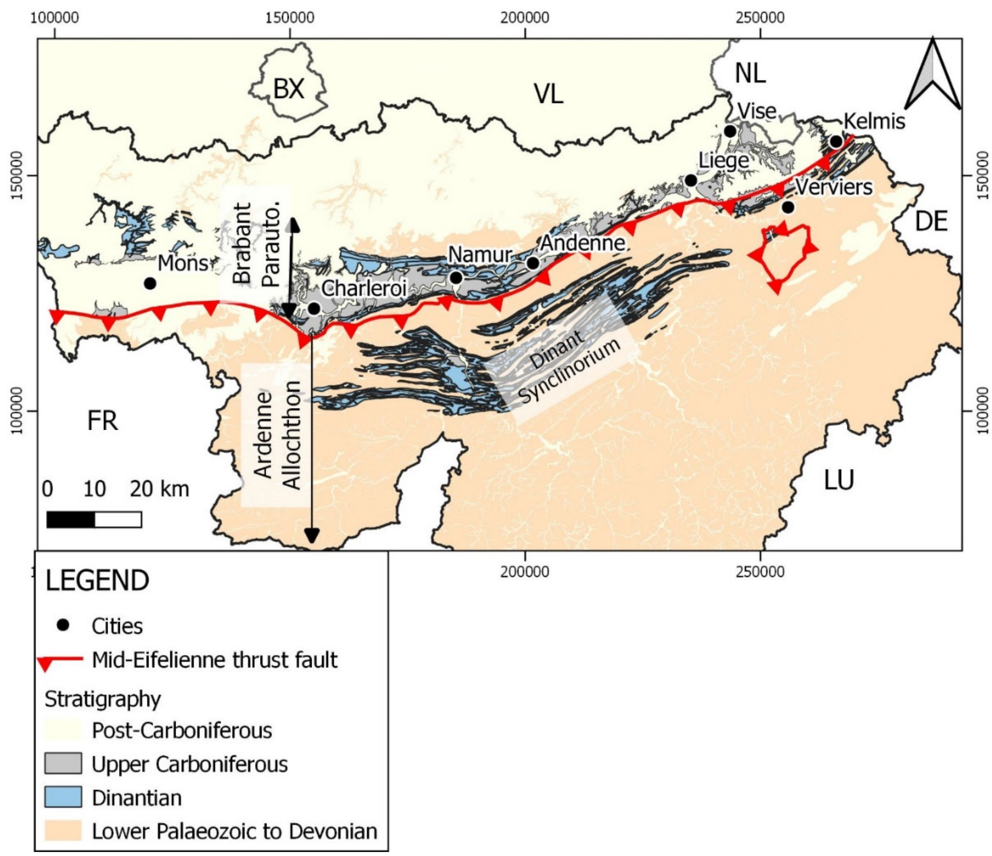


*Figure 13 Simplified geological map of Wallonia showing the three main units relevant for the Dinantian.*

The mapping resource activities in Wallonia in the framework of the DGE-ROLLOUT project focused on the evaluation of the depth of Dinantian formation top and its thickness along the central axis and the northern limb of the Brabant Parautochthon. The main sources of information are heterogeneous depending on the sub-domain structure and composition. The observations conducted during the coal mining industry period were crucial for the resource mapping work, especially in the Mons, Ardenne and Liège areas (Figure 13). For these cases, the applied methodology includes the 3Dmodelling of the deepest coal bed and the evaluation of thickness between this bed and the top of the Dinantian limestone horizons. Such thickness evaluation is usually based on various sources of information, such as a direct observation within a deep borehole or by extrapolation of the thickness information available from the neighbouring outcrop zones of the Dinantian limestone, for instance along the Northern limb of the Brabant Parautochthon. For the other regions (Namur, Visé, Verviers and Kelmis zones) the amount of mining observations is very limited, and the 3D model of the Dinantian formations top was directly conducted through a structural interpretation of the available geological maps, combined with limited deep borehole information.

### Newly acquired data

The DGE-ROLLOUT project has made significant progress in updating the geothermal resource map in Wallonia by leveraging newly acquired data. Specifically, the seismic reflection campaign GEOCOND2022 has played a central role in enhancing the accuracy and insights of the mapping efforts in the central part of Wallonia (Figure 14). This campaign has provided valuable information on the depth of the top and bottom of the Dinantian limestone, the target resource in this region. By integrating the data from GEOCOND2022 seismic reflection campaign, the updated map now reflects a more refined understanding of the geothermal potential, considering the subsurface structural complexity in Wallonia.

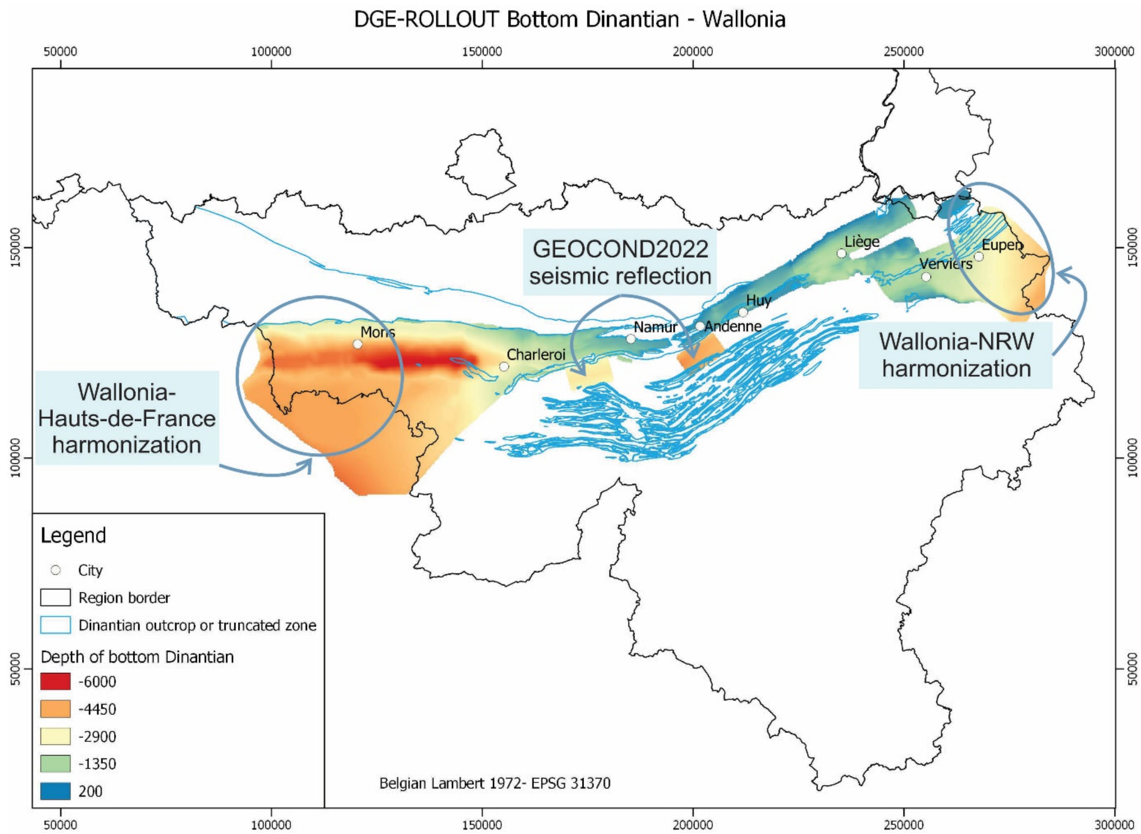


*Figure 14 Map of the Dinantian bottom in Wallonia with the delimitation of the updates following the seismic reflection survey GEOCOND2022 and the transborder harmonization efforts with the Hauts-de-France region and North Rhine-Westphalia (NRW).*

### Transborder harmonization of data

In addition to the mapping update, the DGE-ROLLOUT project has prioritized the transborder harmonization of aquifer depth and thickness data. Collaborative partnerships between various institutions have been established to ensure a comprehensive approach to understanding geothermal resources, not only within Wallonia but also across the neighbouring regions. To ensure the success and effectiveness of the transborder collaborative work, it was essential to conduct several technical meetings among the participating institutions. These meetings served as valuable platforms for knowledge sharing, data exchange, and methodological discussions. Through regular interactions and discussions, the collaborative teams could align their interpretations, address any discrepancies, and harmonize their approaches. Technical meetings fostered a collaborative spirit, enabling experts from different institutions to pool their expertise, validate findings, and collectively enhance the accuracy and reliability of the geothermal resource mapping. Additionally, these meetings promoted a deeper understanding of the geological complexities and regional variations, allowing for a more comprehensive assessment of the transborder geothermal potential.

### Collaborative efforts in Western Wallonia

The collaboration between the Geological Survey of Belgium (GSB), Bureau de Recherches Géologiques et Minières (BRGM), the University of Lille, and the University of Mons has focused on harmonizing the understanding of Dinantian deep resources in Hauts-de-France (France) and the Mons basin (Wallonia). By reinterpreting old seismic lines in Hauts-de-France and incorporating seismic campaign data from the Mons basin, the mapping of the top and bottom depths of the Dinantian limestone in these regions has been significantly improved. This collaboration ensures a more accurate representation of the geothermal resource distribution in Western Wallonia (Figure 14).

### Collaborative efforts in Eastern Wallonia

Similar collaborative efforts have been initiated in Eastern Wallonia (Figure 14) to refine the mapping of deep geothermal resources. The partnership between GSB, GD NRW (Geological Survey of North Rhine-Westphalia), and DMT Group has focused on a stratigraphic and structural reinterpretation of the subsurface along the DEKORP-1A seismic profile. The outcomes of this collaboration have provided enhanced constraints on the depth and distribution of deep Dinantian resources in Eastern Wallonia. As a result, the geothermal potential in this region has been significantly extended southward and the potential resource is also probably deeper than previous evaluations.

***Conclusion***

The ongoing DGE-ROLLOUT project in Wallonia has yielded significant advancements in mapping geothermal resources. The integration of newly acquired seismic data, such as the GEOCOND2022 campaign, has contributed to an updated and refined understanding of the geothermal potential in the region. The model provides a satisfactory evaluation of the resource distribution from the border between France and Germany. Furthermore, collaborative efforts and transborder harmonization of data have facilitated a comprehensive approach to mapping geothermal resources, ensuring a more accurate representation of the top and bottom depths of the Dinantian limestone in both Western and Eastern Wallonia. These advancements provide a solid foundation for future geothermal exploration and utilization projects, promoting sustainable energy development in the region.

Only in a small area located between Visé and Kelmis the information is too scarce to provide a realistic model. The collaboration between the DGE-ROLLOUT and the Meuse-Rhine Interreg E-Test projects (Einstein Telescope) can possibly help to improve the model for this zone.

## Hauts-de-France (France, compiled by BRGM)

In the Hauts-de-France, similar to Wallonia, the Dinantian is divided into three structural units with from south to north. Within each of these units, different data are available for mapping the Dinantian:

- the Ardenne Allochthonous unit (AA):
  - boreholes;
  - outcrops in the Avesnois (to the S-E part).
- the overturned thrust sheet massifs (OTS):
  - boreholes;
  - rocks encountered in mining.
- the Brabant Parautochthonous series (BP):
  - boreholes;
  - the presence of overlying coalfields and mining works;
  - map contours of the top and bottom of the Dinantian series;
  - outcrops in the Boulonnais area.

All these data have been used to build maps of the top and bottom of the Dinantian, and a map showing the outline of the sedimentary area.

### Field data

Most of the area exposed in the Hauts-de-France belongs to the Meso-Cenozoic cover of the Paris Basin. The rocks of the Dinantian are only present at the two extremities of the region, the Boulonnais in the north-west, and the Avesnois in the south-east (Figure 15). They belong to different structural units, respectively the Brabant Parautochthone unit and the Ardenne Allochthonous unit, which are both present in Wallonia too.

***Boulonnais***

In the Boulonnais area, to the north-west, the Palaeozoic terrain is outcropping in the heart of an antiform structural window formed during the Pyrenean dynamics: the Ferques Massif (Figure 16). The Palaeozoic is characterised by thrust sheet structures with NNW vergence. Although the series are generally S-W sloping, they are affected by folds and overlaps with NE vergence. At depth, the geometry of the structures is built from the interpretation of seismic sections in combination with surface data (Figure 17).

***Avesnois***

To the south-east, in the Avesnois area, Palaeozoic series are outcropping the incised valleys and numerous quarries that exploit the Dinantian limestone. Toward the west, the Palaeozoic rocks are covered by sediments of the Paris Basin. Between the valleys, the plateaus are covered with alterations. The Carboniferous rocks are only present in the heart of the synclines, and they are essentially constituted by the Dinantian. The Namurian is only outcropping at the heart of one of the synclines in the central part (Figure 18, Figure 19).

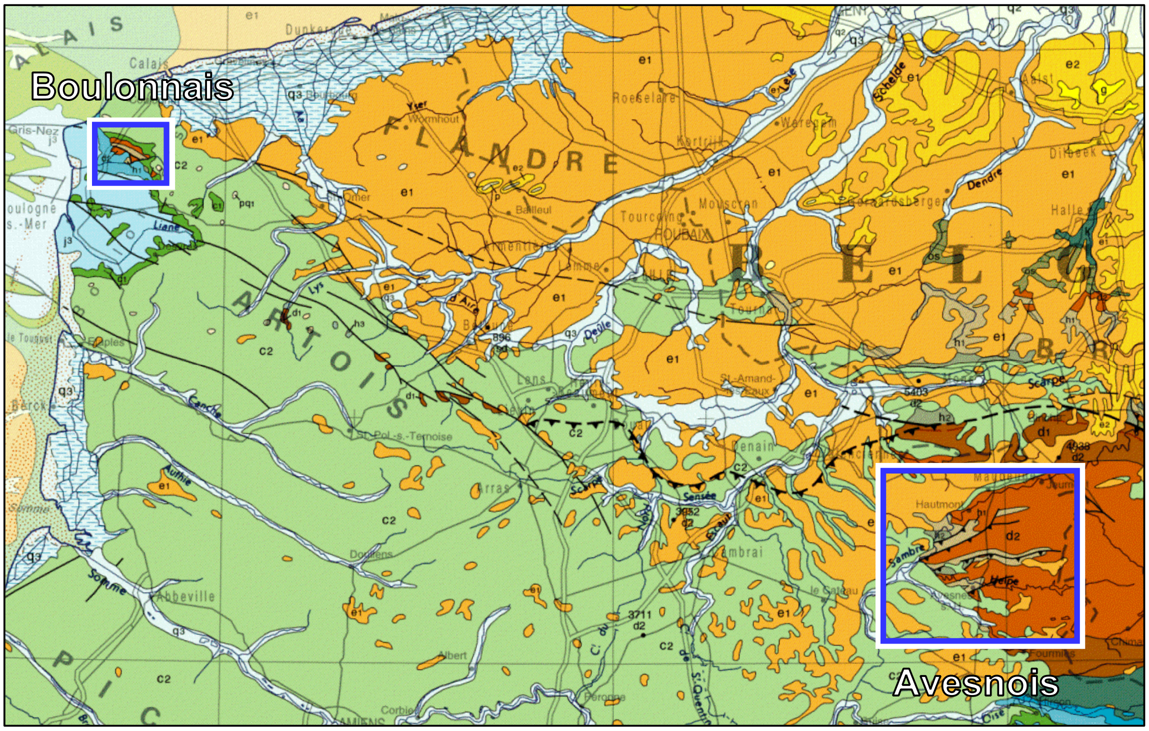


Figure 15 *Geological overview map of Hauts-de-France (extract from the 1/1,000,000 map). Detailed maps of the Boulonnais and Avesnois areas are shown in Figure 16 and Figure 18. Source: http://infoterre.brgm.fr*

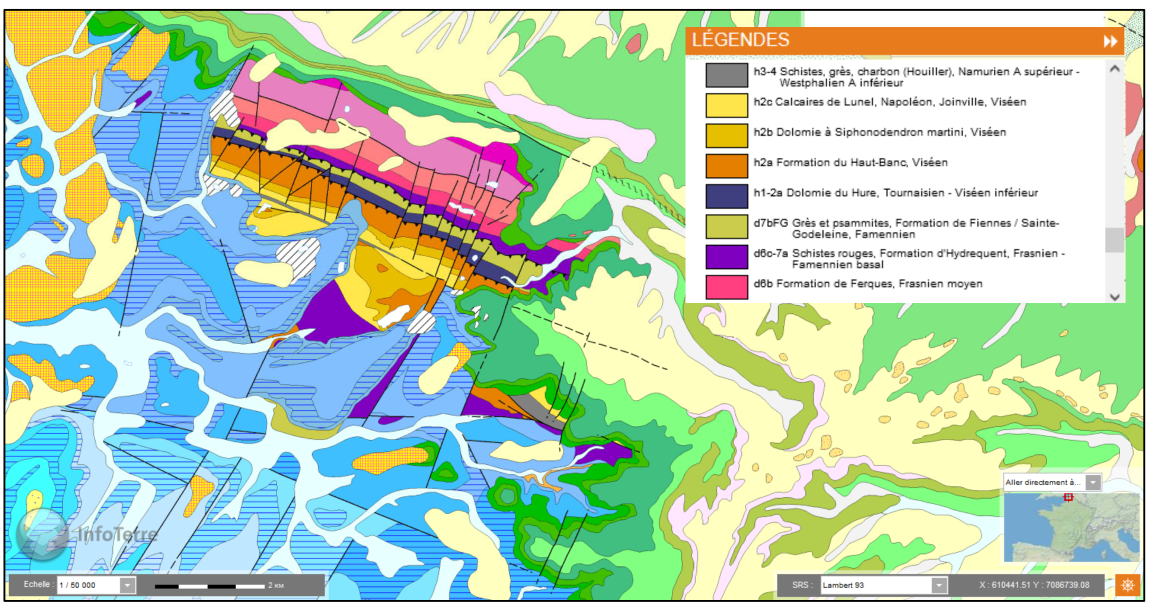


Figure 16 *Extract from the geological maps of Marquise (Mansy et al, 2007) and Guines (Sommé et Hatrival (1971) in the Boulonnais area. See Figure 15 for location. The Dinantian is represented by the units h1-h2 ('Viséen'). Source: http://infoterre.brgm.fr*

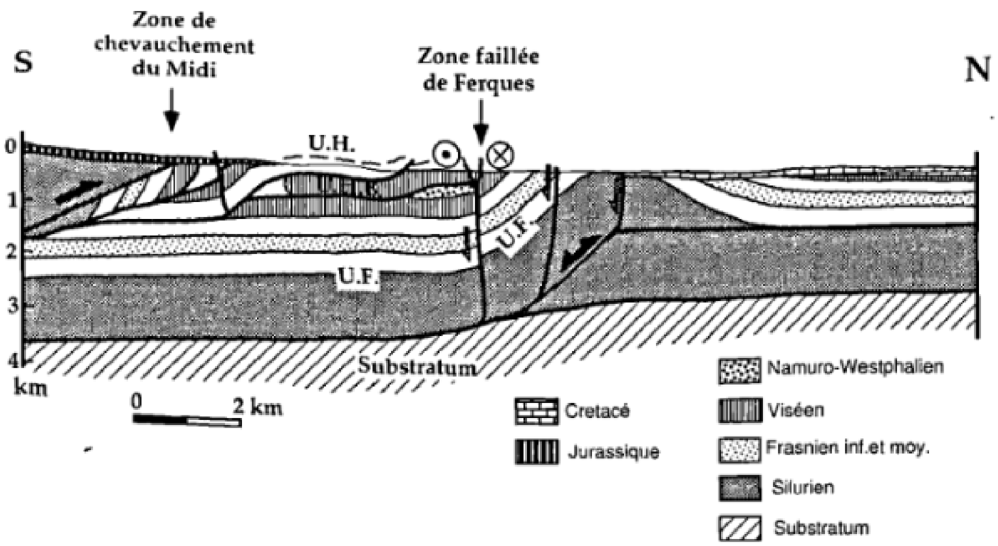


*Figure 17* *Schematic South-North geological cross section showing the Dinantian ('Viséen') with vertical hatching (Averbuch et al. 2001).*

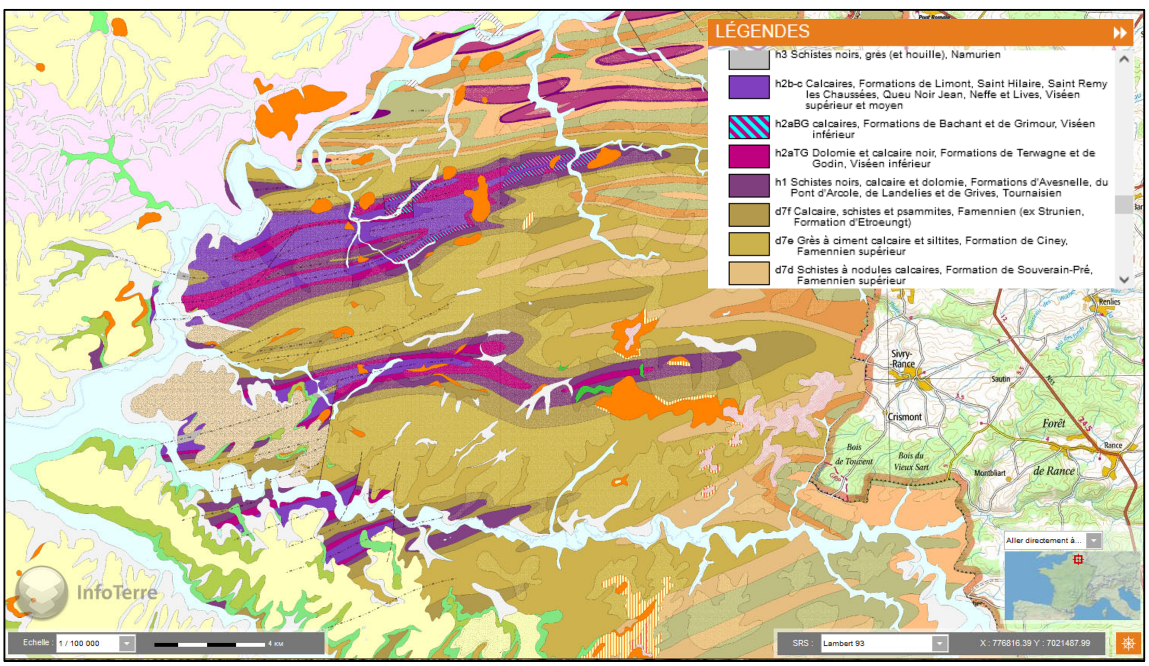


*Figure 18* *Extract from the geological maps of Avesnes, Glageon and Saint Hilaire 1/50000 for the Avesnois area. See Figure 15 for location. The Dinantian is represented in purple by the units h1-h2 ('Viséen'). Source: http://infoterre.brgm.fr*

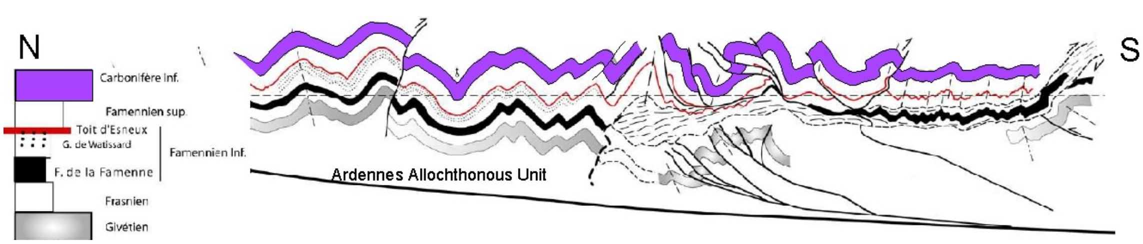


*Figure 19* *North-South cross through the Avesnois area, showing the Dinantian in purple. Modified after Mouloud (2008).*

***Subsurface geology***

Various boreholes that penetrated the Meso- and Cenozoic cover also proved the presence of the Dinantian and other Palaeozoic series deposits. Their distribution is heterogeneous, and the borehole information provides little detailed information on the nature of the deposits. Usually, the boreholes that reach the basement did not specifically investigate the Palaeozoic rocks, and only the thickness of the Meso- and Cenozoic cover and its characteristics are given.

The exploitation of coalfields and hydrocarbon research in the Hauts-de-France region have enabled the production of geological maps. The last summary document dates from 1965 (CFP et al 1965, Figure 20). The 1965 map has been modified using more recent data (drilling, gravimetry, seismic). New contours were established for the Dinantian. Sedimentation areas have been defined on the basis of all these elements and more recent publications (Figure 21).

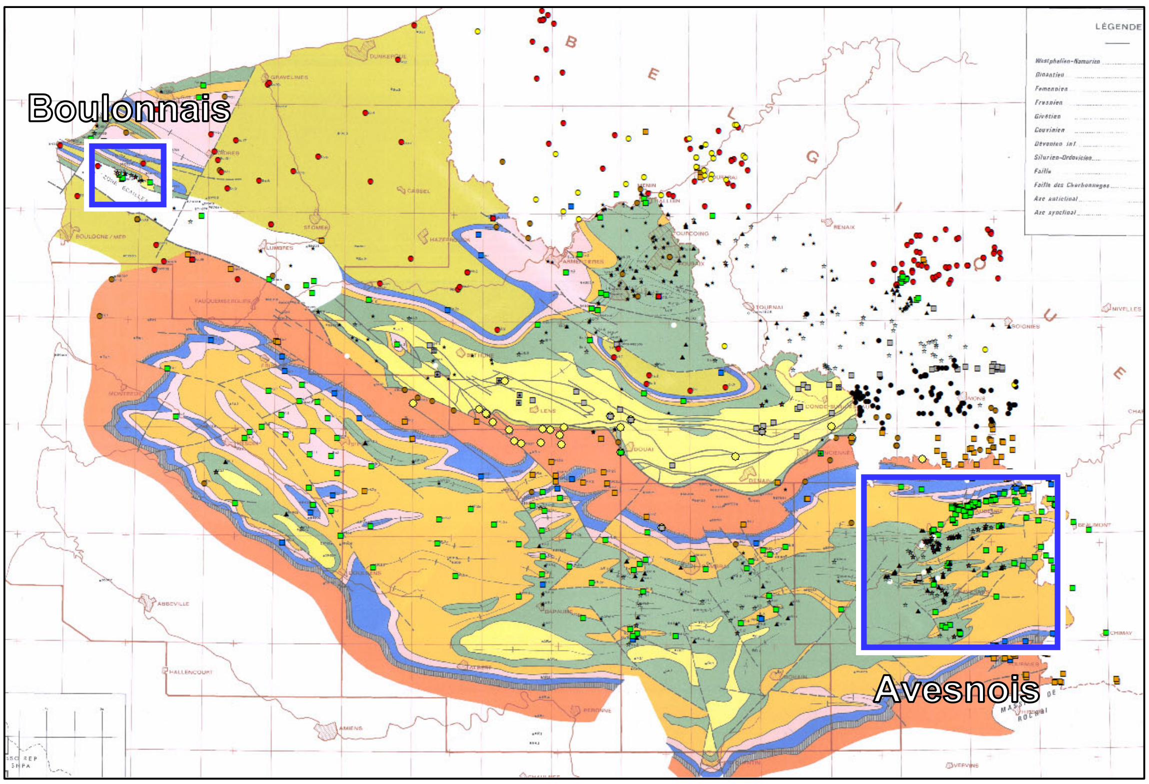


*Figure 20 CFP map with deep borehole data (CFP et al. 1965).*

It has not been possible to produce a map representing the deep geometry of the Dinantian from borehole data alone – the borehole data coverage is too sparse. However, borehole and other subsurface data were used to construct depth maps of the top and bottom of the Dinantian deposits, at least for the northern part of the study area.

Within the three structural units in which the deposits of the Dinantian are present:

- Ardenne Allochthonous unit: maps of the top and bottom of the Dinantian were not produced. The series found in this unit are not considered as potential geothermal targets because they are very strongly faulted and folded;
- Overturned Thrust Sheet Unit: little information is available about the base of the Dinantian series. The top, on the other hand, is relatively well characterised in the near-surface area;

- Parautochthonous Unit: the drilling data provide information on the geometry of the Upper Carboniferous rocks. There is little information on the extension of the series southwards beyond the mining basin and the area where the Dinantian limestones are present under the Meso-Cenozoic cover. Only the Jeumont and Epinoy boreholes provide specific information.

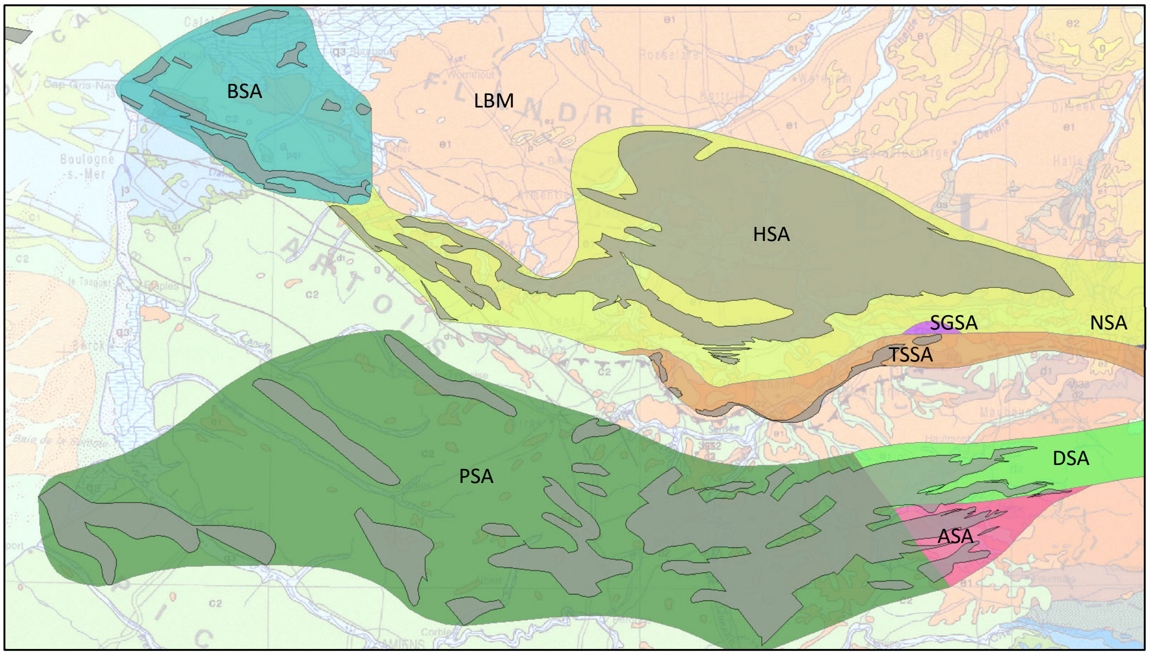


*Figure 21 Sedimentation areas (PSA: Picardie Sedimentation Area; ASA: Avesnois Sedimentation Area; DSA: Dinant Sedimentation Area; TSSA: Thrust Sheets Sedimentation Area; SG SA Saint-Ghislain Sedimentation Area; NSA: Namur Sedimentation Area; HSA: Haineaut Sedimentation Area; BSA: Boulonnais Sedimentation Area and LBM: Massif Brabant).*

On few published seismic lines indicate that the Dinantian layers of the Brabant Parautochthone unit continue under the Ardennes Allochthone well beyond the mining basin (Figure 23). The seismic lines, and their interpretations, are provided in two-way travel time. Depth data is unavailable. Therefore, this information cannot be easily linked to the isobaths of the top and bottom of the Dinantian. (**Error! Reference source not found.**, **Error! Reference source not found.**). Nevertheless, all data are used to construct the Dinantian geological maps. The quality of the results depends on the data. The maps of the western of part of the area must be considered less detailed.

The fault zone that carries the Ardennes allochthonous ends up truncating the series of the Dinantian, limiting their southern extension. As an example, on profile M146 (the easternmost one) the Dinantian is present over the entire length of the profile (Figure 22). For each profile, the depth and the southern limit of the extension of the Dinantian deposits is indicated by a black line (Figure 23). In the west, the southern extension of the Dinantian is relatively small. In the east, the extension limit is much greater towards the south, the north-south distance of the extension of the Dinantian is around 80 km.

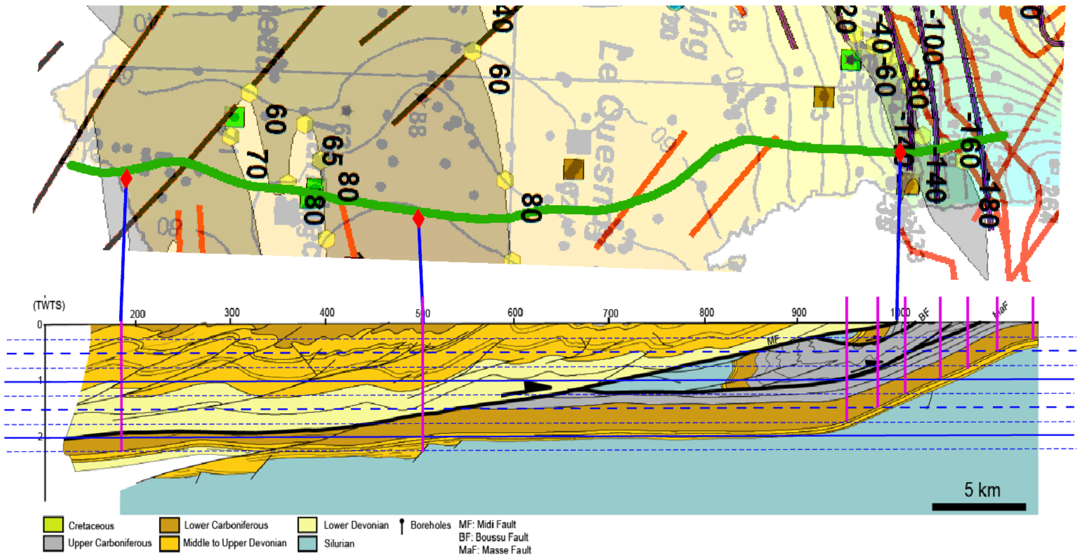


*Figure 22 Interpretation of the M146 line (Mansy et al. 1997) where the Lower Carboniferous located in the Brabant Parautochhonous unit is preserved below the allochthonous units along the entire length of the profile. Figure 23 for location.*

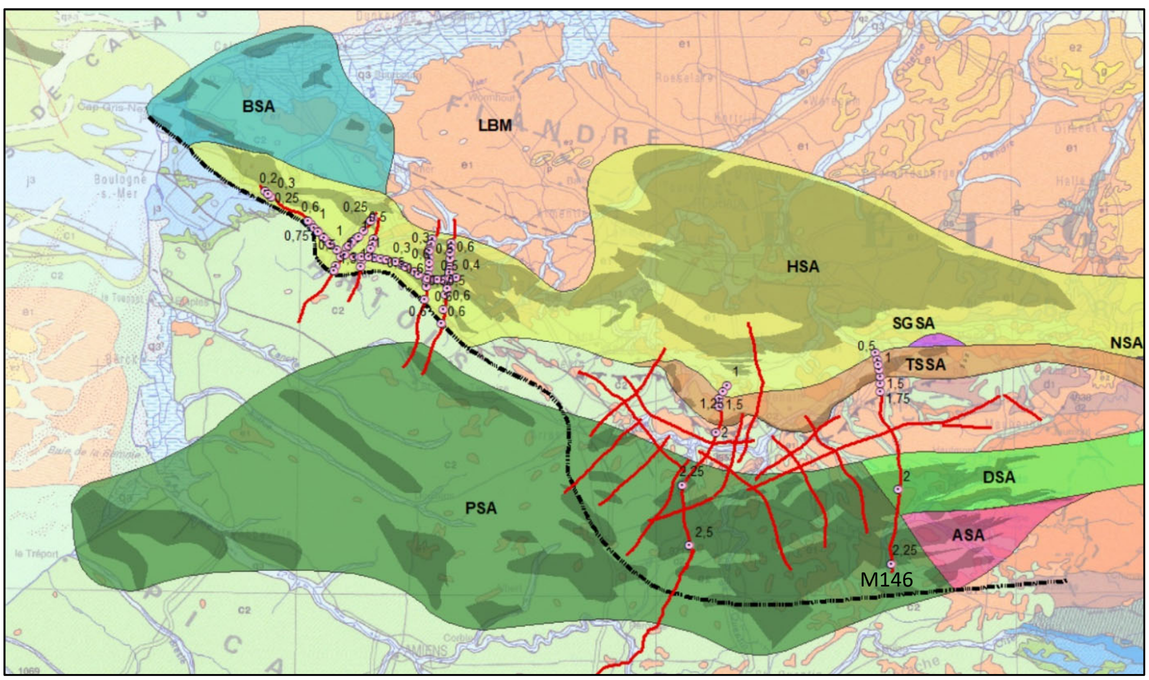


*Figure 23 Published seismic profiles (red lines, section M146 shown in Figure 22 is the easternmost one), pink dots: two-way travel times, dashed black line: southern limit of extension of the Dinantian as defined from the seismic profiles.*

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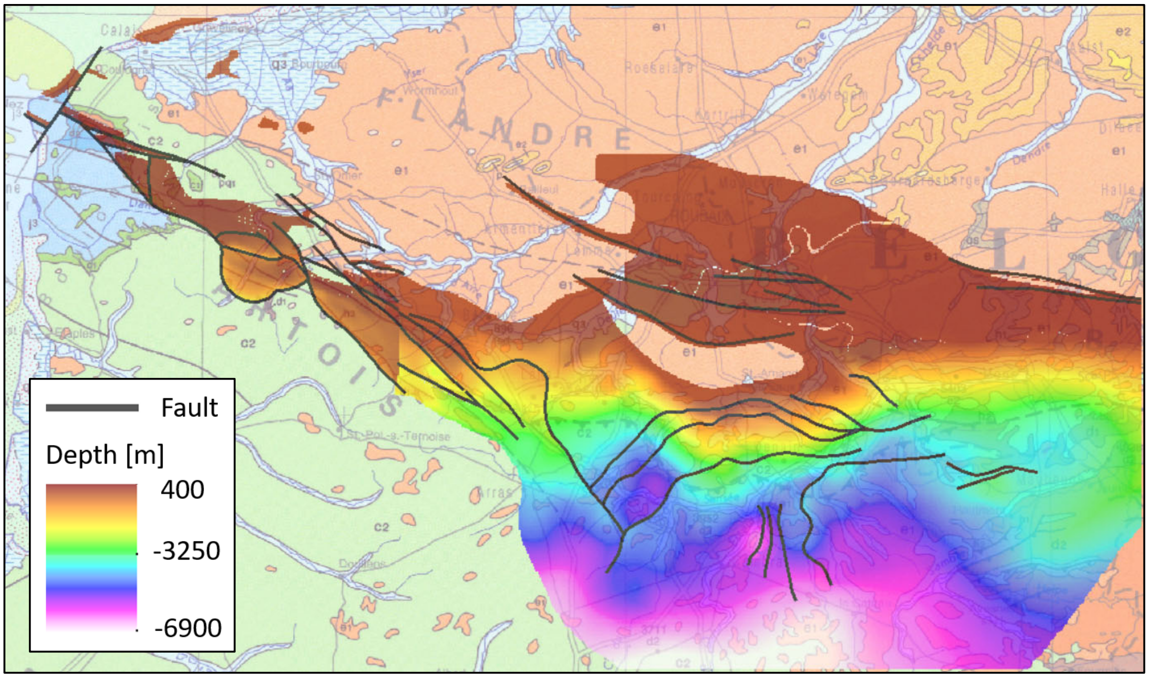


*Figure 24 Depth of the top of the Dinantian limestone.*

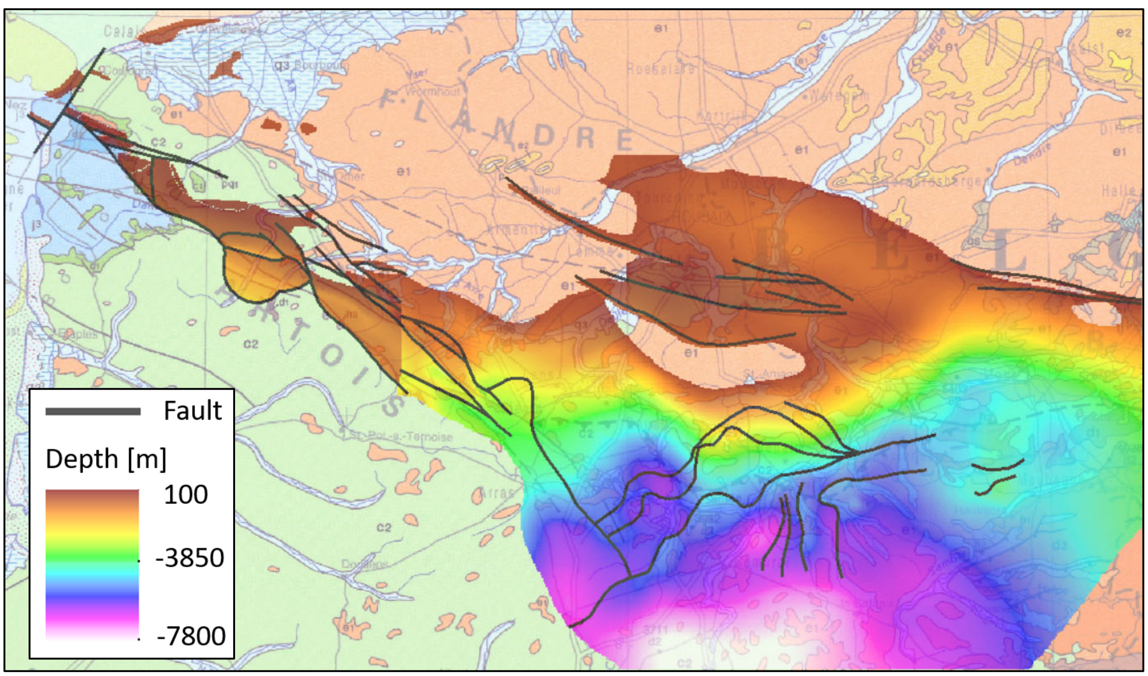


*Figure 25 Depth of the base of the Dinantian limestone.*

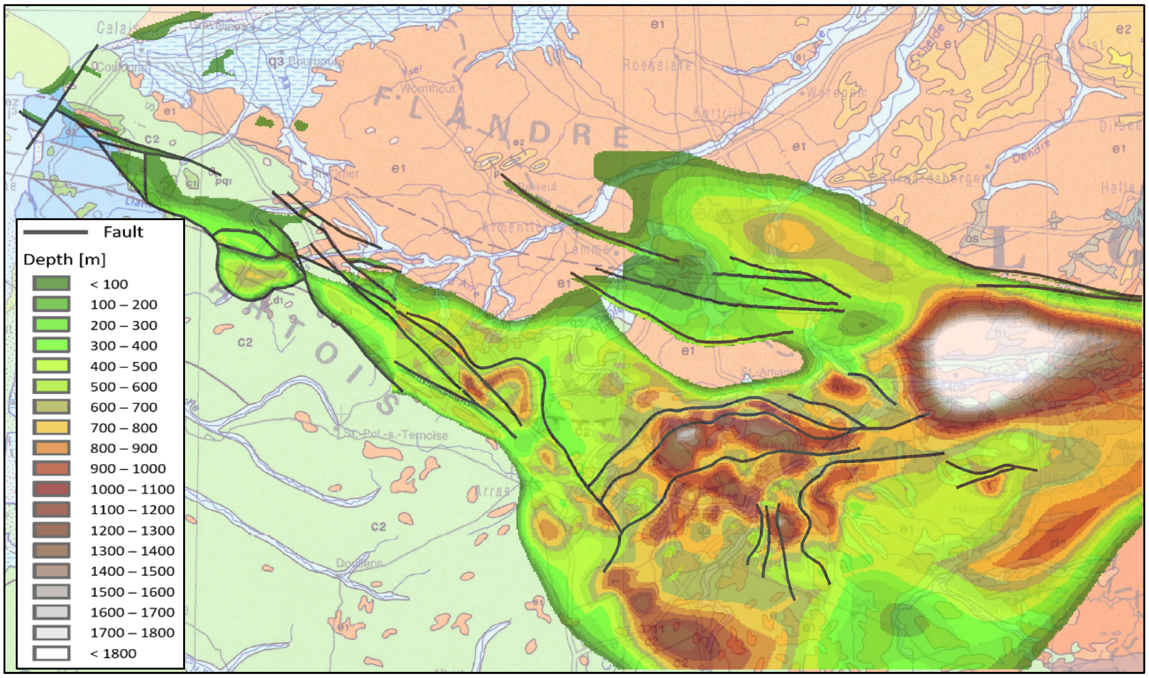


*Figure 26    Thickness of the Dinantian limestone.*

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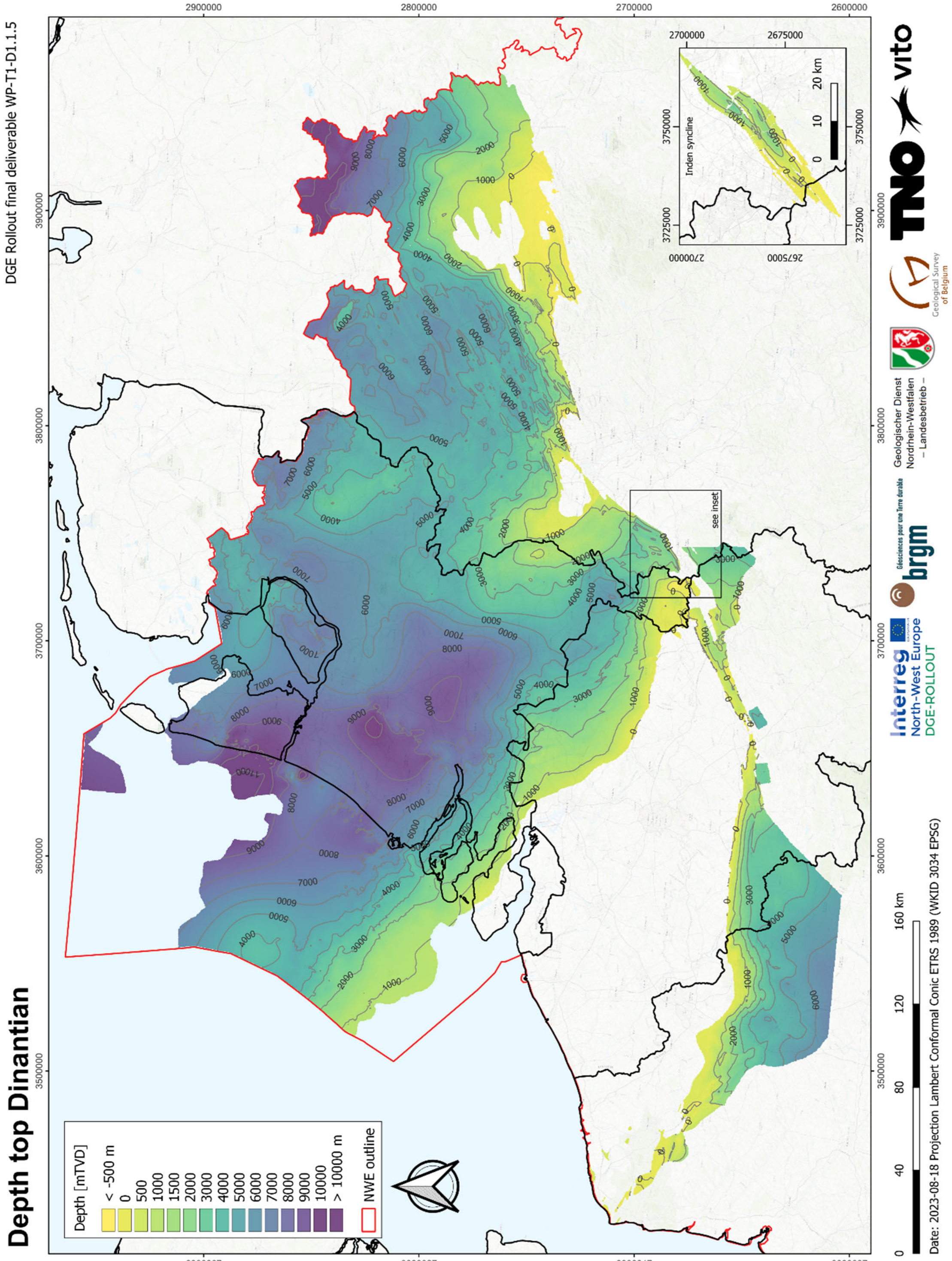
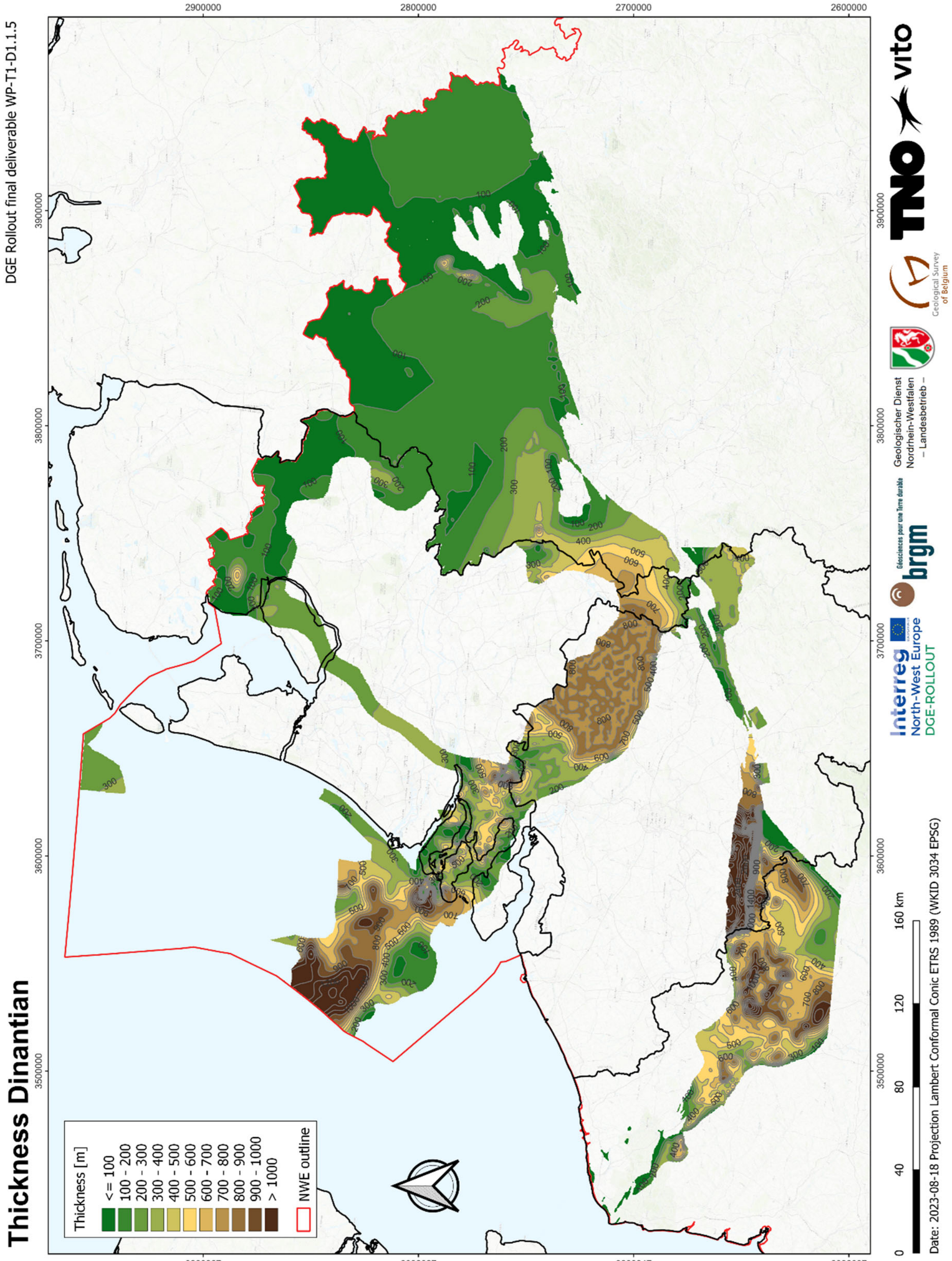
# Appendix 1: Top of the Dinantian in the DGE-ROLLOUT study area.



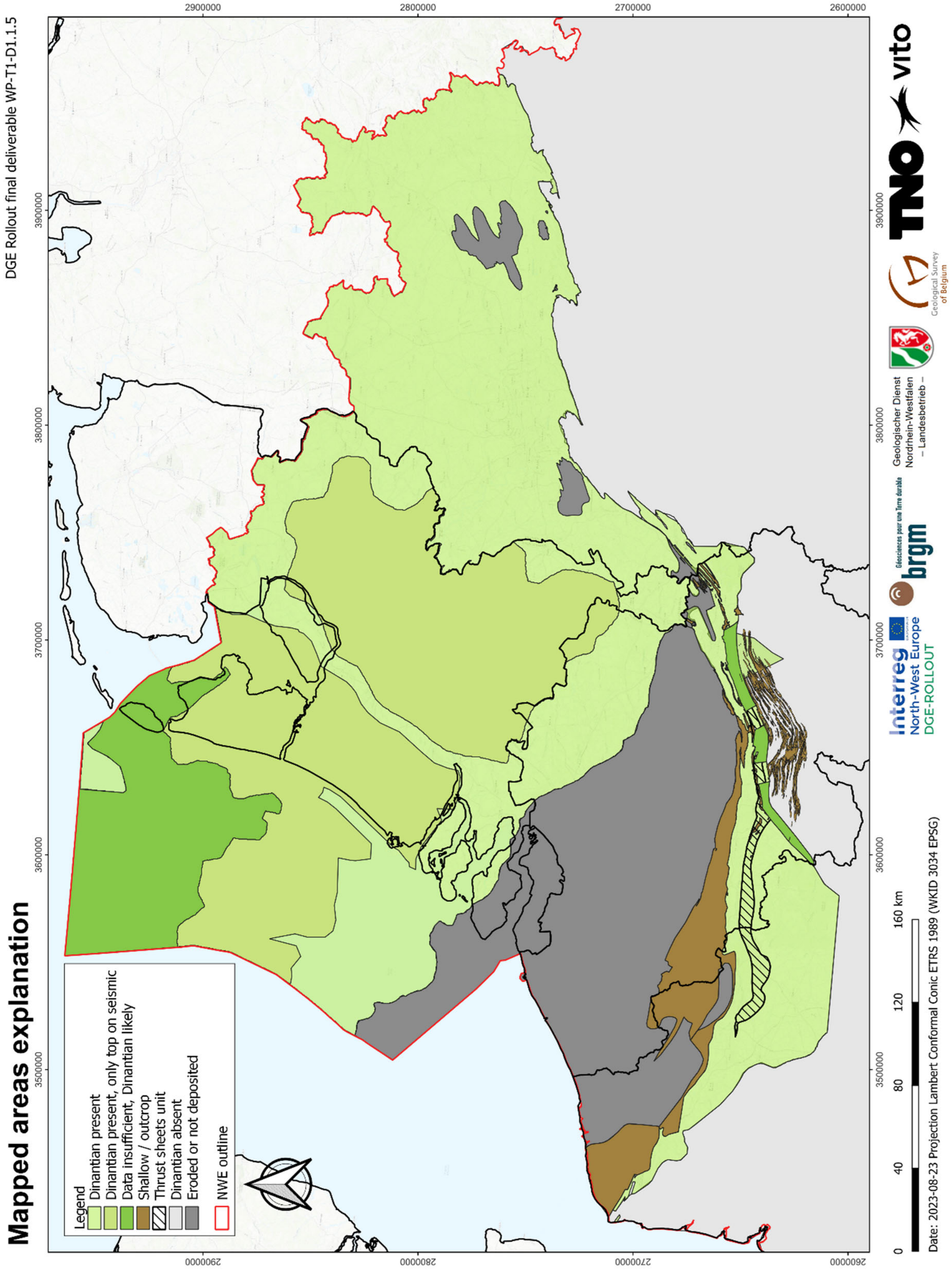

*Note: the inset in the main map is the Inden syncline located in the south-western part of North Rhine-Westphalia. Here, for a large part, the Dinantian occurs at more than one depth that is considered favourable for exploration, of which the inset is the shallower of the two.*

## Appendix 2: Thickness of the Dinantian in the DGE-ROLLOUT study area.




*Note: In a large part of the Netherlands, the data quality is not sufficient for interpreting the depth of the base of the Dinantian. Therefore this area was left blank.*

## Appendix 3: Mapped areas in the DGE-ROLLOUT study area.

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