3D Geomodeling for Europe
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Deliverable 1.5

Final Report incl. lessons learned

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GENERAL INTRODUCTION

This final report of Work package 1 in project “3D Geomodeling for Europe” (3DGEO-EU) provides an overview of the work which has been carried out. Motivation and general approach will be described in chapters 1 and 2. A detailed description of work, challenges, developed results and the way of dissemination for each task and associated deliverables follows in chapter 3. Chapter 4 discusses the lessons learned by harmonizing 3D models along a national border. A general outlook of how to use the harmonized 3D model “NLS3D” and the Cenozoic maps, especially the Rupel map, is given in chapter 5.

The detailed work package results of tasks 1.1 are described in deliverable 1.1 inventory report (Witthöft et al., 2018) and results of task 1.2 in a supporting document for the harmonized 3D model “NLS3D” (Witthöft et al., 2021). This final report describes all tasks and deliverables but in detail it documents work in task 1.3, task 1.4 and task 1.5 and associated deliverables.

The rationale, general approach and final results of the whole project is described in Deliverable 8.5: Summary of project work and results (Knopf et al., 2021).

TABLE OF CONTENTS

1 INTRODUCTION....4

2 APPROACH OF WP1 OF 3DGEO-EU....5

3 TASKS AND DELIVERABLES....6

3.1 Task 1.1 Data inventory and harmonization criteria....6

3.1.1 Objectives....6

3.1.2 Approach....7

3.1.3 Results and dissemination....7

3.2 Task 1.2 A consistent 3D model ”NLS3D” of the cross-border region....7

3.2.1 Objectives....7

3.2.2 Approach....7

3.2.3 Challenges / problems....8

3.2.4 Results and dissemination....8

3.3 Task 1.3 Mapping Cenozoic layers of the cross-border region....12

3.3.1 Objectives....12

3.3.2 Approach....12

3.3.3 Challenges / problems....14

3.3.4 Results and dissemination....15

3.4 Task 1.4 Investigation of geothermal reservoirs and properties....18

3.4.1 Objectives....18

3.4.2 Approach....18

3.4.3 Results and dissemination....19

3.5 Task 1.5 A harmonized decision support map for the Netherlands-Lower Saxony cross-border region....19

3.5.1 Objectives....19

3.5.2 Approach....19

3.5.3 Results and dissemination....20

4 DISCUSSION OF LESSONS LEARNED....21

5 CONCLUSIONS....23

6 REFERENCES....24

1 INTRODUCTION

“Overcoming a national border, which has no relevance in geosciences” was the vision of WP1 in 3DGEO-EU. Geology and usage of underground ends not at the national border between Germany (Lower Saxony) and The Netherlands. GeoERA supported the possibility for LBEG and TNO of working together (see *Table 2*) on harmonization of existing 3D models). Both organisations have detailed 3D models of the geological underground for the states, which end at the border. Due to differences in legal circumstances no detailed knowledge exchange between the two countries was possible while setting up the existing 3d models.

Starting to work on harmonization meant to exam for example the input data, modelled layers, faults, coordinate systems and modeling technique and lead to a detailed description of the existing 3D models and knowledge transfer (see chapter 3.2).

Comparing the existing 3D models lead to the conclusion, that harmonization is possible. To show, that we did not set up a complete new framework, with harmonized input data for generating a new model, we harmonized 10 modelled layers in a way, which shows areas of too high deviations. So the new harmonized 3D model NLS3D comes up with gaps along the national border, where corresponding layers differed and still do. Therefore a new methodology was developed. In Lower Saxony the approach was made to close these gaps of too high deviation between corresponding layers by remodeling two Cenozoic layers and implement these into an updated version of NLS3D.

Geothermal aspects were also taken into account to exam potential geothermal usage of this underground area. Documentation of this approach is described in chapter 3.4.

A decision support map for the usage of the underground, which shows the distribution and thickness of the hydraulic and geological barrier (Rupel Formation) between salt- and freshwater. This map should be regarded as a starting point for developing such a map for the whole region of northwest Europe to give a hand by planning drilling and all kinds of usage of the deeper underground.

2 APPROACH OF WP1 OF 3DGEO-EU

The general approach of work package 1 was to harmonize existing 3D models across the national German-Dutch border to generate a new cross-border harmonized 3D model (see Figure 1). This 3D model should be used to derive further maps showing thickness and distribution of Cenozoic units or geothermal information.

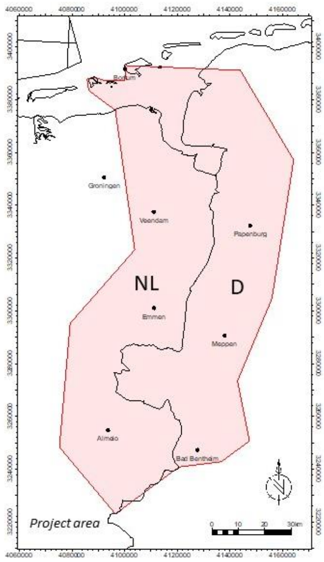

Figure 1: Pilot area of WP1, showing the extent of the harmonized 3D model NLS3D. Also the national border is shown, where the harmonization of existing models was realized.

One of these maps should represent the Rupel Formation, to come up with a decision support map for the usage of the underground. This map should show the distribution and thickness of the hydraulic and geological barrier (Rupel Formation) between salt- and freshwater.

Therefore we structured our work in five tasks. The planning of these tasks and the resulting five deliverables in the period July 2018 (=Month 1) to October 2021 (=Month 40) are shown in Table 1 and *Table 3*.

Table 1: Overview of five tasks and deliverables of WP1 in 3DGEO-EU.

No. of Task	Name of Task	Starting month	Ending month
1.1	Data inventory and harmonization criteria	M1	M6
1.2	A consistent 3D model ”NLS3D” of the cross-border region	M7	M24
1.3	Mapping Cenozoic layers of the cross-border region	M7	M33
1.4	Investigation of geothermal reservoirs and properties	M19	M24
1.5	A harmonized decision support map for the Netherlands-Lower Saxony cross-border region	M30	M34

3 TASKS AND DELIVERABLES

This cross-border pilot area develops a 3D geological model of 10 main (Cenozoic and Mesozoic) horizons, depth and thickness maps of Cenozoic layers, an investigation of geothermal properties for potential geothermal reservoirs and a map of hydraulic barrier between deep saltwater and fresh groundwater in the northern onshore cross-border region of the Netherlands and Germany (Lower Saxony). This project complements a study that strives to harmonize data and geological structures of the subsurface that is intensively used for both energy and groundwater usage.

Data and results for uptake in the IP (see Table 3) were communicated with and transferred to WP7. Finally all digital data and reports are available on the EGDI website.

Table 2: Overview of WP1.

Work package number	WP1	Lead beneficiary		LBEG	
Work package title	Harmonization of Cenozoic and Mesozoic layers in the northern onshore Dutch-German cross-border region for assessment of underground usage				
Participant number	6	8			
Short name of participant	LBEG	TNO			
Person months per participant	72	8			
Start month	M1		End month	M40	

Table 3: Overview of deliverables with names, lead participant, deliverable type, dissemination level and delivery date.

Deliverable number	Deliverable name	Short name of lead participant	Type	Disse-mination level	Delivery date (in months)
D1.1	Inventory report	LBEG	Report	PU	M6
D1.2	NLS3D: A harmonized 3D model	TNO	3D model	PU	M24
D1.3	Maps of Cenozoic layers	LBEG	Digital data	PU	M33
D1.4	Map of hydraulic barrier	LBEG	Digital data	PU	M34
D1.5	Final report incl. lessons learned	LBEG	Report	PU	M39

3.1 Task 1.1 Data inventory and harmonization criteria

3.1.1 Objectives

- Detailed examination of existing 3D models to elucidate differences and commonalities of all different kinds to come up with a set of criteria for harmonization and matching of the cross-border information.

- Investigation of existing geothermal reservoir information of the project area.

3.1.2 Approach

A study area of approximately 30km on both sides of the national border (see Figure 1) was chosen to exam in detail existing 3D models for harmonization of the new cross-border model NLS3D (see Figure 1).
The work was based on four existing 3D models: Geotektonischer Atlas 3D (GTA3D), Digitaal Geologisch Model diep (DGM-deep), Digitaal Geologisch Model Noord-Nederland (DGM-NNL) and Southern Permian Basin Atlas (SPBA). In several monthly online meetings and one face to face meeting input data, extent of the input models, model type, stratigraphical nomemclature, modeled layers, faults, modeling software, confidentiality, avalibilty, output data (sort/type and format), coordinate system and height reference system were discussed. Based on this common developed knowledge first criteria for harmonization were derived.
Also as a starting point for the original planned work we established an inventory of existing maps of Cenozoic reservoirs for the project area.

3.1.3 Results and dissemination

Described content and knowledge base is documented in the inventory report (Witthöft et al., 2018).

Table 4: Overview of deliverable 1.1

Deliverable	Inventory report
Short description, remarks	State of the art inventory of existing 3D models in Lower Saxony and The Netherlands, which were examined for feasibility of harmonization process along the border, which also documents existing maps of Cenozoic reservoir rocks.
Link	Dissemination of this inventory report is organized via GeoERA Homepage: https://geoera.eu/3DGEO-files/3DGEO-EU-D1.1-Inventory-report.pdf

3.2 Task 1.2 A consistent 3D model "NLS3D" of the cross-border region

3.2.1 Objectives

The goal of this task was harmonization of modelled horizons of existing 3D models, based on the developed common knowledge in task 1.1, to generate a cross-border 3D model. Therefore corresponding layers of different 3D models needed to be identified and a methodology for merging corresponding horizons at the national border needed to be developed. Also attempting to harmonize main faults crossing the border.

3.2.2 Approach

In five (partly face to face) meetings and monthly online meetings properties of layers were checked in detail: input data, chronostratigraphy, lithostratigraphy, distribution, cross-border structures and depth to identify corresponding horizons for harmonization. After transforming input data into the same coordinate system, developing and agreeing on a calculation methodology, each comparable layer set with a calculated difference map along the border and according depth histograms were discussed. Corresponding horizons were merged together after: 1) checking high deviations related to cross-border structures in seismic lines with different results at three locations and 2) fixing a threshold for the deviation in percent, which was not allowed to exceed for harmonization. Areas, which exceed this threshold are represented by gaps along the national border in the harmonized horizon.

For improving the fitting of corresponding layers Base Lower/Middle Miocene and Base Rupel were remodeled in Lower Saxony in task 1.3 and also implemented into the new NLS3D model.

Harmonization of main faults was tested at the Gronau Fault Zone. This fault zone was chosen because its complexity. If harmonization appears successful, a working proof of concept could converge toward a working method for the entire border area (Witthöft et al., 2021 and Malz et al., 2021).

3.2.3 Challenges / problems

- coordinate system:
  For elaborating a harmonized 3D model it was important to agree first on a common coordinate system for our pilot area to prevent inaccuracy and mistakes in geographic position. We decided to use the system EPSG:3034 for working without distortion.
- remodeling:
  Partly remapping of two horizons in Lower Saxony in task 1.3 lead to remodeling. This work was very time consuming. After finalizing task 1.3 we had to generate a second version of NLS3D to integrate results of task 1.3 in deliverable 1.2.
- identifying corresponding horizons:
  In general corresponding horizons were identified by checking input data of the existing 3D models. But correlation of Base Breda Formation (DGM-NNL) and 03tmim-tpl and 04 tmiu (GTA3D) needed further scientific investigation.
- development of methodology
  creating a methodology, which fits as well for deeper horizons as for shallower horizons.
- decision of threshold for each corresponding horizon
- differences in structures along the border
- faults

3.2.4 Results and dissemination

The new 3D model "NLS3D – harmonized geological 3D model of deeper underground along the national border between Lower Saxony and the Netherlands", consists of 10 horizons (for a 3D view of this model see Figure 2).**Fehler! Verweisquelle konnte nicht gefunden werden.**

In Table 5 the 10 horizons of NLS3D are described with names, names of the corresponding horizons and the 3D model source.

Table 5: Names of the 10 harmonized lithostratigraphic horizons of the new model NLS3D and their corresponding horizon names in the existing 3D models.

No	Name of the harmonized lithostratigraphic horizon	Description	NL code	German code	3D model source NL	3D model source DE
1	Near Base Lower/Middle Miocene	Early Miocene Unconformity-EMU (NL) Near base Lower/Middle Miocene (NI)	Base NUBA - Breda Formation	Near base Lower/Middle Miocene	DGM deep 5.0	remodelling
2	Near Base Rupelian	Base Boom (base clay layer) in Rupel Formation (NL) and Base Rupel Formation (NI)	Base NMRF - Rupel Formation	Base Rupel	DGM-NNL	remodelling
3	Near Base Middle Eocene	Base Brussels Sand	Base NLFSS - Brussels Sand Member	06 tolm-teoo (teom-tolu)	DGM-NNL	GTA3D
4	Near Base Cenozoic	Top Danian or top of the Chalk Group	Base N - North Sea Supergroup = base NLLFC-Landen Clay Member	07 tpao-teou	DGM deep 5.0	GTA3D
5	Base Upper Cretaceous	Base of the Chalk Group (base Cenomanian)	Base CK - Chalk Group	08 kro (Cenoman - Danian)	DGM deep 5.0	GTA3D
6	Near Base Lower Cretaceous	Approximately near base Ryazanian; may correspond to an unconformity	Base KN - Rijnland Group	09 kru (marine L. Cret. - Oberalb)	DGM deep 5.0	GTA3D
7	Near Base Upper Jurassic	This horizon corresponds to a level varying from the Callovian to the base of the Oxfordian.	Base S - Upper Jurassic groups	10 jo-Wd (Oxford - Wealden)	DGM deep 5.0	GTA3D
8	Near Base Lower Jurassic	Base of the Lias Group. This level corresponds to the mudstone/ sandstone boundary in the upper part of the Rhaetian, which is often an unconformity	Base AT - Altena Group	12 juhe-jutcu (Hettangium - L. Toarc)	DGM deep 5.0	GTA3D
9	Near Base Middle Triassic	Base of the Röt evaporites	Base RN - Upper Germanic Trias Group	14 so-m (U. Buntsandstein - U. Muschelkalk)	DGM deep 5.0	GTA3D
10	Near Base Lower Triassic	Base of the Buntsandstein	Base RB - Lower Germanic Trias Group	15 su-sm (Lower - highest M. Buntsandstein)	DGM deep 5.0	GTA3D

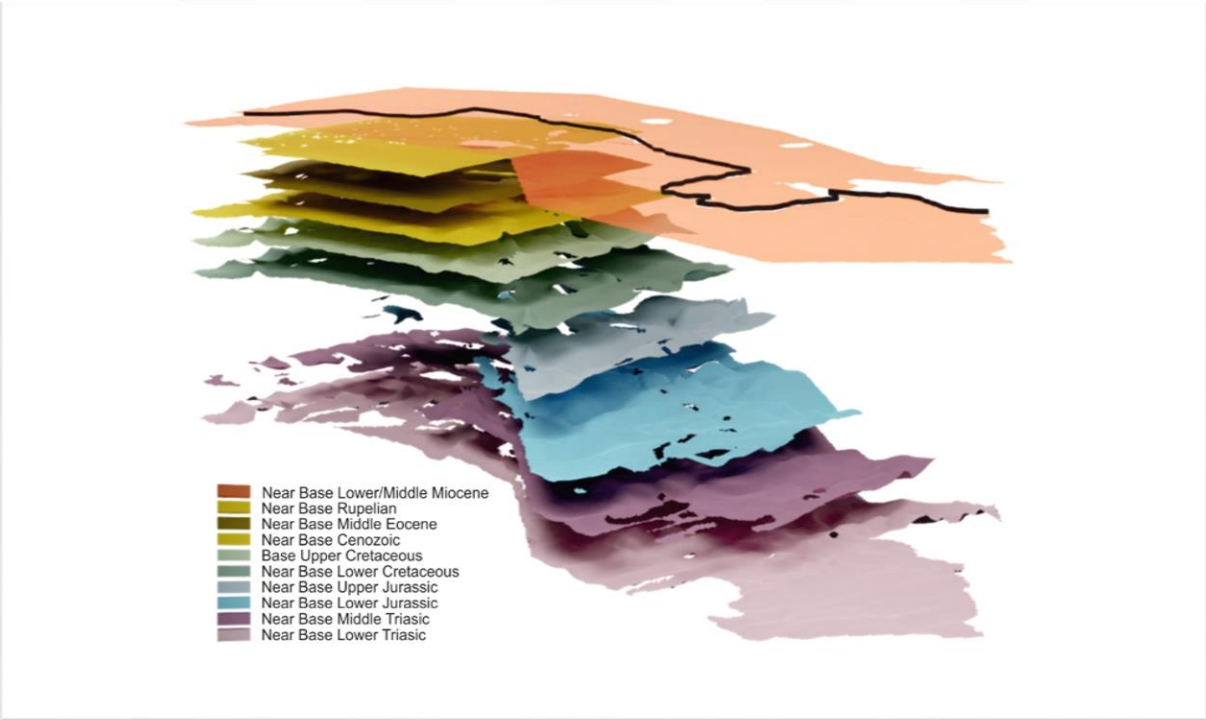

Figure 2: NLS3D – 3D view into the 3D model

NLS3D will be available on EGDI (see *Table 6*). All layers are available as ASCII files for download, in order to provide accessibility for all users.

Table 6: Overview of deliverable 1.2

Deliverable	NLS3D: harmonized geological 3D model of deeper underground along the national border between Lower Saxony and the Netherlands 10 main Cenozoic and Mesozoic horizons • ASCII files of each modeled horizon of NLS3D • Supporting document describing the harmonized model NLS3D.
Short description, remarks	NLS3D is a harmonized onshore cross-border 3D model of the northern part of the Netherlands (NL) and Lower Saxony (D). The model contains 10 Cenozoic and Mesozoic lithostratigraphic layers and has been created by using available data and existing depth models on both sides of the border. The base of each lithostratigraphic layer has been harmonized by using a “deviation percentage method”, where corresponding horizons on both sides of the border with a comparable depth within a predetermined range have been harmonized.
Link	EGDI http://www.europe-geology.eu/ and https://geoera.eu/projects/3dgeo-eu/

The NLS3D model was promoted via LinkedIn by posts of Hans Doornenbal and Melanie Witthöft with more than 50 likes and more than 1000 views (see Figure 3).

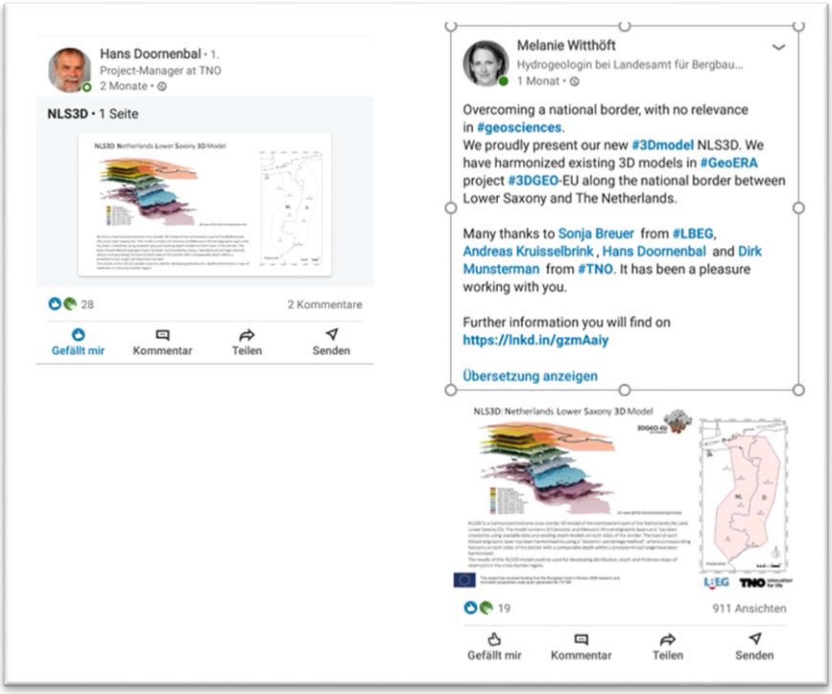

Figure 3: Screenshots of LinkedIn posts

We also had the opportunity to publish NLS3D via the GeoERA Newsletter in June 2020 (see Figure 4).

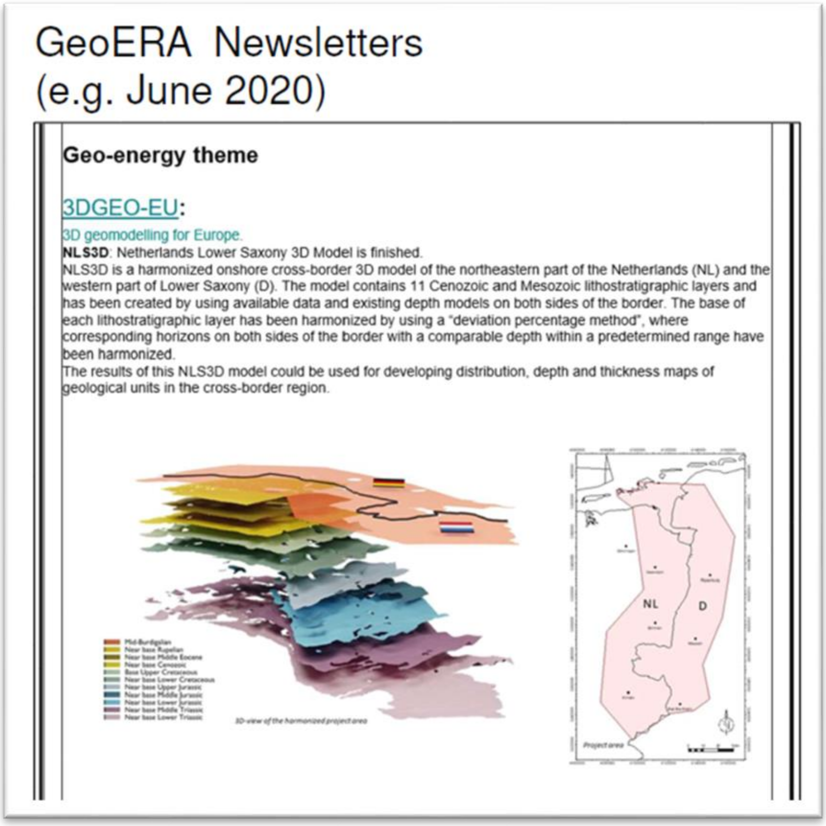

Figure 4: WP1 contribution to the GeoERA Newsletter in June 2020.

3.3 Task 1.3 Mapping Cenozoic layers of the cross-border region

3.3.1 Objectives

The main goal of this task was to generate distribution, depth and thickness maps of Cenozoic layers from the harmonized 3D model “NLS3D” of task 1.2. To improve their quality, two horizons were remodelled at the Lower-Saxony part: Near base Lower/Middle Miocene and Base Rupel. These two horizons were used to derive the decision support map in task 1.5

3.3.2 Approach

In the southern part of the project area remodeling has been carried out in a different way than in the northern part of the project area. Figure 5 shows the area where remodeling of Near Base Lower/Middle Miocene and Base Rupel was based on drillings and cross-sections using the software SubsurfaceViewer (R) (see Figure 6) and GoCAD.

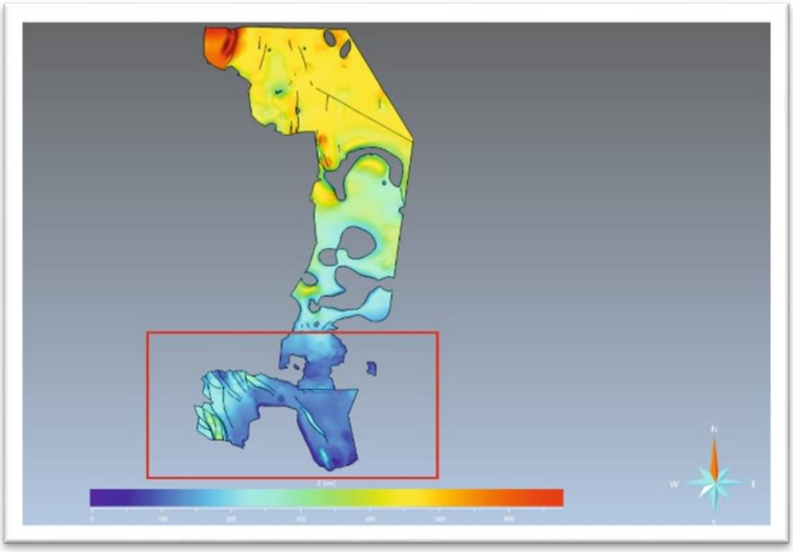

Figure 5: Remodeling of Near Base Lower/Middle Miocene and Base Rupel in Lower Saxony. The red rectangle shows the area that was remodeled with SubsurfaceViewer.

Approximately 4000 boreholes were used for processing, of which about 1500 were drilled deeper than the base of Cenozoic. The remaining boreholes are hydrogeological, shallow geothermal and geoengineering boreholes, most of which do not reach Neogene/Paleogene strata. Most of these wells were correlated via linked cross-sections. A total of 136 cross-sections were made. In addition to the two horizons, the main faults of the area were remodelled based on the GTA structural maps. The software SubsurfaceViewer (R) MX Version 7.2.14 was used for this work.

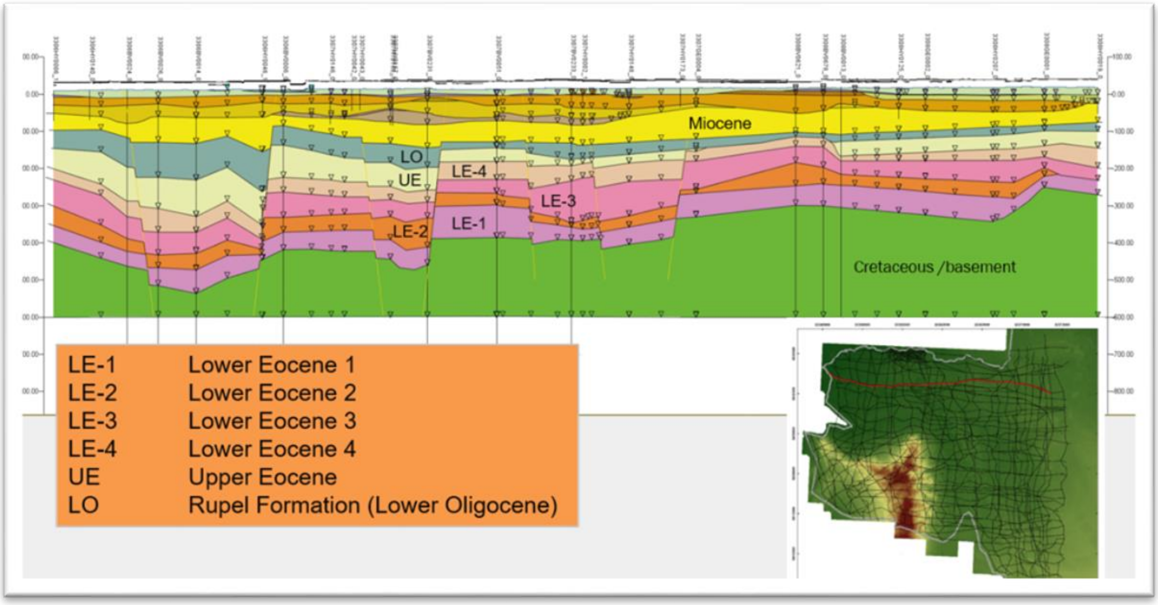

Figure 6: West-east cross-section, showing remodeled horizons LO= Base Rupel and Miocene = Base Lower/Middle Miocene in the "Nordhorn area".

For the remaining area in the northern part Base Rupel was taken from TUNB model (BGR 2021) and Near Base Lower/Middle Miocene were remodeled based on wells, structural information and 2D seismic in GOCAD. All data sets were compiled in GOCAD for implementation in NLS3D.

Local changes in thickness and the distribution limit of the deposits were modeled in detail. Especially the faults and graben structures have an enormous influence on the depth of the Rupel Formation. Seismic information, geophysical measurements of boreholes and information of faults were used to set up cross-sections.

The improvement in quality of the remodeling is shown exemplary for Base Rupel in the "Nordhorn area" (Figure 7).

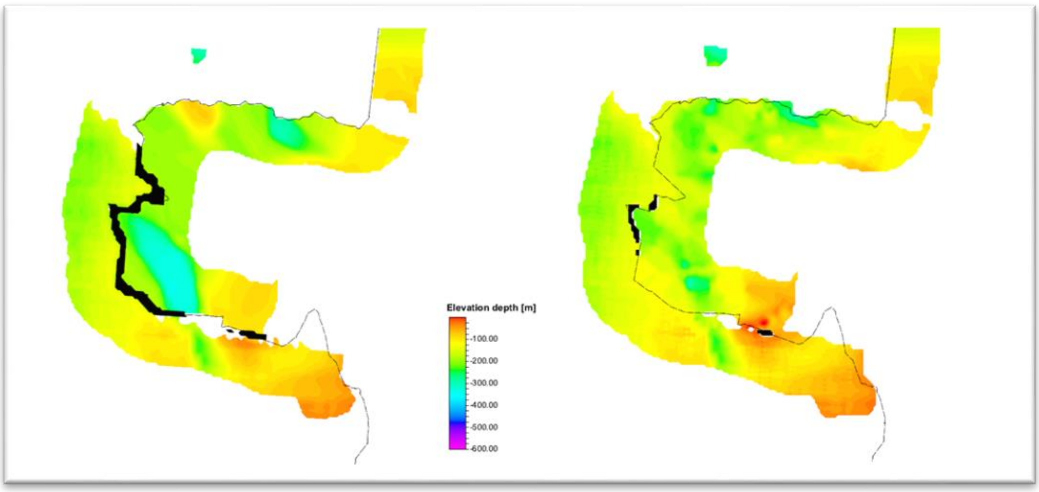

Figure 7: Comparison of the German models with their depth position; left: 05_tolm-tolo from GTA3D; right: remodeled "Nordhorn area". Black spots show areas of no harmonization.

The comparison of the two German models (Figure 7) shows that the new model provides much more detailed depth information than the GTA3D layers.
Comparing the histograms, which show the differences in depth between the German and Dutch models (Figure 8), it becomes clear that the remodelled surface matches the Dutch ones much better and represent a significant improvement.

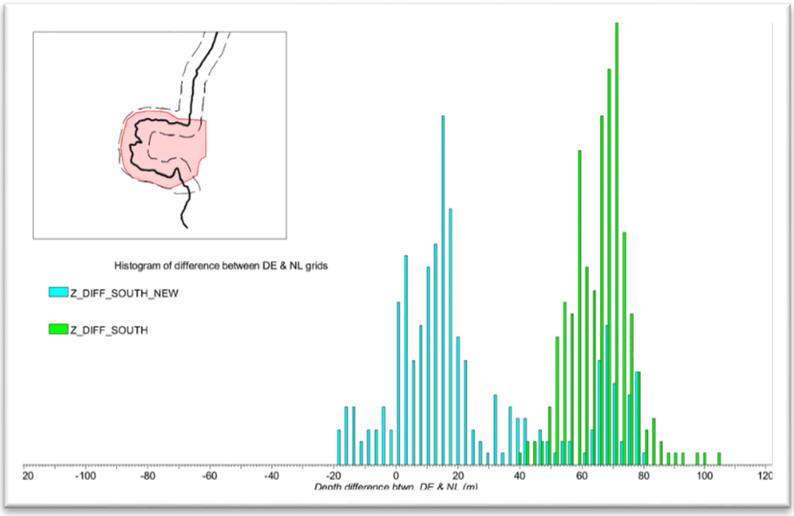

Figure 8: Comparison of the histograms of the depth differences between DE and NL for the remodelled "Nordhorn area" (blue) and the GTA3D (green).

After updating NLS3D model to a second version with the remodeled horizons in Petrel, distribution, depth and thickness maps of Cenozoic units were generated in GoCAD.

NLS3D is made up of four Cenozoic horizons and six Mesozoic horizons. Thickness maps of three units were calculated by using the depth maps of its top and base of the unit i.e.:

- nls3d_v2_02_base_rupelian_thickness_3034
- nls3d_v2_03_near_base_middle_eocene_thickness_3034
- nls3d_04_near_base_cenozoic_thicknessmap_3034.

Thickness of geological units, as shown in this case, is controlled by geological processes and geological structures as salt structures or graben structures. This causes high differences in thickness.
Corresponding depth and distribution maps NLS3D 02 Near base Rupelian, NLS3D 03 Near base Middle Eocene and NLS3D 04 Near base Cenozoic were generated from the horizons of NLS3D.

3.3.3 Challenges / problems

Local intersections in the Cenozoic units occur when comparing the Near Base Rupelian with the units above and below it. In some areas, the depth of the Near Base Rupelian horizon is lower than that of the Near Base Lower/Middle Miocene horizon (see Figure 9).

Figure 9: View of occurring intersections between Near Base Rupelian (beige) and Near base Lower/Middle Miocene (orange).

The most important reason for this overlap is that different input models have been used, which differ significantly in their resolution, type of input data, etc. Another reason is that horizons from DGM-NNL model (Base NMRF - Rupel Formation and Base NLFSS - Brussels Sand Member) are present at locations above saltdomes, although interpretations for these horizons show no occurrence above saltdomes.

The horizons generated in the 3D input models or modeling methods used are not aligned with each other. By calculating thickness maps for Cenozoic units from NLS3D, these overlaps create gaps. As a result, the distribution of the Cenozoic units is partially incompletely represented.

3.3.4 Results and dissemination

Table 7: Overview of thickness maps, input depth maps from NLS3D and properties of thickness maps in meter.

Name of thickness map	Name of top depth map	Name of base depth map	Minimum thick-ness	Mean thick-ness	Maximum thick-ness
nls3d_v2_02_base_ rupelian_thickness_3034	Near Base Lower/Middle Miocene	Near Base Rupelian	5	65	535
nls3d_v2_03_near_base middle_eocene_thickness _3034	Near Base Rupelian	Near Base Middle Eocene	5	157	425
nls3d_04_near_base_ cenozoic_thickness_3034	Near Base Middle Eocene	Near Base Cenozoic	5	243	800

Due to disconformity “nls3d_v2_02_base_rupelian_thickness_3034” (see *Figure 10*) represents thickness of Rupel Formation in this area, including Vessem Member / Rupel Basal Sand Member. As overlying horizon “Near Base Lower/Middle Miocene” was subtracted from “Near Base Rupelian”.

The minimum thickness of 5m results from calculation settings in GOCAD. The average thickness is calculated with 65m. Maximum value is calculated for 535m.

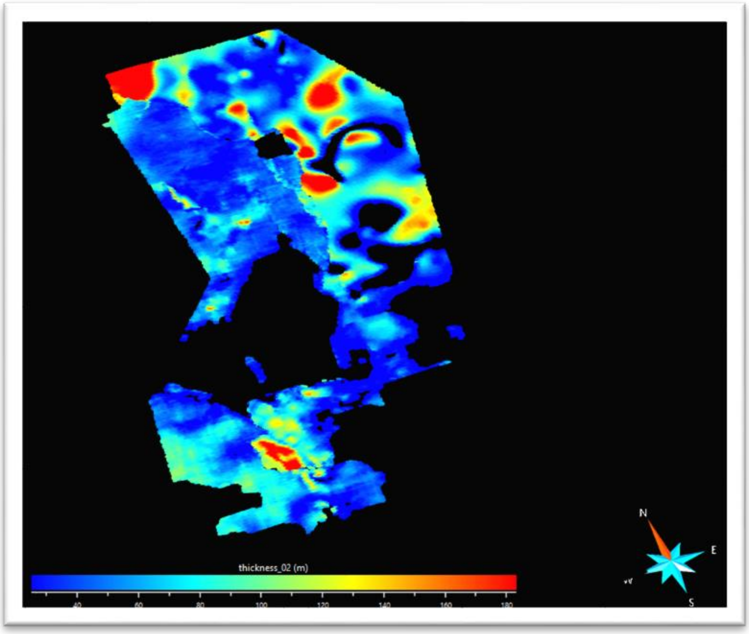

Figure 10: range of thickness for “nls3d_v2_02_base_rupelian_thickness_3034”.

For “nls3d_v2_03_near_base_middle_eocene_thickness_3034” (see *Figure 11*) “Near Base Rupelian” was subtracted from “Near Base Middle Eocene”.

The minimum thickness of 5m results from calculation settings in GOCAD. The average thickness is calculated with 157m. Maximum value is calculated for 425m.

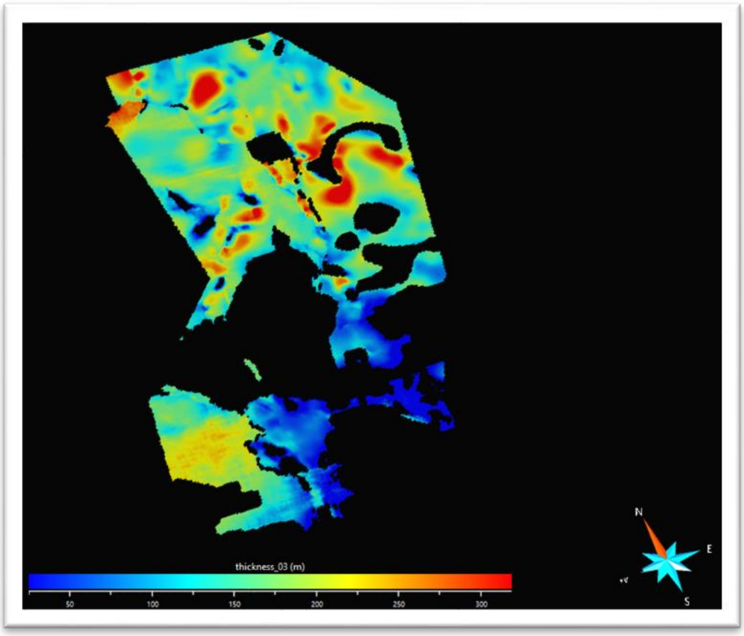

Figure 11: range of thickness for "nls3d_v2_02_base_rupelian_thickness_3034".

The third thickness map "nls3d_04_near_base_cenozoic_thickness_3034" (see Figure 12) results of the difference between the Horizons "Near Base Cenozoic" and "Near Base Middle Eocene".

The minimum thickness of 5m results from calculation settings in GOCAD. The average thickness is calculated with 243m. Maximum value is calculated for 800m.

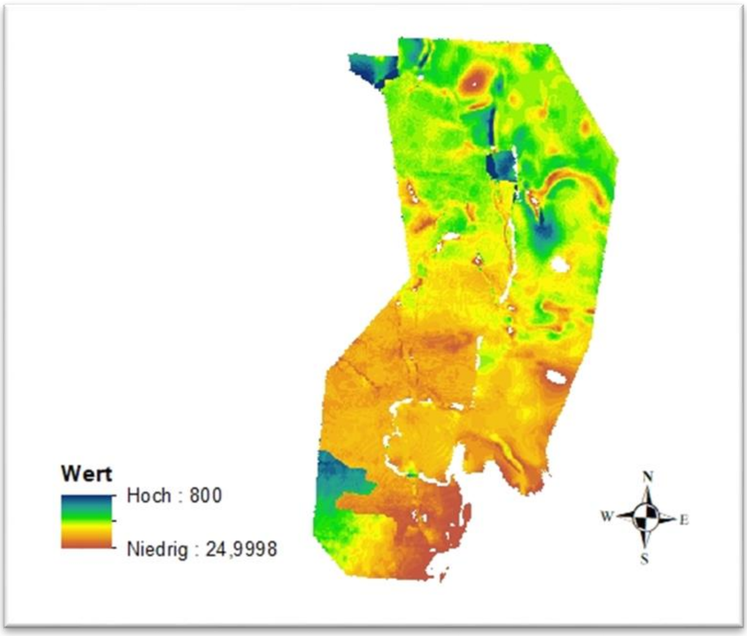

Figure 12: range of thickness for "nls3d_04_near_base_cenozoic_thickness_3034".

Table 8: Overview of deliverable 1.3

Deliverable	Distribution, depth and thickness maps of three Cenozoic units: • nls3d_v2_02_base_rupelian_thickness_3034 • nls3d_v2_03_near_base_middle_eocene_thickness_3034 • nls3d_04_near_base_cenozoic_thickness_3034 (ASCII file of each thickness map)
Short description, remarks	Thickness maps have been derived from the new harminozed cross-border model. These maps show variabilty of thickness in Cenozoic units with a minimun thickness of 5m.
Link	EGDI http://www.europe-geology.eu/

3.4 Task 1.4 Investigation of geothermal reservoirs and properties

3.4.1 Objectives

Investigation of different properties like porosity, permeability and others of potential Cenozoic reservoirs.

3.4.2 Approach

One primary goal was to identify and characterize geothermal reservoirs. In several meetings we discussed potential reservoirs in the project area. In a first step we informed each other about the existing maps and the way of geothermal usage in the both states. An inventory of existing geothermal maps was set up in D1.1.

In following steps lithology, thickness and distribution of Cenozoic horizons were examined to identify potential geothermal reservoirs. Although Quaternary sediments are used intensively for extraction of geothermal energy these could not be involved, because no Quaternary horizons were modeled in NLS3D. Two lithostratigraphic units were discussed in detail, because of promising description, which could serve for potential geothermal usage. Due to few description in wells distribution and thickness of Vessem Member / Rupel Basal Sand Member could only be estimated. Lithology might be promising but further detailed investigation of sedimentation and lithology is necessary to assess thickness and distribution of this unit. Unfortunately no data of porosity and permeability could be found in literature or databases at TNO or LBEG.

The second unit, which was examined, is the Brussels Sand Member / Brüsselsand. The sediments of Eocene age had a promising distribution in the northern part of the project area. Locations of wells describing the “Brüssel Sand” in depth between 180 and 720 m below surface are displayed in Figure 13 . Lithology description in these wells is marly or silty and not as expected sandy.

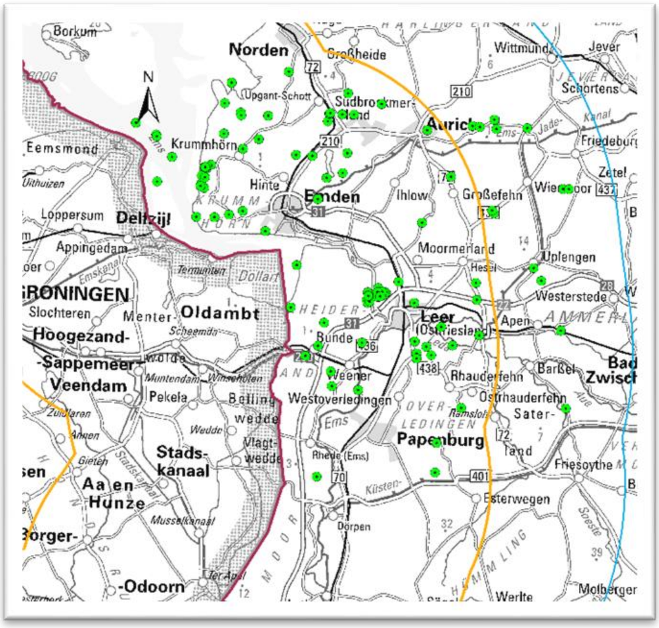

Figure 13: Wells with lithostratigraphic description of Brüssel Sand in Lower Saxony.

Brüssel Sand is described as calcareous, lumachelle bearing, glauconitic fine sandstone with intercalated clay layer (Kockel et al., 1992) in the area of Papenburg.

Lithology might not be as promising as expected but further detailed investigation of sedimentation and lithology is necessary to assess thickness and distribution of this unit. Unfortunately only two values of porosity from sonic logs at two boreholes and no permeability data could be found in literature or databases at TNO or LBEG.

3.4.3 Results and dissemination

An inventory of existing geothermal maps was set up in D1.1.

3.5 Task 1.5 A harmonized decision support map for the Netherlands-Lower Saxony cross-border region

3.5.1 Objectives

For regional planning in an area with conflicts of different subsurface uses like groundwater supply, usage and storage of geothermal energy, production of oil and gas a decision support map, which shows the geological and hydraulic barrier protecting the freshwater for damnifications caused by usage of the deeper subsurface. A decision support map should be used to assess impact of activities in the deeper underground regarding questions of preventive groundwater protection. Depth and distribution of Base Rupelian can be used for administrative and industrial planning.

3.5.2 Approach

After implementation of remodelled layers into the second version of NLS3D horizon Near Base Rupelian was a result of task 1.2. and 1.3. Near Base Rupelian was the base for the decision support map.

3.5.3 *Results and dissemination*

The decision support map shows the depth of the base and the distribution of a very significant barrier. This barrier is build up of the Rupel clay / Rupel Formation in the study area (*see Figure 14).* Where geological processes like sedimentation, erosion or rising of saltdomes did not lead to missing of this unit, this barrier builds up the seal for deeper groundwater aquifers. In general gaps in the map can be interpreted as areas, where Rupel Formation is absent. Along the border gaps represent areas where, Rupel Formation may be present but due to high deviations in depth of Near Base Rupelian thishorizon doesn't fit on these locations.
For regional planning this map is a reliable base for discussions on competing interests concerning usage of geological underground to derive information about Rupel Formation for detailed investigations.

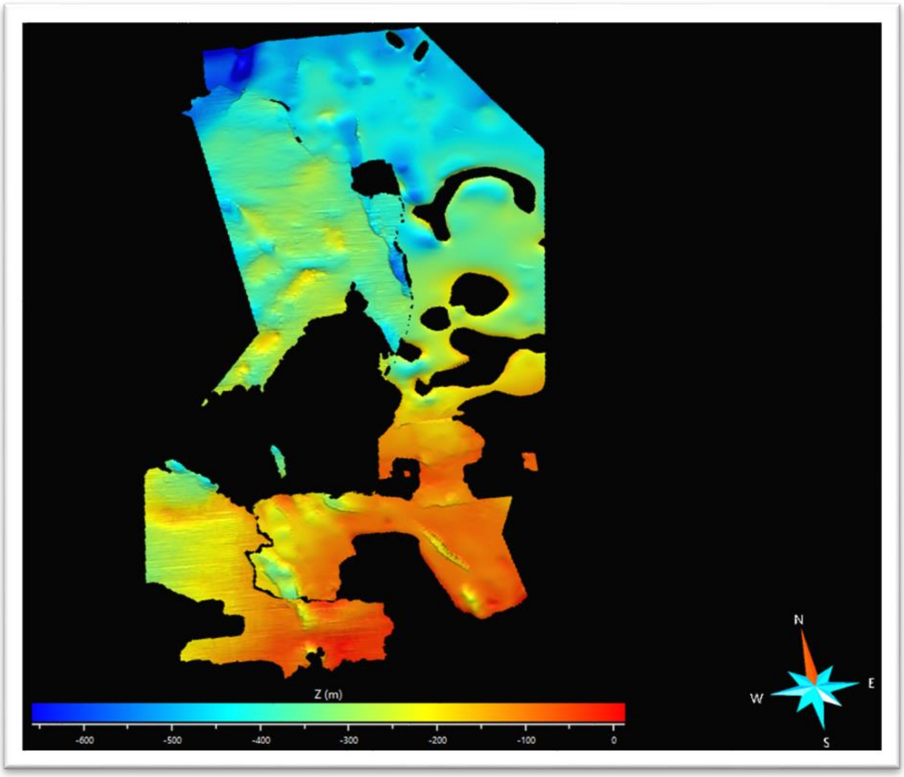

Figure 14: Decision support map showing distribution and depth of "Near Base Rupelian" (NLS3D).

It is planned to promote this map in different ways, when it is published on EGDI.

Table 9: Overview of deliverable 1.4

Deliverable	Decision support map: Geological barrier between freshwater and saltwater
Short description, remarks	For regional planning this Decision support map is a reliable base for discussions on competing interests concerning usage of geological underground to derive information about Rupel Formation for detailed investigations.
Link	EGDI http://www.europe-geology.eu/

4 DISCUSSION OF LESSONS LEARNED

In this work package we dealt with harmonization issues as well as with socioeconomic issues related to geothermal use of the underground and setting up a map to be used for planners and decision makers supporting decision on usage of the subsurface.

For the first main goal of our cross-border work, the harmonization of existing 3D models, we worked on the fact that existing 3D models end at national borders, but geological sediments or structures are not ending at national borders. By comparing the 3D models at both sides of the border a methodology for harmonization has been developed. During this harmonisation process the following lessons have been learned:

- In general the 3D models fit better as expected.
- Horizons based on seismic picked horizons + wells fit better, than horizons based only on wells.
- Data gaps or areas with low density of input data towards the border of the model lead to fuzziness and generate deviations due to uncertainty. These data gaps may have a reason in the circumstances, that data exchange with Germany was not possible in former times.
- Some horizons fit very well, because these horizons are characterized by prominent reflectors, which are strongly formed and can be traced over several tens of kilometres in seismic datasets.
- Differences in depth and/or in structure, which exceed the threshold for harmonization, result in areas, which cannot be harmonized.
- Different interpretations of the sediments in boreholes are used, this lead to misinterpretations of the layers/horizons. For example strongly generalized layer descriptions in boreholes (like North Sea Super Group) might result in invisibleness of geological units during automatic interpretation.
- Changes in the stratigraphic classification and assignment of individual sediments to certain chronostratigraphic stages over the last 70 years led to the fact that in some cases the horizons from boreholes were assigned to the wrong horizons during modeling.
- Vulnerability of the method for harmonizing corresponding horizons - the method was designed to be able to map and compensate the expected high deviation of the deepest horizons very well. Contrary to expectations, the shallowest horizons showed the greatest deviation in the harmonization in relation to the depth.
- It is not possible to harmonize the faults from these 3D models, due to the fact that the Dutch 3D model has interpreted and modelled fault-planes in 3D and the fault planes at the GTA3D model had to be reconstructed and deduced from fault-gaps at horizon levels.
- By comparison of the national stratigraphic charts a separate, transnational stratigraphic classification has been developed, which is perhaps only valid for the model area.
- Intersection problems occur because of usage of layers from different models to create a harmonized 3D model without gaps, it is inevitably necessary to start again with the raw data. First of all, the raw data must be harmonized, especially with regard to

structural features such as faults and salt domes. Then the harmonized raw data can be implemented in a new 3D model.

For the socioeconomic aspect of our work, we generated maps of Cenozoic units. These maps represent in most cases more than one lithostratigraphic unit. Inaccuracies which arise from the points mentioned above are included. But these maps can be used for overview work. For detailed questions regarding geothermal aspects further investigation are necessary.

5 CONCLUSIONS

Work carried out in this Work package and development of a methodology for harmonization show, that harmonization of existing 3D models works. Due to comparable model concepts 10 horizons of existing 3D models could be merged, but disparity in models became evident also. For example not all horizons could be harmonized, because of different reasons, for example no corresponding horizon could be identified on the other side of the border. Big differences in depth and in structure in several cross-border areas result in areas, which cannot be harmonized. These areas are represented by gaps along the national border. To create a harmonized 3D model without gaps, it is inevitably necessary to start again with the raw data and a detailed check of areas represented by gaps in NLS3D. But first of all, the raw data must be harmonized, Descriptions of wells like geological information, stratigraphic nomenclature of geological units and the change of this in the last decades must be examed in detail and harmonized. Processing of seismic data and interpretation of seismics should be executed identical or comparable. As a next step a harmonized velocity model for the conversion from time to depth domain is essential. Then the harmonized raw data can be implemented in a new 3D model. With regard to structural features such as faults and salt domes, harmonization structural information is also necessary.

In the past data sharing was not possible in Germany due to legal restrictions, which have been overcome now. Legal base for working on harmonization of input data and 3D models has improved.

The work on the decision support map should be regarded as a starting point for working in detail on geological units, with a cross-border distribution. Rupel Formation can be regarded as a hydraulic and geological barrier, which protect fresh water resources from saltwater contamination. Promoting such important horizons for decision making and planning processes is very important. Therefore we recommend a more detailed scale of modeling as we started in this project. We recommend the same for other important geological units like the Brussel Sand Member / Brüsselsand, which might bear potential for geothermal usage.

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