Deliverable 1.1

Inventory Report

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GENERAL INTRODUCTION

In WP1 of 3DGEO-EU Lower Saxony and the Netherlands are involved. Lower Saxony is represented by the Authority for Mining, Energy and Geology (Landesamt für Bergbau, Energie und Geologie, LBEG) and the Netherlands are represented by the Netherlands Organisation for Applied Scientific Research (TNO). Both institutions are experienced in three dimensional modeling of the subsurface.

In 3DGEO-EU both partners will work in a cross border pilot area (see Figure 1) on harmonization of existing 3D models and Cenozoic geothermal reservoir maps.

Figure 1: Overview of the pilot area: red box in the left picture marks the participating countries, the blue area in the right picture shows the cross border pilot area in the Netherlands and Lower Saxony (Eurostat, 2018).

This report (deliverable of task 1.1) is a state of the art inventory of existing 3d models (see chapter 1) and Cenozoic geothermal reservoir maps and their properties (see chapter 2) in Lower Saxony and the Netherlands.

This inventory will be the base for the following cross border tasks in this project:

- In task 1.2 LBEG and TNO strive to establish a consistent 3d model of the pilot area. Therefore we present in chapter 3 criteria for harmonization.
- Harmonized distribution, depth and thickness maps of Cenozoic geothermal reservoirs will be the result of task 1.3.
- Properties like porosity, permeability and thermal conductivity will be gathered and loaded into a database in task 1.4, which will be the base to create Cenozoic geothermal maps under task 1.5.
- In task 1.6 a harmonized map of the hydraulic barrier between fresh groundwater and the deep salt groundwater system is presented as a decision support tool for planners.

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1 EXISTING 3D MODELS

Our work is based on four 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 this report the acronyms as mentioned in table 1, will be used.

Table 1: Overview of existing 3D models and used acronyms in this report.

3D models	
acronym	**name**
GTA3D (LBEG)	Geotektonischer Atlas 3D
DGM-deep V5.0 (TNO)	Digitaal Geologisch Model: DGM- diep
DGM-NNL (TNO)	Digitaal Geologisch Model Noord-Nederland
SPBA	Southern Permian Basin Atlas

Elaboration on criteria for harmonization of 3D models requires the knowledge of differences between the datasets. The properties and characteristics of these models will be listed in this chapter mainly as tables to derive criteria which will be used for the harmonization (chapter 3).

1.1 Involved countries

The involved countries, who have worked on the four 3D models are listed in table 2.

Table 2: Overview of involved nations.

3D model	**Involved countries**
GTA3D	Lower Saxony (Germany)
DGM-deep V5.0	The Netherlands
DGM-NNL	The Netherlands
SPBA	United Kingdom, Belgium, The Netherlands, Denmark, Germany and Poland

1.2 Extent

The extent of each 3D model is shown in figure 2. GTA3D and DGM-deep V5.0 extend over the whole country area of Lower Saxony respectively the Netherlands. DGM-NNL extends over the northeastern part of the Netherlands (see Figure 2). Only SPBA is a crossborder model with more countries involved.

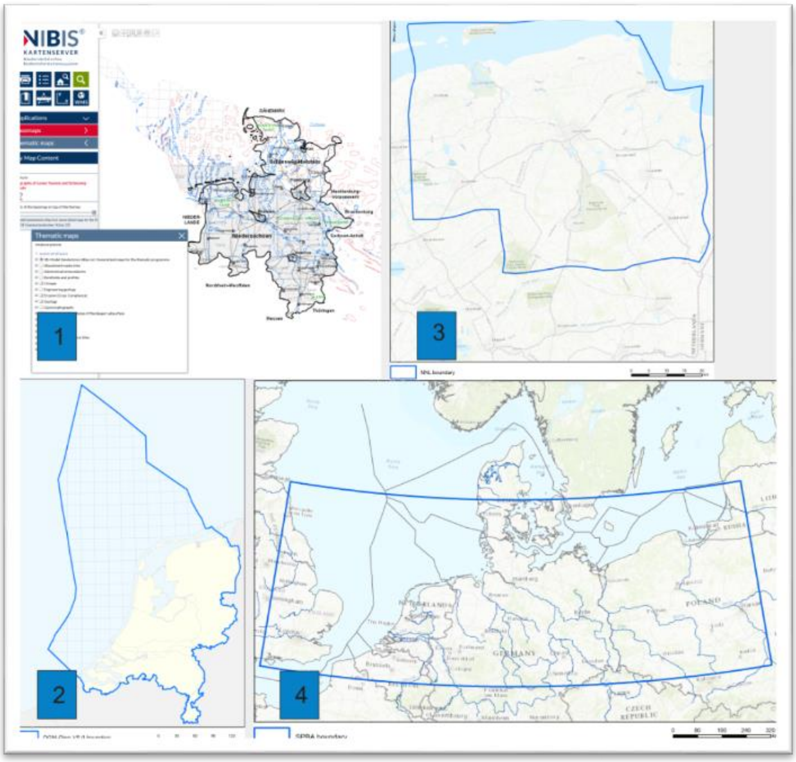


Figure 2: 1) Extent of GTA3D model (grey shadow) (LBEG, 2018), 2) Extent of DGM-deep V5.0 (blue border), 3) Extent of DGM NNL (blue border) and 4) Extent of SPBA model (blue border) (Doornenbal et al., 2010).

1.3 Input data

Table 3: Different input data of existing 3D models.

3D model	Input data
GTA3D	14 depthmaps of the Tectonic Atlas of Northwest Germany and the German North Sea Sector (Baldschuhn et al., 2001); depth of Quaternary basis 1: 500 000 (NLfB, 1995); digital surface model; state of knowledge: ~ 2001
DGM-deep V5.0	seismic data and well data
DGM-NNL	3D seismic data and well data
SPBA	seismic data and well data

Database of the models is quite different at first glance. GTA3D is a model established on an older seismic and geological interpretation, executed before 1996. It is a model based on structural depth maps of the ‘Geotektonischer Atlas von Nordwest-Deutschland und dem deutschen Nordsee-Sektor’ (Baldschuhn et al., 2001). These maps have been generated by interpretation of 2D seismic data and well information. 2D geological cross sections, thickness maps and paleotectonic maps complete these maps. Based on digitized structural maps, triangulated three dimensional surfaces were created to represent the base of the horizons (see Figure 3). For the other 3D models seismic data and well data was used as direct input data.

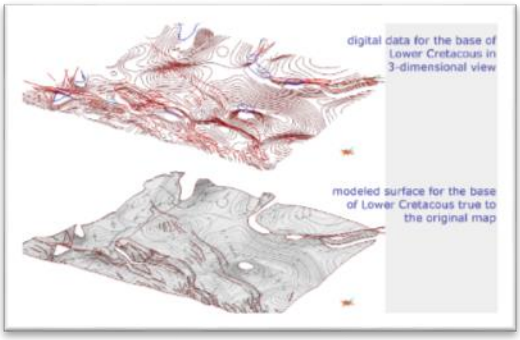


Figure 3: GTA3D – example of the modeling workflow of the Lower Cretaceous horizon, based on digitized maps (Bombien et al. 2012).

In GTA3D, data inconsistencies, caused by intersection of different structural maps in 3D model, have not been revised. Figure 4 shows an example of intersecting base surfaces. Due to 2-dimensional mapping of the input data, which was done in the 1980´s and 1990´s without the use of 3D modeling software, these inconsistencies mainly occur in areas of complex fault systems.

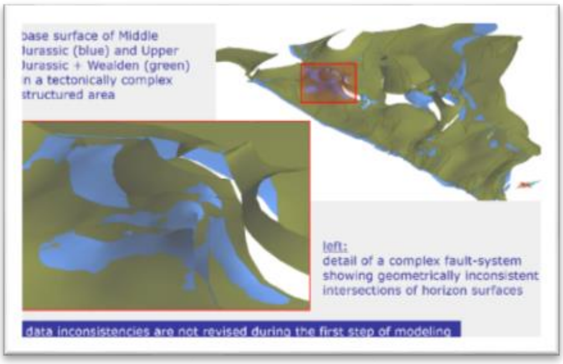


Figure 4: GTA3D - example of data inconsistencies; intersection of base surface of Middle Jurassic (blue) and base surface of Upper Jurassic+Wealden (green) (Helms 2018, unpublished).

1.4 Date of publication

It is necessary to record the date of publication. Table 4 lists the date of publication of the 3D models.

Table 4: Date of first publication.

3D model	Date of publication
GTA3D	17.07.2012
DGM-deep V5.0	Q1 2019
DGM-NNL	Q1 2019
SPBA	June 2010

1.5 Model type

Table 5: Different modeltypes of existing 3D models.

3D model	Model type
GTA3D	regional, main lithostratigraphical intervals
DGM-deep V5.0	regional, main lithostratigraphical intervals
DGM-NNL	detailed, reservoir layers
SPBA	regional, main lithostratigraphical intervals

1.6 Stratigraphical Nomenclature

In general 3D models exist of lithostratigraphic layers which are described in Stratigraphical Nomenclatures (see table 6).

Table 6: Different Stratigraphical Nomenclatures of existing 3D models.

3D model	Stratigraphical Nomenclature
GTA3D	lithostratigraphic units (see Table 7)
DGM-deep V5.0	https://www.dinoloket.nl/nomenclator and see Figure 5
DGM-NNL	https://www.dinoloket.nl/nomenclator and see Figure 5
SPBA	Each of the participating geological surveys has published a lithostratigraphic nomenclature for their country: UK (Cameron et al., 1993; Johnson et al., 1994; Lott & Knox, 1994; Waters et al., 2007), Belgium (Bultynck & Dejonghe, 2002), the Netherlands (Van Adrichem Boogaert & Kouwe, 1993), Denmark (Michelson et al., 2003; Schiøler et al., 2005), Germany (STD 2002; Menning & Hendrich, 2005), and Poland (Wagner, 2008).

Table 7: Stratigraphic terms in northwestern part of Germany, Age in million years (Ma) modified after (Baldschuhn et al., 2001) based on (Menning, 1997).

Age of base	Epoch (german)	Stratigraphic Unit (german)	Code (german)	Stratigraphic Series or stage (english)
1,8 Ma	Quartär	Quartär	(q)	Pleistocene-Holocene
	Neogen (Jungtertiär)	Pliozän	(tpl)	Pliocene
24 Ma		Miozän	(tmi)	Miocene
	Paläogen Alttertiär)	Oligozän	(tol)	Oligocene
		Eozän	(teo)	Eocene
		Oberpaläozän	(tpao)	Upper Paleocene
65 Ma		Dan	(td)	Danian
	Oberkreide	Maastricht	(krma)	Maastrichtian
		Campan	(krca)	Campanian
		Santon	(krsa)	Santonian
		Coniac	(krcc)	Coniacian
		Turon	(krt)	Turonian
99 Ma		Cenoman	(krc)	Cenomaian
continued on next page				

Age of base	Epoch (german)	Stratigraphic Unit (german)	Code (german)	Stratigraphic Series or stage (english)
		Alb	(krl)	Albian
		Apt	(krp)	Aptian
		Barrême	(krb)	Barremian
	Unterkreide	Hauterive	(krh)	Hauterivian
		Valangin	(krv)	Valanginian
144 Ma		Berrias = Wealden	(Wd)	Berriasian
		Serpulit	(joS)	Tithonian
		Münder Mergel	(joM)	Tithonian
		Eimbeckhäuser P.-K.	(joE)	Tithonian
	Oberjura	Gigas-Schichten	(joG)	Tithonian
	(Malm)	Kimmeridge	joKI)	Kimmeridgian
		Korallenoolith	(joK)	Oxfordian
159 Ma		Heersumer Sch.	(joH)	Oxfordian
		Callovium	(jmcl)	Callovian
	Dogger	Bathonium	(jmbt)	Bathonian
	(Mittlerer Jura)	Bajocium	(jmbj)	Bajocian
180 Ma		Aalenium	(jmal)	Aalenian
		Toarcium	(jutc)	Toarcian
	Lias	Pliensbachium	(jupl)	Pliensbachian
	(Unterer Jura)	Sinemurium	(jusi)	Sinemurian
206 Ma		Hettangium	(juhe)	Hettangian
		Rhät	(ko)	Rhaetian
		Steinmergelkeuper	(km4)	Norian
		Oberer Gipskeuper	(km3)	Carnian
	Keuper	Schilfsandstein	(km2)	Carnian
		Unterer Gipskeuper	(km1)	Ladinian
231 Ma		Lettenkeuper	(ku)	Ladinian
		Ob. Muschelkalk	(mo)	Ladinian-Ansian
	Muschelkalk	Mittl. Muschelkalk	(mm)	Ansian
240 Ma		Unt. Muschelkalk	(mu)	Ansian
	Ob.Buntsandstein	Röt	(so)	Ansian
		Solling-Folge	(smS)	Olenekian
	Mittl.	Hardegsen-Folge	(smH)	Olenekian
	Buntsandstein	Detfuth-Folge	(smD)	Olenekian
		Volpriehausen-Folge	(smV)	Olenekian
		Quickborn-Folge	(smQ)	Olenekian
	Unt.	Bernburg-Folge	(suB)	Induan
251 Ma	Buntsandstein	Calvörde-Folge	(suC)	Induan
		Mölln-Zyklus	(z7)	Changhsingian
		Friesland-Zyklus	(z6)	Changhsingian
		Ohre-Zyklus	(z5)	Changhsingian
	Zechstein	Aller-Zyklus	(z4)	Changhsingian
		Leine-Zyklus	(z3)	Wuchiapingian
		Staßfurt-Zyklus	(z2)	Wuchiapingian
258 Ma		Werra-Zyklus	(z1)	Wuchiapingian
	Rotliegend	Oberrotliegend	(ro)	Artiskian-Wuchiapingian
300 Ma		Unterrotliegend	(ru)	Gzhelian-Artiskian
		Stefan	(cst)	Kasimovian-Gzhelian
	Oberkarbon	Westfal	(cw)	Bashkirian-Kasimovian
326,3 Ma		Namur	(cn)	Serpukhovian-Bashkirian
353,8 Ma	Unterkarbon	Dinant	(cd)	Tournasisian-Serpukhovian

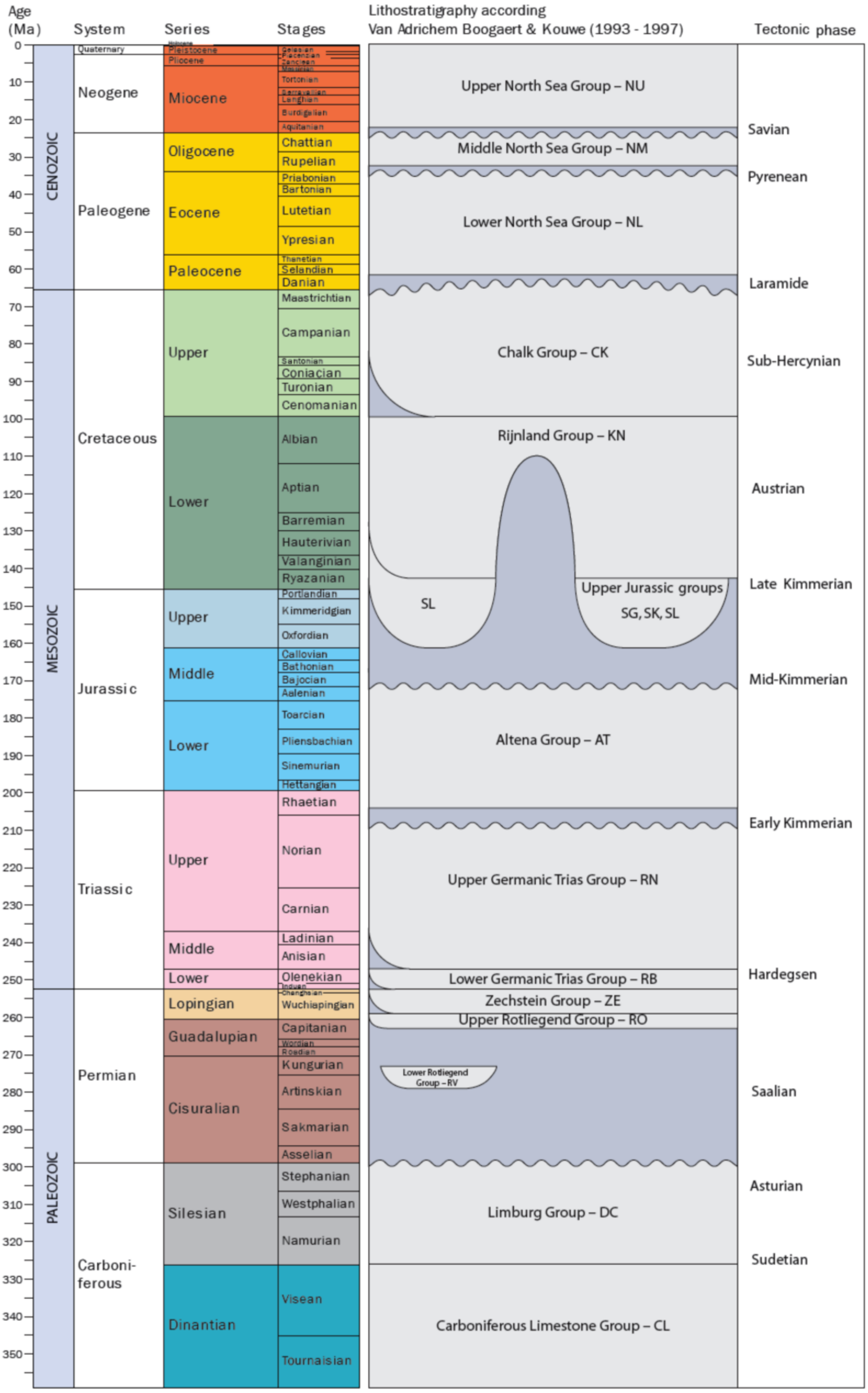


Figure 5: Stratigraphical Nomenclature used in DGM-deep V5.0 and DGM-NNL (TNO, 2018).

1.7 Modeled layers

Table 8: Different modeled layers of existing 3D models.

3D model	Modeled layers
GTA3D	15 layers (see Table 9 and Figure 6)
DGM-deep V5.0	NU, N, CK, KN, S, ATPO, AT, RN, RB, ZE, RO + 2 Carb.horizons (see Table 10)
DGM-NNL	67 layers (see Table 10)
SPBA	regional, main lithostratigraphical intervals (see Figure 7 and Figure 8)

Table 9: 14 lithostratigrahic units published in GTA; in GTA3D Quaternary base was additionally modeled.

Stratigraphic Units Geotectonic Atlas NW-Germany	Acronym
Base deepest Middle Miocene (Reinbeck)(NN5) to highest Pliocene	03_tmim-tpl
Base deepest Lower Miocene (Vierlande) (NN1) to youngest Lower Miocene (Hemmoor) (NN4)	04_tmiu
Base Middle Oligocene (Rupel) (NP23) to youngest Upper Oligocene (Neochatt) (NP25)	05_tolm-tolo
Base Brussels Sand to Top Lower Oligocene	06_tolm-teoo
Base Upper Paleocene (Landen) (NP8) to youngest Lower Eocene (Lower Eocene 4) (NP13)	07_tpao-teou
Base Cenoman to highest Dan	08_kro
Base deepest marine Lower Cretaceous (Valangin) to highest Lower Cretaceous (Oberalb)	09_kru
Base deepest Upper Jurassic (Oxford) to "Wealden" (Berrias)	10_jo-Wd
Base highest Lias (Obertoarcium) to highest Dogger (Callovium)	11_jutco-jmclo
Base lowest Lias (Hettangium) to Upper Lias (Lower Toarcium, Posidonia Shale)	12_juhe-jutcu
Base deepest Keuper (Lettenkeuper) to Upper Keuper (Upper Rhaetian)	13_k
Base Upper Buntsandstein (Roetsalinar) to Upper Muschelkalk (Ceratitenschichten)	14_so-m
Base deepest Lower Buntsandstein (Calvoerde) to highest Middle Buntsandstein (Solling)	15_su-sm
Base deepest Zechstein (Kupferschiefer Werra Folge) (T1) to highest Zechstein (Moelln-Cycle) (z7) oder Broeckelschiefer	16_z

Geologische Einheiten	System/ Periode	Ärathem/ Ära	Alter [Ma] (DSK 2002)
Quartär ungegliedert	Quartär	Känozoikum	1,8 – 0
Mittelmiozän bis Pliozän	Tertiär		16,5 – 1,8
Untermiozän			23,8 – 16,5
Rupel bis Oberoligozän			32,5 – 23,8
Mitteloligozän bis Obereozän			49 – 32,5
Oberpaläozän bis Untereozän			58 – 49
Oberkreide	Kreide	Mesozoikum	99 – 65
Marine Unterkreide			142 – 99
Oberjura und "Wealden"	Jura/Kreide		156,5 – 137
Mitteljura (Dogger)	Jura		178 – 156,5
Unterjura (Lias)			200 – 178
Keuper	Trias		235 – 200
Röt und Muschelkalk			244,5 – 235
Unterer und Mittlerer Buntsandstein			251 – 244,5
Zechstein	Perm	Paläozoikum	258 – 251

Figure 6: General legend of geological units, age and colours used in 3dD model GTAD3D (LBEG, 2008).

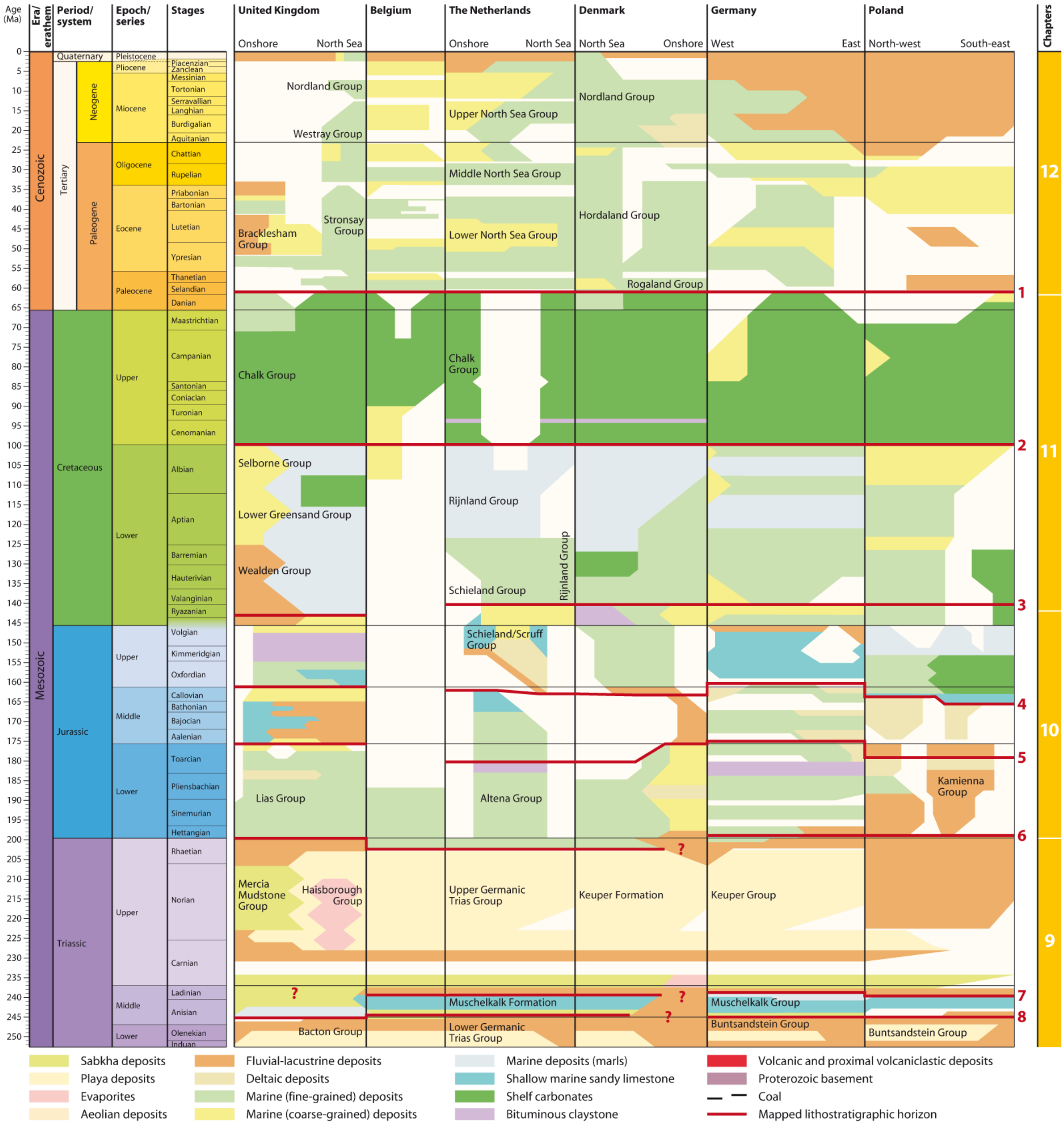
Table 10: Stratigraphic units and model layers of DGM-deep V5.0 and DGM-NNL (Ten Veen et.al., in prep).

Quaternary	Naaldwijk
	Boxtel
	Eem
	Drente
	Drachten
	Urk Tynje
	Peelo
	Urk
	Appelscha
Neogene	Peize
	Maassluis
	Oosterhout
	BREDA (BASE NU)
Paleogene	Rupel Clay
	VESSEM MEMBER
	ASSE MEMBER
	BRUSSEL MEMBER
	IEPER MEMBER
	Basal Dongen Tuffite
	LANDEN CLAY (BASE N)
Late Cretaceous	Ommelanden Formation
	Plenus Marl
	TEXEL FORMATION (BASE CK)
Early Cretaceous	Upper Holland Marl
	Middle Holland Claystone
	Lower Holland Marl
	Vlieland Claystone I
	Friesland Member
	Vlieland Claystone II
	BENTHEIM SANDSTONE (BASE KN)
Late Jurassic	Upper Coevorden
	Middle Coevorden
	Lower Coevorden
	Serpulite Member
	Weiteveen Upper Marl
	Weiteveen Upper Evaporite
	Weiteveen Lower Marl
	Weiteveen Lower Evaporite
	WEITEVEEN BASAL CLASTICS (BASE S)

Early and Middle Jurassic	Werkendam Formation
	Aalburg Formation
	SLEEN FORMATION (BASE AT)
Triassic	Upper Keuper Claystone
	Dolomitic Keuper
	Red Keuper Claystone
	Red Keuper Evaporite
	Middle Keuper Claystone
	Main Keuper Evaporite
	Lower Keuper Claystone
	Upper Muschelkalk
	Middle Muschelkalk Marl
	Muschelkalk Evaporite
	Lower Muschelkalk
	Upper Röt Claystone
	Upper Röt Evaporite
	Intermediate Röt Claystone
	Main Röt Evaporite
	SOLLING CLAYSTONE (BASE RN)
	Basal Solling Sandstone
	Hardegsen Formation
	Detfurth Claystone
	Lower Detfurth Sandstone
	Volpriehausen Clay-Siltstone
	Lower Volpriehausen Sandstone
	Rogenstein
	MAIN CLAYSTONE (BASE RB)
Permian	**ZECHSTEIN GROUP (BASE ZE)**

No.	Name of mapped lithostratigraphic horizon	Description	Approximate age (Ma)
1	Near base Tertiary	Top Danian or top of the Chalk Group	61
2	Base Upper Cretaceous	Base of the Chalk Group (base Cenomanian)	100
3	Near base Lower Cretaceous	Approximately near base Ryazanian; may correspond to an unconformity	140
4	Near base Upper Jurassic	This horizon corresponds to a level varying from the Callovian to the base of the Oxfordian.	162
5	Near base Middle Jurassic	This level corresponds to the top of the Lias Group (base West Sole Group and equivalents in the UK; top of the Posidonia Shale Formation in the Netherlands) and is a marked unconformity over much of the area	176
6	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	201
7	Near base Upper Triassic	This level corresponds to a change from clastic-dominated to limestone-dominated sediments. It is not mapped in the UK and Denmark	237
8	Near base Middle Triassic	Base of the Röt evaporites	245
9	Near base Lower Triassic	Base of the Buntsandstein	253
10	Base Zechstein	The base-Kupferschiefer reflector is mostly indistinct or not present because of low impedance contrast. In general, the seismic reflector that has been used is a younger horizon: top basal anhydrite (Stassfurt series). An agreed thickness has been added to this marker to create the base-Zechstein map	258
11	Base upper Rotliegend	This level corresponds with the base of the upper Rotliegend clastics. In general, the horizon was created by combining the upper Rotliegend thickness map, based on well data, and the depth of the base-Zechstein horizon	265

Figure 7: Overview of the lithostratigraphic horizons mapped in the SPBA area. These horizons have been numbered from 1 to 11 and are indicated in Figure 8 (Doornenbal et al., 2010).



Age (Ma)
Era/erathem
Period/system
Epoch/series
Stages
United Kingdom
Belgium
The Netherlands
Denmark
Germany
Poland
Chapters
Onshore
North Sea
Onshore
North Sea
North Sea
Onshore
West
East
North-west
South-east
Cenozoic
Mesozoic
Quaternary
Tertiary
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper
Lower
Upper
Middle
Lower
Upper
Middle
Lower
Piacenzian
Zanclean
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Ryazanian
Volgian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
Nordland Group
Westray Group
Upper North Sea Group
Nordland Group
Middle North Sea Group
Brackelsham Group
Stronsay Group
Lower North Sea Group
Hordaland Group
Rogaland Group
Chalk Group
Chalk Group
Selborne Group
Lower Greensand Group
Wealden Group
Rijnland Group
Schieland Group
Rijnland Group
Schieland/Scruff Group
Lias Group
Altena Group
Kamienna Group
Mercia Mudstone Group
Haisborough Group
Upper Germanic Trias Group
Keuper Formation
Keuper Group
Muschelkalk Formation
Muschelkalk Group
Bacton Group
Lower Germanic Trias Group
Buntsandstein Group
Buntsandstein Group
Sabkha deposits
Playa deposits
Evaporites
Aeolian deposits
Fluvial-lacustrine deposits
Deltaic deposits
Marine (fine-grained) deposits
Marine (coarse-grained) deposits
Marine deposits (marls)
Shallow marine sandy limestone
Shelf carbonates
Bituminous claystone
Volcanic and proximal volcaniclastic deposits
Proterozoic basement
Coal
Mapped lithostratigraphic horizon

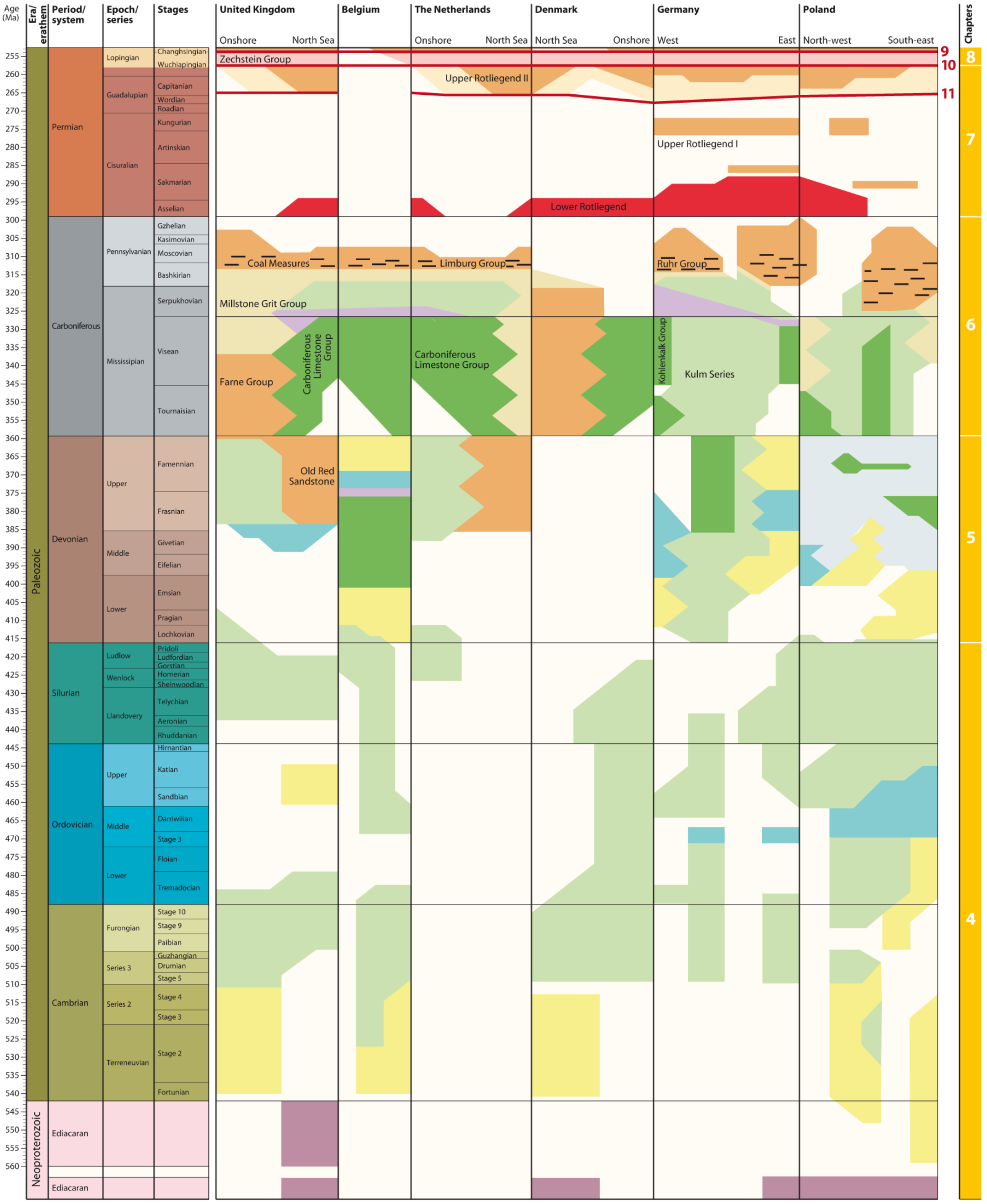


Figure 8: Stratigraphical correlation chart as used for SPBA; red lines and numbers show the (seismically mapped and) modeled layers (Doornenbal et al., 2010).

1.8 Faults

Information and data about faults and fault systems have been treated differently in the 3D models (see Table 11).

Table 11: Treatment of fault information in 3D models.

3D model	Representation of faults
GTA3D	no fault surfaces or correlation of fault traces were included; the vertical displacement on the stratigraphic horizons show indirectly the existence of faults.
DGM-deep V5.0	Fault surfaces have been mapped in seismics and partly modeled in 3D
DGM-NNL	Fault surfaces have been mapped in seismics and modeled in detail in 3D
SPBA	Main fault traces were retrieved from existing depth maps

In GTA3D, faults are not shown as fault surfaces. Information about faults in original GTA maps (see Figure 9) were transferred into the model as vertical displacements within the stratigraphic horizons.

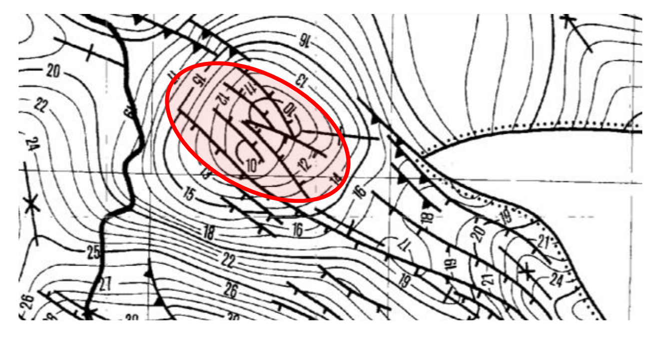


Figure 9: Detail of GTA map "base Lower Jurassic" showing fault traces and additional information (e.g., dip angle and dip direction and the fault shows a horizontal and vertical displacement) (e.g., red circle) of faults; modified after (Baldschuhn et al. 2001).

In the models DGM-deep and DGM-NNL faults have been mapped during the seismic interpretation. In the next step, the faults have been modelled in 3D by using the Petrel software. In the SPBA model the main faults have been retrieved from existing depth maps.

1.9 Publications

Table 12: Publication list.

3D model	Publications
GTA3D	Bombien et al. (2012) Der Geotektonische Atlas von Niedersachsen und dem deutschen Nordseesektor als geologisches 3D-Modell. In: Geowissenschaftliche Mitteilungen : GMit / Berufsverband Deutscher Geowissenschaftler.- 48 (2012), Seite 6-13.
DGM-deep V5.0	Kombrink, H., Doornenbal, J.C., Duin. E.J.T, den Dulk, M., van Gessel, S.F., ten Veen, J.H. & Witmans, N. (2012) New insights into the geological structure of the Netherlands; results of a detailed mapping project. Netherlands Journal of Geoscience 91-4: 419-446.
DGM-NNL	Ten Veen, J.H., Kruisselbrink, A.F., den Dulk, M. and Witmans, N., in prep. Digital Geological Model Noord Nederland (DGM-NNL), TNO report, xx pp.
SPBA	Doornenbal, J.C. and Stevenson, A.G. (editors), 2010. Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications b.v. (Houten). ISBN 978-90-73781-61-0

1.10 Modeling software

Table 13: Used 3D modeling software for generating existing 3D models.

3D model	Modeling software
GTA3D	Paradigm Gocad
DGM-deep V5.0	Petrel
DGM-NNL	Petrel
SPBA	Petrel

Different modeling software was used. While Lower Saxony modeled with Paradigm Gocad, the Netherlands used Petrel software. GTA3D consists of triangulated surfaces (ts-files) and DGM-deep, DGM-NNL and SPBA were modeled as grids.

1.11 Confidentiality and availability

Table 14: Confidentiality of existing 3d models and information about data availability.

3D model	Confidendiality and availabililty
GTA3D	public on http://nibis.lbeg.de/cardomap3/?TH=1410 as 3dpdf or browser version
DGM-deep V5.0	public on www.nlog.nl and www.dinoloket.nl, Q1 2019
DGM-NNL	public, Q1 2019
SPBA	Atlas public via www.nlog.nl, GIS product (maps+databases) for sale

1.12 Output data (sort/type, format)

Table 15: Description of output data.

3D model	Output data
GTA3D	3D pdf (scale 1: 100 000) or GST-browser version; Gocad-t-surf-Format; cross sections and artificial well information on http://nibis.lbeg.de/cardomap3/
DGM-deep V5.0	twt-, isopach-, depth-, V0-maps in pdf, arc-grid and zmap-grid, see https://www.nlog.nl/en/dgm-deep-v4-onshore
DGM-NNL	twt-, isopach-, depth maps
SPBA	Atlas on paper and pdf; GIS-product on DVD

1.13 Coordinate system

Table 16: Overview of coordinate system of existing 3D models.

3D model	Coordinate system
GTA3D	ETRS89 / UTM zone 32N (zE-N) (Europäisches Terrestrisches Referenzsystem von 1989 / Universale Transversale Mercatorabbildung Zone 32N) (EPSG 4647)
DGM-deep V5.0	Amersfoort/RD New, spheroid: Bessel 1841 (EPSG 28992)
DGM-NNL	Amersfoort/RD New, spheroid: Bessel 1841 (EPSG 28992)
SPBA	Lambert conformal conical (EPSG 5643)

1.14 Height reference system

Table 17: Overview of height reference system of existing 3D models

3D model	Height reference system
GTA3D	DE_DHHN92_NH
DGM-deep V5.0	onshore: Actueel Hoogtebestand Nederland v2 (AHN2) with reference level NAP (Nieuw Amsterdams Peil; offshore: msl (mid sea level)
DGM-NNL	Actueel Hoogtebestand Nederland v2 (AHN2) with reference level NAP (Nieuw Amsterdams Peil
SPBA	msl (mid sea level)

2 EXISTING MAPS OF CENOZOIC RESERVOIR ROCKS

In this chapter an inventory of existing maps of Cenozoic reservoir rocks of the study area is described.
In the Netherlands a public, web-based geographical information system "ThermoGIS V2.0" has been developed with the main goal of supporting companies and the government to develop geothermal energy in the Netherlands (see https://www.thermogis.nl/en). ThermoGIS provides depth, thickness, porosity and permeability maps of many potential aquifers in the Netherlands. Geothermal performance maps are calculated with the use of an integrated, stochastic, techno-economic performance module. The most important outputs of ThermoGIS are geothermal potential maps of the Netherlands that can be viewed in a map viewer. For our study area ThermoGIS provides two important aquifers i.e. Vessem Member (NMRFV) and the Brussels Sand Member (NLFFS), which are also geothermal reservoirs.
In Lower Saxony average thermal conductivity maps provide non-interpolated point information, which is based on well data. Avarage values per well are available for depths intervals from ground level to 40 m, 60 m, 80 m and 100 m depth. For our study area these maps show information mostly for quaternary deposits, which mostly consist of quaternary aquifers and in deeper parts of tertiary aquitards.
These existing maps will not be used in this project. The deliverable of task 1.5 will be geothermal maps for the pilot area based on our modeling work.

Main modeled Cenozoic layers such as top Neogene, base Neogene and base Paleogene from the existing models GTA3D, DGM-deep and DGM-NNL will be harmonized. Subsequently by using these layers as a geometrical reference together with the geometry (top, depth, thickness) from public wells the geometrical (top, base, thickness) maps of the geothermal reservoirs will be generated for the Cenozoic subsurface in the pilot area.

2.1 Input data

Table 18: different input data of existing maps

map	input data
Thermal conductivity for vertical heat exchangers (reference depth to 40m)	well information from ground levelup to 40m depth, assessment of thermal conductivity (after VDI (2010), LBEG measurements and Ad-Hoc AG Hydrogeologie (2008), groundwatersurface
Thermal conductivity for vertical heat exchangers (reference depth to 60m)	well information from ground levelup to 60m depth, assessment of thermal conductivity (after VDI (2010), LBEG measurements and Ad-Hoc AG Hydrogeologie (2008), groundwatersurface
Thermal conductivity for vertical heat exchangers (reference depth to 80m)	well information from ground levelup to 80m depth, assessment of thermal conductivity (after VDI (2010), LBEG measurements and Ad-Hoc AG Hydrogeologie (2008), groundwatersurface
Thermal conductivity for vertical heat exchangers (reference depth to 100m)	well information from ground levelup to 100m depth, assessment of thermal conductivity (after VDI (2010), LBEG measurements and Ad-Hoc AG Hydrogeologie (2008), groundwatersurface
ThermoGIS 2.0 - NLFFS – Brussels sand Member	Some harmonized main modeled Cenozoic layers together with the geometry (top, depth, thickness) from wells
ThermoGIS 2.0 – NMRFV – Vessem Member	Some harmonized main modeled Cenozoic layers together with the geometry (top, depth, thickness) from wells

2.2 Output data (sort/type, format)

Table 19: description of output data of existing maps

map	output data
Thermal conductivity for vertical heat exchangers (reference depth 40m)	point information with additional depth information
Thermal conductivity for vertical heat exchangers (reference depth 60m)	point information with additional depth information
Thermal conductivity for vertical heat exchangers (reference depth 80m)	point information with additional depth information
Thermal conductivity for vertical heat exchangers (reference depth 100m)	point information with additional depth information
ThermoGIS 2.0 - NLFFS – Brussels sand Member	Top, base, thickness, porosity and permeability maps as grid+pdf
ThermoGIS 2.0 - NMRFV – Vessem Member	Top, base, thickness, porosity and permeability

	maps as grid+pdf

2.3 Confidentiality and availability

Table 20: status of confidentiality and link to the output data

map	Confidentiality and availability
Thermal conductivity for vertical heat exchangers (reference depth to 40m)	public under http://nibis.lbeg.de/cardomap3/
Thermal conductivity for vertical heat exchangers (reference depth to 60m)	public under http://nibis.lbeg.de/cardomap3/
Thermal conductivity for vertical heat exchangers (reference depth to 80m)	public under http://nibis.lbeg.de/cardomap3/
Thermal conductivity for vertical heat exchangers (reference depth to 100m)	public under http://nibis.lbeg.de/cardomap3/
ThermoGIS 2.0 - NLFFS – Brussels sand Member	Public under https://www.thermogis.nl/en/map-viewer
ThermoGIS 2.0 - NMRFV – Vessem Member	Public under https://www.thermogis.nl/en/map-viewer

3 HARMONIZATION

For compilation of existing 3D models well and seismic data have been used. The decision, which layers have been modeled was derived on base of the input data. Therfore seismostratigraphic or lithostratigraphic horizons may be the base for the different models. In January 2019 we start to strive the harmonization of existing 3D models to a consistent 3D model for several Mesozoic main intervals (chapter 3.1) and some Cenozic intervals (chapter 3.2). During this work we will examine for which of these four 3d models a harmonization is possible and in which range. Detailled inventory of modeled layers will be the basis for the following work. Realisation of harmonisation is only possible, if it is geological reasonable. Otherwise modeled layers are completely different ant not comparable or traceable in other models.
In chapter 1 the differences between the four 3D models have been described. For elaborating a harmonized 3D model it is important to agree first on a common coordinate system for our pilot area to prevent inaccuracy and mistakes in geographic position.

3.1 Harmonized main Mesozoic stratigraphic units

During the SPBA project the seismic interpreted main horizons in the different countries have been already compared, also for Germany and the Netherlands (GTA3D and DGM-deep, see Figure 8). For the Mesozoic a total of eight horizons have been mapped, from base Triassic to base Cenozoic (see Figure 11). For three horizons, i.e. near Base Upper Jurassic, near base Middle Jurassic and near Base Lower Jurassic, the seismic interpreted horizons were picked on different stratigraphic positions on both sides of the German-Dutch border (see Figure 8). For each of these three horizons we have to determine the difference in age and in depth, afterwards we have to decide how to solve the differences.

3.2 Harmonising Cenozoic stratigraphic units

GTA3D depicts the Cenozoic layers in more detail with six stratigraphic layers: see table 9. DGM-NNL depicts Cenozoic layers more in detail: see table 10. DGM-deep depicts two Cenozoic horizons: base Upper North Sea Group (near base Neogene) and base Lower North Sea Group (near base Paleogene). In Figure 10 the seismic mapped horizons for Cenozoic are indicated, which have been modelled in the GTA3D (Germany) and DGM-NNL (Northeast-Netherlands) models. From this figure we could conclude that the following four horizons were seismically mapped on approximately the same level in both models GTA3D and DGM-NNL:

- base Landen Clay Member (NLLFC = 07 tpao-teou),
- base Brussels Sand Member (NLFFS=06 tolm-teoo),
- base Rupel Formation (NMRF= 05 tolm-tolo) and
- base Quaternary.

Only for the seismically mapped base Upper North Sea Group (=NUBA) in DGM-deep or DGM-NNL it should be decided whether it will be possible to harmonise this level with ”04 tmiu” or ”03 tmim-tpl” in the GTA3D model. The five mentioned horizons above could be harmonized along the German-Dutch border, only on the Dutch side of the pilot area some horizons should still be seismically mapped in the area outside the DGM-NNL area. Subsequently by combining these main horizons as a geometrical reference together with the geometry (top, depth, thickness) from public wells the

geometrical maps (top, base, thickness) of the geothermal reservoirs will be generated for the Cenozoic (except Holocene) subsurface in the pilot area.
The geometrical maps of these geothermal reservoirs (aquifers) will be the base for the geothermal property maps, which will be created in Task 1.5.

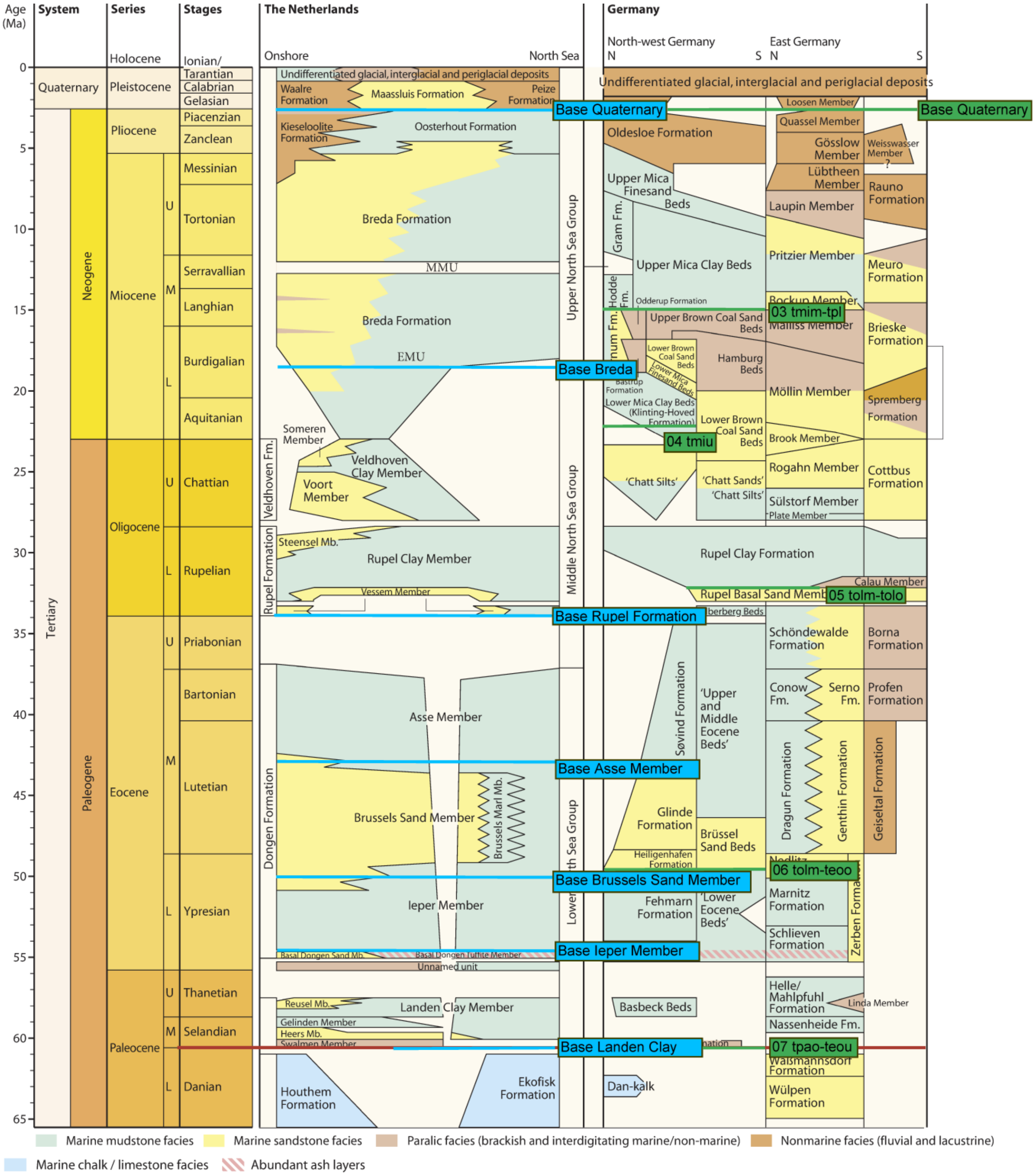


Figure 10: Tectonostratigrafic Chart for Cenozoic (modified after (Doornenbal and Stevenson, 2010)). The red line is the seismically mapped near base Cenozoic in the SPBA-project. Blue lines show the seismically mapped horizons of DGM-NNL (Rupel Formation consists of modeled layers: Rupel Clay and Vessem Member) and the green lines show the seismically mapped horizons of GTA3D.

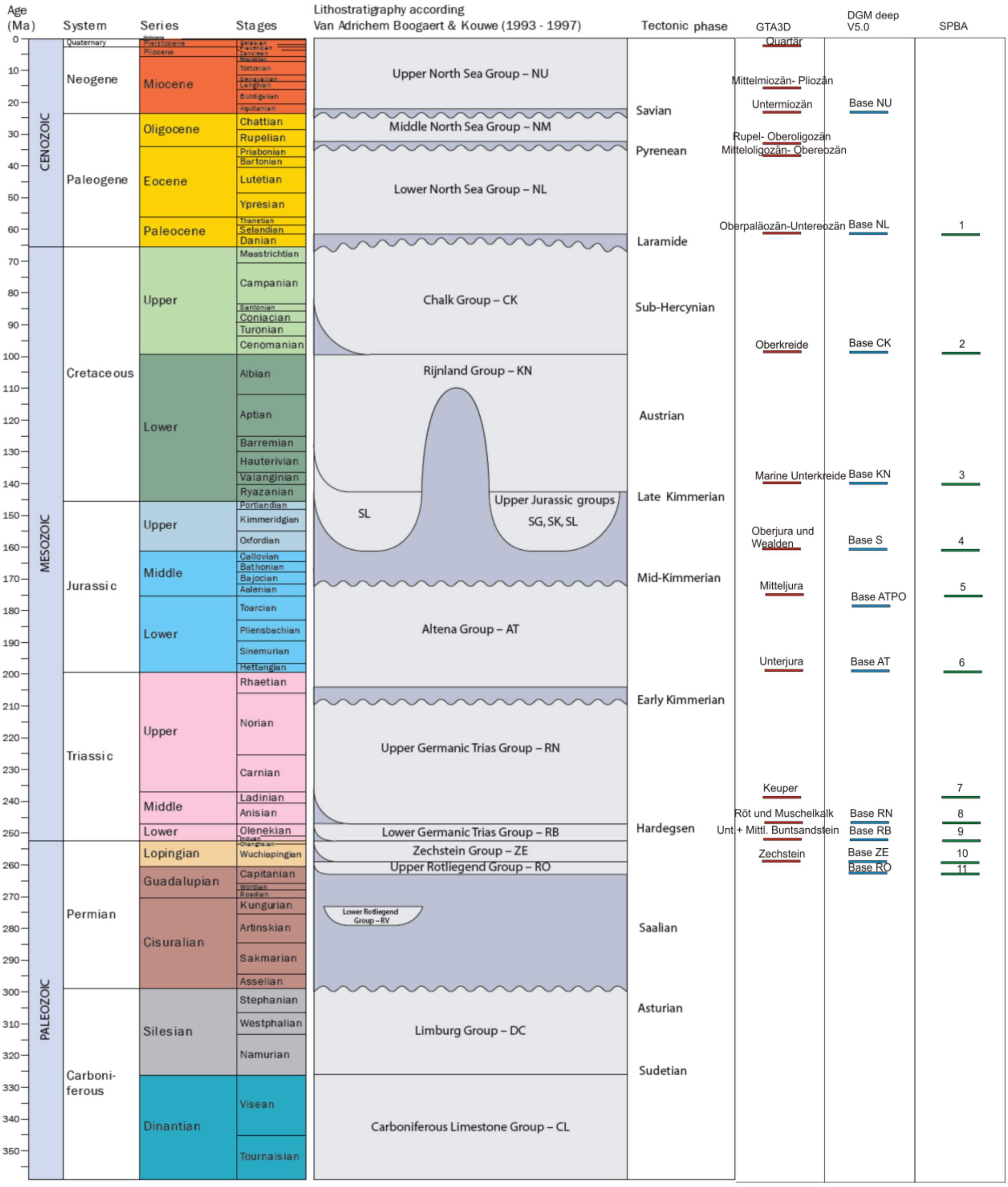


Figure 11: correlation of modelled layers for GTA3D (red lines), DGM deep (blue lines) and SPBA (green lines) with names of the modeled horizons(modified after (Kombrink et al., 2012))

3.3 Faults

As described in Chapter 1.8 the treatment of fault data also needs to be harmonized. Due to the absence of 3D fault surfaces in GTA3D it only might be possible to harmonize the main faults or fault systems, which have a sufficient horizontal length or a big vertical displacement (see Figure 12 and Figure 13).

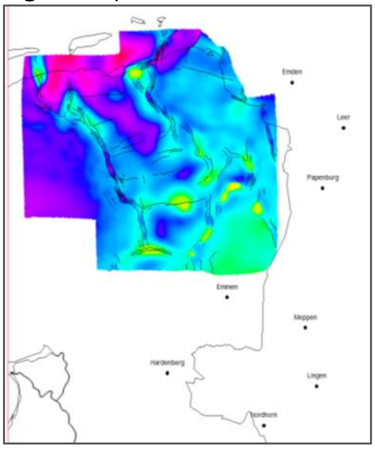


Figure 12: few fault zones crossing the German-Dutch border (from DGM-NNL)

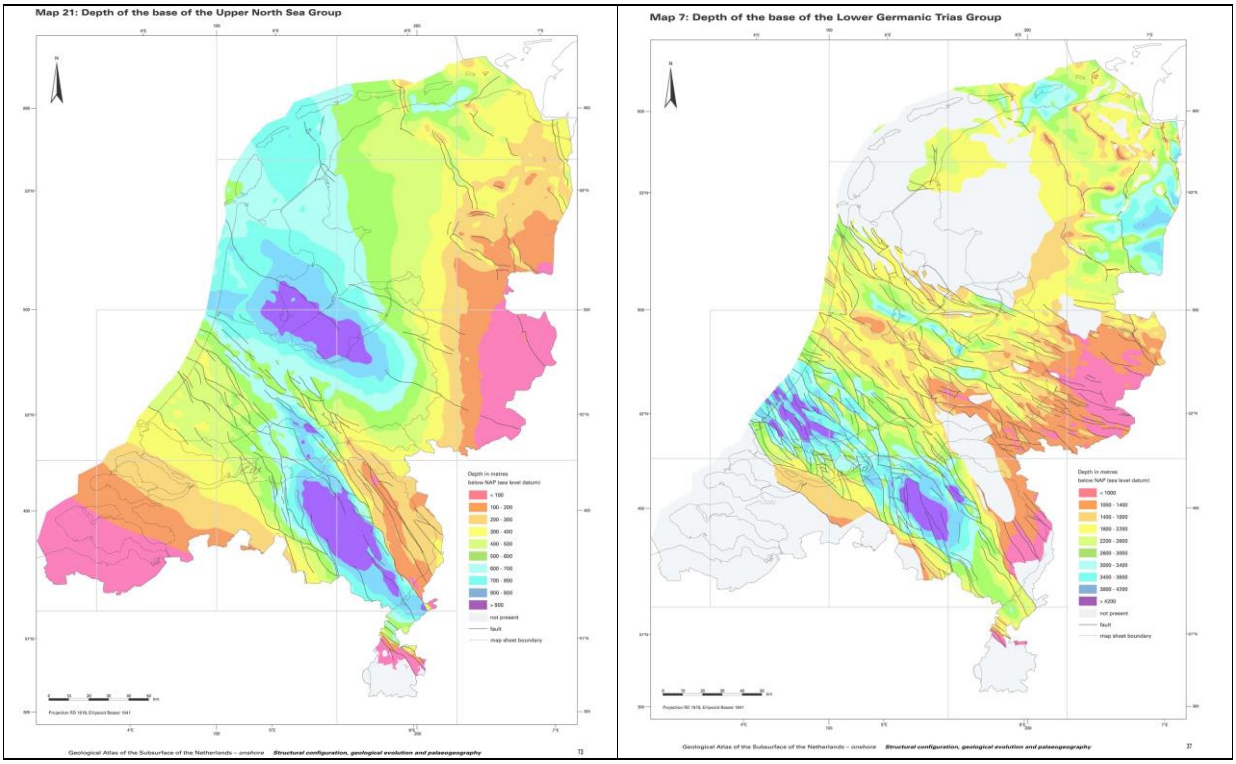


Figure 13: Depth maps of the base of the Upper North Sea Group and the base of the Lower Germanic Trias Group which clearly show that a few faults are crossing the German-Dutch border in the pilot area

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