DEVELOPMENT OF 3D STRUCTURAL MODELS OF GEOTHERMAL USABLE HORIZONS IN THE AREA OF NORTHWESTERN GERMANY

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ABSTRACT

In Germany, the political priorities for geothermal energy have changed in the last years. The focus is now on heat production rather than power production. Therefore, intermediate and low enthalpy resources are increasingly interesting for geothermal development. As part of the project Geofaces (funded by the Federal Ministry for Economic Affairs and Energy), 3D models of formations with geothermal potential in medium depth have been developed and supplemented by means of geologic and geophysical data and the 3D modelling software GOCAD/SKUA. In the next step, these 3D models will be converted to volumetric models and attributed with the 3D temperature model of the Leibniz Institute for Applied Geophysics (LIAG). The resulting models will be incorporated into the data stock of the geothermal information system (GeotIS).

1. INTRODUCTION

In recent years, major progress was made in 3D modelling of geological structures. 3D models of the subsurface can display the size, shape, location and depth of geologic bodies whereas maps are limited to topographic representations without much complexity. Today's 3D modelling software enables geoscientists to create models that show different structural properties like faults for example as well as the volume of stratigraphic units. Current 3D models are the base of numeric hydrological and geothermal models.

In the Lower Saxony Basin, which is a sub-basin of the western part of the North German Basin, the sandstones of the Middle Jurassic, German Wealden and Valanginian are considered as favourable target formations for geothermal exploration. Other favourable formations include Lower Cretaceous sandstones, which are located in the north of the Lower Saxony Basin in the area of the lineaments of Leer-Bremen and Uelzen. Furthermore, the Cenomanian–Turonian aquifer of the Muenster Chalk Basin (Münsterländer Kreidebecken) is most likely also suitable for geothermal utilization.

Previous 3D models are composed merely of top and base surfaces of formations or stratigraphic units because of software limitations. In the meantime, it is possible to include stratigraphic cross sections, unconformities and further structural elements for the development of stratigraphic consistent 3D models. Within the course of this project, current 3D models in GeotIS have to be supplemented and extended (Fig. 1). Especially in the Lower Saxony Basin sandstones of the German Wealden and Valanginian exhibit suitable properties for geothermal usage with respect to porosity and permeability (Kuder et al. 2014). In the north of the Lower Saxony Basin in the area of the Ems mouth and the lineaments of Leer-Bremen and Uelzen the occurrence of Lower Cretaceous sandstones is proven by wells (Knopf 2011). Within the Lower Saxony Basin the sandstones of the Middle Jurassic also display a local reservoir quality for geothermal usage (Frisch & Kockel 2004, Knopf 2011). Most recently, a 3D model of an Upper Cretaceous aquifer within the Muenster Chalk Basin has been included in GeotIS. It is composed of two surfaces, base of Cenomanian and top of Turonian. This Upper Cretaceous aquifer consists of limestones with intercalations of sandstones.

Figure 1: Web page of GeotIS: green depicts areas in which 3D models already exist. The red marker indicates the area of prospective 3D models.

2. METHODOLOGY

The North German Basin is a rift basin located in central and west Europe, which deepened successive from the Permian up to the end of the Cretaceous. During this period, several layer of sediments were deposited, which have been designated as a target horizon for geothermal usage. Various criteria, which are significant for geothermal usage had to be fulfilled by the target horizons like a minimum thickness of 20 m (Rockel & Schneider 1992; Rockel et al. 1997) a wide geographical extension and a formation temperature with a supposed minimum of 40 °C. The goal of the structural modelling is a three-dimensional visualisation of geological bodies, including one or more aquifers. Only if a top and a base surface confine a formation it could be regarded as geological body. The true vertical thickness of a geological body represents the stratigraphic thickness without corrections for bed dip and deviation of the wellbore that penetrates the layer. In contrast the cumulative thickness of the aquifer only considers the permeable sandstone units.

The 3D models were built with the Paradigm software GOCAD. In general triangulated top and base surfaces were modelled by use of structural maps and additional data like wells etc. In lack of information about the dip of faults, all faults were simply modelled as vertical planes. Solely for the top surface in the area of the Muenster Chalk Basin no information about faults were available at all. After the creation of the 3D models using contour maps, local adjustments to available well profiles of the particular stratigraphic unit were necessary in some cases (Fig. 2). Distances to neighbouring layers were illustrated and intersections of surfaces were corrected if required.

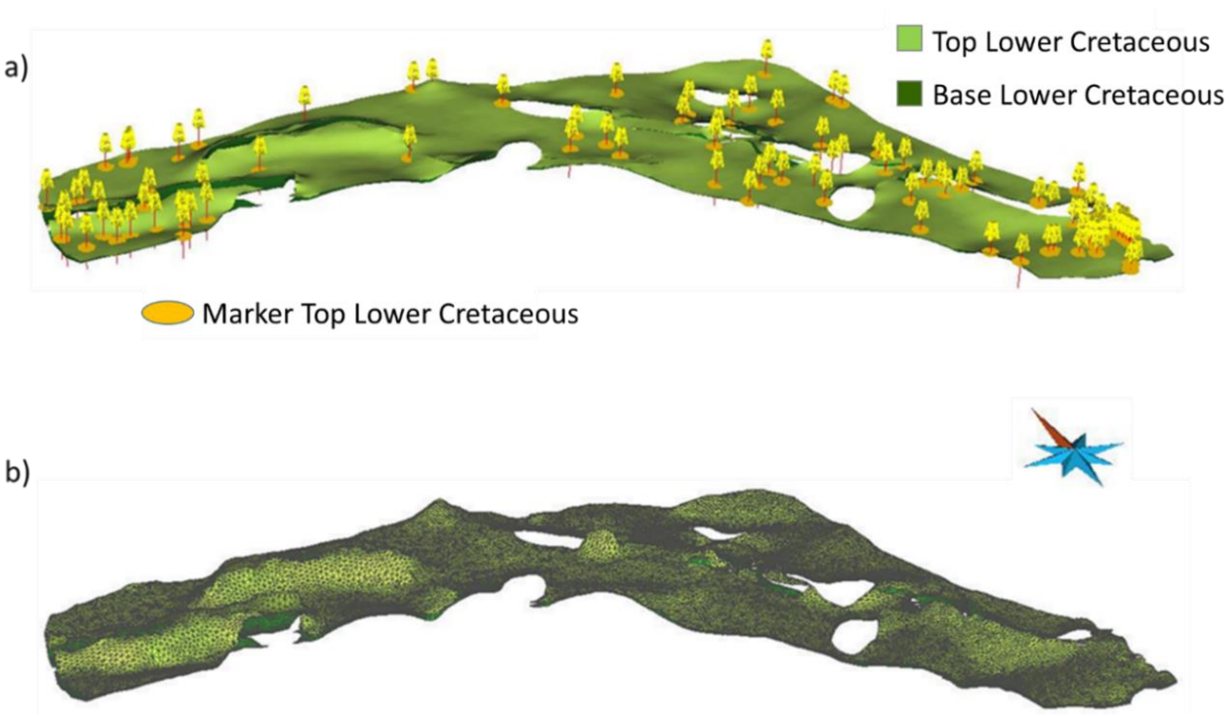

Figure 2: Top and Basis of the 3D model of the Uelzen Lineament (extract) with well locations and horizon markers. b) Same model overlaid by mesh (two times exaggerated).

3. RESULTS

As part of the project Geofaces (funded by the Federal Ministry for Economic Affairs and Energy), 3D models of various formations in medium depth levels have been developed and supplemented by means of geologic and geophysical data and the 3D modelling software GOCAD/SKUA. The new 3D models fill some of the gaps in the region of western Germany and in the north of Westphalia in GeotIS (Fig. 3).

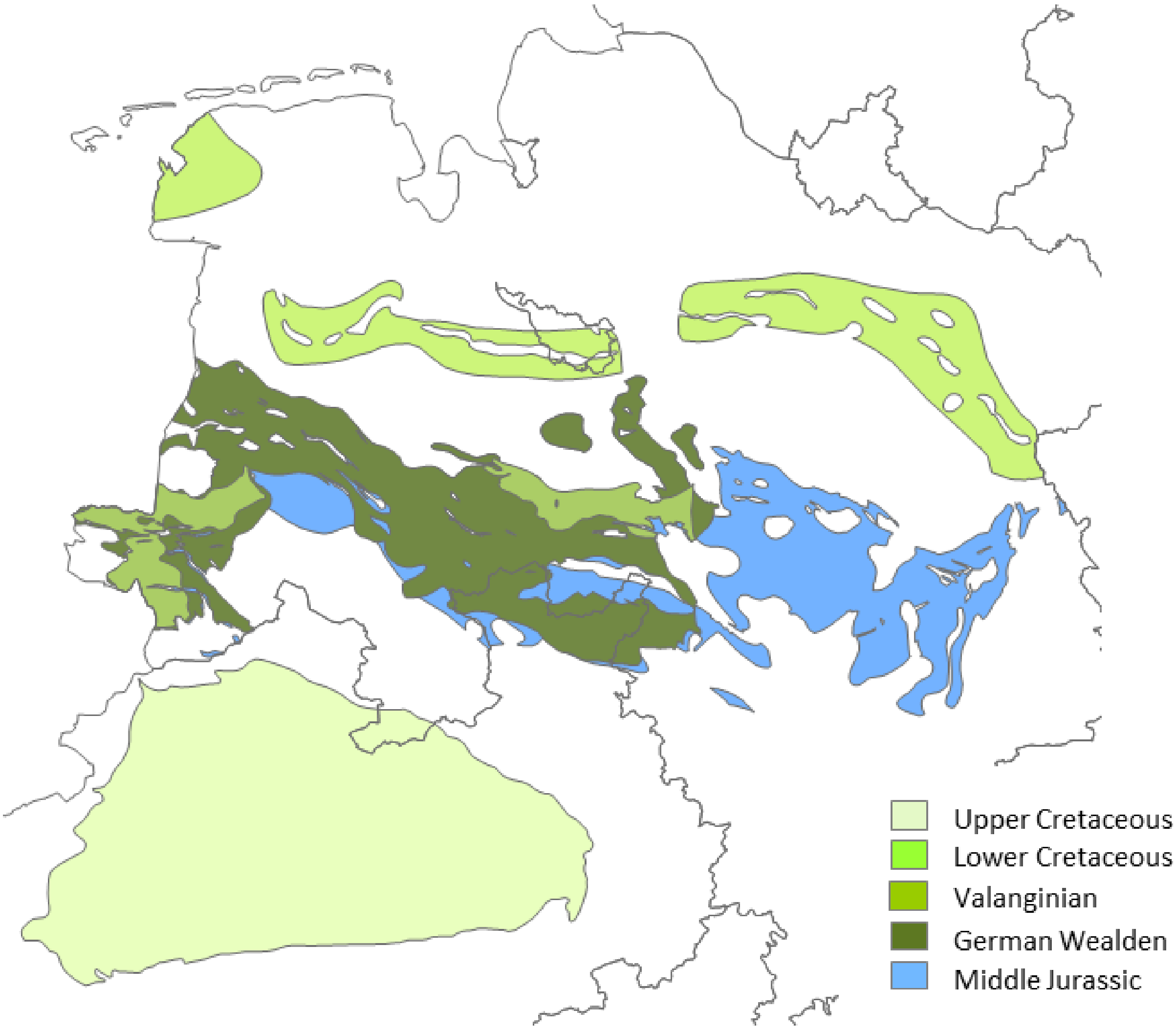

Figure 3: Position of the newly constructed 3D models within the North German Basin and the Muenster Chalk Basin.

3.1 Middle Jurassic Sandstones (Aalenian to Callovian)

The selection and clipping of the area with sandstones of the Middle Jurassic (Aalenian to Callovian) in the Lower Saxony Basin was carried out after Müller & Reinhold (2011) and Knopf (2011). A minimum vertical thickness of about 10 m and a minimum depth of about 800 m were assumed as criteria for the selection of the model coverage. The modelling was based on the Geotectonical Atlas (Baldschuhn et al. 2001) and the Southern Permian Basin Atlas (Doornenbal & Stevenson 2010). Well profiles were used for further adjustment of the modelled surfaces. 252 horizon markers for the top Callovian and 417 horizon markers for the base Aalenian were used. The modelling of the fault characteristics was carried out after Doornenbal & Stevenson (2010) (Fig. 4). Compared with the Lower Jurassic the Middle Jurassic claystones are intercalated more often by sandstone layers (Hoth et al. 2007). Major sandstone horizons are the Dogger Beta sandstones of the Aalenian which were proven in the northeast of the investigated area and which were delivered from the east. Afterwards in the timeframe of the Bajocian and Bathonian primarily deltaic and coastal shallow marine clastic rocks and claystones were deposited (Ziegler 1990). Relevant is the Garantian sandstone from the Bajocian which is spread within the central part of Lower Saxony and which was delivered from a deltaic fan from the north (Boigk 1981). Likewise, sandstones of the Bathonian referred to as Cornbrash facies were also delivered from the north (Frisch & Kockel 2004). They are widely spread within the southeast and west of the Lower Saxony Basin. In the stratigraphic table, the sandstones from the Lower Bathonian in the western part of the basin were also called Wuertembergica sandstones (Knopf 2011).

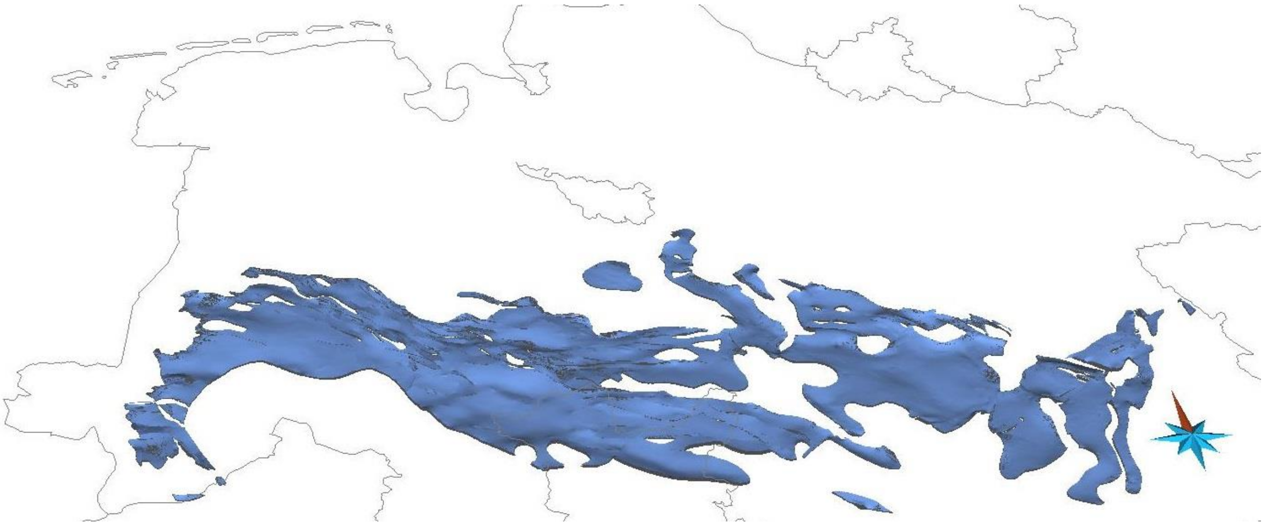

Figure 4: Suitable area for geothermal usage within the North German Basin (Middle Jurassic – Aalenian to Callovian).

3.2 Lower Cretaceous deposits (German Wealden)

The selection and clipping of the area with deposits of the Lower Cretaceous (German Wealden) within the western part of the Lower Saxony Basin was carried out after Kuder et al. (2014). Within the eastern part of the Lower Saxony Basin a model of the German Wealden already exists in the GeotIS system. The newly build model continued this work towards the western part of the basin. The modelling was realised regarding the Geotectonical Atlas (Baldschuhn et al. 2001) and the Southern Permian Basin Atlas (Doornenbal & Stevenson 2010). The modelled top surface was aligned to horizon markers of 1676 wells and 1254 well markers were used for the base of the Wealden. The modelling of the fault characteristics was conducted after Doornenbal & Stevenson (2010) (Fig. 5). In contrast to the Wealden at the locus typicus in England the German Wealden refers stratigraphically to the Bückeberg formation. After Schulz & Röhling (2000) the sandstones are of fluviatile origin of a braided river system with a very heterogeneous fabric. They consist of an alternation of fine sandstones and siltstones with intercalations of clay beds. Some sections are conglomeratic. Fine to middle grained sandstones with typical flask coating dominate. The claystones of the Wealden are mostly grey to dark grey. Towards the western part of the basin they turned into greenish grey and several limestone horizons occur. Within the single sequences the grain size decreases from the base to the top (Beutler et al. 1994).

Figure 5: Suitable area for geothermal usage within the North German Basin (German Wealden).

3.3 Lower Cretaceous deposits (Valanginian)

The selection and clipping of the area with deposits of the Lower Cretaceous (Valanginian) within the western part of the Lower Saxony Basin was realised regarding Kuder et al. (2014) and Haenel & Staroste (1988). The modelling was carried out after the Geotectonical Atlas (Baldschuhn et al. 2001) and the Atlas of Geothermal Resources in the European Community, Austria and Switzerland (Haenel & Staroste 1988). For the alignment of the modelled surface to horizon markers, 1493 wells for the top Bentheim sandstone existed and 521 wells for the base Bentheim sandstone were used. For the Valendis sandstone 536 wells were available for the adjustment of the top surface and 318 wells existed for the adjustment of the base surface. The modelling of the fault characteristics was carried out for the top Valanginian after Haenel & Staroste (1988) and for the base Valanginian after Doornenbal & Stevenson (2010) (Fig. 6). The characteristics of the Wealden and the Valanginian sandstones in the central part of Lower Saxony are mostly identical. The Bentheim sandstone is a brown to red coloured fine to middle grained quartz sandstone bounded by concretions of grains. Sometimes there is a cementation of predominantly dolomitic limestone (Kemper 1976). The thickness of this unit is recognised as net thickness that represent 70 to 100 % of the total thickness (Haenel & Staroste 1988).

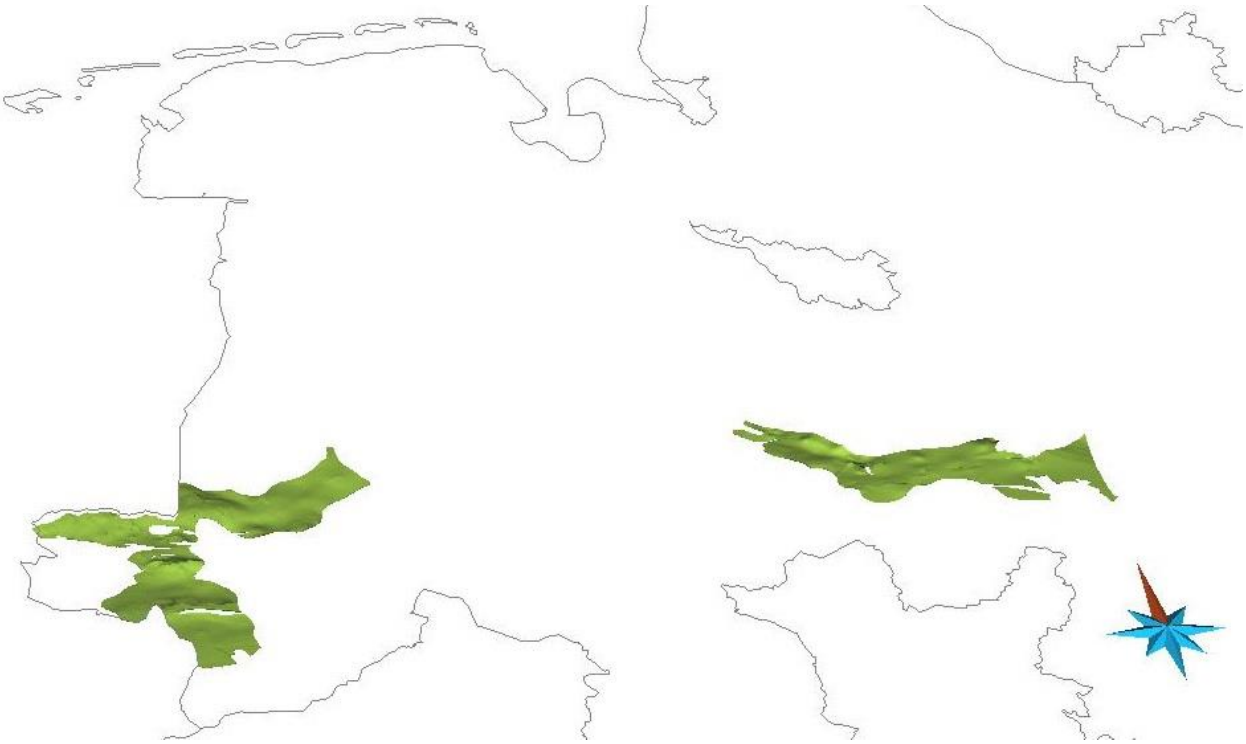

Figure 6: Suitable area for geothermal usage within the Lower Saxony Basin (Valanginian). On the left: Bentheim sandstone. On the right: Valendis sandstone.

3.4 Lower Cretaceous deposits (Berriasian to Albian)

The selection and clipping of the area with deposits of the Lower Cretaceous (Berriasian to Albian) in the north of the North German Basin was carried out after Müller & Reinhold (2011) and Knopf (2011). A minimum vertical thickness of about 10 m and a minimum depth of about 800 m were assumed as criteria for the selection of the model coverage. The modelling was based on the Geotectonical Atlas (Baldschuhn et al. 2001) and the Southern Permian Basin Atlas (Doornenbal & Stevenson 2010). Target areas are the Ems mouth and the lineaments of Leer-Bremen and Uelzen. For the alignment of the modelled surface to horizon markers, 165 wells for the top Albian and 163 wells for the base Berriasian were available. The modelling of the fault characteristics was conducted after Doornenbal & Stevenson (2010) (Fig. 7).

The most important sandstone horizons within the Lower Cretaceous in the north of the Lower Saxony Basin are assigned to the stages of the Berriasian (Obernkirchen sandstone), Valanginian (Bentheim sandstone, Dichotomiten sandstone) and Hauterivian (Gildehaus sandstone). For the upper part of the Lower Cretaceous only the Albian Hils sandstone is proven by wells in the outer southeast of the distribution area. Information about the thickness of the sandstones derived from the borehole database, which displays values of several decimetres. Except in the area of the Ems mouth values of about 50 m thickness are proven (Knopf 2011).

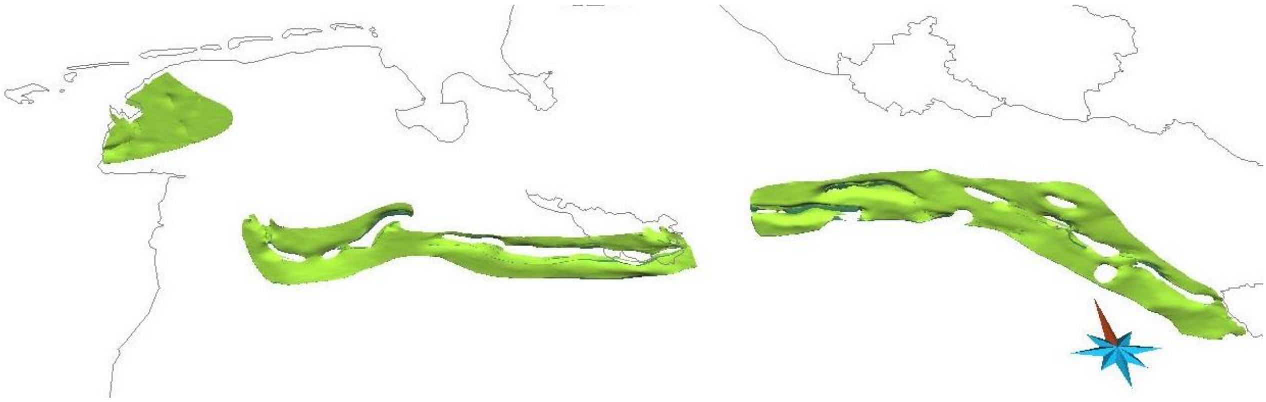

Figure 7: Suitable area for geothermal usage in the north of the North German Basin (Lower Cretaceous – Berriasian to Albian). On the left: Ems mouth. In the middle: Leer-Bremen lineament. On the right: Uelzen lineament.

3.5 Upper Cretaceous deposits (Cenomanian to Turonian)

The selection and clipping of the area with deposits of the Upper Cretaceous (Cenomanian to Turonian) in the Muenster chalk Basin was carried out after Baldschuhn et al. (2001) and Dölling & Juch (2009). The modelling at the base Cenomanian was realised regarding the Geotectonical Atlas (Baldschuhn et al. 2001). Several cross sections and wells were used to perform the modelling of the top Turonian. For the adaptation of the modelled surface 19 wells for the top Turonian and 22 wells for the base Cenomanian were used. The modelling of the fault characteristics was realised regarding Doornenbal & Stevenson (2010) and the Geological Survey of North Rhine-Westfalia (Fig. 8, 9). The stratification of sediments within the central Muenster region is considered as undisturbed in comparison with others (Dölling & Juch 2009). After Michel & Struckmeier (1985), the cretaceous aquifer is a fissured and jointed limestone with intercalations of sandstones. Centre and margin could be distinguished by the content of salt within the connate water. Towards the basin and with increasing depth the salt content rises.

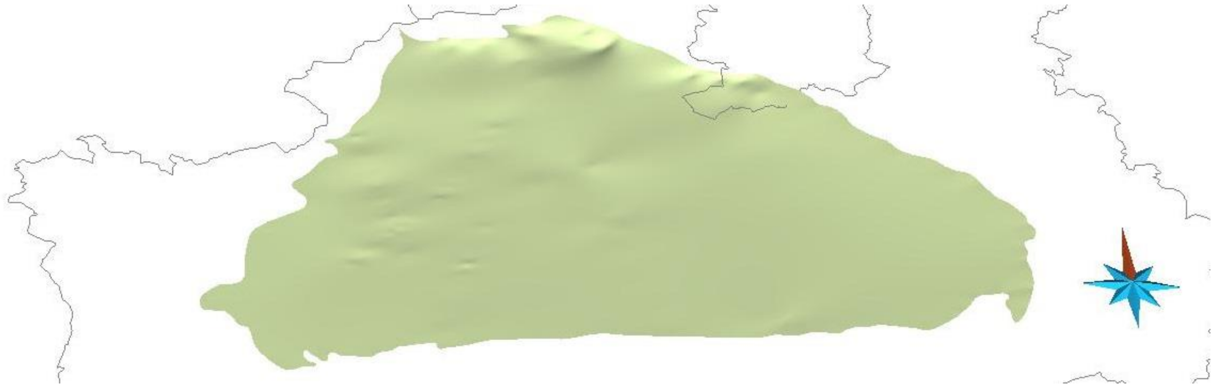

Figure 8: Suitable area for geothermal usage in the Muenster Chalk Basin (Upper Cretaceous – top Turonian).

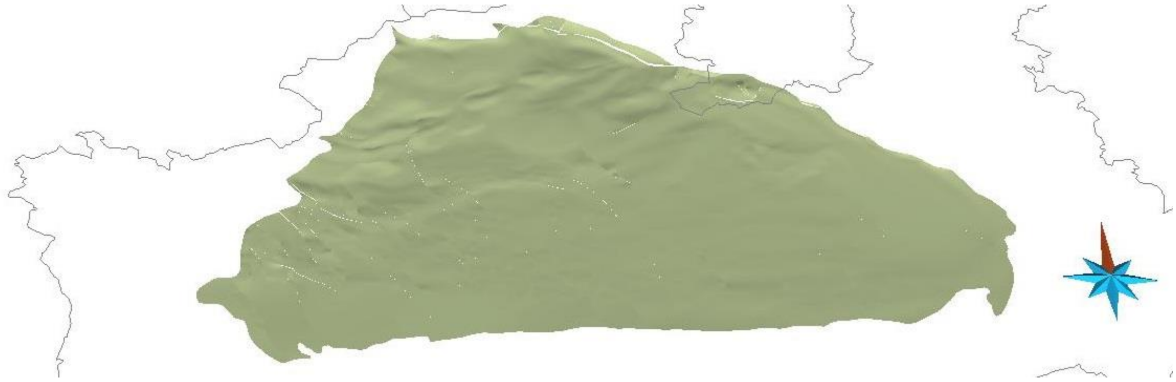

Figure 9: Suitable area for geothermal usage in the Muenster Chalk Basin (Upper Cretaceous – base Cenomanian).

4. CONCLUSIONS

Five new 3D models extend the available structural data in GeotIS within the area of the North German Basin and the Muenster Chalk Basin. The horizons show intermediate temperatures of above 40 °C and are therefore suitable for geothermal heat production. The newly constructed models encompass the sandstones of the Middle Jurassic, German Wealden and Valanginian within the Lower Saxony Basin. Moreover, the Lower Cretaceous sandstones near the Ems mouth and the lineaments of Leer-Bremen and Uelzen in the north of the North German Basin were modelled. In addition, the Cenomanian–Turonian aquifer within the Muenster Chalk Basin was also part of this work. The 3D models will be incorporated into the data stock of the geothermal information system (GeotIS).

In the next step, these 3D models will be converted to volumetric models and attributed with the 3D temperature model of the Leibniz-Institute for Applied Geophysics (LIAG) for a better visualization in GeotIS.

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