

Methods for Evaluating the Hydraulic Barrier Effects of the Emscher Marl Following Cessation of German Hard-coal Mining

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Abstract After the end of German hard coal mining in 2018 the pumping rate of deeper salty mine-water will be gradually reduced and the mine water levels will consequently rise. This will lead to ground heave and eventually outflow of mine water to the south which is free of any overburden. In the course of the consequent flooding an estimation of the sealing effect of the Emscher marl is necessary so as to predict the potential future conditions. Due to the flooding, faults might be reactivated. Using a numerical model the effect of the clay content in the faults of the overburden has been modelled, with the results showing that the high clay content of the marl is effectively sealing the faults. The results of these studies clearly show that the Emscher marl is quite impervious over a large area, especially where there is a high thickness of marl given. This barrier of marls one seals the shallow drinking water against the salt water in deeper formations.

Keywords Hydraulic barrier, hard coal mining, closure

Introduction

The cessation of German hard-coal mining in 2018 compels the mining industry to leave their mine workings in environmentally acceptable conditions with low – but indefinitely long-term - maintenance costs. The pumping of salty mine water will be reduced gradually, but this will raise the water level to a higher, near surface level. However, due to the significant subsidence of the whole Ruhr-area, with magnitudes of up to 30 m, it will not be possible to ultimately stop pumping and let the water rise to the original water level and could flood the Cretaceous formations. On the other hand, the so called Emscher Marl, a marly and argillaceous limestone, is developed throughout the Ruhr district and acts as an effective hydraulic barrier. The thickness of this marl increases towards the north and it should act as an impervious barrier for the migration of water.

Based on a regional geological model an additional study was carried out for the area of Hamm to investigate the permeability distributions in the subsurface layer above the Carboniferous formation in a smaller research area. This research included also the assessment of permeability values of the known fault system. With the construction of a detailed static subsurface model in Petrel (Schlumberger Ltd.) with the petrophysical parameters, it was possible to conclude that the shallow subsurface has, in general, a high probability of low permeability and sealed faults.

Stratigraphy and structure

The research area, which lies in the eastern part of the German mining district, is built of several stratigraphic units which are influenced by the development of tectonic events. The principal structure can be subdivided into three parts (fig. 1):

- the deeper subsurface with the Palaeozoic especially the Carboniferous and the Permian formations;
- the upper subsurface mainly with Mesozoic sediments and carbonates like the Triassic, the Jurassic and the Cretaceous formations;
- the Cenozoic surface layers with Paleogene and Neogene sediments.

The Carboniferous formations consist of faulted and folded hard rocks which pinch out at the surface to the south of the research area (HILDEN et al. 1995). The Variscian tectonic movement in the Lower Carboniferous led to the folding of a basin, which was filled in the Upper Carboniferous with about 2,000 m sediments of deep marine sandstones and shales (HILDEN et al. 1995). Paralic periods formed coal layers in different thicknesses in the Carboniferous.

In the south-western and western part of the Münsterland Cretaceous Basin Permian, Triassic and Jurassic sediments overlay the Carboniferous formations (HAHNE & SCHMIDT 1982), whereas in the research area the Cretaceous formations are lying with an unconformity on top of the Carboniferous.

During the beginning of the Cretaceous era the area of Münster was mainly a continental region (HISS & SCHÖNEFELD 2000). With a marine transgression in the Middle-Albian the Cretaceous deposition started. The later Upper Cretaceous sediments were sequences of sandstones, shales and carbonates with different spatial distributions and thicknesses up to 2,000 m (ARNOLD 1964). In the Turonian the deposition of marls and carbonates continued, with clean carbonates being more dominant in the research area. Because of the ongoing transgression and the sea level rise in the Coniacian, more shaley carbonates, as a part of deeper marine environments, were deposited (HISS & SCHÖNEFELD 2000). The name of this regional stratigraphical unit is the Emscher-Marl. Due to changes in the basin geometry in the Santonian more sandy sediments were deposited. In the Campanian the basin geometry changed even more to shallower marine environments (Hilden et al. 1995).

With a discontinuity the Neogene is the next stratigraphic unit which can be mapped in the research area. The Paleogene could be found only in the western part (HAHNE & SCHMIDT 1982). The whole research area is covered with glacial sediments of the Pleistocene which vary in thicknesses and spatial distribution.

The tectonic structure of the research area can be separated into two units:

- the intensively folded and faulted Carboniferous;
- the relatively little influenced lower subsurface of the Cretaceous.

Modelling

For the evaluation of the potential impact of the successive rebound of the salty mine water level it was necessary to generate a combined stratigraphic-lithological Model within the extent of the “East” colliery dewatering system. The construction of the static subsurface model of the Cretaceous strata was done with the modelling software Petrel. Overall the modelling process is split in four major steps:

- Preparation and import of datasets.
- Structural and stratigraphical modelling.
- Petrophysical modelling of lithologies, NTG, porosity, permeability.
- Fault analysis.

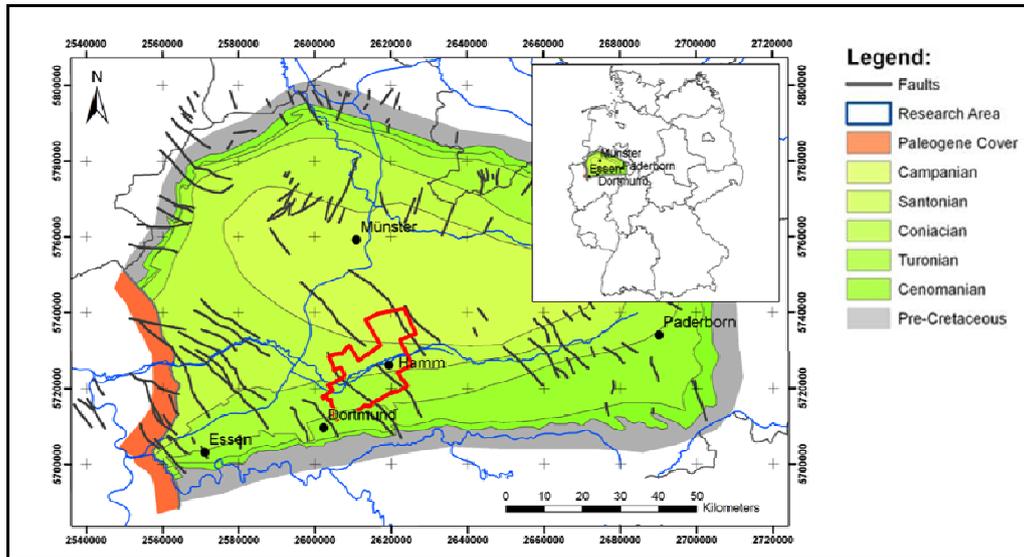


Fig. 1 Geological map of the Münsterland Cretaceous Basin, and the research area, including the simplified fault systems (after HILDEN et al. 1995; red line: research area)

Data input

The huge number of wells, as well as the uncertainties of the data and the data quality, needed to be considered during the initial period of the static subsurface modelling process. The well information was the most essential and critical input to the model, and therefore only high quality wells were chosen in the first step. Wells with a minimum resolution of 12 described lithological units were selected from the database. This means that the wells capture the main- and sub-stratigraphic units of the Carboniferous, the Cenomanian, the Turonian, Coniacian and Neogene with enough precision. To have an even spatial distribution of the wells, not only the quality was important but also their positions in the research area. Based on these two key criteria 29 wells were chosen out of the total data set of 130 wells. The well locations and the well trajectories were imported to the reservoir modelling software Petrel.

In the second modelling step the major tectonic elements were chosen. This selection was mainly based on HILDEN et al. (1995) for the Cretaceous formations and DROZDZEWSKI et al. (1982) for the known tectonic elements of the Carboniferous formations. To enable the static modelling process and to reduce the complexity of the subsurface model, it was assumed that the faults which penetrate the subsurface above the Carboniferous formations are nearly vertical. The approach of FERRIL & MORRIS (2008) for the modelling of fault zones in mixed incompetent and competent carbonate systems was not considered. Therefore, in this approach faults are modelled, depending on the competence of the rock, as being more or less thick fault zones.

In a third step the detailed lithological descriptions of the wells were chosen as the major petrophysical input. In addition to these litho-logs, the published measurements of the NTG (Net to gross = shale content), the porosity and the permeability evaluations were imported, all based on the stratigraphical unit. These parameters were varied over a wide range so as to get an overall understanding of the end-members of the possible petrophysical distribution.

Stratigraphic model

Overall, 43 exploratory wells were assessed and revised regarding their stratigraphical and lithological logs to fulfil the requirements of the exploratory software. As there is a huge number of exploratory wells, a representative number of wells and shafts were selected which possess a high resolution of the strata and show an equal distribution within the observation area. The known tectonic elements, consisting of 14 normal faults, were used as further essential input data. To avoid boundary effects in the model and to improve the calculation of the petrophysical parameter on both sides of the faults, it was useful to incorporate additional wells outside the model boundary.

Based on the standard procedure of fault modelling the fault lines were converted to fault planes, which resulted in a structural model and a grid model. With the use of the well-tops, the horizons of the Carboniferous and the Neogene, i.e. the two major stratigraphic units, were built. The other stratigraphic units of the Cenomanian, Turonian, Lower Campanian and the Neogene were constructed as zones (fig. 2).

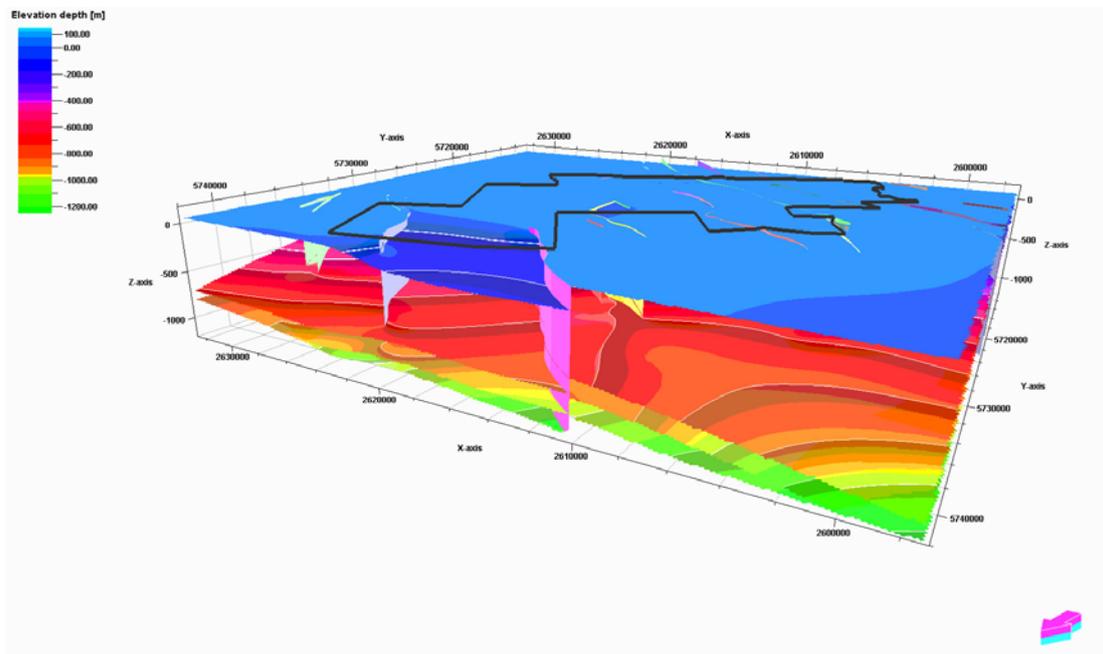


Fig. 2 Stratigraphic-structural subsurface model of the research area

Petrophysical modeling

In the next modelling step all the different logs were up-scaled in the model for the Cretaceous strata. With the up-scaling the grid cells along the well trajectories were populated with the values of the logs. To cover a wide spectrum of possible petrophysical property values, not only singular but also a spectrum of values were assessed. For all petrophysical parameters a minimal distribution (Low Case, LC), a median distribution (Base Case, BC) and a maximum orrensdistribution (High Case, HC) were retrieved from extensive published values (Correns 1949, Baltes 1998, Thielemann 2000).

This resulted in one lithological-, three NTG-, three porosity- and three permeability-upscaled models.

Net to Gross (NTG)

The modelling of the naturally-occurring shale to sand ratios (Net to Gross, NTG) was executed according to the lithologies in the exploration wells and shafts. The NTG-values were partially modified after the published range given by CORRENS (1949) and BALTES (1998).

Fault analysis

After the simulation all the petrophysical parameters the fault analysis was run in the fourth major modelling step. The fault analysis gave results for calculation of the Shale Gauge Ratio (SGR) and for the permeability of the fault cells. The SGR is the calculation of the shale moved along a reference point of the fault plane. For this calculation of the three HC-, BC- and LC-NTG models was performed in Petrel.

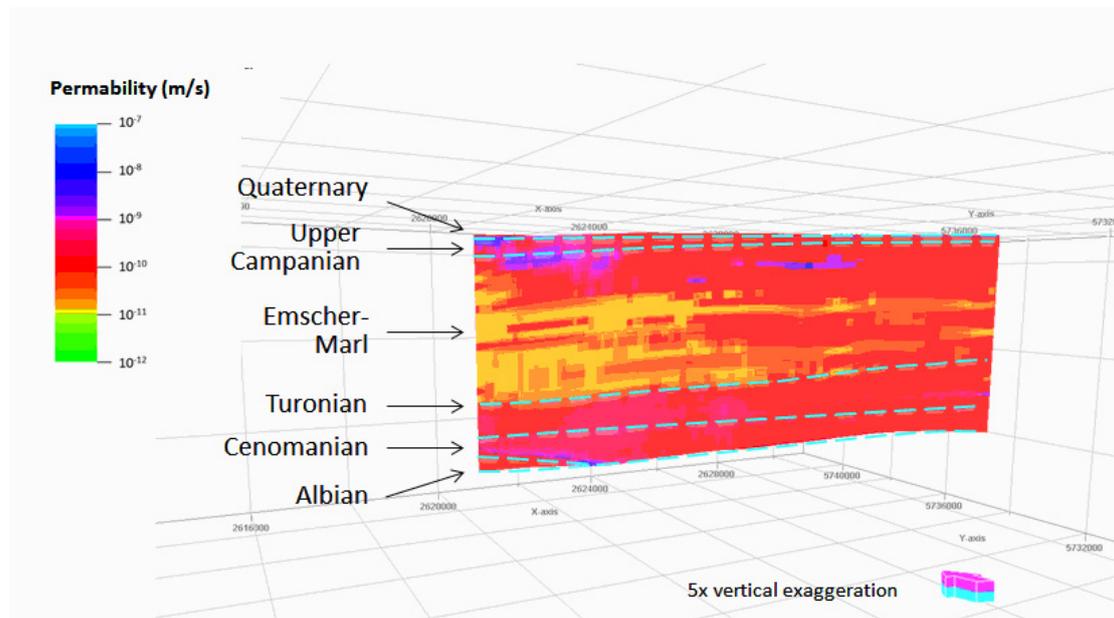


Fig. 3 Results of the fault-permeability modelling (Base Case) for the Sachsen-fault

Results

A three-dimensional model of the overburden of the Münster Cretaceous Basin was built up on the basis of detailed borehole data which comprise the lithological and petrophysical properties of the dewatering system. The results of the modelled fault-properties serve as a profound basis for the successive rebound of the salty mine water and a possible contamination of the drinking water wells in the shallow aquifers.

As a first result the model shows no infiltration of mine water into the deep Cretaceous formations if the water rises up to a level of approx. 960 m BSL. With successive rising of the mine-water up to a level of about 600 m BSL it will intrude into the Cenomanian and Turonian layers that act as deep aquifers. The modelling of permeability showed very low values in the Emscher-Marl for all three scenarios; for example, the calculated values range from approx. $k_f = 10^{-9}$ m/s to $k_f = 10^{-11}$ m/s, which is classified as ‘very low permeable’ according to the obligatory German Industry Standard DIN 18130-1. Because of its very low permeability, and its massive thickness of up to 600 m, the marl is proved to be an effective geohydraulic barrier in this region. Therefore, the deep Cenomanian and Turonian aquifer is sealed by the impermeable Emscher-Marl (Coniacian to Middle Santonian) so that a free groundwater table cannot develop within these layers. The fault analysis clearly shows that

the smearing-effect of the clay minerals in the fault-plane (Shale Gauge Ratio) results in an additional degree of sealing. The calculated fault-permeability shows very low values (according to the German Industry Standard) ranging from about $k_f = 10^{-11}$ m/s to $k_f = 10^{-10}$ m/s for the Emscher-Marl.

Because of the density of the Emscher-Marl and its faults, it is considered that the rise of groundwater levels will cause no problem to the water supply of this area.

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