Gas-Shale Exploration in Germany
with MT Systems ADU from Metronix

by

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This is a brief overview of the MT measurements in Northern Germany linked to the gas shale deposits. The relation of the MT and the genesis of the deposits are simplified for readers getting in contact with this matter for the very first time and all complexity has been skipped.

From 1992 to 2004 more than 200 MT sites have been measured in Northern Germany with Metronix data loggers (MMS-03e, ADU-6, ADU-07e).

The program was initiated by the German BGR (Federal Institute for Geosciences and Natural Resources).

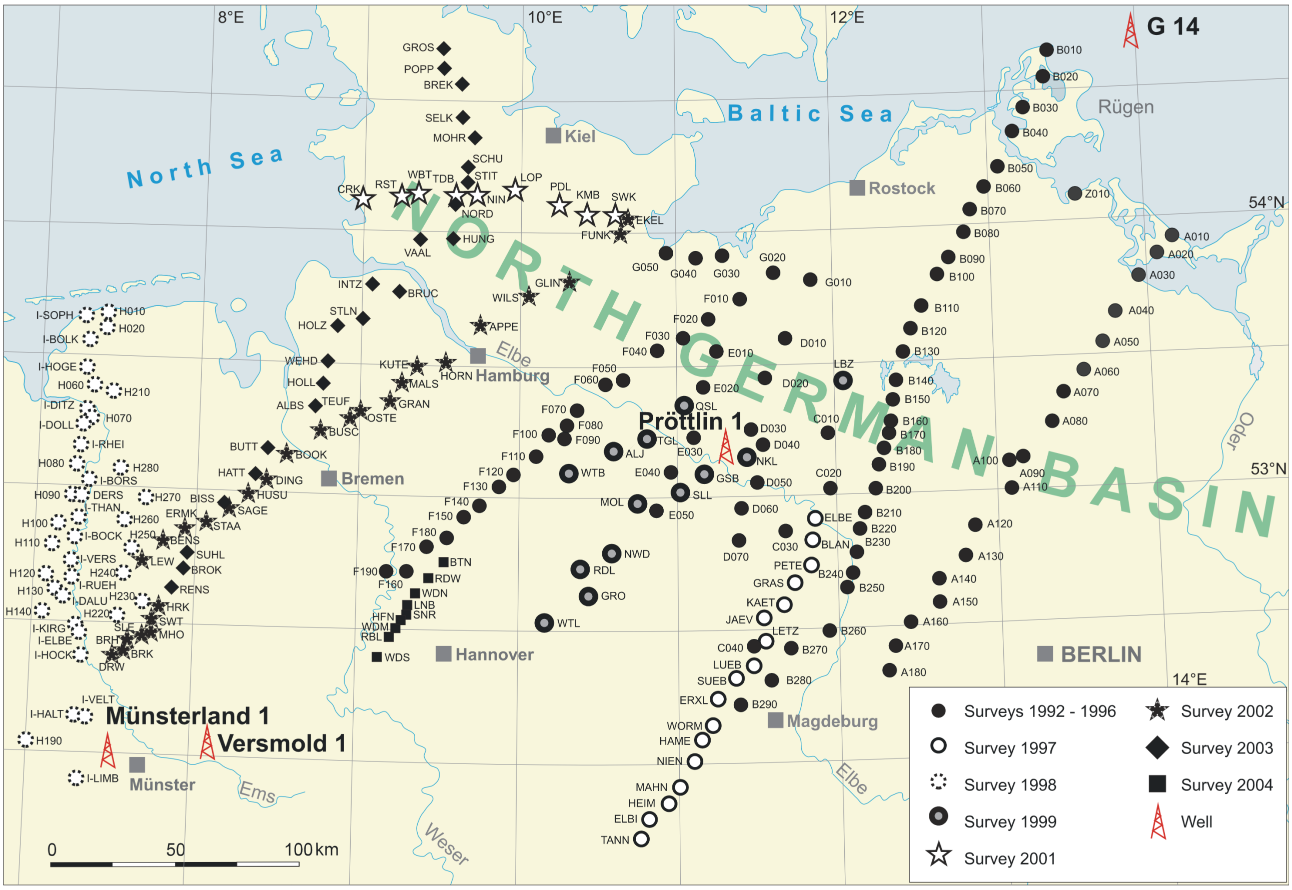

Figure 1 MT sites in Northern Germany 1992 - 2004

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Black Shales in Northern Germany / Northern Europe

Figure 2 Pyrite Segment inside a black shale; located Ireland

Black shales belong to mainly marine sedimentation.

1) Mostly the black shales contain deposited algal matter. In warm climate zones and shallow basins without water circulation (similar like we have at the Black Sea today, but which is already a deep basin) algal are deposited at sea bottom. In case this process is *fast and massive*, a significant layer of algal grows with respect that the decomposition is *anaerobe* (otherwise the algal will be eaten by bottom dwellers). The algal must have a higher *sulfur content:* during the diagenesis the sulfure will react with iron ions and will be processed to pyrite (FeS_2).

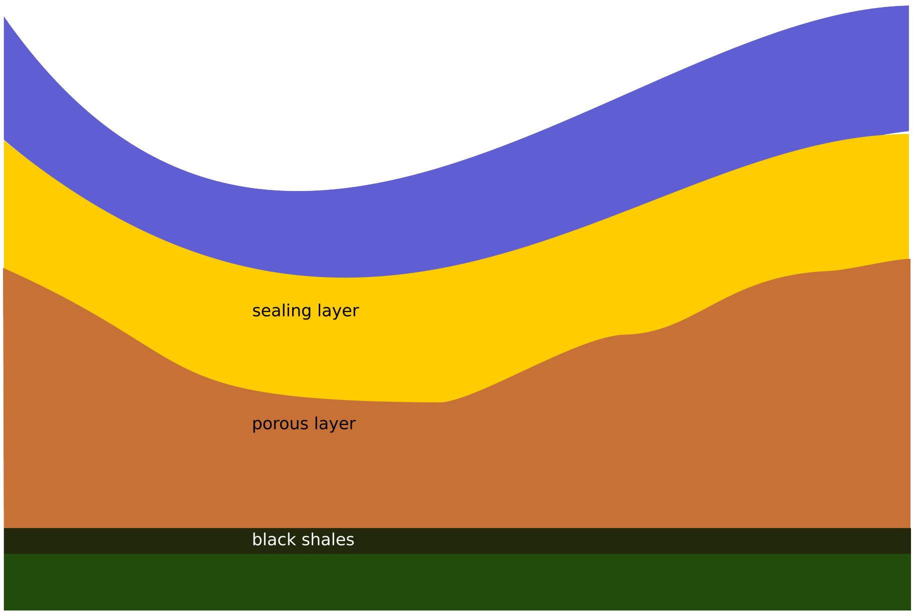


Figure 3 Example sedimentation

2) Due to ongoing subsidence additional sediments are deposited on top. If in those sediments porosity remains after burial then reservoir rocks will exist (a sandstone or carbonates for example, have the capability to store hydrocarbons). This layer later *can* contain the oil or gas from the black shales.

3) As a third pillar of an effective hydrocarbon system there must be a sealing layer on top of these two layers is needed to seal the reservoir.

4) When the above mentioned processes are finished there is a possibility that the process of generating hydrocarbons can start. E.g due to subsidence and sufficient heat flow the black shale layer is diagenised ("coked") and hydrocarbon are generated and expelled through natural fracturing. This process takes place between **80°-200°**C.

If the layer was heated longer time above 200°C the hydrocarbons are mostly expelled: so the hydrocarbon content of the black shale layer approaches to zero – *but* – the layer becomes more and more conductive (and can be seen with MT).

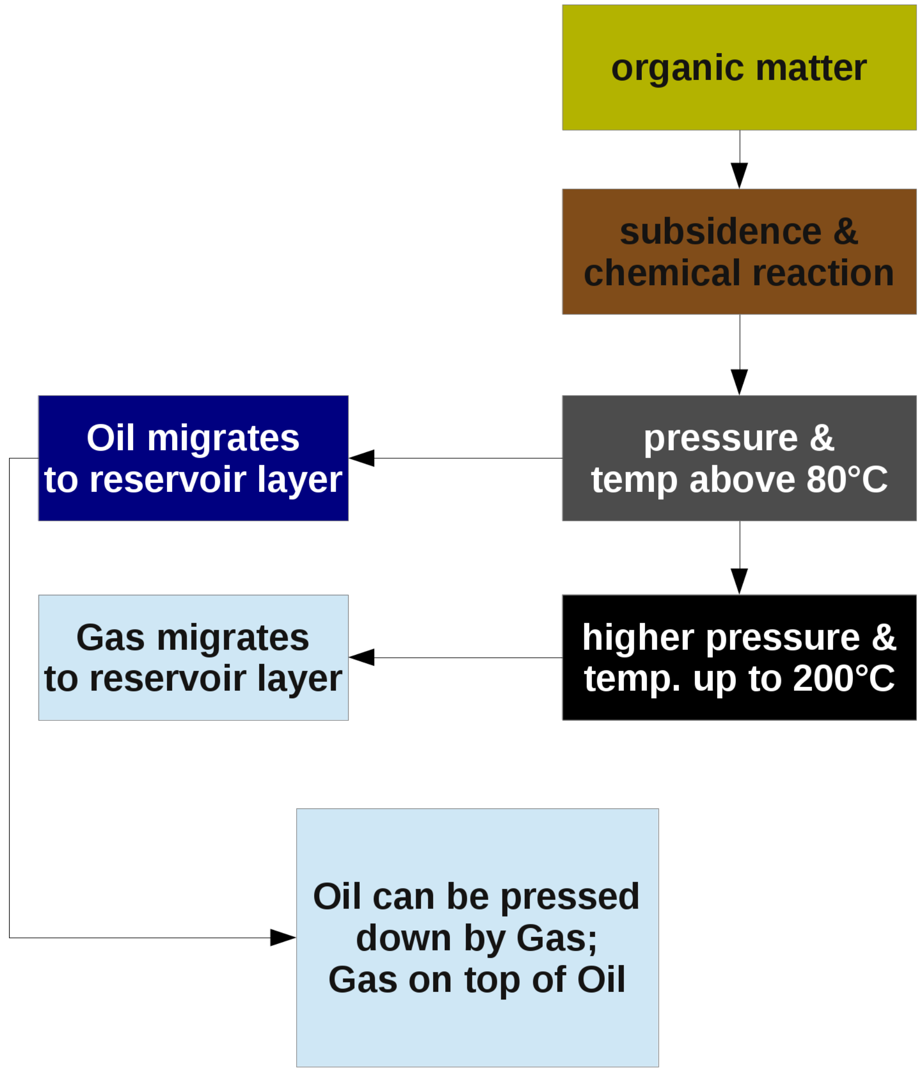


Figure 4 Simplified reservoir generation

5) At the same time or before the basin must be re-formed due to tectonic forces. Otherwise the oil and gas can not be trapped and the hydrocarbons will leak to the surface and is lost.

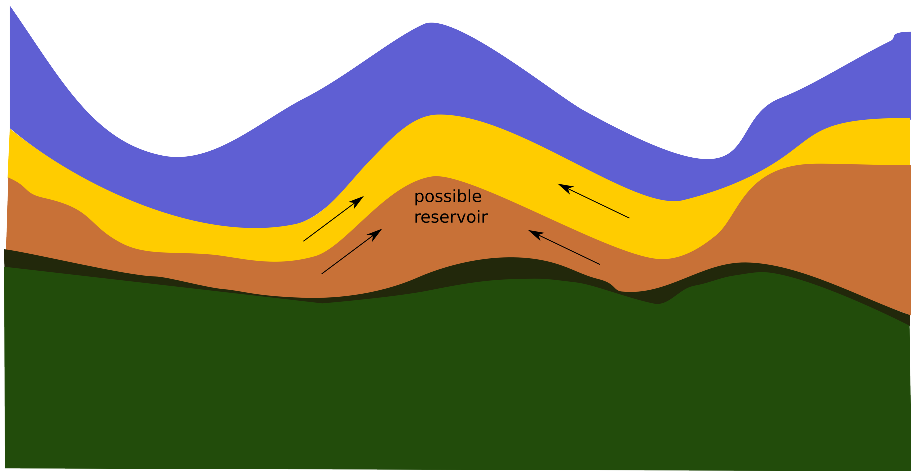


Figure 5 basin after re-formation with possible reservoir area in the center

Hence: on the one hand tectonic activity is necessary to form a reservoir type structure; on the other hand too frequent or high earthquake activity will crack the sealing layers and the deposit will leak out. In Northern Germany the typical half-life time of a gas deposit is 60 MA

Figure 6 Oil field, Wietze, Germany, year 1910. Courtesy of Deutsches Erdoelmuseum.

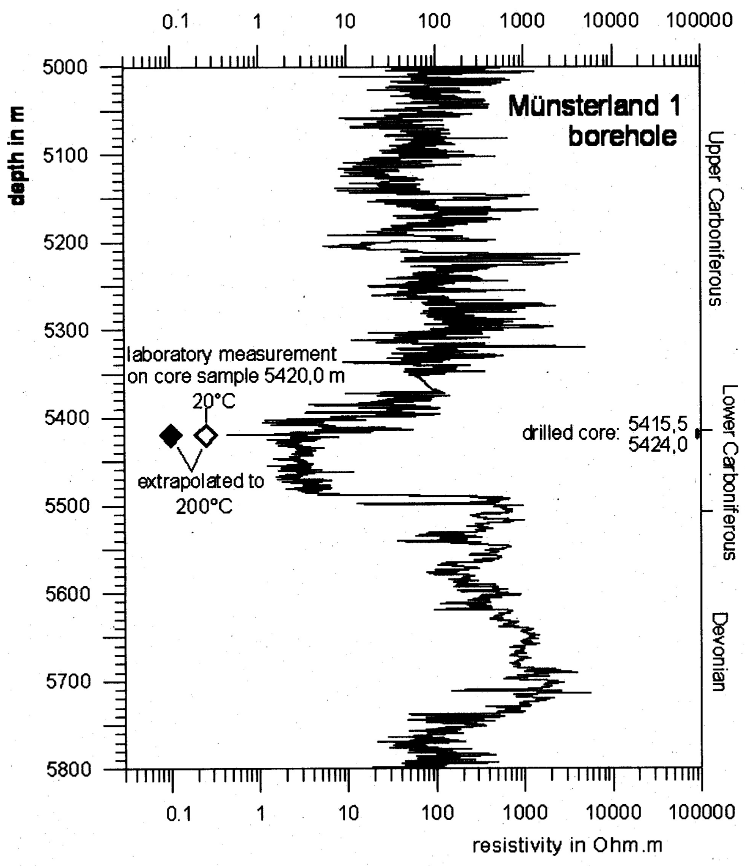


Figure 7 Results from drilling; a black shale layer of more than 100m thickness

This drilling from Northern Germany shows a conductive layer at 5400 m depth. The high conductivity is an indicator that the black shale layer has been diagenised one or several times.

If this layer is too deep or too old there may be no reservoir on top anymore.

The former reservoirs generated in the Perm/Trias age (250 MA ago) are not existing anymore. Every reservoir has a natural leakage and will dissolve after some MA (typically 60 MA in Northern Germany)

Example, the Glückstadt Graben

Results from a nearby drilling can identify the presence of middle to late Paleozoic, lower carboniferous black shales (320-360 MA) below lower Permian seen at 6 km.

The MT profile is south of the drilling location where the graben structure is deeper and the conductor is seen here at greater depth in the center of graben (> 10 km), but not seen on the flanks.

The shallow conductors are related to sediments with high content of conductive fluids. At greater depth there is no porosity anymore and no conductive fluids. Therefore we can differentiate between fluid conductivity at shallow depth and rock (black shales) conductivity at greater depths.

In Northern Germany we have the situation that we have porous layers and sealing layers:

- Rotliegend sandstone (red bed sandstone) (260-300MA) below Zechstein Salt (upper Permian) (250 MA) with
- Triassic sandstone (245 MA) below Triassic Salt (240 MA).

Below two kinds of source rocks are present: either upper carboniferous coals (320 MA) or lower carboniferous black shales (350 MA).

The MT method is able to recognize this type of rocks and identify the geological process. In case of the black shales the MT acts as an indirect indicator: not the reservoir itself is detected. Where the conductive layers are present a reservoir might have been generated. Together with an analysis of the geological structure and age of the formation decision to drill can be made.

MT results can be combined with results from drilling and geology and other geophysical methods such as reflection and refraction seismic, gravity and magnetics.

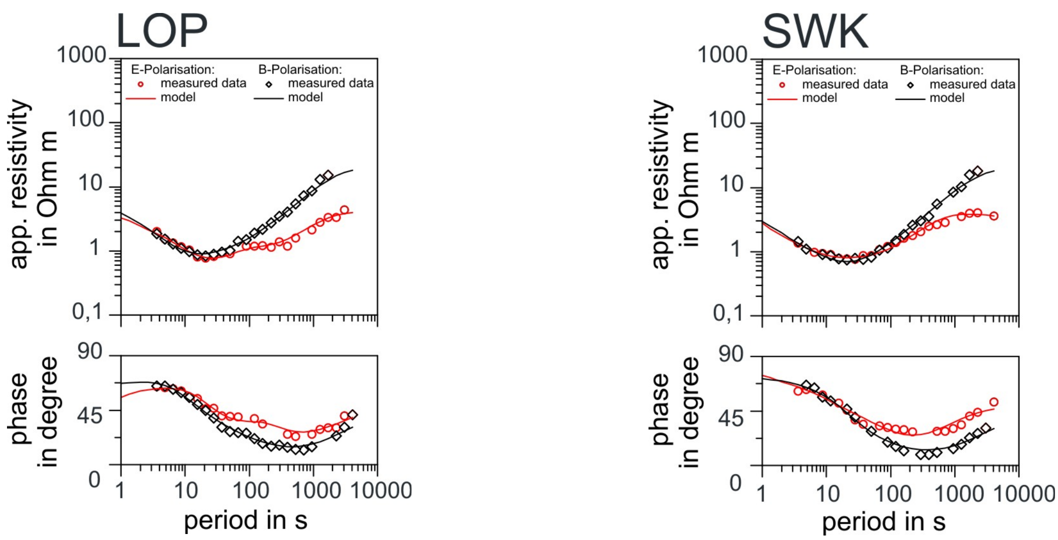


Figure 8 Central and Eastern Part

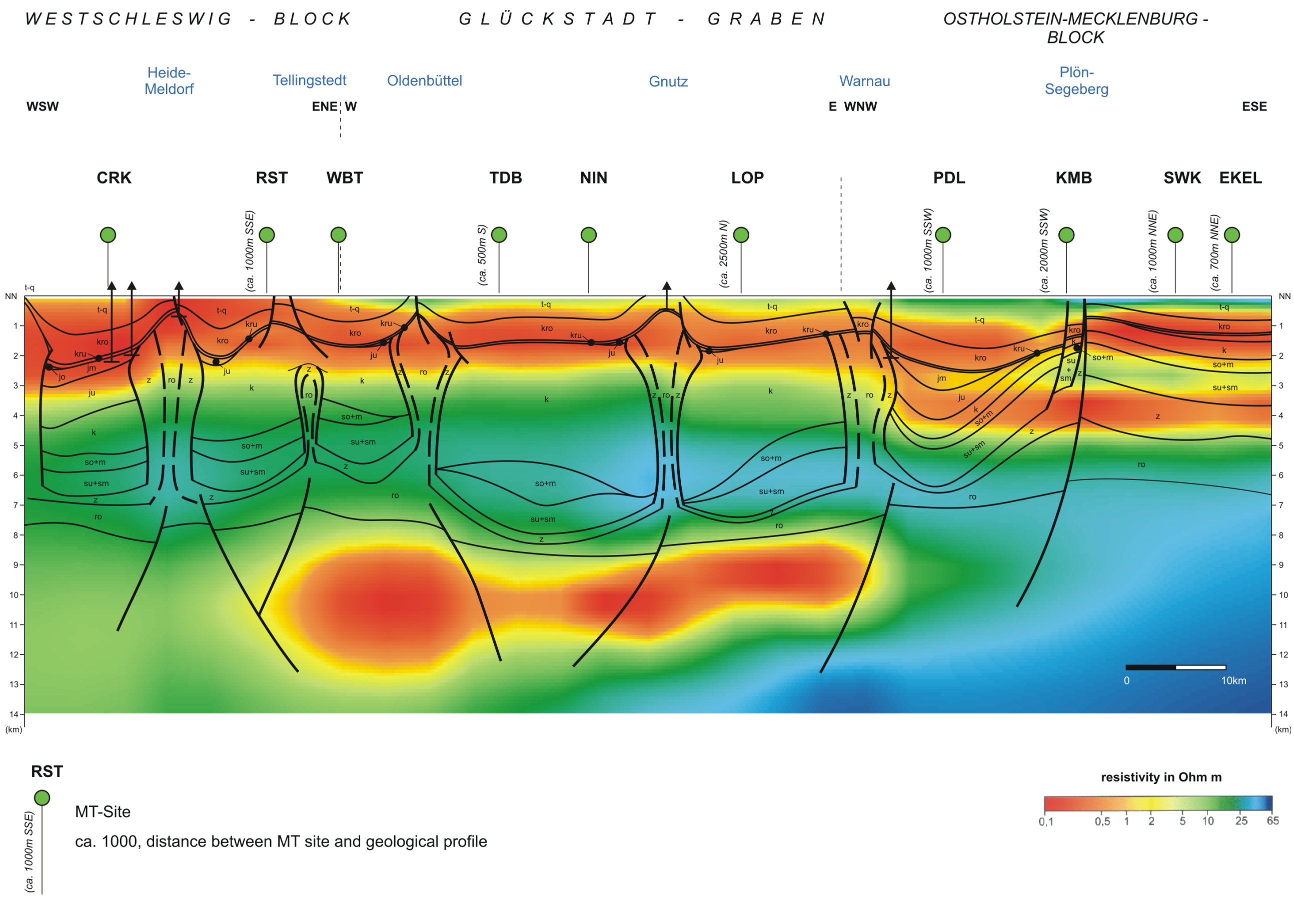


Figure 9 2D Inversion result from the GG Profile (Glückstadt Graben)

The black outlines are from the geology and from seismic results

Additionally:

In Northern Germany we can see salt domes quite often (as seen in the outlines of figure 9)

The salt structure itself can be difficult for MT measurements because the electrical currents can be re-directed by these structures and cause static shift). If there are conductive top layers however the risk is lower.

At some of these salt structures reservoirs can be found.

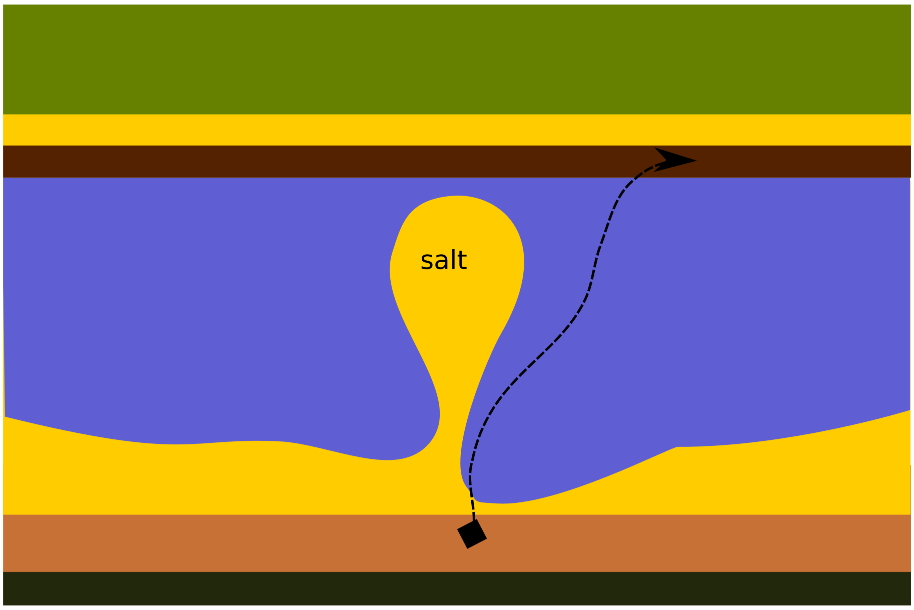
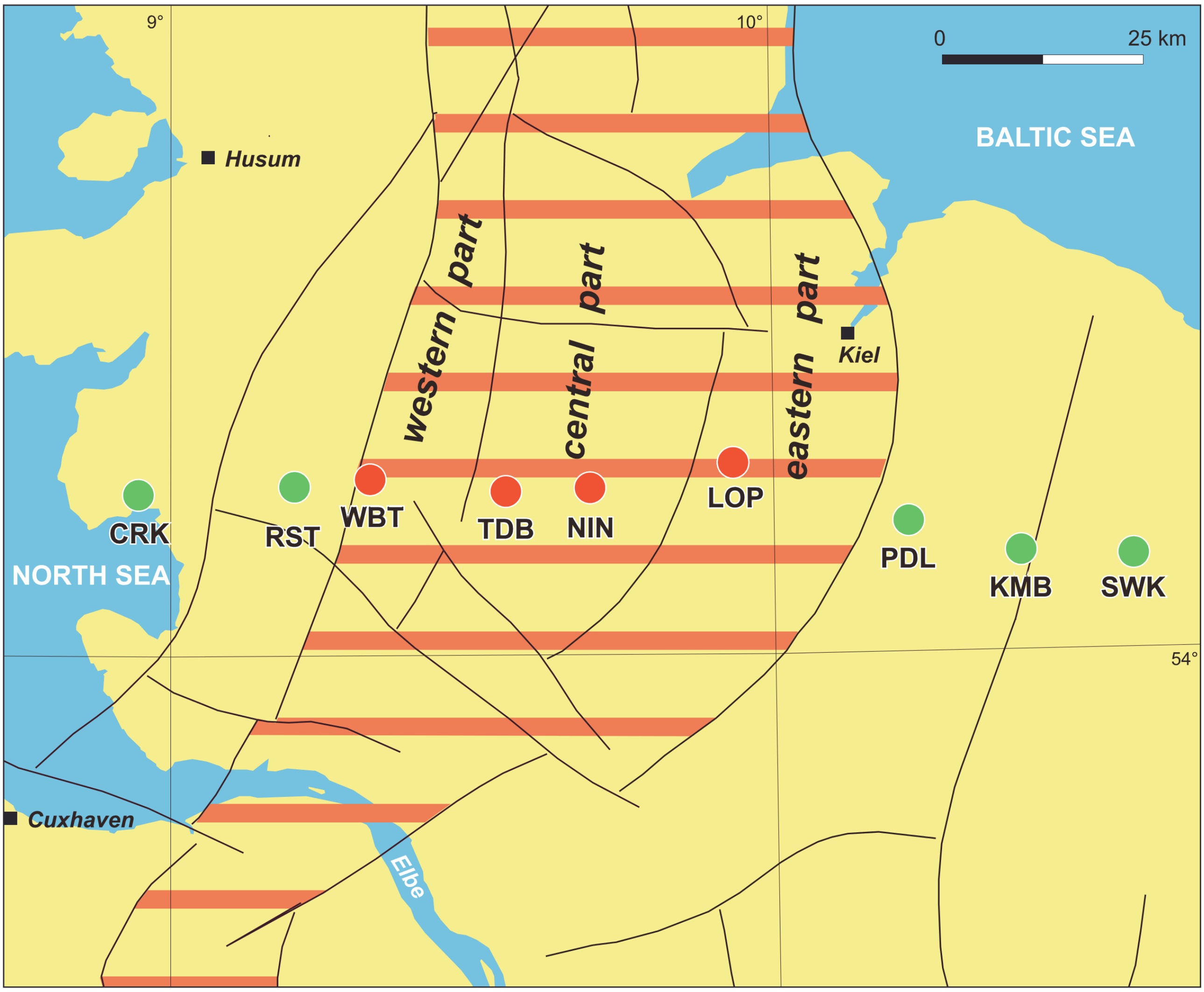


Figure 10 reservoir migration

A typical pattern in Northern Germany is a reservoir migration. In case the sealing layer is defective (or as shown here, the sealing migrates into a salt dome) it may occur that the gas can move to the next sealing layer.

In this case the gas is much older than the layer where the reservoir is found.

In this case the result from MT would show a very deep conductor, but the gas reservoir is quite shallow. MT would indicate areas of possible exploration.



Good conductor in Lower Carboniferous sediments (Rhenohercynian Alum shale)

Non conductive sediments in the pre Westphalian

Figure 11 Graben Structure re-modelled after MT

After combination of several geophysical methods including the MT, this graben structure becomes visible today. Former geological maps did not show this area because the basin structure was only assumed to more southern areas.

The Glückstadt Graben is a good example where geophysical methods change a former geological model.

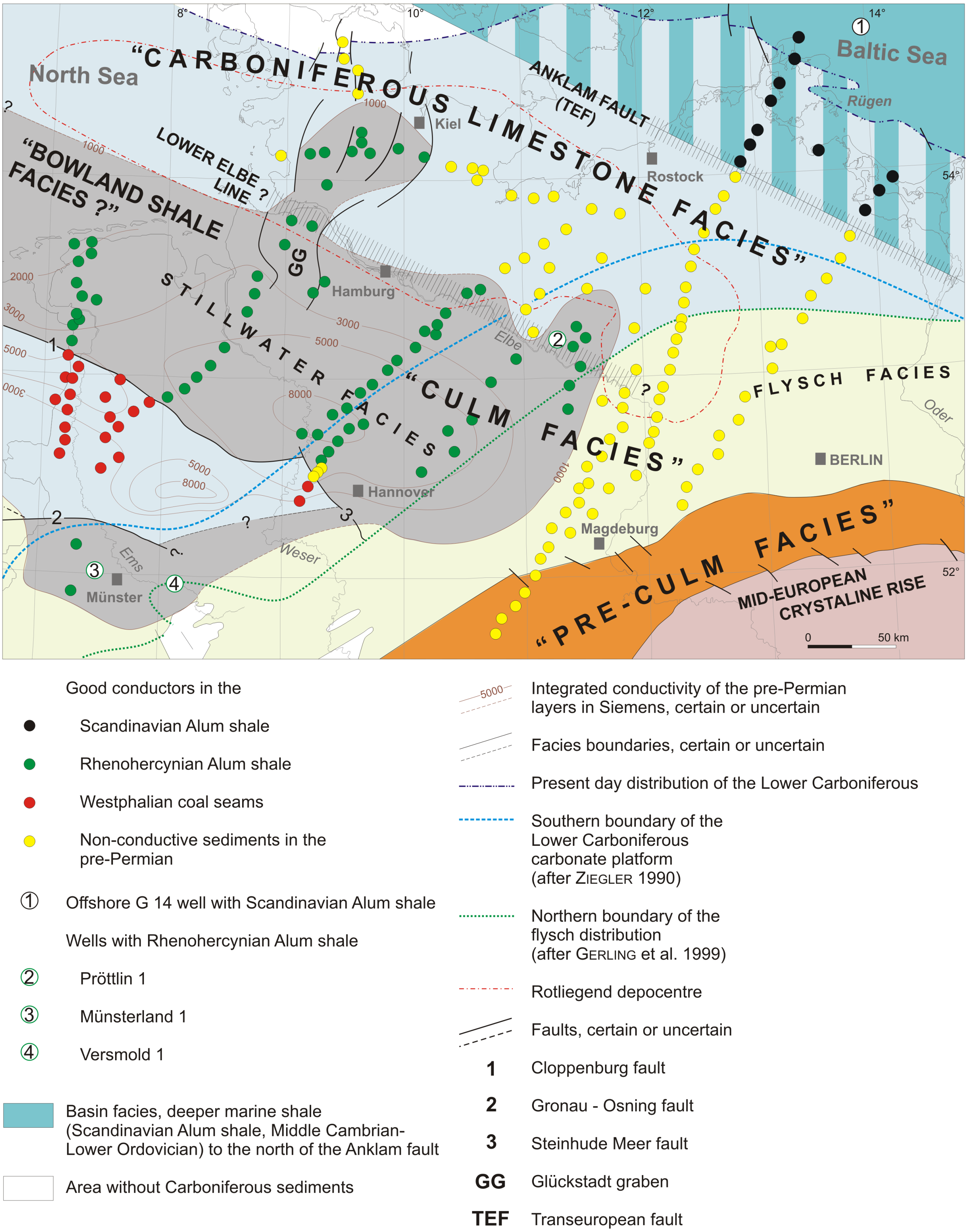


Figure 12 - Including the results from the MT, especially in the GG area

The Bowland stillwater (black shale) facies has been drawn from the MT results.

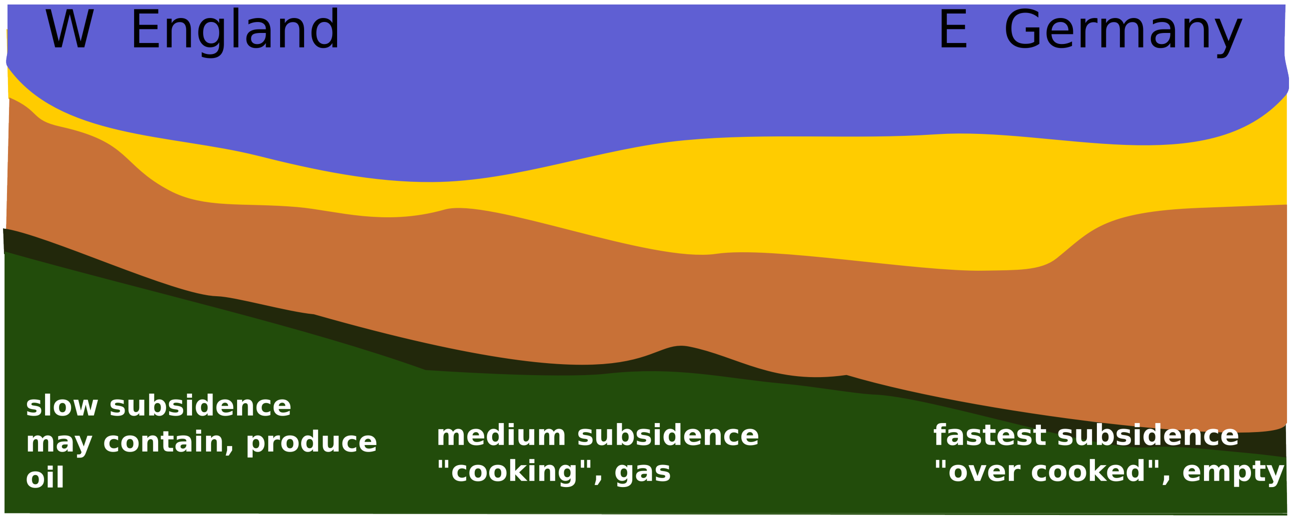


Figure 13 Same layer, different geological status

The black shales in Northern Germany have been subsided quite deep (as shown in the Glückstadt-Graben) In this area the generation of Oil and Gars started approx. in the late Permian (300-250 MA). These reservoirs are not filled anymore because the gas has already moved out.

Looking to the more western part we come to more shallow structures. The rocks were not subsided as deep as in the eastern part and much slower. Therefore they “cooking process” also started much later and the reservoirs get filled much later and today still contain gas.

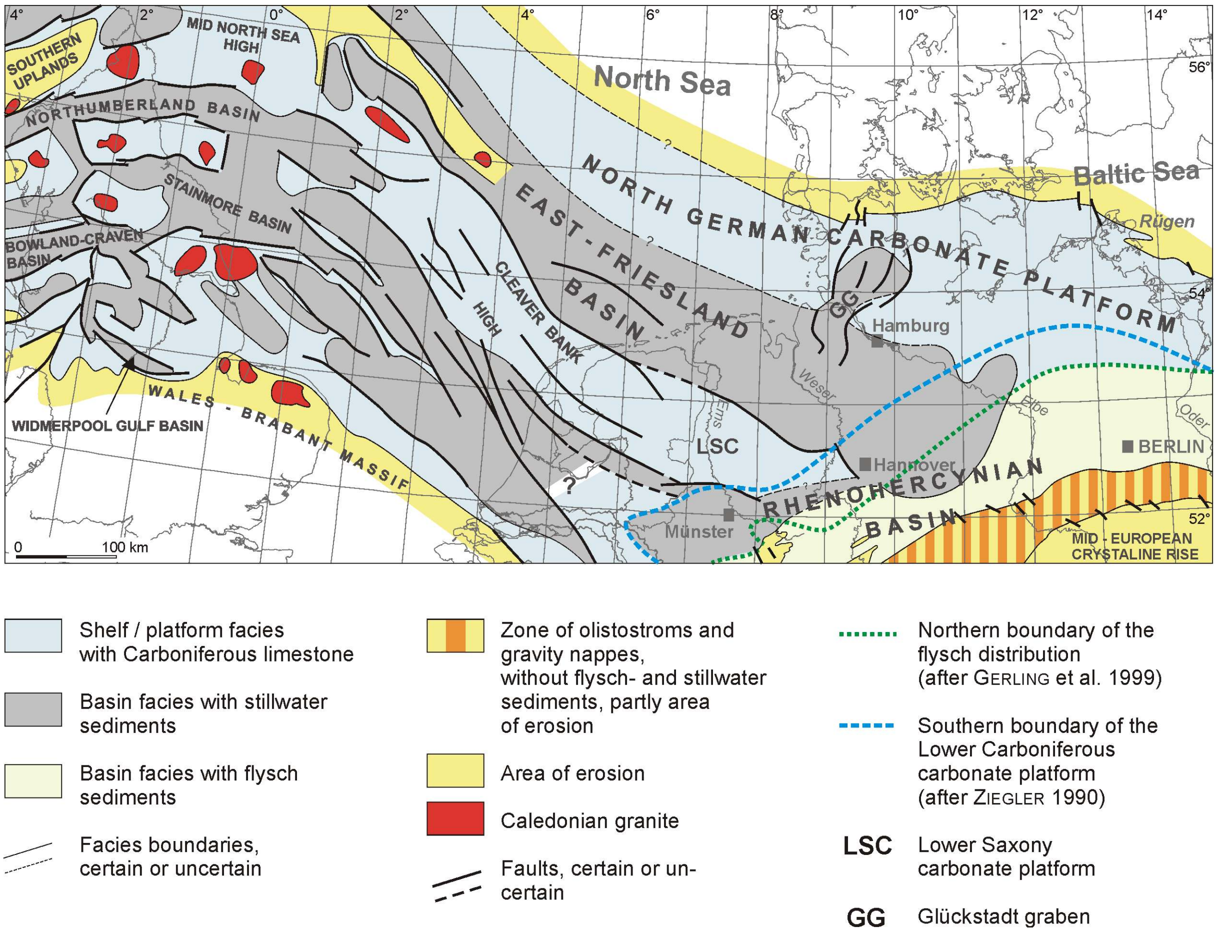


Figure 14 Stillwater facies including the North Sea

The construction black shales layer map was especially possible with the MT method. Seismic measurements could additionally prove the results.

In the Western part of this map, in North Sea, many gas and oil fields are today in production. Even though many have been drilled before this study was completed, understanding these processes today allow a more efficient exploration controlled by geophysical methods, especially the MT.

The maps and results shown here are the work of more than 30 years of investigation.

Thank you to Norbert Hoffmann and Heinz-Jürgen Brink for giving comments.