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

# Metronix 公司使用 ADU 大地电磁系统在德国勘探页岩气的运用效果

*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.

此次报告是对于在德国北部、关于页岩气储藏进行的一次大地电磁测量的概述。简述了运用 MT 方法探测与页岩气成藏条件之间的关系。

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).

从1992年到2004年的12年间，在德国北部完成了200多个测点的测量，使用的仪器是 Metronix 公司生产的记录仪（MMS-03e，ADU-06，ADU-07e）。

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

此项目是由德国联邦地球科学和自然资源研究所（简称 BGR）发起的图一中的不同标记显示了不同区域测量进行的时间，右侧几条黑色圆点标记的测线是有 Ulrich Matzander 在1992年~1996年完成的，左侧几条测线是由 Dr.Bernhard 在1998年~2003年、2004年完成的。他们年轻的时候大多时间都是在野外进行实地测量的。

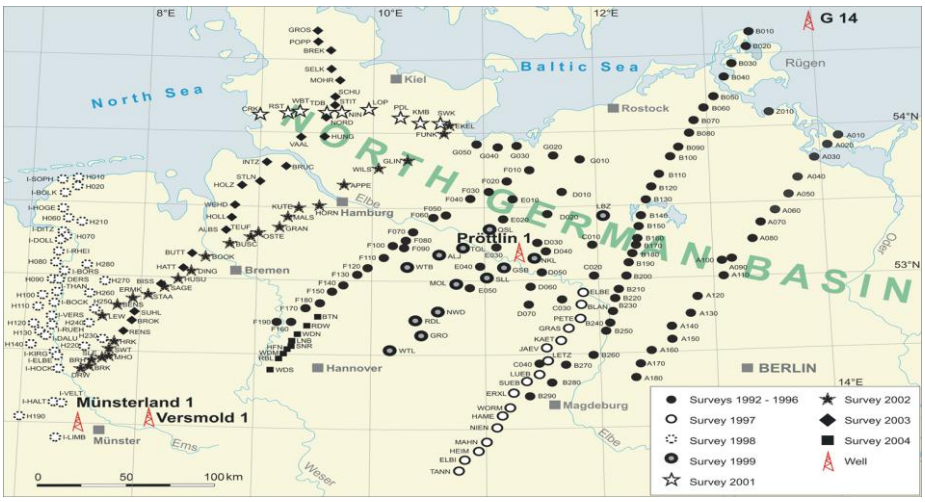



Figure 1 MT sites in Northern Germany 1992 - 2004

# Black Shales in Northern Germany / Northern Europe


Figure 2 Pyrite Segment inside a black shale; located Ireland 含有黄铁矿的黑页岩，来自爱尔兰

Black shales belong to mainly marine sedimentation.

黑页岩主要形成于海洋的沉积作用

**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 ($FeS_2$).

1）大多数黑页岩中包含藻类物质，在气候温暖的、没有水循环的低浅盆地区域，例如今天的黑海，藻类物质沉积在海底，假设沉积过程发生得迅速且彻底，大量的没有被底层生物吃掉的藻类会被厌氧生物所分解，藻类物质含有大量 S，在成岩过程中，S 与 Fe 反应生成

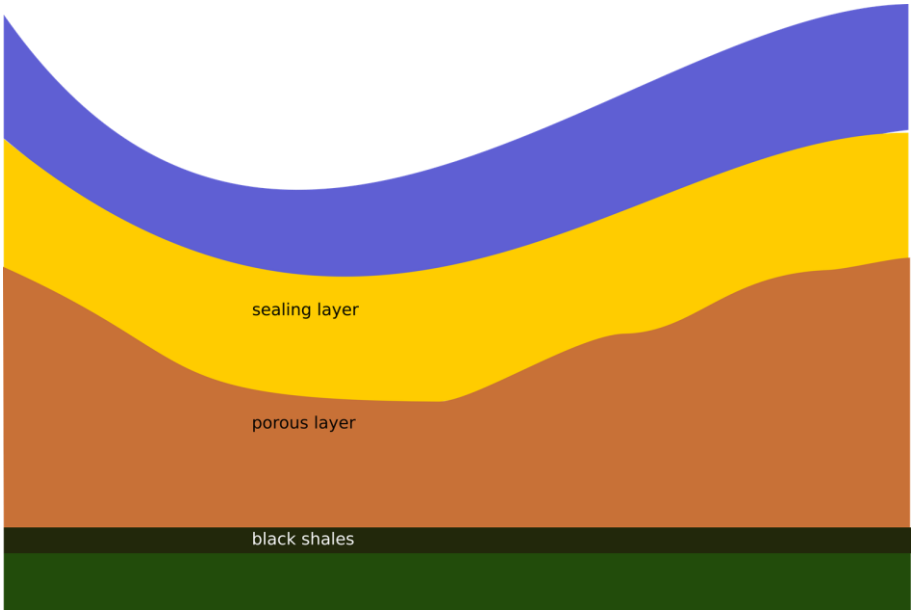



Figure 3 Example sedimentation 几个必要的成油气条件，黑页岩层（生油层）、储油层、盖油层）

**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.

2）在持续的沉积作用下，如果这些沉积物的多孔性仍然存在，那么储层就存在了（例如砂岩和碳酸盐都可以作为储层存储黑页岩中产生的油或气）。

**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.

3） 第三个必要条件就是盖层，可以将油和气封闭起来

**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** ℃.

If the layer was heated longer time above 200 ℃ 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).

4）如果以上条件都满足，那么有可能产生碳氢化合物，沉积物在足够热量的作用下，就会产生碳氢化合物，碳氢化合物通过自然裂隙上升到储层，所需温度为80~200度。如果黑色页岩经历加热时间较长，那么碳氢化合物大多数都跑掉了。也就是说页岩中不再含有碳氢化合物，但是于此同时，页岩电导率会越来越高，最终可以经由 MT 方法探测到。

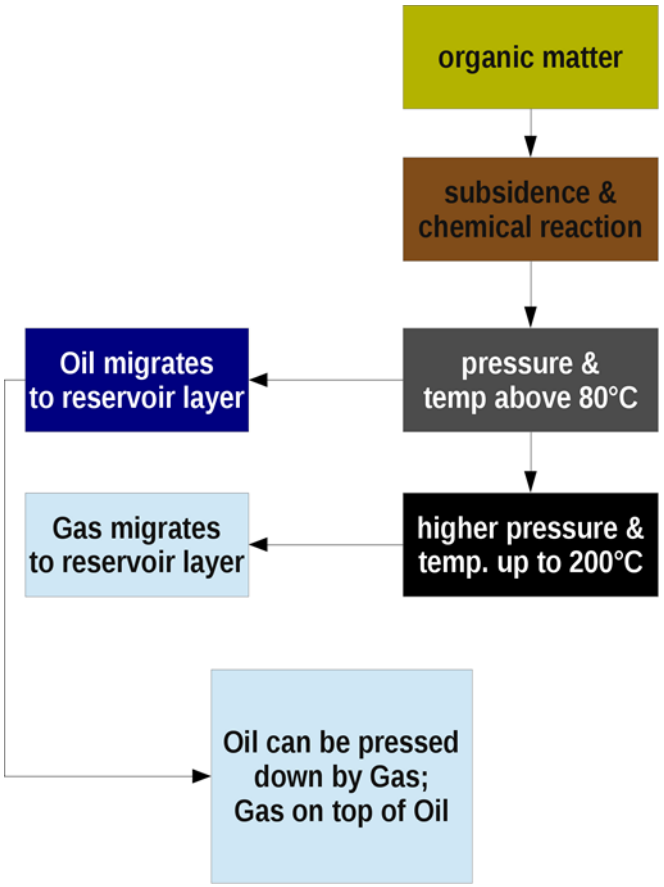



Figure 4 Simplified reservoir generation

**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.

5）与此同时或在此之前，盆地必须在构造力作用下产生一定形变，否则油和气无法存储，碳氢化合物就会升至顶层跑掉了。

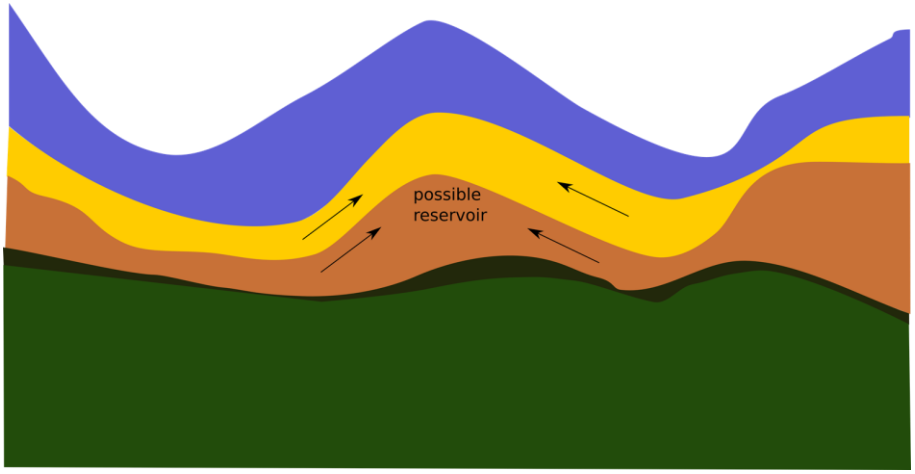



Figure 5 basin after re-formation with possible reservoir area in the center

图5 构造力作用下，盆地被挤压，两侧的气会泄露掉，而中间部分的油气则被保存下来

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

因此，一方面构造运动会产生储层结构，另一方面，过于频繁或剧烈的构造运动也会破坏盖层，导致油气泄漏。在德国北部，典型的半衰期为6千万年，即使形成油气，6千万年后也会消失殆尽。

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

图6 1910年的德国油田，就在 Metronix 公司所在城市附近

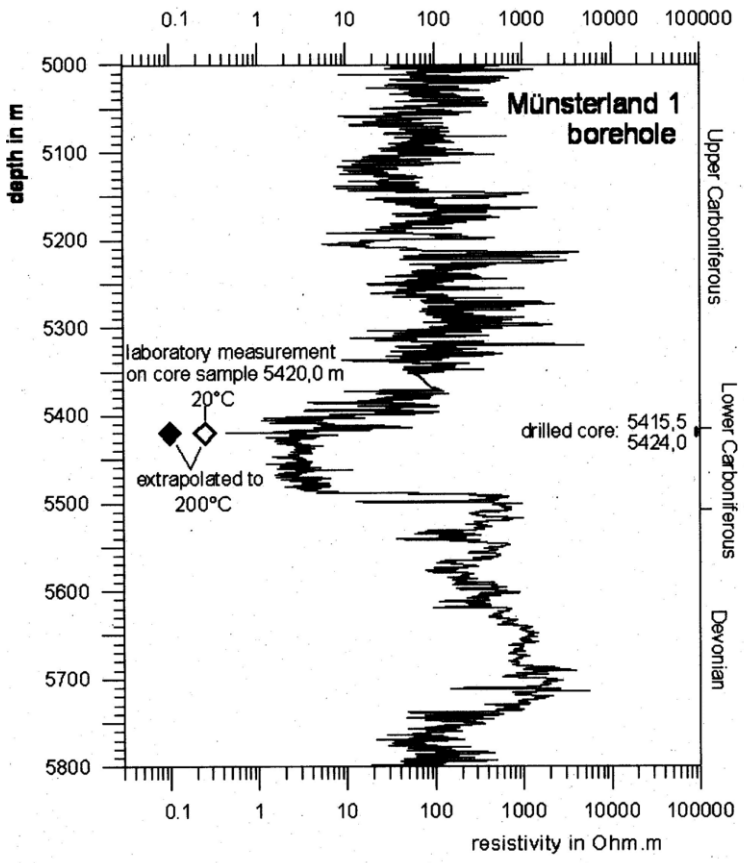



Figure 7 Results from drilling; a black shale layer of more than 100m thickness

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)

在5400米深处存在一个黑页岩电导层，高电导率表明此黑页岩层已经数次被加热产生油和气。如果此页岩层太深或者年代太久，那么可能储层已不复存在。之前的储层产生于25千万年前，现在已经不复存在了。

所有的储层都会好产生泄漏并最终消失（之前提到过、德国北部的情况是6千万年后油和气将全部会发）

# 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.

通过 MT 方法探测到的是黑页岩层而不是储层，还要通过地质结构分析及形成年代的判定，最后打钻进行证实。

MT 结果需要与钻孔结果相结合，还需要结合地质和其他地球物理方法，如反射法、折射法、重力法或磁法等。

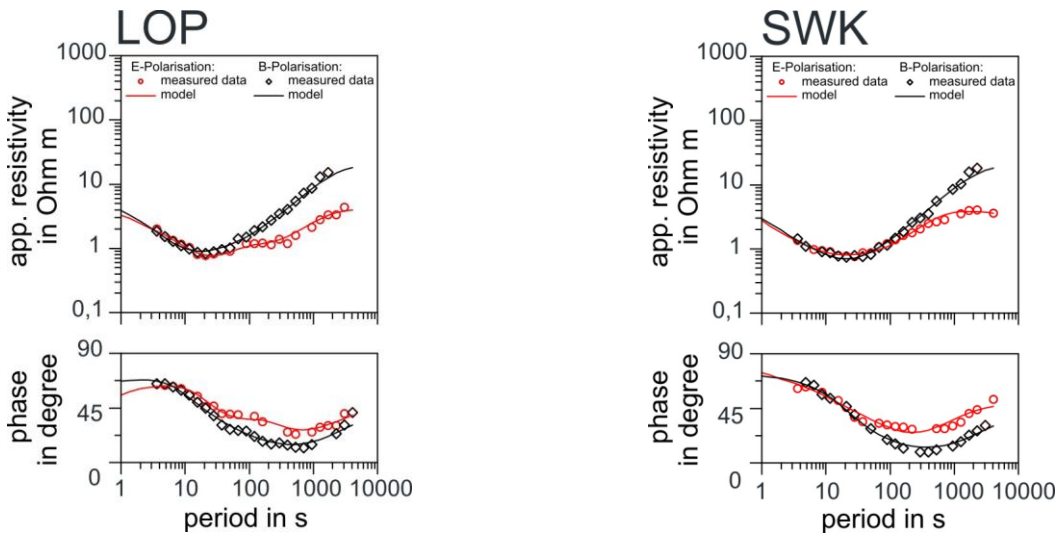



Figure 8 Central and Eastern Part

图 8 测区中部及东部的视电阻率曲线

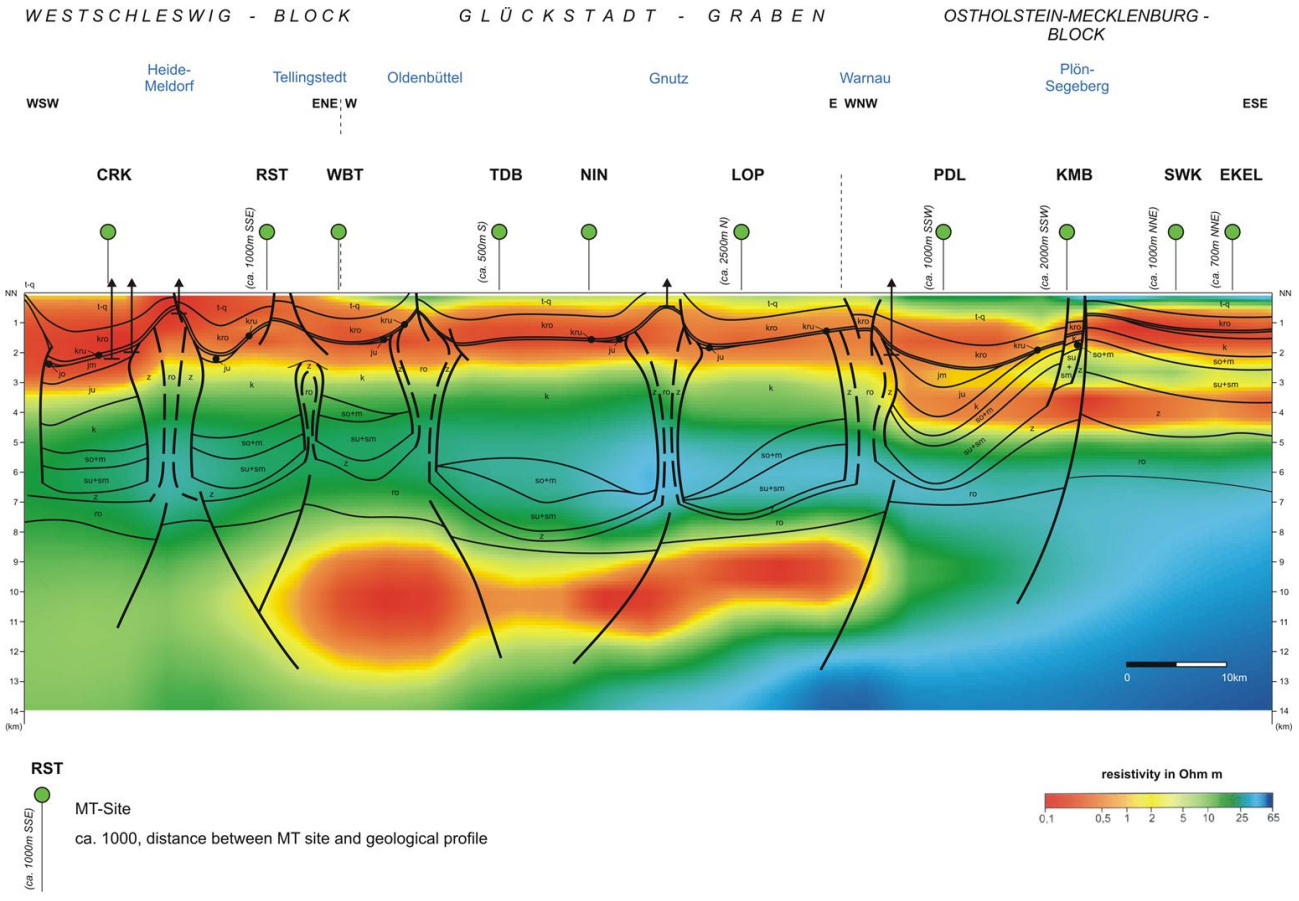



Figure 9 2D Inversion result from the GG Profile (Glückstadt Graben)

图 9 GG 测线的 2 维反演结果，黑色轮廓线来自于地质及地震结果

The black outlines are from the geology and from seismic results

可以看到 10km 深度有一层黑页岩，在 WBT 测点到 LOP 测点之间。表层为高导层但不是页岩层。

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.

在德国北部盐丘很常见，盐结构本身很困难用 MT 探测，因为电流方向被改变而产生静态偏移，但是如果顶部有电导层，则相对容易些。

在一些盐结构中可以找到储层。

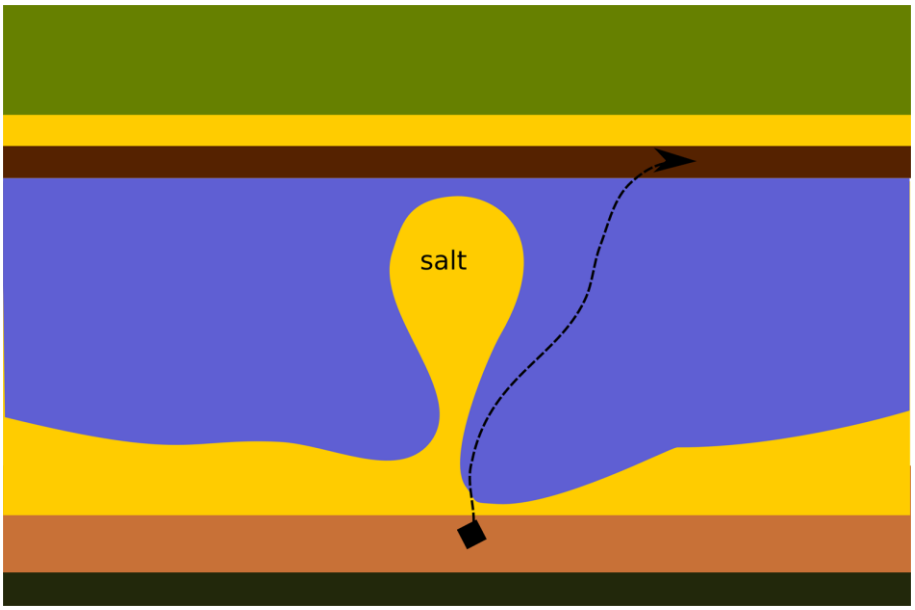



Figure 10 reservoir migration

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.

在德国北部一种典型的页岩气为类似蓄水池模式，当盖层被破坏时（或如上图所示盖层发生移动）天然气可能移动到下一个储层。

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

在这种情况下，天然气的形成年代就会比当前储层老很多。

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.

在这种地质条件下通过 MT 探测可能会在深部发现高导体，但天然气储层可能很浅，此时通过 MT 可以指导那些是适合探头区域。

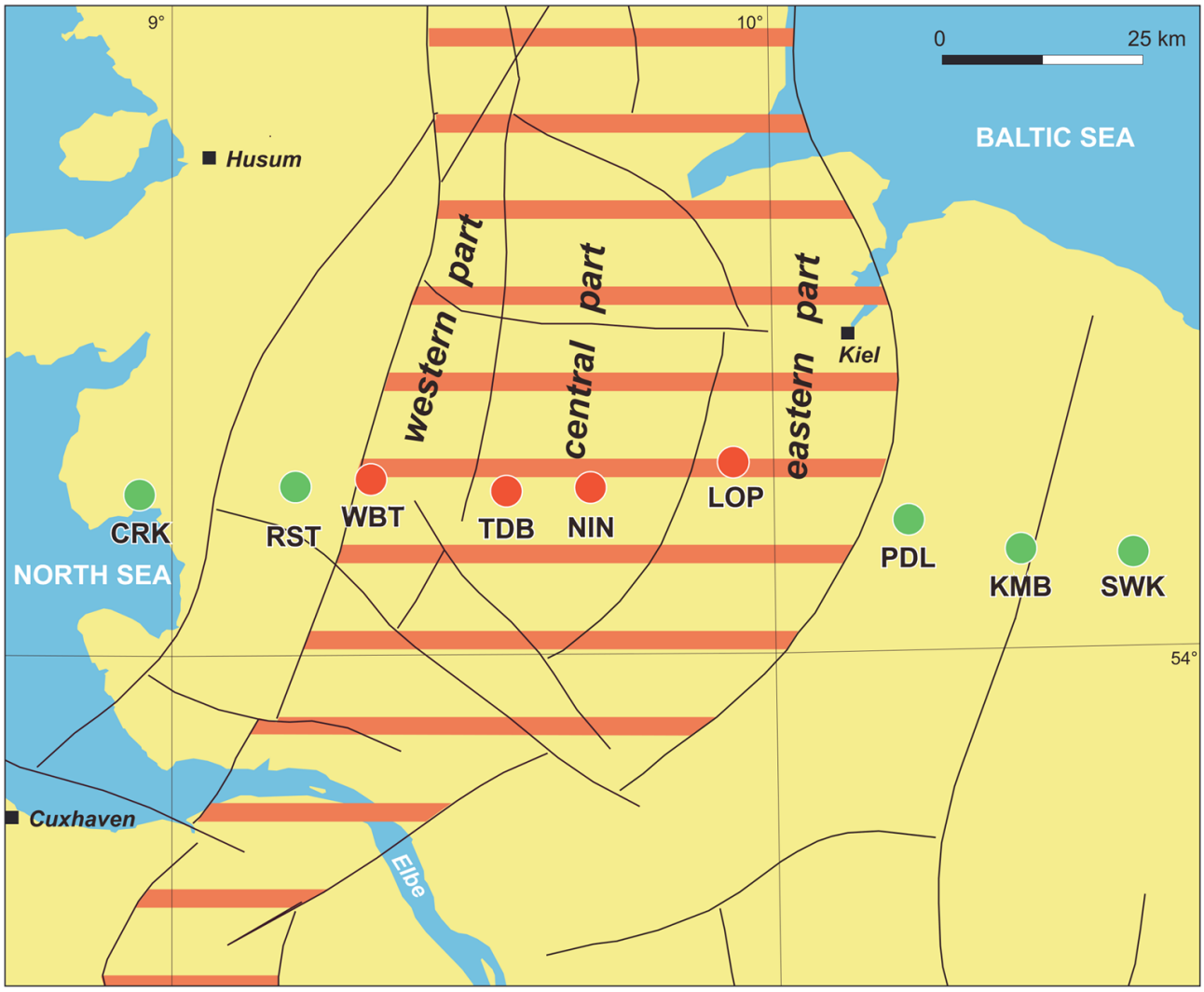



Figure 11 Graben Structure re-modelled after MT

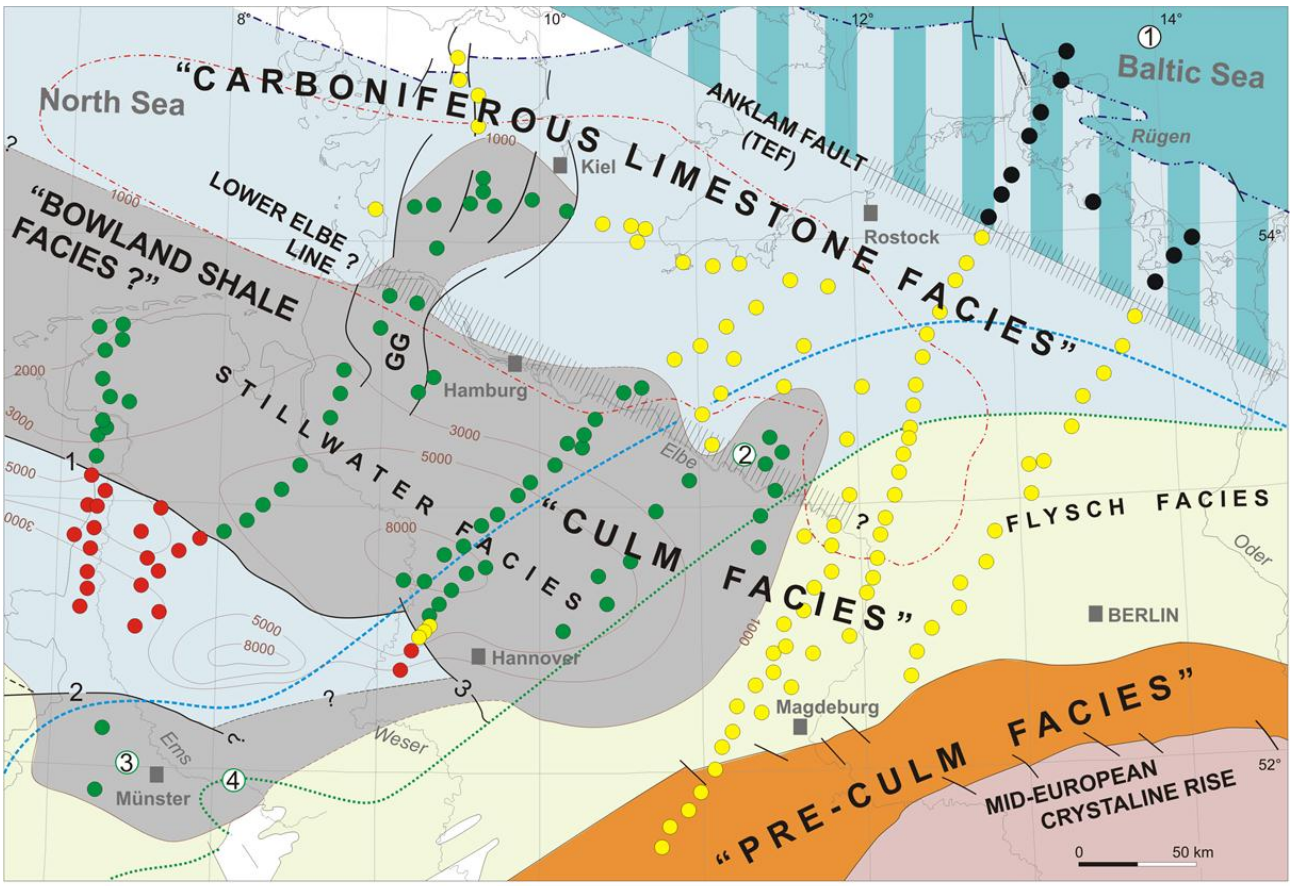
图11　通过 MT 工作后重新做的地堑构造模型

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.

通过联合 MT 在内的多种地球物理方法勘探，现在这个地堑构造的地质情况已经比较清楚了，以前的地质图中没有这个区域的地质情况，因为它的地质构造只是通过南部区域的地质模型推断的。

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

Glückstadt 地堑是通过地球物理勘探后修正原有地质模型一个很好的例子。




Good conductors in the

- Scandinavian Alum shale
- Rhenohercynian Alum shale
- Westphalian coal seams
- Non-conductive sediments in the pre-Permian

① Offshore G 14 well with Scandinavian Alum shale

Wells with Rhenohercynian Alum shale

② Pröttlin 1

③ Münsterland 1

④ Versmold 1

Basin facies, deeper marine shale (Scandinavian Alum shale, Middle Cambrian-Lower Ordovician) to the north of the Anklam fault

Area without Carboniferous sediments

5000 Integrated conductivity of the pre-Permian layers in Siemens, certain or uncertain

Facies boundaries, certain or uncertain

Present day distribution of the Lower Carboniferous

Southern boundary of the Lower Carboniferous carbonate platform (after ZIEGLER 1990)

Northern boundary of the flysch distribution (after GERLING et al. 1999)

Rotliegend depocentre

Faults, certain or uncertain

1 Cloppenburg fault

2 Gronau - Osning fault

3 Steinhude Meer fault

GG Glückstadt graben

TEF Transeuropean fault

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.

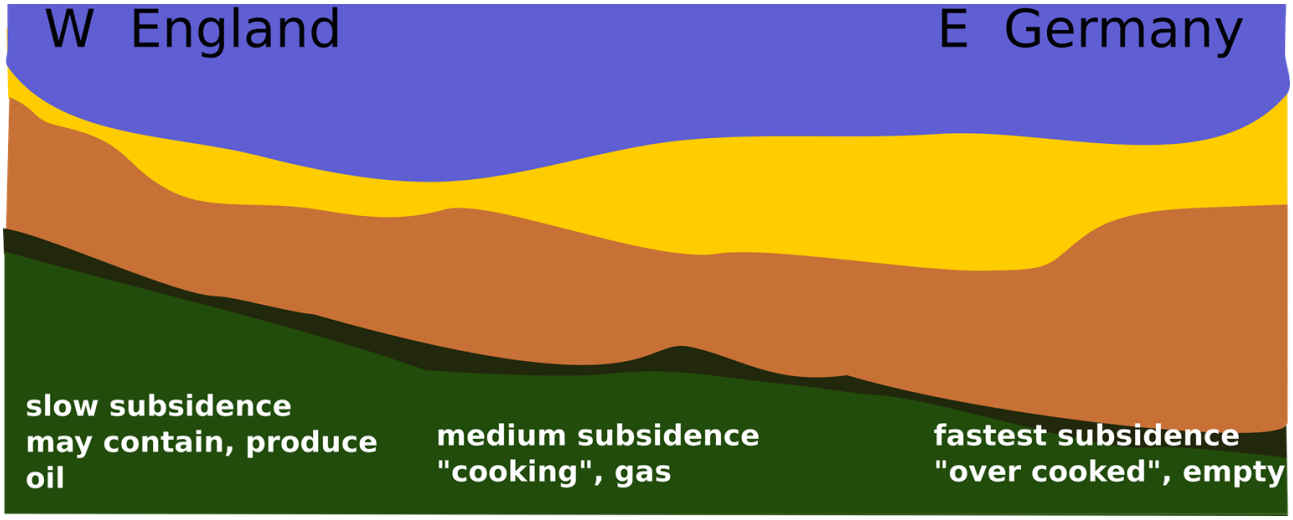



Figure 13 Same layer, different geological status

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.

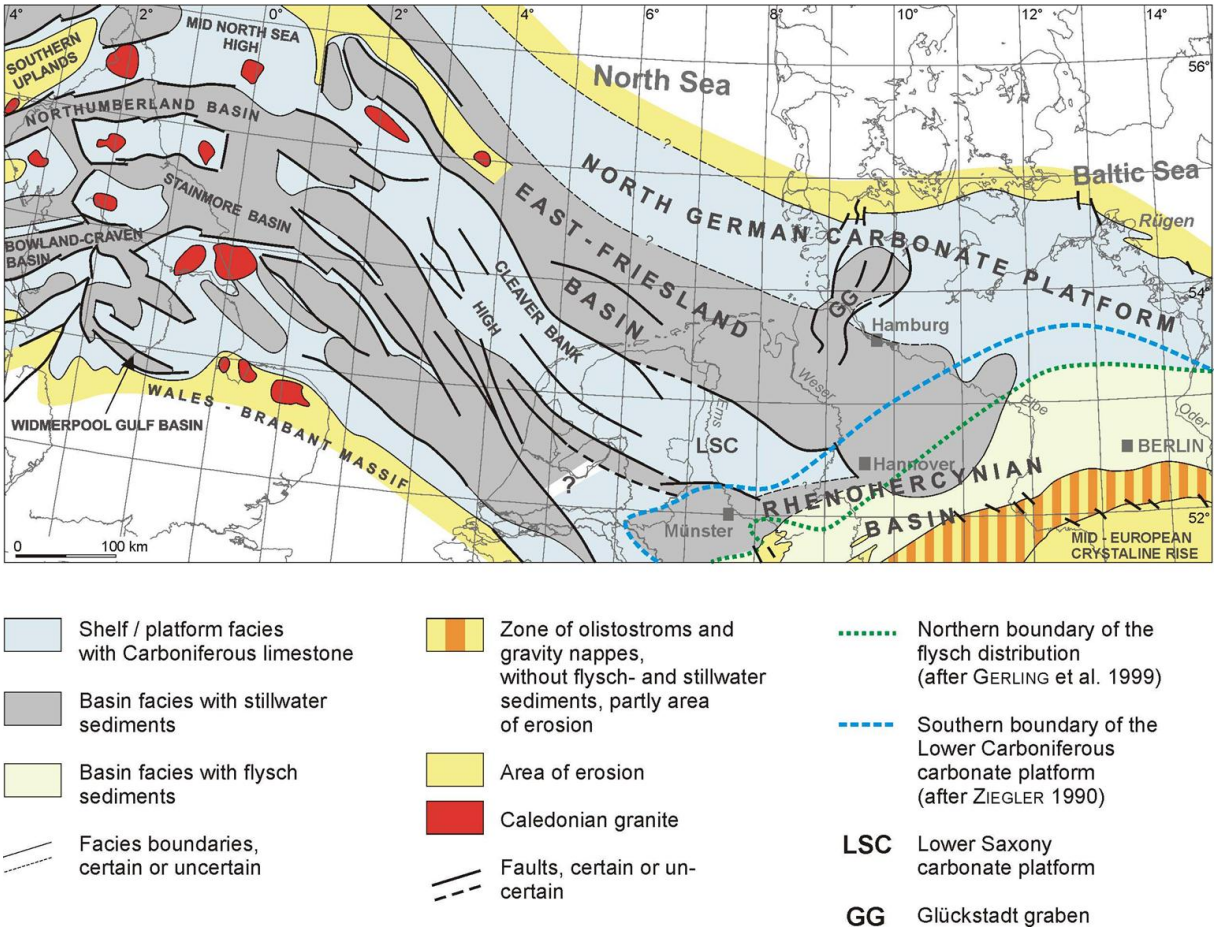



Figure 14 Stillwater facies including the North Sea

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

通过 MT 方法勘探页岩气是一个很有效的方法，另外还可以通过地震进一步证实 MT 的结果

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.

在上图西部（北部海域），今天仍然后很多油气田在开采，由于页岩层埋藏较浅，所以成气过程开始较晚，现在仍含有天然气。甚至在进行本次研究之前已经打过很多钻孔，这也有利于开展更深入的勘查工作，包括地球物理勘查，尤其是 MT 测量。

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

这个图显示的是过去30年的结果。

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