A Magnetotelluric and Organo-geochemical Model of the Occurrence of Black Shale (Potential Source Rock) in the Deep Subsurface of the North German Basin

Norbert Hoffmann[1], Peter Gerling[2], Wolfgang Müller[2], and Hartmut Jödicke[3]

[1]Bundesanstalt für Geowissenschaften und Rohstoffe, Dienstbereich Berlin, Wilhelmstr. 25-30, D-13593 Berlin
[2]Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, D-30655 Hannover
[3]Institut für Geophysik der Universität Münster, Correnstr. 24, D-48149 Münster

Introduction

In the past 10 to 15 years, the interest in the deep subsurface of the North German basin and its oil and gas potential has grown considerably. Geophysical studies on the geological-tectonic structure of the deep basin, its genesis and development as well as the time-space distribution of hydrocarbons have been concentrated primarily on reflection seismics. However, at depths below the prominent Zechstein-base reflector, few structural details are available. Besides other potential methods providing information at this depth range, e.g. magnetics and gravity, the magnetotelluric method is well suited to investigate the electrical conductivity distribution. Since 1993, magnetotelluric surveys (Fig. 1) focused on hydrocarbon exploration have been performed in Northern Germany by the Federal Institute for Geosciences and Natural Resources (BGR) in cooperation with the Institute of Geophysics of the University of Münster (Hoffmann et al. 1998). This not very often used hydrocarbon exploration method is based on the observation that the electrical properties of highly mature source rock drastically change from poor to extremely good conductivity due to the pre-graphitization of organic matter when the metaanthracite stage of coalification is reached (Jödicke 1991). Using the magnetotelluric method, such conductors may be readily localized at large depths.

Results and discussion

The deep gas potential below the currently active Permian and Upper Carboniferous plays in northern Germany has been studied by the BGR during the years 1990 to 1995 in an integrated geological, geophysical, and geochemical approach (e.g. Stahl et al. 1996, Gerling et al. 1999). Highly mature source rock of more than 5.5% of maximum vitrinite reflectance (R_{max}), containing type III kerogen, has been demonstrated to still have a gas generating potential. Moreover, hydrous pyrolysis experiments have revealed that methane generation is even possible for some types of black shale (containing marine organic matter) at R_{max} values above 5% if enough water is available (Everlien 1997).

Currently, we try for the first time to directly correlate magnetotelluric and geochemical data with the aim of creating models of the regional distribution of potential pre-Westphalian source rock in the North German basin.

The magnetotelluric data show that a regional distribution of pre-Westphalian source rock (Figs. 2 and 3) is unlikely to exist in the depocenter of the North German Rotliegend basin because deep good conductors are missing. In contrast, Cambro-Ordovicianblack shale makes up good-conducting layers northeast of that area. This facies has been encountered inwells and outcrops in Scandinavia. The good-conducting layers south of the central Rotliegend basin can be correlated with the Dinantian and Early Namurian black shale encountered in wells (Hoffmann et al. 1998).

Althoughpyrolysis experiments still attribute a certain amount of gas formation potential to the Cambro-Ordovician source rock, this potential is not realistic due to high maturities. The prerequisites in the area of the Dinantian/Early Namurian source rock, however, have to be discussed differently: Depending on the maturity of the organic substances, this type of rock generates gas of disparate qualities along the Rotliegend fairways. Such gases have been identified in several gas fields by using gas and isotope geochemical reservoir data (Fig. 4).

Conclusions

- Magnetotelluric measurements provide new paleogeographical and tectonic information on the deep subsurface.
- Gas generation of pre-Westphalian source rock can be locally identified by evaluating gas and isotope geochemical data in gas reservoirs. Magnetotelluric data can be used to put this information in a regional context.
- An excellent example of the efficiency of this method is the exploration of the Ems Estuary gas province: The appearance of good-conducting layers in the pre-Westphalian subsurface coincides with high contents of hydrocarbon gases originating from pre-Westphalian marine source rock in the Rotliegend gas fields (Fig. 4).
- A similar conclusion can be drawn from the deposits in the Rotliegend fairway further to the east. Since there the maturity of the pre-Westphalian marine source rock is already beyond methane formation, the input in gas fields merely consists of nitrogen.
- Basically, the whole area with its Dinantian-Namurian source rock is quite interesting for the deep gas exploration. For example, a gas genesis from pre-Westphalian source rock is assumed in the Alfeld-Elzegas field south of Hannover (GERLING et al. 1999). The same is true for large areas in The Netherlands and for almost the entire southern North Sea (GERLING et al. 1998).
- As in the Rotliegend depocenter area no indications for an extensive distribution of pre-Westphalian source rock can be derived from magnetotelluric data, exploration for deepgas does not seem to be very promising there (Figs. 2 and 3).

This initial and integrative approach has already revealed new exploration incentives. In pursuing it, we expect further information on the extent of deep marine source rock. More details of our study can be found in the forthcoming paper by HOFFMANN et al. (2001).

References

EVERLIEN, G. (1997): Hydrous Pyrolysis of High-Maturity Paleozoic Coals and Black Shales from Central Europe and Adjacent Areas - Thermodynamic Considerations. – Geol. Jb. **D103**: 43-64; Hannover

GERLING, P., LOKHORST, A., NICHOLSON, R.A. & KOTARBA, M. (1998): Natural Gas from pre-Westphalian Sources in Northwest Europe – a new Exploration Target? – 1998 International Gas Research Conference, 8-11 November 1998, San Diego, California USA, Proceedings (CD-Rom): 219-229

GERLING, P., KOCKEL, F. & KRULL, P. (1999): Das Kohlenwasserstoff-Potential des Präwestfals im Norddeutschen Becken – Eine Synthese. – DGMK-Forschungsbericht **433**: XII+ 107 S.; Hamburg

HOFFMANN N., JÖDICKE, H. & GERLING, P. (2001): The distribution of Pre-Westphalian Source Rocks in the North German Basin – Evidence from Magnetotelluric and Geochemical Data. – Geologie en Mijnbouw/ Netherlands Journal of Geosciences, (in press)

HOFFMANN, N., JÖDICKE, H., FLUCHE, B.. & MÜLLER, W. (1998): Modellvorstellungen zur Verbreitung potentieller präwestphalischer Erdgas-Muttergesteine in Norddeutschland – Ergebnisse neuer magnetotellurischer Messungen. – Z. angew. Geol. **44**: 140-158; Stuttgart

JÖDICKE, H.(1991): Zonen hoher elektrischer Krustenleitfähigkeit im Rhenoherzynikum und seinem nördlichen Vorland. – Hochschulschriften Bd. **24**, Lit. Verlag; Münster, Hamburg

STAHL, W. J., GERLING, P., BANDLOWA, T., BRÜCKNER-RÖHLING, S., EVERLIEN, G., HOFFMANN, N., KESSEL, G., KOCH, J., KOCKEL, F., KRULL, P., MITTAG-BRENDEL, E., SOHNS, E. & WEHNER, H. (1996): Deep natural gas, a challenge for the future? – In: KÜRSTEN, M (ed.): World Energy, a Changing Scene, Proc. of the 7th Int. Symp. Held in Hannover, Germany, at the Federal Institute for Geosciences and Natural Resources, Oct. 25-27, 1994: 169-191; Stuttgart

Fig.1: Magnetotelluric sites in the North German Basin

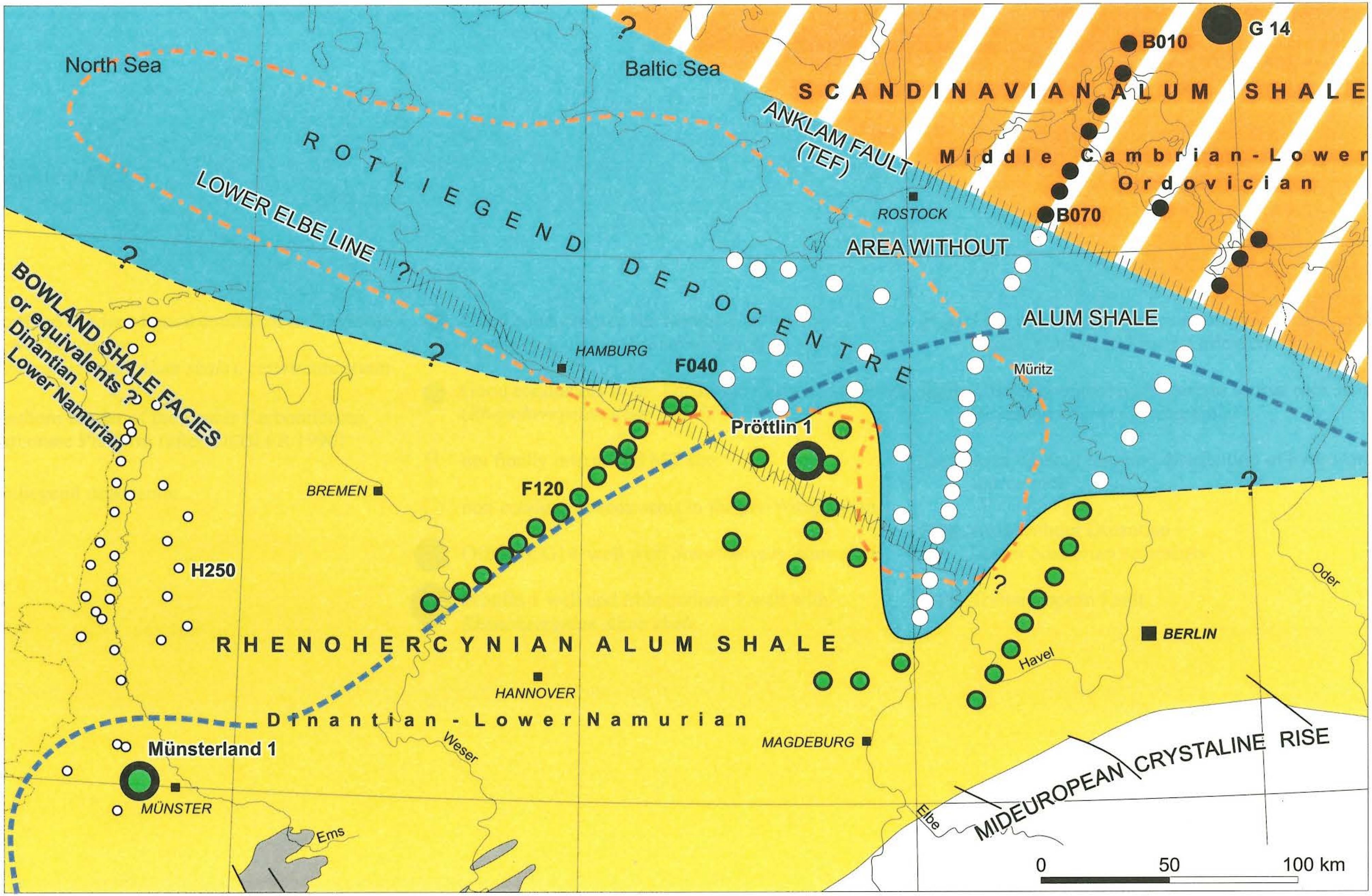

Fig.2: Regional distribution of potential pre- Westphalian gas source rocks in the deep subsurface of the North German basin as derived from electrical conductivity and organo-geochemical data.

Fig.3: Legend for Fig.2

- Northern border of good conductor in Dinantian - Lower Namurian (*Rhenoherzynian Alum shale*), certain/uncertain
- Southern border of the Lower Carboniferous Carbonate Platform (after ZIEGLER 1990)
- Rotliegend depocentre

- Good conductors in the Middle Cambrian - Lower Ordovician (*Scandinavian Alum shale*)
- Good conductors in the Dinantian - Lower Namurian (*Rhenohercynian Alum shale*)
- not finally interpreted MT site
- non-conductive sediments in the pre-Westphalian
- Offshore G14 well with *Scandinavian Alum shale*
- Pröttlin 1 well and Münsterland 1 well with *Rhenohercynian Alum shale*

- Area of potential hydrocarbon source rock in the Middle Cambrian-Lower Ordovician
- Area of potential hydrocarbon source rock in the Dinantian - Lower Namurian
- Area without regional distribution of hydrocarbon source rock
- Area without Dinantian - Lower Namurian sediments
- TEF Transeuropean Fault

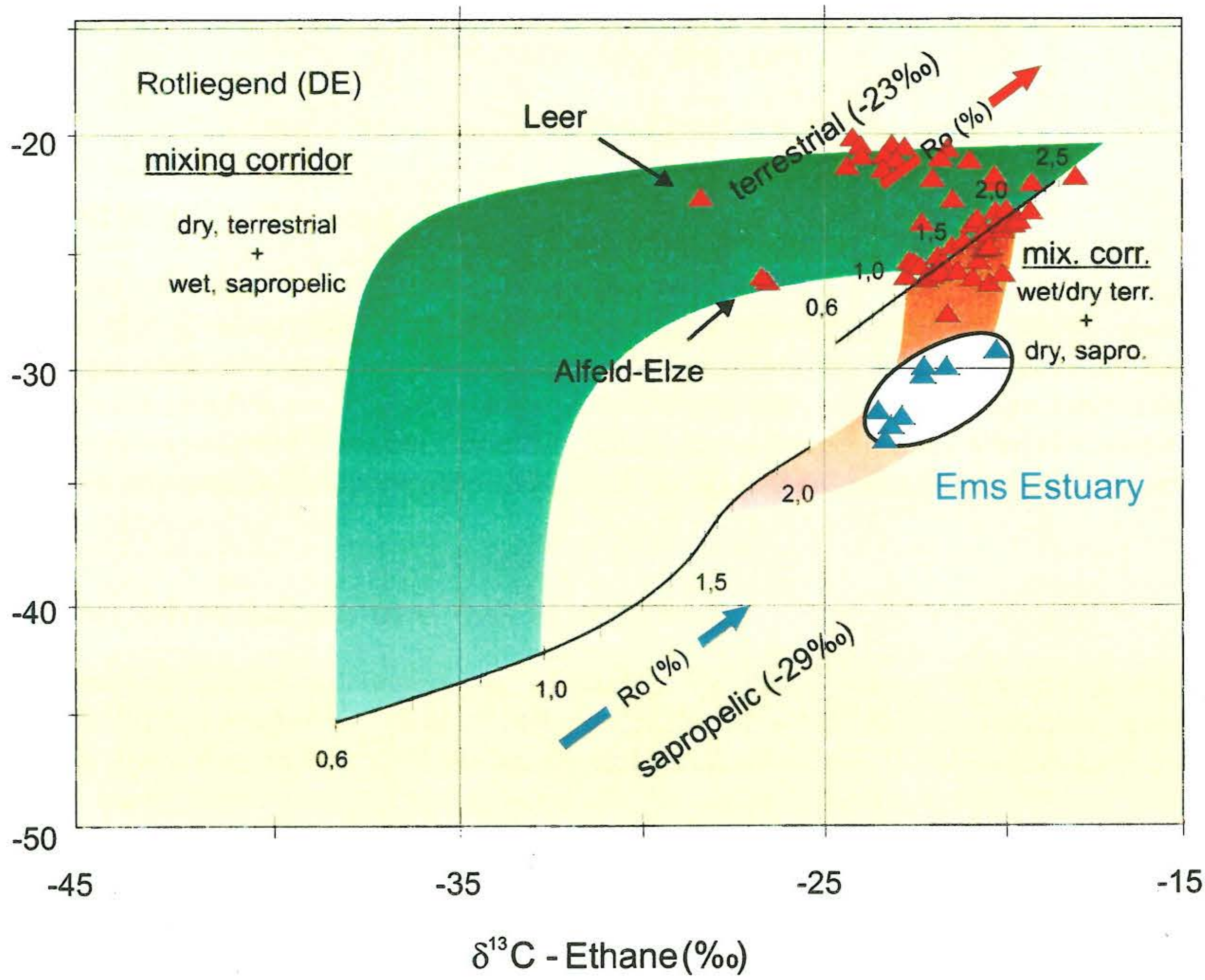

Fig.4: Carbon isotope ratios of methane and ethane can be used to estimate type and maturity of a gas - generating source rock, or gas mixtures from different source rocks. Most of the Rotliegend natural gases clearly originate from Upper Carboniferous (Westphalian) coal, some have a minor admixture deriving from poorly mature marine source rock, whereas the Ems Estuary gases partially originate from highly mature marine source rock, presumably Lower Namurian and/or Dinantian Alum shales.