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Miocene depositional environment and climate in western Europe: The lignite deposits of the Lower Rhine Basin, Germany

Alexander T. Stock [a], Ralf Littke [a,*], Andreas Lücke [b], Laura Zieger [a], Thomas Thielemann [c]

[a] Institute of Geology and Geochemistry of Petroleum and Coal, Energy and Mineral Resources (EMR), RWTH Aachen University, Lochnerstr. 4-20, 52056 Aachen, Germany
[b] Institute of Bio- and Geosciences, IBG-3: Agrosphere, Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428 Jülich, Germany
[c] RWE Power AG, PET-L, Stüttgenweg 2, 50935 Cologne, Germany

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ABSTRACT

Miocene lignites representing a depositional history of about 7 million years (18–11 Ma before present) have been studied by organic petrological and organic geochemical methods including analysis of stable carbon and oxygen isotopes. The three lignite seams investigated (Morken, Frimmersdorf, Garzweiler) developed from peats which grew in a nutrient depleted paralic environment situated close to the sea. All seams have low ash/mineral matter contents, but seam Frimmersdorf is richer in sulfur as compared to seams Morken and Garzweiler. Sulfur richness and distribution in seam Frimmersdorf might be due to the diagenetic effect of sulfate reduction and pyrite precipitation following flooding by the sea and deposition of the marine Neurath sands on top of seam Frimmersdorf.

Geochemical palaeotemperature analysis (GDGT) revealed a warm climate during deposition of the peats representing lignite seams Morken and Frimmersdorf which shifted towards lower temperatures (2–3 °C) during deposition of the uppermost seam Garzweiler, i.e., at about 13–11 Ma before present. This trend is basically supported by cellulose oxygen isotope values which show a significant scatter, however. Carbon isotope values are less variable, indicating predominance of angiosperms in the peat vegetation and rather stable environmental conditions as well as floral assemblage. Organic petrological studies reveal predominance of small plants and a nutrient depleted environment. A modified Groundwater Index (GWIac) was applied, suggesting deposition above the general groundwater level.

1. Introduction

The large Miocene lignite deposits in Central Europe are excellent archives for the environmental and climatic evolution reflecting optimum tectonic and climatic conditions for peat growth during this time. In a warm and humid climate, peats grew over a time span of more than 10 million years, leading to a cumulative thickness of up to 100 m of lignite. Peat deposition was interrupted by several periods, during which marine and fluvial sands and clays were deposited. The lignites represent the largest resource of this kind in Europe with total reserves of 40 billion tons (BGR, 2014) and have been mined in several open pit mines over the last decades. They have been the subject of various palynological (Figueiral et al., 1999; Teichmüller, 1958; von der Brelie and Wolf, 1981), petrographical (Dehmer, 1988; Hagemann and Wolf, 1987; Naeth et al., 2004; Teichmüller, 1962) and chemical studies in the past (Bechtel et al., 2002; Teichmüller and Thomson, 1958).

In the present study the depositional and early diagenetic conditions during the Lower to Middle/Upper Miocene in the Lower Rhine Basin (Fig. 1) were investigated through the combination of petrographical, geochemical and isotope analysis. While the petrographical analysis allows for a detailed assessment of the depositional conditions, especially through the application of i) ash and mineral contents and ii) maceral composition and maceral indices (Calder et al., 1991; Diessel, 1986; Taylor et al., 1998), the applied geochemical analysis of glycerol dialkyl glycerol tetraethers (GDGTs), remnants from Crenoarcheota, but also from soil bacteria, allows for a direct temperature assessment (Schouten et al., 2007). Combined with isotopic trends obtained from $\delta^{13}C$ and $\delta^{18}O$ isotope analysis, this data can be used to reconstruct environmental conditions and trends governed by the tectonic and climatic dynamics during the time of peat deposition.

The stable isotope composition of plant material is primarily controlled by climatic conditions such as temperature, humidity/precipitation and soil water content. Since the Miocene peat-forming vegetation was composed almost exclusively of C3 trees and shrubs, the $\delta^{13}C$-values are not affected by a change between C3 and C4 plants (Lücke et al., 1999; Schleser, 1995). To avoid misinterpretation of data

* Corresponding author.
E-mail address: ralf.littke@emr.rwth-aachen.de (R. Littke).

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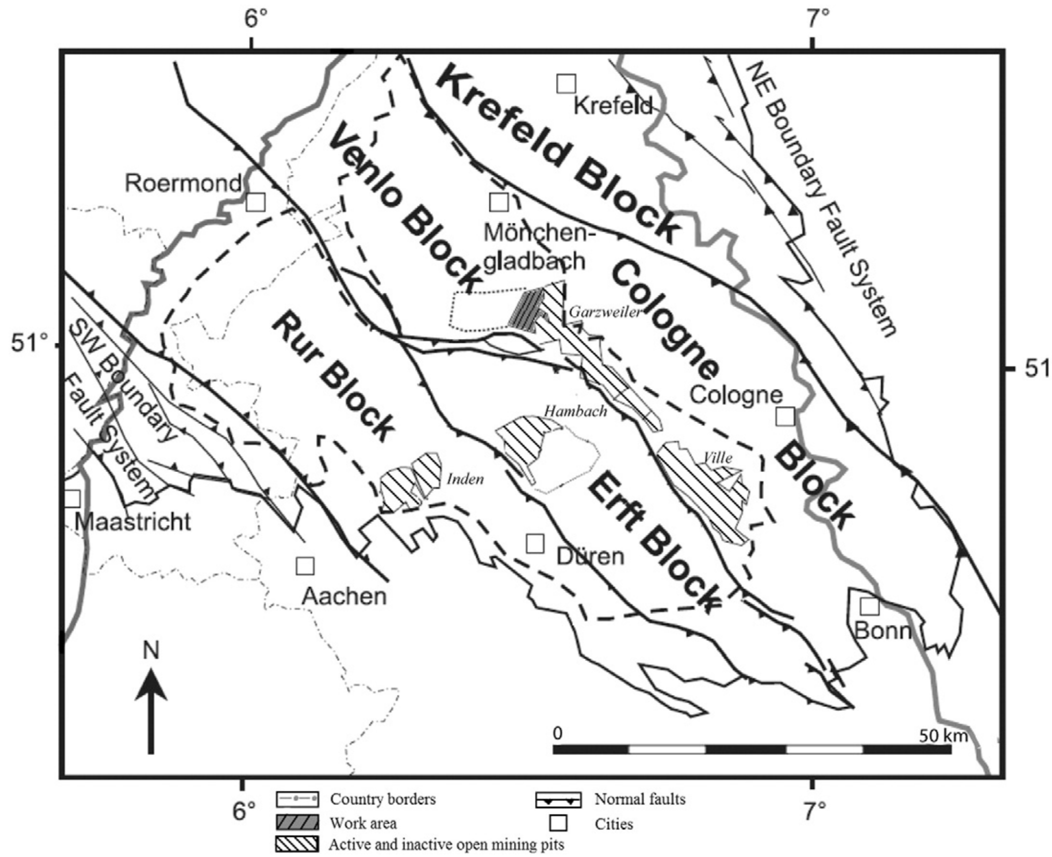

Fig. 1. Major structural elements of the Lower Rhine Embayment and location of the Garzweiler mining pit. After Naeth et al., 2004.

due to impacts by e.g., local and biological factors influencing the isotopic signatures of individual plants (Benner et al., 1987), measurements were conducted both on bulk lignite samples as well as on extracted cellulose.

2. Geological setting and paleoenvironment

The Lower Rhine Basin is a Tertiary structure located in the foreland of the Rhenish Massif in northwestern Germany. It is trending north-west to south-east and has been subject to subsidence, evidence of which is found in steep normal faults running north-west to south-east (Fig. 1) (Schäfer, 1994). In combination with sea-level fluctuations, the subsidence since the Oligocene led to several marine transgressions into the Lower Rhine Basin (Schäfer and Utescher, 2014; Schäfer et al., 2005).

Folded Devonian and Carboniferous rocks compose the basement of the basin and have been buried to great depth already in Late Carboniferous times (Littke et al., 1994). This sedimentary sequence containing black shales and hard coals is locally and unconformably overlain by unfolded Mesozoic rocks in the south-western and northern parts (Hager, 1993), remnants of a thicker Mesozoic sequence that was largely eroded (Karg et al., 2005). Graben formation started during the Oligocene leading to continuous sedimentation in the area of the Lower Rhine Basin.

Peat deposition began during the Upper Oligocene (Chattian)/Lower Miocene (Aquitanium, Burdigalium) in the Köln formation. The main onset of massive peat deposition started during the Lower/Middle Miocene and led to the deposition of locally up to 300 m thick peats of the main seam (Hager, 1993) in the Ville formation (Fig. 2). In this formation, these deposits contain up to three major seams, each of them with a regionally variable occurrence. From oldest to youngest, they are named: Morken, Frimmersdorf and Garzweiler. Regionally, seams Frimmersdorf and Garzweiler can show additional compartmentalization, into the Frimmersdorf a and b seams, and the Garzweiler I, II and III seams. Reasons for this compartmentalization are manifold. One major reason is marine transgressions from the northwest leading to deposition of the Frimmersdorf sands and the Neurath sands.

The Ville formation, hosting the three seams is overlain by the Inden formation in the Upper Miocene and the Rotton and Reuver series deposited in the Pliocene and Pleistocene. The deposition of thick and wide-spread peats ended with the Inden formation. Marine transgressions, which were most pronounced during the Oligocene and Middle Miocene ceased with the transition into the Upper Miocene, after the deposition of the marine Neurath sands, leading to a more continental facies (Naeth et al., 2004). Especially during the Miocene depositional conditions were those of a paralic environment in a humid, warm climate. These conditions favored peat growth in swamps and raised bogs, leading to a predominantly angiosperm dominated vegetation (von der Brelie and Wolf, 1981). The overlying Pliocene is of fluvial origin and contains only minor coal seams.

Paleo-temperature records from isotope data (Fig. 3) and from palynological analysis indicate a cooling period during the Oligocene after the warmest period of the Cenozoic during the Eocene. With the transition of the Upper Oligocene into the Lower Miocene temperatures once again increased resulting in the Mid-Miocene climatic optimum. Mean annual surface temperatures in Central Europe during this time are believed to have ranged between 16 and 21 °C, based on palynological observations (Mosbrugger and Utescher, 1997; Schwarzbach, 1966). Temperatures in Germany, during the deposition of the main seam in the Lower/Middle Miocene are interpreted to have ranged between 9 and 28 °C (Utescher et al., 2000, 2012). These high temperatures combined with a humid climate led to the deposition of the largest peat deposits in Europe. However, with the onset of the Upper Miocene temperatures started to decrease, initiating a trend that is continuous until today (Fig. 3; Zachos et al., 2001).