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Surface and subsurface expressions of gas seepage to the seabed—examples from the Southern North Sea

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Abstract

Expressions of gas seepage observable within North Sea seismic and acoustic data include seabed pockmarks, seepage plumes in the water column, acoustic blanking, shallow enhanced reflectors, and shallow seismic chimneys. Three areas were selected for a marine survey in which 60 vibrocores were taken. Gas content of the seabed sediment samples (methane and ethane concentrations of 2 to10,395 vppm and 0.5 to 2.2 vppm respectively were observed in the headspace gas) and carbon stable isotope ratios of methane (−88.3 to −30.5 ‰) were determined, in order to examine if geochemical anomalies confirm the interpretation of geophysical anomalies. In a few cases they did, whereas in other cases it was questionable whether only slightly elevated concentrations may be considered as a confirmation of the interpretation of geophysical anomalies. In the case of a seabed pockmark methane concentrations in headspace gas were elevated (122.6 vppm) in the samples taken from the centre of the pockmark compared with 5–10 vppm background values away from the pockmark. Very high concentrations of methane (up to 10,395 vppm) were found near an active vent, which had previously been identified via a seepage plume in the water column. Shallow enhanced reflectors in a 2D seismic profile confirm the presence of gas in the subsurface at this site. The methane concentrations (5 to 172 vppm) and carbon isotope ratios ranging from −88.9 to −30.5 ‰ found in samples taken above a Jurassic condensate field provide indications for leakage of a mixture of thermogenic and biogenic hydrocarbons to the seabed.

Keywords: Gas seeps; Pockmarks; North Sea

1. Introduction

In most of the world's hydrocarbon basins phenomena related to the migration of hydrocarbons to the near-surface environment or to seepage into the biosphere can be found. We present observations from the southern North Sea basin, where various expressions of seepage to the seabed have been examined. The study of hydrocarbon seepage in general may be carried out for different reasons. First, the observation and measurement of seepage (through the detection of seismic anomalies and the determination of concentrations and stable isotope ratios from geochemical analysis of soil or seabed samples) can be used as an exploration tool. Second, hydrocarbon seepage and related accumulations of shallow gas may constitute a geohazard for drilling operations. Furthermore, natural seepage of hydrocarbons into the atmosphere may contribute to the greenhouse gases and therefore to global climate change. Finally, geological sequestration of CO_2 is being considered as a means for mitigating climate change caused by human-induced release of CO_2 into the atmosphere. The seepage of gas (primarily methane) in the southern North Sea may be regarded as a natural analogue to potential leakage of CO_2 from future subsurface storage locations.

2. Geological setting

The present day southern North Sea basin can be viewed as a sedimentary basin which was dominated by rifting during most of the Mesozoic, with an acceleration in rifting activity at the transition from the Jurassic to the Cretaceous and which was basically in a post-rift sag phase during the Cenozoic (Ziegler, 1990). Occasionally rifting or thermal subsidence was interrupted by compressional tectonic events, such as those related to the Alpine deformation

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phases. Salt tectonics, mainly involving mobilization of the Permian Zechstein evaporates, play a major role in most of the basin. The principal source rocks for hydrocarbons in the Netherlands part of the southern North Sea basin are the Upper Carboniferous coal beds and the Lower Jurassic Posidonia Shale, containing both marine algal sapropel and land derived organic material (type II kerogen). In the study area in the northern part of the Netherlands North Sea sector (Fig. 1), there are in addition a number of potential source rocks within the Kimmeridgian-Ryazanian sequences. These include the shales of the Middle Graben Formation and the bituminous Clay Deep Formation, which contains marine algal sapropel of the type I kerogen (Wong et al., 1989). The extent to which the Jurassic source rocks may be mature strongly depends on the location with respect to the main structural feature in the area, the N–S trending Dutch Central Graben. For instance the eastern section of block F2 and the western part of block F3 (Fig. 2) are in the inner part of the Central Graben where maximum subsidence took place and the Lower Jurassic shales entered the wet gas generation phase during the Jurassic. Even in the adjacent Outer Graben the base of the Zechstein is buried at depths of more than 5000 m and thick Triassic and Jurassic series are present (Schroot, 1991). Basin modelling in the area is

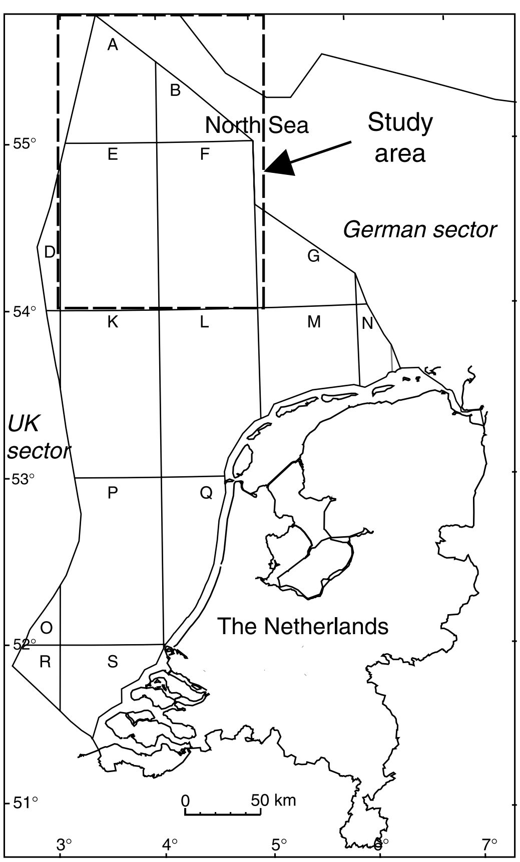

Fig. 1. The Netherlands North Sea sector showing the location of the study area consisting of quadrants A, B, E and F. Each full quadrant consists of 18 license blocks.

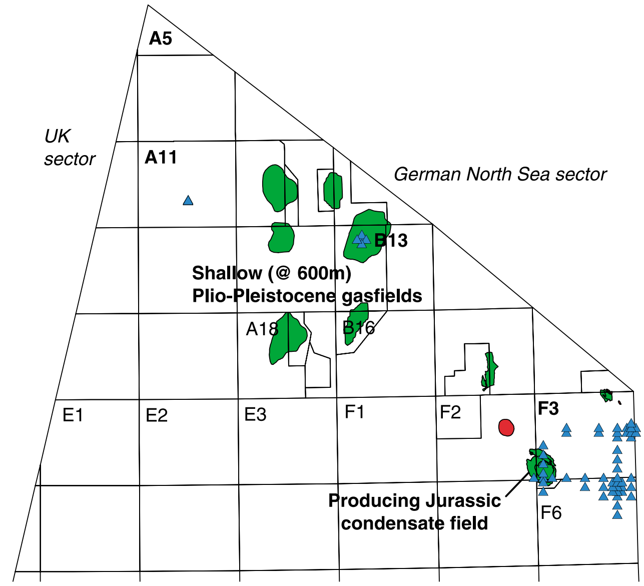

Fig. 2. Part of the study area with the locations of oil, gas and condensate fields; triangles show the positions of the 60 vibrocores taken in 2002.

somewhat complicated by the tectonic inversion which took place during the Late Cretaceous.

While the Netherlands part of the Southern North Sea basin (Fig. 1) is typically a gas basin, with mainly Carboniferous source rocks, there are a number of oil and condensate fields holding hydrocarbons from Jurassic source rocks. In addition, there is a group of shallow gas fields, notably in the A and B blocks, with reservoirs of Pliocene to Pleistocene age, typically at depths of 600–700 m, where the origin of the gas has been subject to debate. The gas consists almost exclusively of methane.

The sedimentary section in which shallow gas and the migration to the seabed are observed postdates the Mid-Miocene unconformity, a surface which is buried at 1000 to 1500 m depth in the north of the Netherlands North Sea. From the end of the Miocene onwards a complex fan delta system, with associated pro-delta deposits, gradually evolving into a fluvial delta and alluvial plain, prograded from the east over the Mid-Miocene unconformity (Sha, 1991; Overeem, 2002). These wedge-shaped units represent material from a large Baltic River System mainly consisting of mature sands, and fining to the west and upwards.

Fluctuations in eustatic sea-level together with tectonic movements and shifting depocenters resulted in regressive and transgressive deposits. The marine facies was initially situated west, later northwest of the terrestrial facies. During the latest parts of the Early Pleistocene and the earlier parts of the Middle Pleistocene coastlines were situated periodically around the northern tip of or to the north of the Netherlands sector (Jeffery et al., 1991). However, occasional transgressions, interrupting the prevailing alluvial plain conditions, reached as far south as the present Dutch north coast. Sediments are predominately sandy with