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Research paper

Generation, migration, entrapment and leakage of microbial gas in the Dutch part of the Southern North Sea Delta

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ABSTRACT

Understanding the shallow gas system is critical for assessing its potential as an energy source, for evaluating the possible hazard of shallow gas for drilling and wind farm locations and for evaluating the effect of gas emissions at the seabed on marine ecosystems and climate. This paper presents the key elements and processes of the microbial shallow gas system in the Plio-Pleistocene Dutch Southern North Sea Delta based on recent findings from different projects. Geochemical and carbon isotopic composition of shallow gas occurrences in the delta are indicative of a microbial origin of the gas. Shallow gas mainly occurs in stratigraphic traps and stacked anticlinal structures above salt structures, as indicated by identified direct hydrocarbon indicators on seismic, such as bright spots. Organic matter in the delta deposits is of predominantly land plant origin with TOC values varying between < 1% and 5%, and mostly between 1 and 2%. Simulations of temperature and burial history in combination with dedicated 1D simulations of microbial gas generation reveal that gas generation in the delta started in Early Pleistocene Calabrian times and is still ongoing. Simulated volumes of gas generation are more than enough to fill published estimated volumes of shallow gas prospects in the delta. The geometry of the E-W prograding delta sequences and the close interbedding of interglacial silty/sandy and glacial clayey/silty sediments focus gas migration updip through the foresets towards the topsets of the delta sequences, and ultimately into the anticlinal stacked traps. Grain-size based calculations of the permeability and capillary seal capacity of clayey/silty seals of the stratigraphic and anticlinal traps provided first estimates of permeability values ranging from 2.8E-20 m^2 to 1.1E-18 m^2 and capillary seal capacity values between 10m and 24m. Comparison of gas column heights derived from grain-size based calculations, cross plots of neutron and density logs and pressure measurements, with trap heights derived from seismic bright spots suggests that many traps in stacked bright spots are not filled to structural spill point. This suggests that filling of the stacked reservoirs is not related to fill-spill migration, but rather to leakage through the top seal. In absence of fault and fracture zones crossing the seal, this leakage is related to the capillary seal capacity and permeability of the top seal. The leakage extends, locally, to the seabed.

The microbial gas system in the delta today is a highly dynamic system driven by ongoing burial of the delta sediments and microbial gas generation.

1. Introduction

Shallow gas accumulations concern gas accumulations located at a depth of less than about 1000 m. Worldwide, and also in the Netherlands, increasing attention is focused on shallow gas accumulations and leakage of shallow gas to the seabed for various reasons, including the significance of shallow gas as an important energy resource, as a possible geohazard for drilling and wind farm locations, and the effect of gas emissions at the seabed on marine ecosystems and climate (Gentz, 2013; Judd and Hovland, 2009; Mau et al., 2015; Rollet et al., 2006; Römer et al., 2017; Schroot et al., 2005; Ten Veen et al., 2014; Van den Boogaard et al., 2013).

Several boreholes encountered shallow gas accumulations in Plio-Pleistocene Southern North Sea Delta (SNS delta) deposits in the Dutch northern offshore since the late 1980s (e.g. A12-03, A15-02, A18-02, A18-02S1, B10-03, B13-03, B16-01, B17-05, B17-06, F02-05) (Fig. 1). In addition, indicators of shallow gas and gas leakage in the Dutch northern offshore have been recognized since many years and include subsurface seismic indicators, such as bright spots, flat spots and gas chimneys (Foschi et al., 2018; Kombrink et al., 2012b; Kuhlmann and

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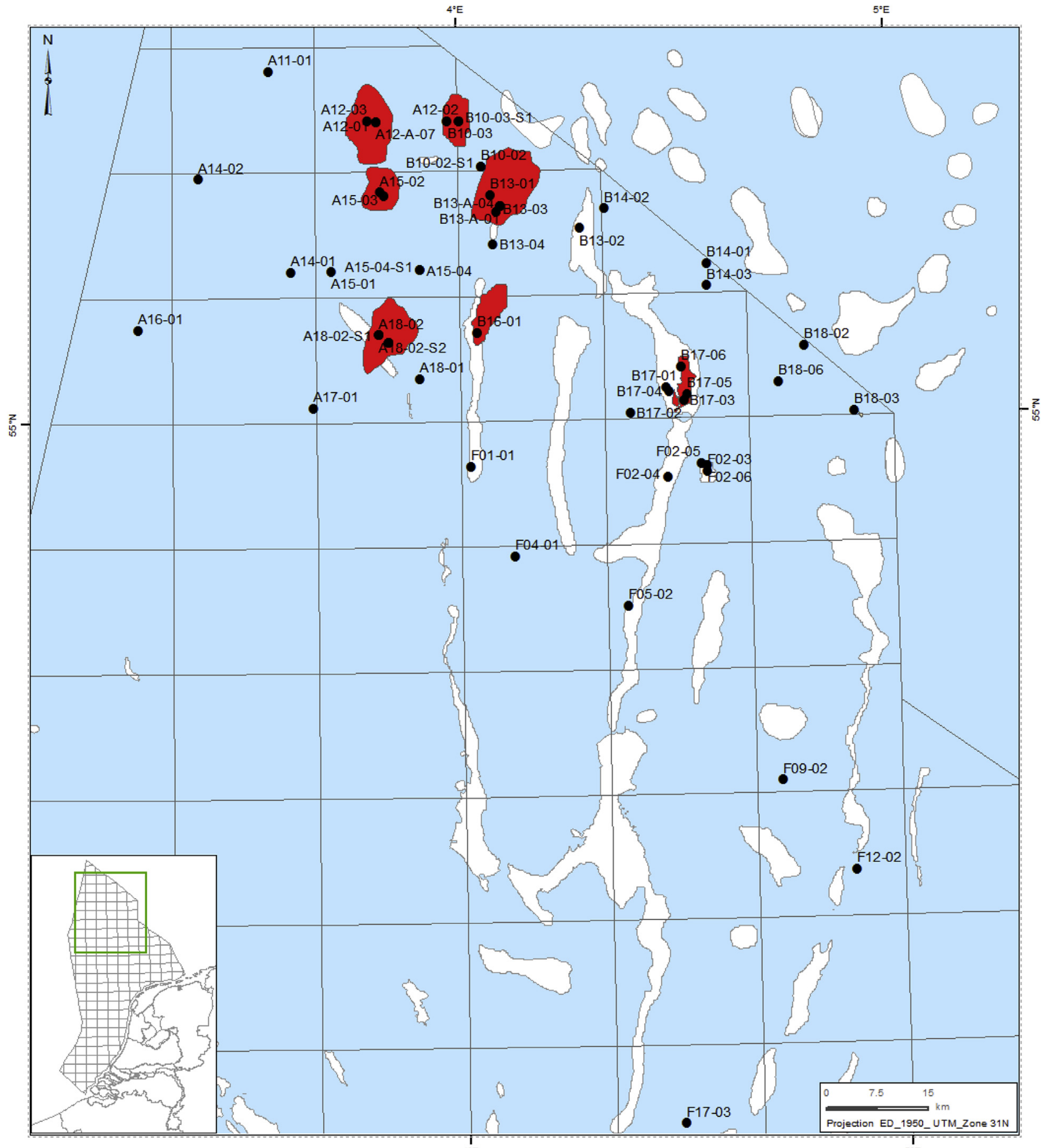

Fig. 1. Location of study area, showing shallow gas accumulations (in red), salt structures (in white) and location of wells. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Wong, 2008; Stuart and Huuse, 2012; Ten Veen et al., 2013, 2014; Van den Boogaard and Hoetz, 2012; Williams and Gent, 2015), pockmarks at the seabed (Laban, 1999; Schroot and Schüttenhelm, 2003), and gas emissions from the seabed (Brussaard, 2013; Gentz, 2013; Mau et al., 2015; Römer et al., 2017; Schroot et al., 2005). Inventory of bright spots on seismic data showed that many of the potential gas accumulations occur in stratigraphic traps or in multiple stacked reservoirs in anticlinal traps above salt structures and are sometimes associated with faults (Kombrink et al., 2012b; Kuhlmann and Wong, 2008; Schroot and Schüttenhelm, 2003; Schroot et al., 2005; Ten Veen et al., 2013, 2014; Van den Boogaard and Hoetz, 2012; Williams and Gent, 2015) (Fig. 2). Van den Boogaard et al. (2013) presented a preliminary total volume estimate for the shallow gas play of 36–118 billion cubic metres Gas Initially In Place (bcm GIIP).

The shallow gas fields (Fig. 1) were not developed initially due to the limited strength of the unconsolidated sandy reservoir and the expected early water breakthrough and sand production (Van den Boogaard and Hoetz, 2012). Gas field A12-FA is the first shallow gas field that was taken into production in 2007. This was almost 30 years after borehole A12-03 encountered the shallow gas field A12-FA in 1988. Three other shallow gas fields in the northern offshore are currently in production: the second shallow gas field HANP (also called F02a-Pliocene field) came into production in 2009, followed by field B13-FA in 2011, and field A18-FA in January 2016.