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# Derisking Shallow Gas as Exploration Target by Seismic Characterisation

M. van den Boogaard* (EBN B.V.) & G. Hoetz (EBN B.V.)

## SUMMARY

The Netherlands is the first country in the North Sea area in which shallow gas is developed and has proven to be a valuable resource. Amongst 3 successfully producing fields and 5 more proven accumulations, EBN has identified more than 150 additional leads from shallow seismic anomalies (bright spots). The play consists of relatively clean reservoir sands deposited in a Cenozoic fluvio-deltaic system. Seals are formed by shales. Whereas most of the gas samples reveal a biogenic origin, gas chimneys and associated faults might indicate that a thermogenic origin is well possible, as is the scenario of secondary biogenic gas.

While flat spots, velocity pull-down effects, attenuation, gas chimneys and pockmarks at the seabed can be recognized in relation to the amplitude anomalies, gas saturation remains the largest subsurface uncertainty due to the non-linear behaviour of seismic P-wave velocity with saturation. EBN has developed a system in which the individual leads are ranked based on their geometrical and seismic characteristics. This paper presents the results of the modelling work that has been done aiming to further explore the relation of the bright spots to gas saturation, including the analysis of seismic data in the pre-stack domain (AVO).

## Introduction

The Cenozoic in the Netherlands is known to host abundant shallow seismic amplitude anomalies related to hydrocarbons. The Netherlands is the first of all North Sea countries in which these accumulations have been developed. With three gas fields currently producing, the play has proven to be a valuable resource. This paper focusses on shallow amplitude anomalies, also referred to as *bright spots*, in the northern Dutch offshore area. The work includes an overview of the shallow gas resources and the results of a seismic characterisation system established to help selecting those *bright spots* that have highest development potential.

The occurrence of *bright spots* in the study area has been known from seismic data since the early seventies. Flat spots, velocity pull-down effects, attenuation, gas chimneys and pockmarks at the seabed related to the amplitude anomalies can be recognized (figure 1). In the eighties, the presence of producible gas was proven by wells in several accumulations. For a long time however, shallow gas was just considered a drilling hazard and better to be avoided. Moreover, the play remained undeveloped because early water break-through and sand production were expected due to the unconsolidated nature of the reservoirs.

After years of studying by several operators, Chevron was the first company that developed the play in The Netherlands. A12-FA started producing in 2007 and was by then amongst the best producing fields in the country. Nowadays, two more fields are producing; F02a-B-Pliocene (2009) and B13-FA (2011) operated by Dana and Chevron respectively. The success of the producing fields has raised the interest from the industry. Moreover, the prospective area is largely covered by recent 3D seismic data, which significantly contributes to evaluating the development potential.

As the state participant in exploration and production, EBN B.V. inventorised the occurrence of *bright spots* and many more opportunities have been identified (figure 1). First volume estimates look promising and several leads fit economic development. While seismic characteristics indicate the presence of gas, water saturation remains uncertain, since these features do not distinguish high from low saturations or even lithological effects. To get a better grip on the portfolio and its potential, EBN has developed a seismic characterization system in which more than 150 shallow leads are ranked. This has resulted in a better understanding of the observed features and the gas volumes in place. The highest ranking *bright spots* are expected to be further explored by the industry in the near future. Yet, testing by the drill bit remains necessary in order to ultimately derisk the leads.

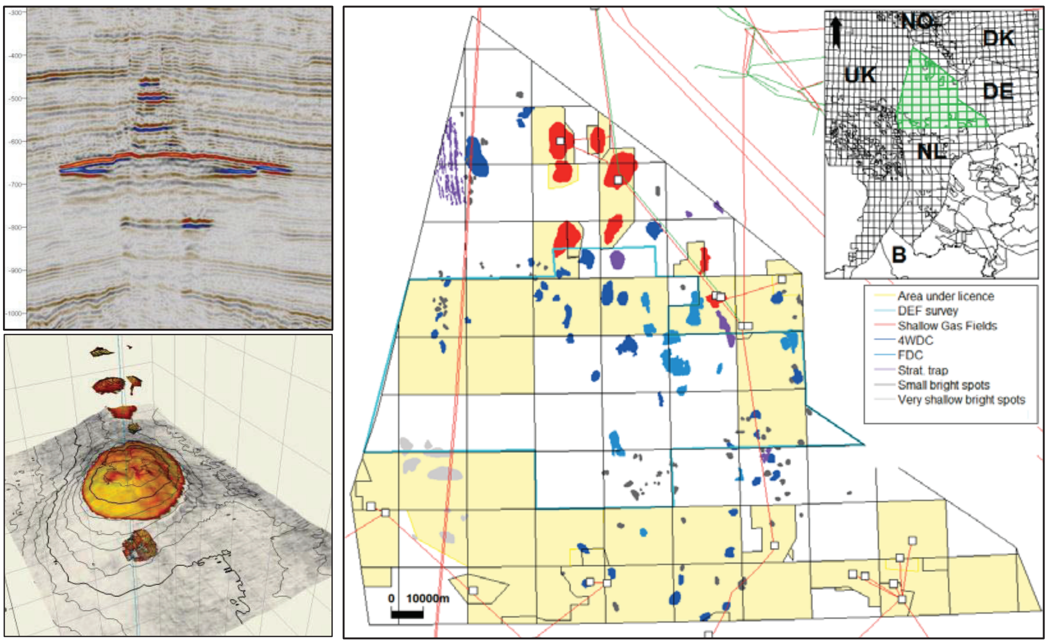


***Figure 1*** *Left: Amplitude anomaly observed in the study area and its time contour map with imposed seismic amplitude (650ms, 10km$^{2}$.). Right: Shallow gas fields and leads in the Dutch North Sea area, colour-coded based on the bright spot characterisation system.*

## Geological setting

In the northern Dutch offshore shallow gas occurs in unconsolidated Cenozoic sediments under relatively low pressures. The accumulations are often situated above the Mid-Miocene Unconformity over salt domes and occasionally associated faults can be observed. Reservoirs consist of fairly clean sands with porosities of 20-35% and generally good permeability. Often stacked anomalies are present. Reservoir thickness usually ranges 5-20m and pressures are 50-80bar. Shales form the sealing layers and are modelled to have sufficient capillary seal capacity (Verweij et al., 2014). The sediments are deposited within a large fluvio-deltaic system and originate from the Fennoscandian shield (Overeem et al., 2001). Typically reservoir depth ranges 300-800m below a water depth of some 30-50m.

Since shallow gas was long considered a drilling hazard, few of the amplitude anomalies have been tested by wells. Of those around 85% showed mobile gas whilst the remainder found no or only low saturation gas. The fields that have been drilled show gas compositions of more than 99% methane, pointing towards a biogenic source. Verweij et al. (2013) have modelled biogenic sourcing to be a plausible scenario in the study area. However, there are wells of which the gas samples combined with the observation of gas chimneys and faults suggest a deeper thermogenic origin. A mixture of both mechanisms might well be a possible.

## Shallow Gas Portfolio

A preliminary screening study has indicated that the northern Dutch offshore (A-H blocks) hosts most *bright spots*. Hence this area is the focus of this paper (figure 1). Whereas most of the proven shallow fields have been identified and drilled based on 2D seismic lines, the region is now extensively covered by 3D seismic data including the large Multi-Client Survey over the DEF blocks, available since 2012. In this 24,000 km2 large area, around 200 wells have been drilled, yet mostly for deeper targets and avoiding the shallow amplitude anomalies.

### *Shallow Gas Developments in the Dutch Offshore*

Three shallow gas fields are currently producing: A12-FA (since 2007), F02a-B-Pliocene (since 2009), and B13-FA (since 2011) and development of five more fields is under consideration. Horizontal wells and sand control measures such as gravel packs and sand screens (Chevron, 2009) have proven to be successful and no water or sand production has been encountered so far. Gas saturation in the producing reservoirs is some 55-60% and recovery factors are expected to range 60-75%.

### *Shallow Gas Potential & Opportunities*

By scanning all 3D seismic data for anomalies using root mean square amplitude maps, more than 150 leads have been identified. A geometrical characterisation scheme based on trapping system, depth, area, number of stacked reservoirs and vertical relief was developed in order to select those leads that have highest potential for development (Van den Boogaard and Hoetz, 2012). Four-way-dip closures (4WDC), fault-dip closures (FDC) and stratigraphic traps are recognized (figure 1), of which the former two have lowest risk since they resemble the producing fields. Anomalies smaller than 2km$^2$ or shallower than 250ms have been excluded from the current analysis as associated volumes appear too small for development.

Initial screening of shallow gas resources resulted in total volume range estimate of 36 to 118 bcm GIIP (2009, report on www.ebn.nl). In the current work volumes are calculated for all individual prospective *bright spots* and factsheets that describe these leads in detail are created. So far, geological aspects of 17 leads have been analysed in detail of which several appear economically attractive. Detailed subsurface analysis of specific leads is work in progress.

## Seismic characterization/classification

Whereas the geometrical characterisation scheme is helpful in ranking the potential accumulations, gas saturation remains the key challenge due to the non-linear behaviour of seismic P-wave velocity with saturation. This means that even low saturation results in a clear anomalous signature on seismic data. In order to get a better insight in the prospectivity of the anomalies, the *bright spot* characterisation system has been extended to include important seismic features (Van den Boogaard et al., 2013). While the former system relates primarily to the volumetrics, the extended system links to the presence of hydrocarbons and comprises direct hydrocarbon indicators (DHI's): relative amplitude, the presence of flat spots, velocity pull-down, attenuation and the occurrence of gas chimneys. This paper presents the results of a modelling study aiming to further explore the relation of these features to gas saturation.

*Relative amplitude*

Gassmann fluid substitution is used to simulate the seismic response of a water vs. gas bearing sandstone. In the context of this study it is demonstrated that Gassmann fluid substitution is approximately valid in these unconsolidated reservoirs, albeit relative amplitudes differ from those in real seismic data and finding fit-for-purpose fluid substitution methods is work in progress. The modelled seismic response for a simple sand-shale layer cake model with gas saturations ranging from 0 to 70% shows that low and high saturations cannot be distinguished from one another based on relative amplitude alone, as is to be expected based on the p-velocity behaviour with respect to saturation.

*AVO*

The second modelling step was investigating the amplitude-versus-offset (AVO) signature. The same layer cake model has been used and a class 3 response of the Rutherford and Williams classification (1989) can be identified independent of saturation (figure 2). It is interesting to note the variance in amplitude between low and high saturations, particularly at high incident angles. This suggests that the pre-stack response of shallow gas might be used to distinguish low from high gas saturation. Therefore, part of the follow-up work includes analysis of seismic data in the pre-stack domain. Potentially this might be key in derisking the play, although this should ultimately come from the bit.

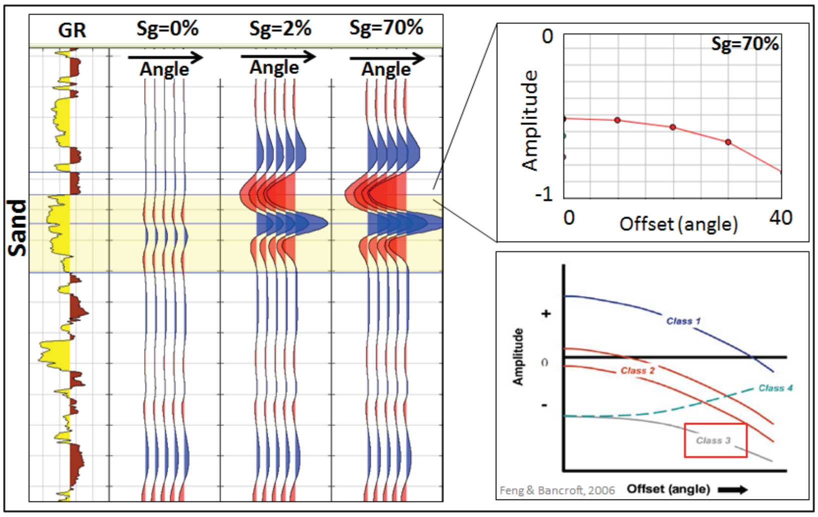


***Figure 2.*** *Modelled AVO response of a shale to gas bearing sand transition. A class 3 response can be identified.*

*Flat spots*

Flat spots can often be recognized below a particular amplitude anomaly. However, these direct hydrocarbon indicators, revealing a gas water contact, are not always visible, as is the case for producing field A12-FA. Modelling showed that the presence of a flat spot strongly depends on the vertical relief, thickness and column height of the reservoir. This work demonstrates that a flat spot is positive evidence for hydrocarbons and a good indicator for thickness and column height, but leads that lack a flat spot could well be attractive for development.

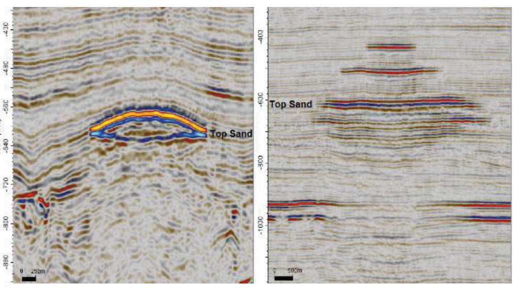


***Figure 3.*** *Left: Bright spot with clear flat spot and velocity pull-down effect (DHI's). Right: Amplitude anomaly of producing field that lacks visible flat spot.*

*Velocity pull-down effects*

Due to the reduced P-wave velocity in the presence of gas, pull-down effects can frequently be recognized on seismic data on both the primary event (figure 4) and the flat spot (figure 3). The extent of pull-down is modelled to be related to gas column, not to saturation. Yet, when the effect is absent, it should be concluded that the anomaly originates from very low gas saturation or a lithological effect.

*Attenuation & Gas chimneys*

Attenuation and gas chimneys are often observed in relation to *bright spots* (figure 4). Both features point towards the presence of gas; although attenuation and gas chimneys are not always easily distinguishable. A quantitative analysis of attenuation is work in progress, however as for the pull-down effect, it can be assumed that the absence of attenuation is explained by no or low amounts of gas. Gas chimneys above *bright spots* indicate leakage towards the sea floor, while chimneys below indicate a deep source of the gas. This contradicts the gas composition in many of the wells that point towards a biogenic origin (Verweij et al., 2013). However, the observation of gas chimneys below the amplitude anomaly suggests a mixture of biogenic and thermogenic gas might well be possible, as is the scenario of secondary biogenic gas.

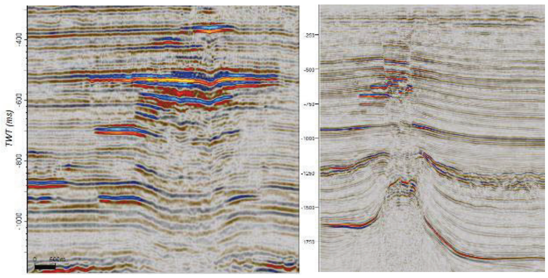

***Figure 3.*** *Left: Bright spot with velocity pull-down effect and attenuation below the main anomaly. Right: Bright spot with associated faults and indications for a gas chimney.*

**Conclusions**

The Netherlands is the first country in the North Sea region in which the shallow gas play has proven to be a valuable resource. Currently there are three successfully producing fields. EBN has identified more than 150 leads based on seismic amplitude anomalies. Reservoir characteristics of the Cenozoic sands are generally good and in terms of volumes several leads are expected to rank economically. Gas saturation remains the largest subsurface uncertainty, since *bright spots* also originate from low gas saturation or lithological effects. EBN has developed a characterisation system that helps in selecting those leads that have highest potential. This system is built on a geometrical as well as a seismic characterisation. The latter includes an analysis of DHI's such as relative amplitude, the presence of flat spots, velocity pull-down, attenuation and the occurrence of gas chimneys.

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