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Utilizing Sea Floor Samples to De-risk the Petroleum System - A Case Study from Mid Norway

K.H. Dittmers* (DEA Norge As), R. Hatton (CVC Ltd)

Summary

DEA Norge has over several years collected a comprehensive dataset of surface seafloor samples in conjunction operated licenses and concession rounds. This paper will outline our learnings, best practice proposals and some caveats concerning data handling, survey design and data collection. A major learning was that it proved to be important to utilize reference data from exploration wells in order to calibrate seafloor sample data collected over prospects and to establish the relevance and reliability of observed anomalies. Another common observation was that in most cases “the signal” (i.e. hydrocarbons) is transported both laterally by dipping layers in the overburden and vertically by faults / seal leakage. Combining sea floor samples with geochemical data from well bores and sufficiently dense sea floor samples around reference wells allows charge and hydrocarbon phase to be de-risked. The key to successfully de-risking prospects is to differentiate between anomalies caused by vertical seepage (prospect specific signal) and those caused by more regional lateral transport (“play component”). In many cases, however, it can be difficult to differentiate between the two

Introduction

DEA Norge was exploring a stratigraphic play offshore in the Norwegian Sea and set out to rank prospects using a seabed sediment samples. In order to do so, DEA Norge undertook a geochemical and geomicrobial survey in 2012-13. Due to the inconclusive nature of the results, a denser grid of seabed samples was collected the following year. Sampling also included data from reference wells within the license (Figure 1) and nearby discoveries. The intention of the study was to perform a DFI risk update in light of this new information. However, we conclude that it is more reasonable to use the results presented here to de-risk the total Petroleum System, due to ambiguities associated with lateral migration. We identified complex interrelationships between anomalies and the underlying petroleum system. Though direct, prospect-scale correlations were identified locally, we concluded that the potential of the results lay mainly in de-risking the total petroleum system due to correlative ambiguities arising from lateral migration, which cannot exclude a direct source signal.
Samples from the nearby gas/condensate discoveries seemed to map the reservoir charge directly from below. Samples from within the license show condensate/oil anomalies although they are officially classified as either dry (Hans) or as small gas discovery (Fritz) suggesting that anomaly geometry being moderated by fault conduits in the overburden (Figures 1 & 2). The prospect seems to be a combination of vertical seepage, whilst a part of the signal is transported laterally. We distinguished the prospect specific signal by using calibration wells in the area and carefully reviewing seismic sections with coring positions to"trace" the signal. The data collected over the prospect (Figure 1) are more oil prone signal with respect to the reference wells, which are gas prone (Figure 2).

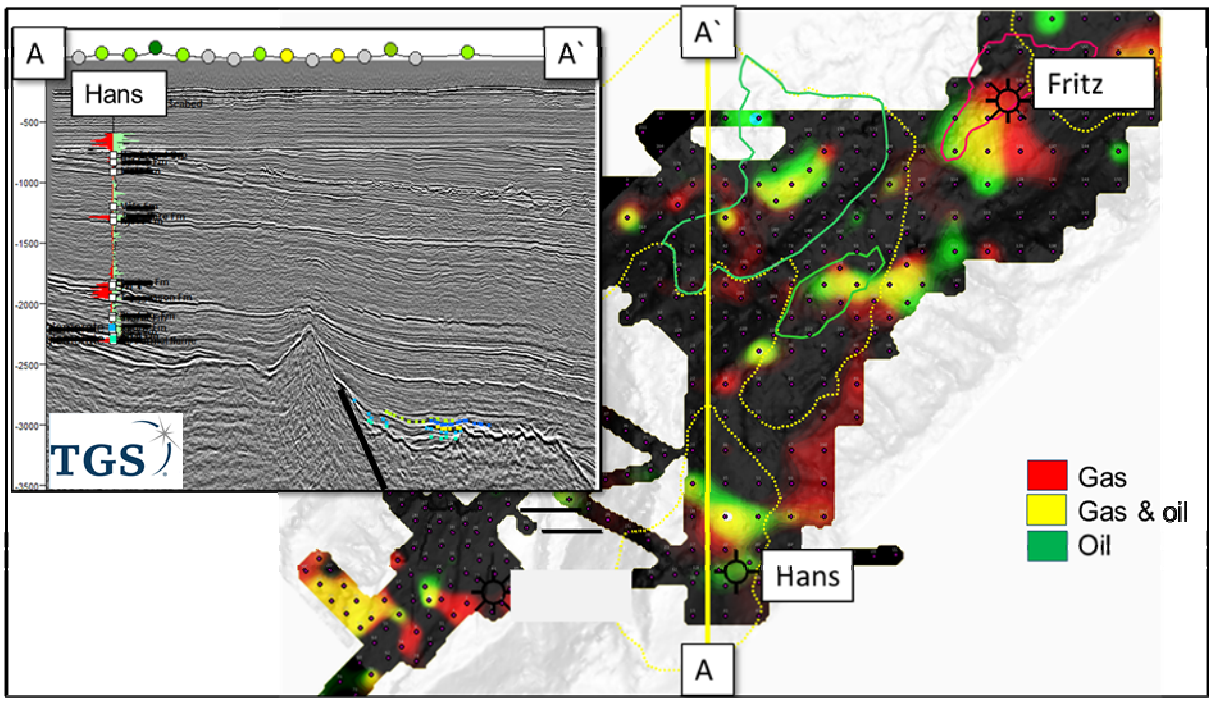

Figure 1: *Traffic light classification of seafloor samples used and N-S seismic line across prospect. MPOG anomalies plotted as circles on top of the seismic line. The Hans Well is displayed with FIS data. Note that FIS anomalies are associated with distinct intervals that can be traced laterally (for final interpretation see Figure 3). Data courtesy of TGS and FIT.*

Method

Gravity core samples of seabed sediments were acquired for laboratory analysis in 2012 on a nominal 1 km grid taking in the stratigraphic prospects, adjacent deeper basin and basin margin zones, plus the Fritz (gas) and Hans (oil) well sites (Figure 1). Subsequently, in 2013, we acquired infill samples to

better define selected anomalies and also coverage of geologically analogous discoveries in a nearby concession for interpretative constraint.

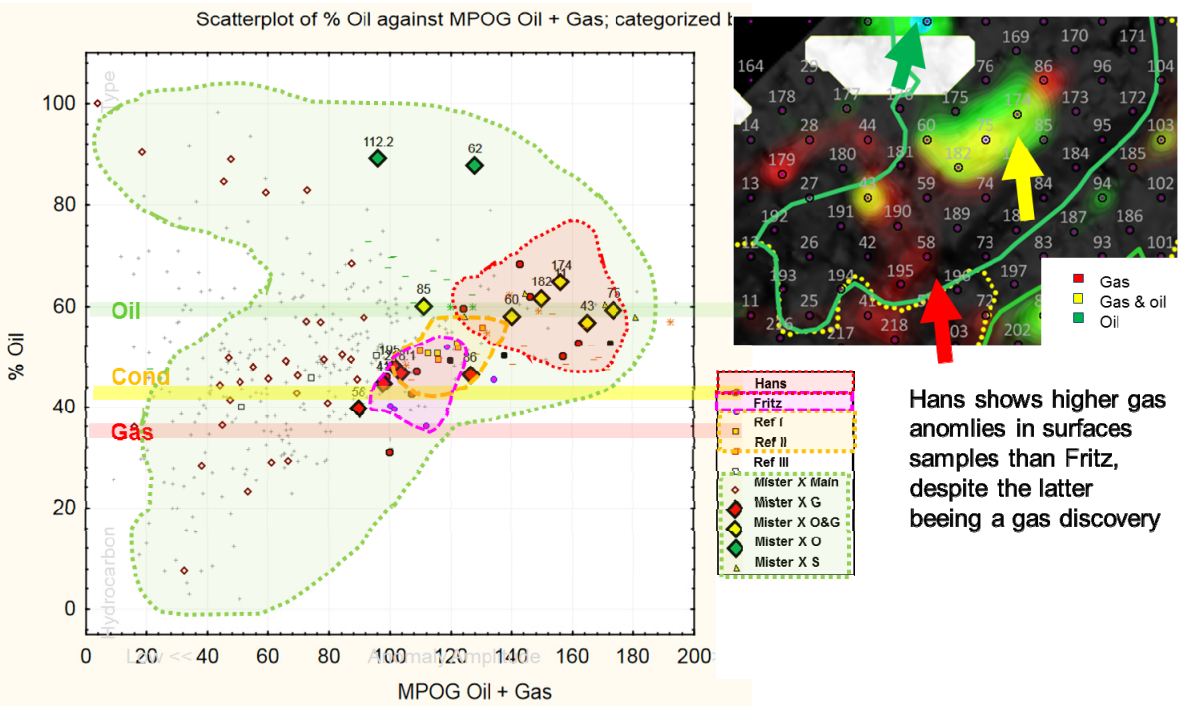

Figure 2: *Anomaly characterisation scatter plot displays normalized MPOG Oil +Gas versus Oil anomalies. Observe the difference clusters. Highlighted is data from the prospect (red-yellow-green) and condensate/gas discovery wells Ref I-III within (blue box). Note that prospect values (in green shading) show a significant number of oil prone samples and show higher values of oil & gas.*

The most reliable indicators for thermogenic hydrocarbons were the microbial data ("Microbial Prospecting for Oil and Gas" MPOG, Wagner et al., 2002), calibrated by well control data. It indicated geospatially coherent multipoint anomalies that fit the geology: discoveries, fault (subcrops), layer subcrops and Fluid Inclusion Screening (FIS, http://fittulsa.com/) data at wells. Sampling in a grid enabled us to map ends of migration pathways, as well as background data.
Microbial Prospecting for Oil and Gas (MPOG), after Wagner et al. (2002) measures the activity of hydrocarbon-oxidizing bacteria in surface soil or sediment samples. Higher bacterial activity is thought to reflect a greater supply of gaseous hydrocarbons coming from deeper-seated oil or gas reservoirs, and thus a higher microbial population. This differentiates between hydrocarbon-prospective areas and areas without hydrocarbon indications (background level). MPOG claims to be able to differentiate between an oil and gas signal, by separately identifying methane and C_2–C_6 hydrocarbon-oxidizing bacteria.
We identified gas-prone and oil-prone microbial anomalies with reference to a corporate MPOG database of some 1,000 records from the Norwegian shelf and imaged these using the red-green colour scheme exemplified in (Figure 1& 2).

Workflow/Findings

First we investigated the spatial distribution of the signal; here the structural frame work (seismic) is important. In our study we quickly established a clear relationship between basement faults and signal distribution at the surface. Furthermore, we identified a subset of high signals that were associated with a dipping carrier bed subcrop, indicating lateral transport of the signal (Figure 3).

The utilization of scatter plots (Figure 2) plotting gas vs oil calibrated against reference wells was helpful. This proved to be a powerful tool to identify the relative strength of the signal/anomaly and to be able to predict HC phase as we had both gas and condensate analogue wells in our study (Ref I-III, Hans and Fritz in Figure 2). Both gas and oil anomalies are present but there is also an overall condensate signature, as evidenced by Hans and Fritz gas wells. The data from directly above the prospect are clearly more oil prone than all of the sampled reference wells (Figure 2). Additionally, the anomalies associated with the subcrop show similar composition as anomalies overlying the prospect. Samples with the clearest oil signature were found over the prospect.

The above findings enable us to distinguish between a direct signal, transported vertically by small fractures in the overburden and a component/fraction that was subjected to lateral transport due to dipping beds in the overburden. Proof of this is seen in a prominent anomaly coinciding with the subcrop of the "dipping beds". The base Tertiary amplitude anomaly indicates the top end of the migration pathway, which explains the relative oil prone anomalies aligned with the base Tertiary subcrop (Figure 2 & 3). This lateral transport can also explain the false positive oil signature in the Hans and Fritz wells.

Tying FIS data from wells to seismic also gave valuable insights. As shown in Figure 3, FIS anomalies are clearly confined to certain intervals ("carrier beds"). Elevated values are found in layers that are more sand-prone. These intervals are inclined, allowing for lateral transport. Samples with higher values occur on top of major basement features and fault offsets (green circles & arrows in Figure 3).

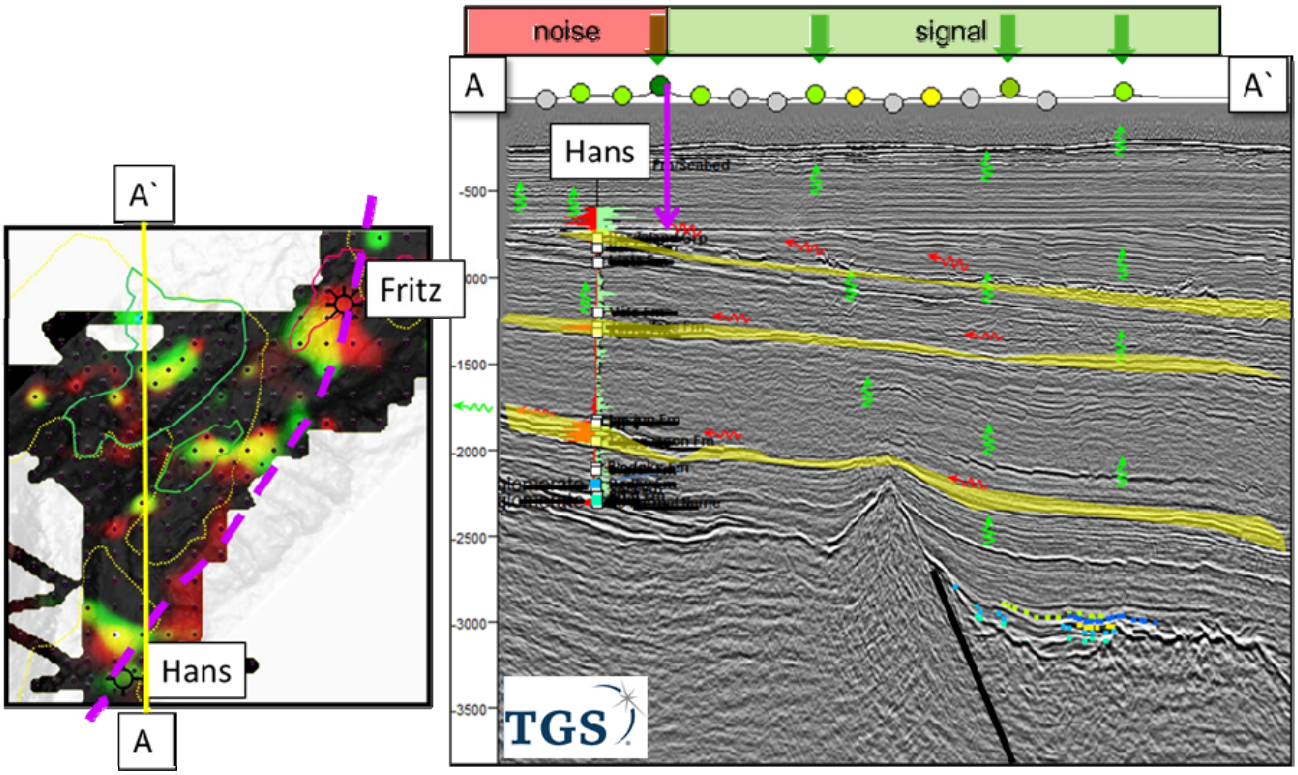

***Figure 3**: N-S seismic line across prospect. The Hans well is displayed with FIS data, yellow colour indicates sandier, carrier interval. Note that FIS anomalies are associated with these intervals. Wavy arrows represent proposed flow/migration path, purple line and arrow indicates the subcrop line. Data courtesy of TGS*

Quantifying the relative amount of lateral and vertical seepage is impossible at this stage of the study, but would be a very interesting topic to investigate further. A potential next step could be to model processes in the subsurface to gain a better understanding of the dynamics of material transport, utilizing flow simulators for example.

Evidence from other studies:
Similar observations that confirm lateral transport in the overburden are made by Chand et al., (2012) in the Barents Sea and by a study by BP Thrasher et al., (1996) on the Haltenbanken. They conclude that leakage does not necessary occur directly above accumulations, and shallow gas and oil occur at the seabed where the Paleocene crops out along the Norwegian margin. Oil seepage is displaced by up to 50 km between accumulations and source kitchens.
In the Barents Sea, Vadakkepuliyambatta et al., (2013) established that largest fluid-flow features occur above major deep-seated faults in the area suggesting a close relationship between the two.

Conclusions
MPOG analysis of shallow coring indicates contribution both from lateral and vertical migration, however the respective amount is difficult to assess. This is confirmed by offset wells with FIS data and study of geosections (interpreted seismic). They indicate a component of lateral migration causing Hans and Fritz-like oil anomalies, despite being classified as dry wells (NPD). While data from reference discoveries are gas prone, prospect samples are clearly more oil prone. This information was used to decrease the source risk, which as a consequence was set to proven.

Major learnings:
Careful study of seismic data that fits the sampling pattern is very important in understanding the role of faults, trace signal pathways, identify "carrier beds", and to map subcrop morphology. Patterns in sampling proved to be very advantageous. The importance of good well calibration is evident, ideally with different HC content/phase. Information of fluid inclusions proved to be helpful too (FIS Data in this case). Anomalies plotted in scatter diagrams proved to be a very useful visualisation tool.
It is often claimed that seepage occurs only vertically. We hope to have outlined that instead lateral migration can in principle result with the same signatures as vertical migration above the prospect. The key is that rather than utilizing this data as a direct HC indicator to de-risk the prospect, they are used to de-risk the petroleum system as a whole.

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