SUCCESSFULNESS OF SHALLOW GAS SEISMIC PREDICTIONS - A CASE HISTORY

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1. Introduction

The presence of shallow gas represents a potential problem in connection with offshore drilling operations. The risk of a kick which could develop into a blowout situation requires that adequate safety and operational precautions are taken before and during the actual drilling phase. Seismic surveys can be used to identify shallow gas anomalies giving important information for the drilling programme.

Technica has performed a shallow gas risk analysis where a new and different type of approach was used to integrate several aspects of shallow gas. The main purpose of the study was to establish a historic risk profile, and to evaluate on a common format and framework how and to what extent the risk would be reduced if specific safety measures were implemented.

This paper will concentrate on the historic experience related to the shallow gas seismic predictions on the Norwegian Continental Shelf, but will also discuss shallow gas indicators whilst drilling.

2. Shallow Gas Risk Level

Shallow gas is generally defined to be gas accumulations encountered in the top 1000 m of section. A shallow gas blowout is characterized by drilling into a high-pressure gas zone in this top hole section of the well, with both primary and secondary control measures failing. The hydrostatic pressure of the mud in the wellbore constitutes the primary barrier, while subsea or surface valves typically make up the second barrier. The special concern with the blowout risk during top hole drilling compared with reservoir blowouts, is that shut-in of the well may not be possible (BOP not installed) or desirable at shallow depths (formation breakdown risk), as well the experienced problems with surface diverter arrangement.

According to blowout statistics for the North Sea and US Outer Continental Shelf in the period 1970 - 1985 [5], the following basic shallow gas blowout frequencies can be estimated:

- P(shallow gas blowout while drilling an exploration well) = 3.5×10^{-3}

- P(shallow gas blowout while drilling a development well) = 9.2×10^{-4}

According to NPD statistics [1], shallow gas has been reported in 150 of the 558 wildcat and appraisal wells drilled on the NCS in the period up to 1987.

3. Shallow Gas Risk Management

The potential risk of a shallow gas blowout during tophole drilling requires special safety concern related to both the pre-drilling phase, actual drilling and well control situations. The objective of this safety and risk management would be to:

- Prevent drilling on a shallow gas location (if possible)
- Prevent loss of primary well control during drilling
- Prevent flow to the platform
- Prevent flow outside casing
- Prevent ignition on the platform
- Reduce the consequences (duration)

Proposed measures for risk reduction may sometimes be presented individually as a basis for selection, with the result that no optimum decision with respect to safety and cost may be achieved. However, by the development and use of an integrated risk analytical approach, it can be possible to assess the safety and economic implications of each individual measure on a common format according to a baseline risk level [4].

As indicated above, the use of high resolution shallow seismic surveys to identify shallow gas, provides one of several measures to reduce the blowout risk associated with shallow gas. Ideally, site surveys can be used to avoid spudding in a planned well at a location where shallow gas is present, but this requires:

i) Non-presence of shallow gas in the planned well must be correctly predicted, or

ii) Presence of shallow gas must have been predicted in the planned well, near-by relocation is possible (to still reach possible "pay zone") and non-presence of shallow gas on the relocated well location must be correctly predicted.

If several exploration wells have been drilled in the area, further experience can be gained from these wells when selecting the drilling location. During development drilling detailed knowledge would normally be available to make better predictions about any existence of shallow gas. The blowout statistics show however that this does not eliminate the shallow gas blowout risk.

The decision-process behind the shallow gas predictions is associated with two key elements, the restricted time available before a decision must be made (time factor) and the extensive human involvement in seismic methods and their interpretations (human factors). The following list of activities applies generally for an exploration well:

1. Seismic investigations
2. Selection of well location
3. Preparation of geological prognosis and drilling programme
   a. Plan site survey
   b. Field evaluation
   c. Site survey
   d. Prepare drilling programme
4. Send drilling programme to NPD
5. Consent of drilling programme from NPD
6. Spud-in
7. Drilling (and testing)
8. Plug and abandon
9. Prepare completion report to NPD and partners

The importance to have relevant and up-to-date information available when interpreting seismic data means that good communication between departments within companies and between operators and contractors is important. Availability of shallow seismic data from centralised databases are being considered for the Norwegian sector, and has proved successful in the Gulf of Mexico [3]. This could also help the decision-making process and allow better predictions to be made.

A correct prediction of shallow gas affects also the success of other risk reducing measures. This has to do both with the drill crew alterness to shallow gas (their belief in the predictions) and to what precautions/ actions to take during the planning stage or the actual drilling phase. An example; setting the 20" casing above the gas bearing zone makes it possible to increase the mud weight and to install the BOP. This action helps in avoiding loss of primary well control (increased mud weight), flow to platform (BOP installed) and flow outside casing (casing installed). The largest risk reducing effect this measure would have, will be if the 20" casing was set prior to drilling into the gas pocket. This requires exact knowledge of the shallow gas presence and at correct depth. Wrong predictions, shallow gas is encountered when it is not predicted and vica versa, may mean that the casing programme has to be altered during drilling leading to economical losses.

4. Statistical Data Collection of Seismic Surveys and Drilling Experience

Database

The statistical analysis of the seismic predictability was based on a detailed review of about 60 exploration wells drilled in four different areas on the Norwegian Continental Shelf (NCS), mainly in areas where shallow gas could be expected. This represents about 10% of the exploration wells drilled on the NCS. Both wildcats and appraisal wells drilled in the period 1978 - 1986 were studied.

The number of wells drilled for the four different areas on the NCS which have been analysed were 3, 13, 14 and 31, respectively.

The following type of documentation were evaluated for each well:

- Drilling programme with geological prognosis
- Daily drilling reports
- Well completion reports (including MWD, mud and electric logs)

Shallow gas logging indicators (e.g. ROP, gas units and other logging results) were collected and systematized for:

- well depths where shallow gas had been predicted (but not necessarily encountered or caused problems), and for

- well depths where shallow gas well control actions (e.g. kick, flow checks) were experienced.

Definitions

Shallow gas prediction was based on the site survey and the shallow gas prognosis expressed in the drilling programme. The predicted gas sand zones was also registered.

Indication of encountered shallow gas was based on MWD (while drilling) results and/or by electric logging (after drilling). The interpretation of the electric logs (completion logs) was performed in collaboration with oil company geologists, using the following three key parameters:

- GR: The Gamma Ray was used to identify whether sand or shale zone was present. GR (measured in API units) will decrease in a sand zone.

- dT: The Sonic log was also used to confirm the existence of sand zone. Transit travel time (dT, measured in microsecond per foot) will increase, i.e. sonic velocity will decrease in a sand zone.

- R: The Resistivity log was used to identify whether a sand zone (low GR and high dT) was gas or water bearing. Resistivity (measured in ohms m) will increase if gas is present, or decrease if water was present.

Thus, a gas bearing sand zone was interpreted from low GR, high dT and high R peaks.

5. Reliability of Site Survey Predictions

The statistical analysis of the the shallow gas predictions was performed on two levels of detail:

i) The first approach has only considered whether gas was predicted/encountered in in the well, without analysing the depth of predictions/occurrence.

ii) The second approach goes a bit further by analysing the depth of encountered gas zone versus the predicted zones.

Gas in Well

Figure 4.1 shows for all wells, firstly the probability that shallow gas has been predicted in a well and secondly, the probabilities of encountering or not encountering shallow gas given that gas is not predicted or predicted.

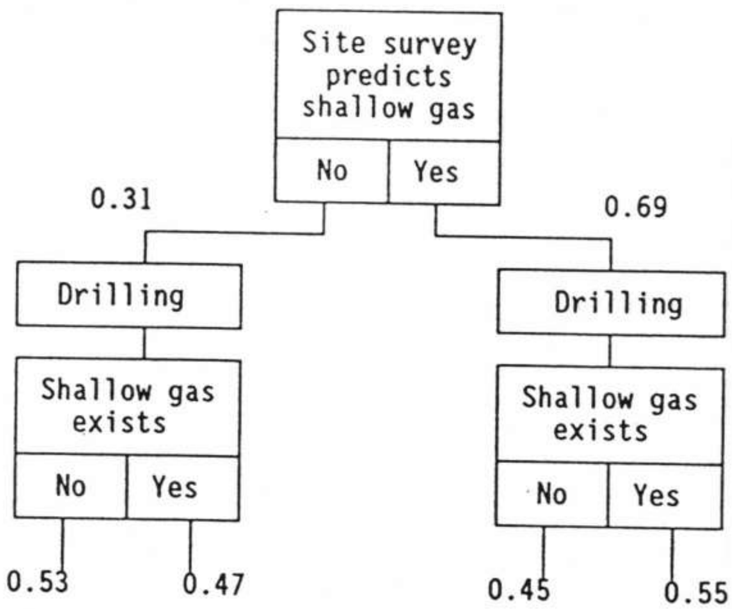

Figure 4.1 Shallow gas predictions versus actual for all wells

The probability of predicting shallow gas in a well was 0.69 all areas included.

The probability of encountering shallow gas in a well was 0.55 when shallow gas was predicted and 0.47 when shallow gas was not predicted. The probability of <u>not</u> encountering shallow gas in a well was 0.45 or 0.53 when shallow gas was predicted or not predicted, respectively.

Based on this approach, the chance of correctly predict the presence or non-presence of shallow gas was estimated as 55% or 53%, respectively.

Depth of Gas Zone in Well

Taking into account the depth of the predicted or encountered zones, the following prediction statuses had to be defined:

- Status 0 (Wrong prediction):
  i) Predicted gas zone, but gas is not encountered, or
  ii) no predicted gas zone, but gas is encountered.

- Status 1 (Nearly wrong prediction):
  Gas zone is encountered, but none at predicted depth.

- Status 2 (Nearly correct prediction):
  At least one (but not all) gas zone is encountered at predicted depth, or all predicted zones are encountered, but new zones are encountered as well.

- Status 3 (Correct prediction):
  i) All predicted gas zones are encountered at predicted depth.
  ii) No gas zone predicted and none encountered.

Concerning the comparison between predicted and actual gas zones it was made an allowance of uncertainty of +/- 20 m. Hence, if any actual zone was more than than 20 m from a predicted level, it was not classified as predicted.

Treating states 0 and 1 as "wrong prediction", and states 2 and 3 as "correct prediction" gave the following results:

The probability of correct prediction was 0.43, all areas included.

Regardless of the detail of the analysis approach, the historical experience from the four NCS areas indicated a 50/50 chance that the predictions were wrong. This covers both cases when encountered shallow gas is not predicted, as well as when predicted shallow gas is not encountered.

6. Human Factors Evaluation of Seismic Interpretations

A human factors analysis of the decision problems associated with shallow gas predictions was performed using socalled signal detection theory. Evidence of shallow gas ("signal"), on a seismic map, could be misinterpreted with something that looks like shallow gas ("noise"). This confusion is influenced by two factors. One is the extent to which the signal and noise distribution overlap each other, i.e. how easily they can be distinguished by the person doing the task, also called "sensitivity". The second factor, is the individual choice of criterion of when to call an indication a signal or noise, also called "response bias".

A quantitative calculation of sensitivity and response bias was performed for various geographical areas, using the following parameters (see Figure 6.1):

- False alarm: A noise event is treated as a signal
- Correct accepts: A noise event is correctly predicted as lack of shallow gas
- Misses: A signal is treated as noise
- Hits: A signal is correctly predicted as shallow gas

The results for the various geographical areas are shown in Figure 6.2. The diagonal line represent predictions which are chance responding, i.e. values above this line are better than chance (=tossing a coin), and vice versa. It was generally evident that the chance of making a correct prediction based on seismic analyses is poor: in the order of 50/50 per well. One may argue that these predictions have an adverse effect on safety, since, if taken seriously by the drill crew, they may result in lack of attention to shallow gas warning signals at depth intervals predicted as safe. On the other hand, Figure 6.2 shows that there is a bias towards reporting shallow gas when there is none (false alarms). This could result in drill crews developing a sceptical attitude towards seismic surveys and thus ignoring them. In fact this study indicated that the drill crew should pay little attention to the results of seismic surveys whether or not shallow gas was predicted. Instead, they should be constantly alert during top hole drilling, using appropriate warning signals.

The results point to the need to improve seismic surveys and the training of staff whose job is to interpret the seismic data. A training problem has also been suggested by other authors [2,3]. The study described in this paper indicates that both interpreter sensitivity and response bias need improvement. Variability in bias can be reduced by providing standards against which interpreters can make judgements. For example, it could be easy to develop a standard set of seismic surveys showing examples where shallow gas was or was not actually found. Fixed criteria could then be produced which specify visual indicators that are to be regarded as shallow gas and those that are not.This type of approach has been used in other industries where visual inspection judgement are required.

Improved sensitivity depends both on the extent to which the signal and noise distributions (Figure 6.1) can be separated by improved survey techniques and on the training of the interpreters to recognise the difference between signals and noise. Providing feedback to interpreters on the accuracy of their assessment is a very good way to improve performance. Without such feedback, performance will not change. Feed forward information is also useful. Advance knowledge of the likelihood of shallow gas in a particular location can at least allow interpreters to "probability match" in terms of the frequency of their choice of response.

7. Analysis of Shallow Gas Warning Signals During Drilling

The study of the reliability of shallow gas seismic predictions indicates that the drill crew should pay very little attention to non shallow gas predictions, and be constantly alert during top hole drilling. The shallow gas risk assessment by Technica did therefore also consider in detail the warning signals during drilling.

Various parameters can be used during drilling operations to detect high pressure zones and/or gas bearing sand zones in the shallow part of the well; ref. Table 7.1. Totally, more than 400 drilling situations were analysed with respect to warning signals and well control actions. This did also include lost circulation/returns, mud loss, swabbing events, as well as serious shallow gas events such as blowouts, severe gas kicks and gas migration.

TABLE 7.1 : SHALLOW GAS DETECTION PARAMETERS

Drilling parameters	**MWD parameters**
1. Rate of penetration (ROP)	8. Gamma ray
2. Weight on bit (WOB)	9. Resistivity
3. Torque	
Drilling mud parameters	**Electric logging**
4. Gas trends in return mud	10. Gamma ray
5. Mud level in pit	11. Resistivity
6. Mud return flow	12. Interval transit time (sonic)
7. Sand in shale shaker samples	

A questionnaire survey was carried out among on- and offshore drill crew, engineers and supervisors to evaluate human confidence in the above-mentioned shallow gas warning signals. A paired comparison technique was used: The 12 indicators were presented in pairs and respondents were asked to identify which of the indicators in each pair they had most confidence in, ignoring other factors. The combined results showed a clear preference for the following ranked warning signals:

1. Increasing mud return flow
2. Increasing mud level in pit (pit gain)
3. Increasing gas in return mud (gas peak)
4. Increase in ROP (drilling break)
5. Increase in resistivity (MWD)

It should be noted that the two first indicators will appear very late in a gas kick sequence, and hence their importance in an effort to avoid a serious incident from developing is marginal. In nearly half of serious shallow gas events, these signals were experienced before remedial well control action was taken. The actual reliability of the three other indicators was estimated as follows:

Gas peak:

1 out of 3 reported gas peaks indicates a true gas zone. Furthermore, only 1 out of 3 gas zones generates a gas peak. Flow check response was taken in 62% of the reported gas peaks.

Drilling break:

1 out of 8 reported drilling breaks indicates a true gas zone. Furthermore, only 1 out of 8 gas zones results in a drilling break. Reported drilling breaks were acted upon in 96% of the cases.

Increased resistivity (MWD):

Measurement while drilling (MWD) is a relatively new method which proved to give positive response in 3 out of 4 cases when penetrating a shallow gas sand. When MWD worked, it detected gas in 87% of the cases where electric logging showed gas.

Gas peaks and drilling breaks seem to be less reliable than MWD, which is somewhat different from the perceived reliability opinion by the drilling personnel. The interpretation during drilling for when a gas measurement shall be considered as a gas peak which may require emergency well control action, may also be subject to human error.

Although the combined questionnaire results indicates a clear ranking of the most critical indicators, this analysis showed significant differences in the individual responses. Some personnel seem to have very poor confidence in some of the above indicators. This may explain why, in retrospect, many serious drilling incidents seem to take place despite clear indications of downhole problems: Personnel with different points of view and biases as to what constitutes a significant warning may not be able to communicate adequately, resulting in filtering and bypass of important information. This is perhaps one of the most important safety problems in offshore drilling operations.

8. Concluding Remarks

Risk analysis and safety assessment methodology provides useful tools to carry out a critical and systematic review of drilling operations and the associated planning and procedural aspects related to shallow gas.

This study indicates that the drill crew should pay very little attention to non shallow gas prediction, and be constantly alert during top hole drilling, using appropriate warning signals. Further development of shallow seismic and training of staff to interpret the seismic data is however generally important. Consistent interpretation of shallow gas indicators during planning or drilling is important to avoid filtering and bypass of important information.

9. Acknowledgement

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10. References

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Figure 6.1 : A VISUAL DESCRIPTION OF THE DEFINITION OF HITS, CORRECT ACCEPT, FALSE ALARMS AND MISSES

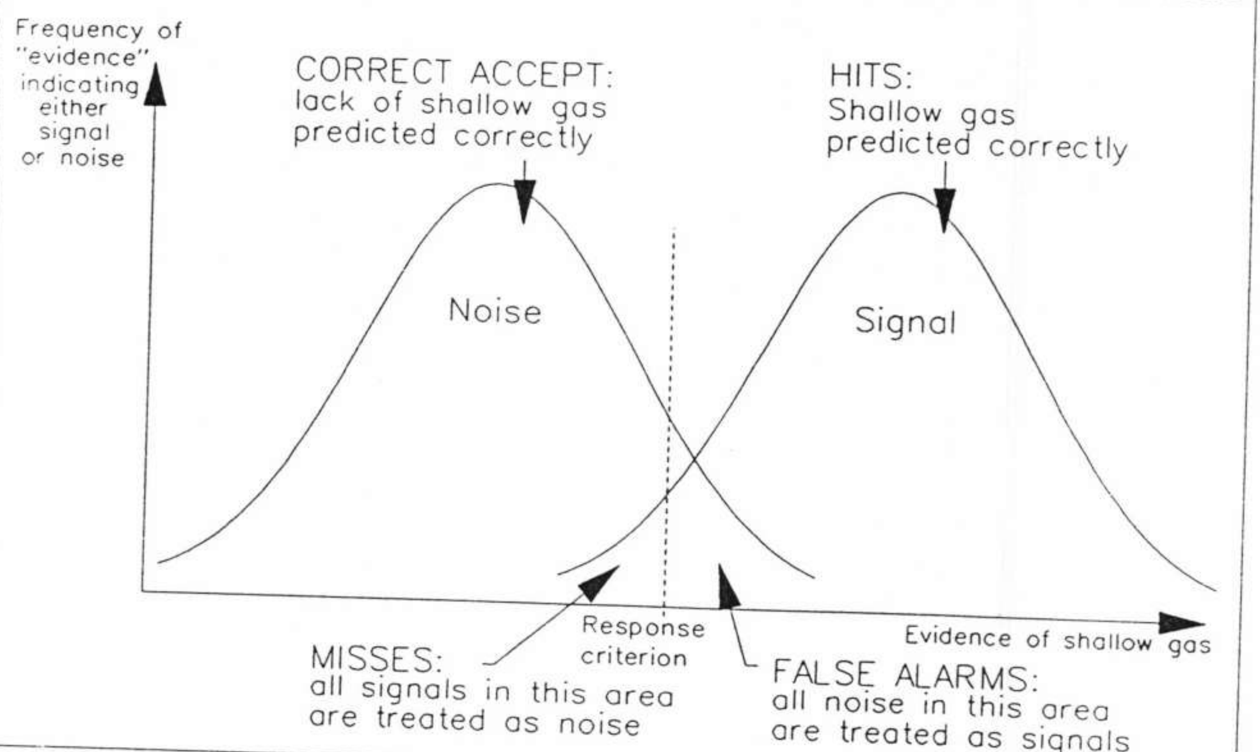

Figure 6.2 : PROBABILITY OF HITS VERSUS PROBABILITY OF FALSE ALARMS