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Observations from Systematic Depth Conversion Reviews - Biased Depth Estimates and the Impact on the Drilling Portfolio

H.L.J.G. Hoetz* (EBN B.V.)

SUMMARY

Systematic well reviews are essential for improving on future drilling performance. The accuracy of depth prognosis results has being analyzed in detail using an extensive dataset; 253 recently drilled petroleum wells in the Netherlands. The outcome reflects uncertainties in seismic interpretation and –more importantly- velocity models. The data indicates that the predicted depth at reservoir level shows an uncertainty of 1.2% (1 sigma). Also a clear bias towards predicting too shallow is evident from the dataset. A possible explanation based on the mechanism of selection bias is being presented.

Introduction

Understanding the subsurface is the key to successful wells. In the highly mature, but geologically complex, petroleum province of the Netherlands virtually all well planning relies on 3D seismic which is often of high quality. Velocity model building and time-depth conversion is a crucial step in all depth predictions.

The Dutch state oil company EBN is participating in most upstream activity in the Netherlands and has access to the well results. As such it is possible to conduct extensive reviews of the performance of the different operators in the country. This allows for a compilation of statistics on exploration success ratios, volume predictions and project costs (EBN 2012, Hoetz 2012). Interesting observations can be made in the area of predicting reservoir depth.

From all the subsurface parameters being prognosed pre-drilling, few can be tied down so unambiguously as the reservoir depth. The well reviews disclosed that at least one third of the wells with poor results (i.e. lower well rates, smaller volumes proven) suffer from poor depth prognosis. In those cases typically wells came in deeper than anticipated and often show reduced hydrocarbon columns compared to the prognosis.

The challenge of predicting depth is the consequence of the highly variable geology which characterises the Northern Permian Basin. Different rock types (sands, shales, carbonates and evaporites) often underwent a complex tectonic history giving rise to significant structuration (Fig 1). Variations in lithology, burial history, pore pressures and stresses do result in complex velocity distributions.

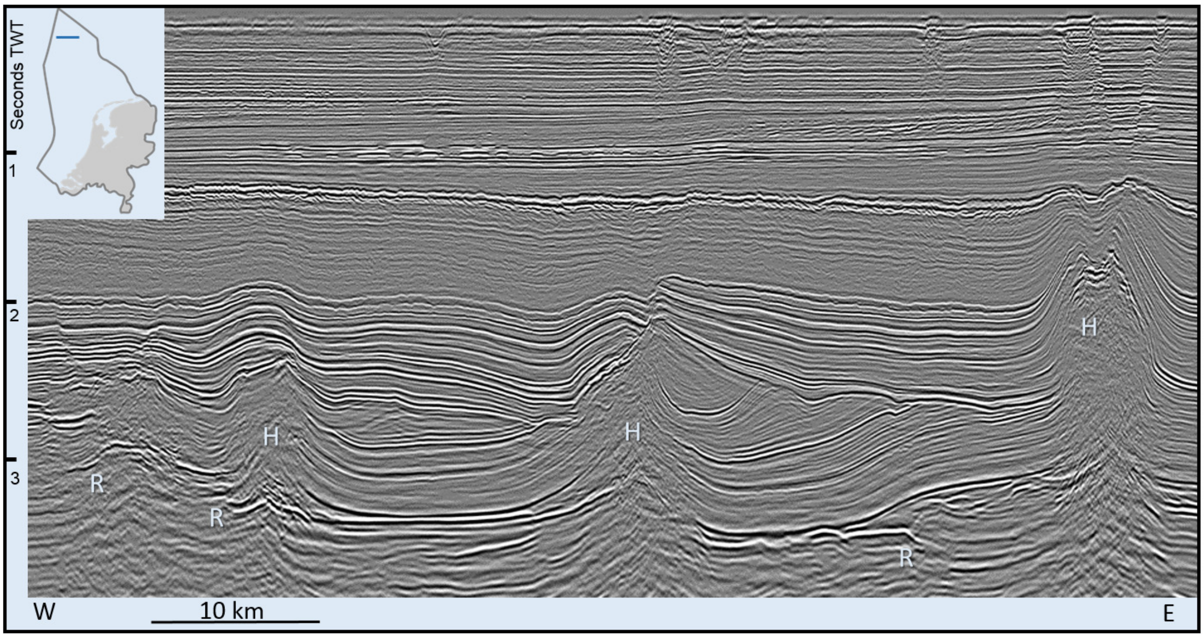

Figure 1 *Example seismic line showing typical structuration in the Dutch subsurface caused by rifting (R) and halokinesis (H). This, in combination with heterogeneous rocktypes, leads to time-depth conversion challenges.*

Analysis

Assessing the quality and precision of depth conversion workflows requires a sizable dataset to be statistically meaningful. For this purpose 253 petroleum wells recently drilled in the Netherlands have been analysed and the depth prognosis as described in the well proposal was compared with the depth of key markers actually found. Also the methodology used for the depth conversion was tracked. It appears that most mapping, being the basis for the depth prognosis, follows a workflow of *layer-cake* time-depth conversion using 3D PreSDM data. Velocities for these layers are being derived from well data and/or pro-velocities and are parameterized in various ways (Al-Chalabi 2015, Robein 2012). Interval velocity maps, velocity functions (Vo, K) and 3D gridded velocities are being used frequently. In most cases, the depth prognosis for key overburden horizons was also available for the review. The depth outcome was not only compared with prognosed depth but also with the reported uncertainty range where available. Often the uncertainty range is specified as plus/minus 2 standard deviation (sigma). Assuming a normal distribution, this implies that around 95% of the predictions are supposed to fall within this range.

Two examples of the *actual versus prognosis* comparison are given in figure 2. Both wells have encountered comparable stratigraphy but are situated in different localities. Example 1 found the objective reservoir (T. ROT) deep compared to the prognosis by 38 meter. From the prognosis errors at the overburden (seismic) markers it can be concluded that the depth error originates from the Chalk layer, i.e. the layer between the markers B. NS (Base North Sea) and the T. KN (Top L. Cretaceous). Further analysis confirmed that the velocity of the Chalk layer was underestimated. This velocity error has propagated down and led to the reservoir depth error. In example 2, the depth errors for the first two markers was insignificant. Subsequent markers came in shallow to prognosis. However the thickness of the Zechstein layer (between the markers T.ZE and T. ROCL) was mis-predicted by some 90 m. As a consequence the reservoir (T.ROSLU) came in deep to prognosis by 80 m; a result that was outside the uncertainty range specified pre-drilling.

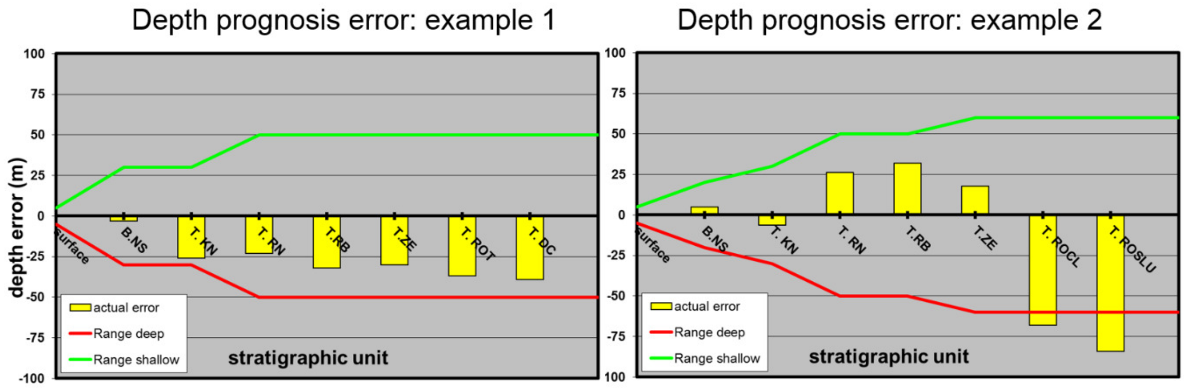

***Figure 2** Depth prognosis errors for two different wells with comparable geology: reservoir (Rotliegend) and key overburden markers. Pre-drill uncertainty ranges (2 sigma) for reference.*

Given the large number of wells available it was possible to derive meaningful statistics on the quality of the depth prognosis. For example, now it is possible to investigate whether certain areas are more challenging to predict depth for. Also the quality of the predictions can be linked to certain workflows or to specific operators.

An interesting observation can be made by looking at all the 253 depth predictions of the main objective reservoir tops (Fig. 3). The depth errors range from - 219m to +130m. Whilst the average top reservoir depth in the wells amounts to 3010 m (TVDmsl) the depth errors show a standard deviation of 38 m. In line with expectation, exploration wells typically show larger depth errors than development wells. Looking at all wells, it turns out that there is a clear bias (10 m) in the depth errors towards being *deep to prognosis*. In the well population studied, the number of wells being *deep* is almost double the number of wells being *shallow* to prognosis.

This observation suggests that the drilling portfolio (exploration, appraisal and development wells) is being assessed too optimistically as depth is often correlated with hydrocarbon column and volumes. A similar bias is indeed encountered in reviews of exploration portfolio results (EBN 2012, Mathieu 2015).

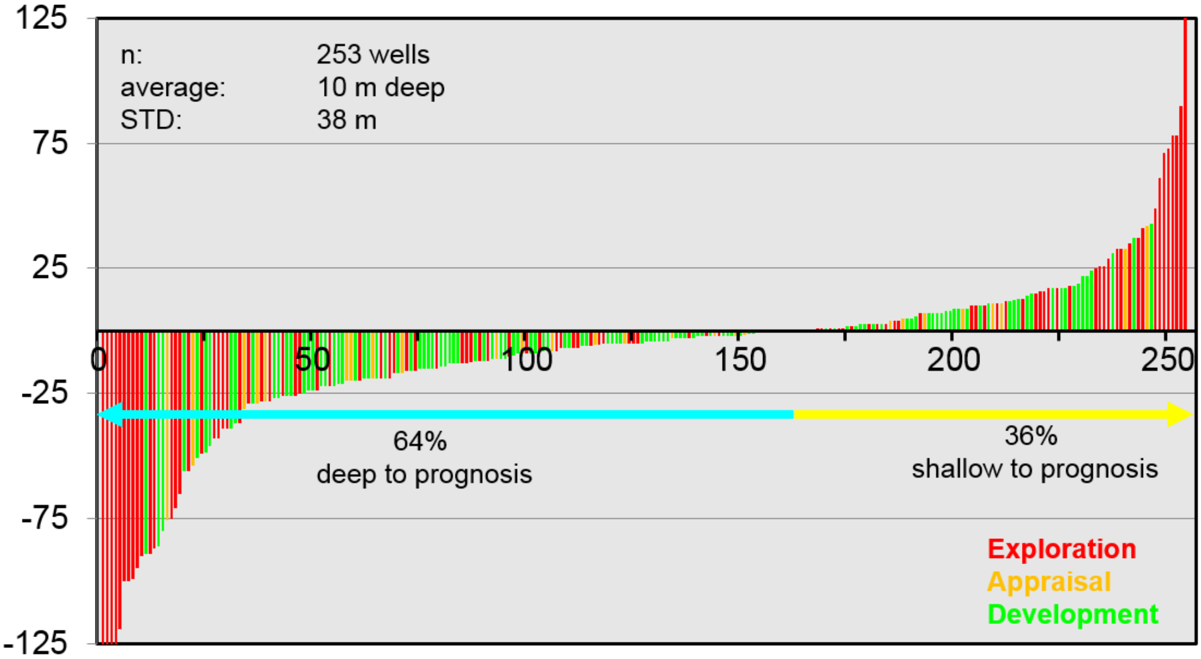

Figure 3 *Depth prognosis errors (in m) for 253 wells: sorted from deep to shallow with respect to prognosed depth. Well type is color-coded as per legend.*

Why biased depth estimates?

A possible explanation for the bias in the depth estimates is given by a mechanism that can be referred to as *selection bias*. It is important to realize that we do not have precise knowledge of the subsurface. Our evaluations, including the depth maps, are the result of seismic interpretation and velocity assumptions which do contain noise. If we would conduct random drilling on these maps and compare actuals versus prognosis, -most likely- no bias would show up. However, in reality we do not drill randomly, moreover we put a lot of effort in selecting our targets carefully. In many cases, during concept selection, an important selection criterion is structural height. In those cases where modest hydrocarbon columns are likely (or where the contact is already pinned down) often the planned well is aiming for a crestal position. The depth map available, with its inherent uncertainty, is a key factor in guiding the location picking. Due to the uncertainty, the crestal areas, as expressed on the depthmap, are partly *genuine highs*, partly *spurious highs*. *Selection bias* acts equivalent to Darwin's principle (Darwin 1859). The ranking of the drillable targets in a portfolio is analogous to the natural selection related to the survival of the fittest. Whether the selected location was really crestal ("*fit*") or only perceived crestal; that will show only after drilling.

Implications

If hard data tell us that certain prognosed parameters, like depth of the reservoir, tend to have a bias, the question arises whether it is possible to mitigate for this effect in future well projects. The *selection bias* effect could certainly be significant when entire portfolios of drilling targets are being taken into account. A basic approach would be to "correct" for the observed bias by simply adding 10 meters to the depth prognosis values. Obviously, if this *de-bias correction* approach would have been implemented prior to drilling the 253 wells in this dataset, no more remaining bias would have shown up. However, likely certain wells would have failed to screen for drilling because the 10 meter depth shift (*de-bias correction*) would have translated into reduced (prognosed) HC columns and/or productivity. Given the fact that various well projects in highly mature areas, like the North Sea, are already fairly marginal, any *de-bias correction* could cause these projects to become sub-economic. Hence applying a simple de-bias correction would impact negatively on the drilling portfolio and reduce the amount of opportunities.

An alternative way to address the *depth selection bias* being is to carry out the technical evaluation meticulously. In that case evaluation errors might be detected and –perhaps- the uncertainties can be reduced. Already just being aware that *selection bias* might be present in an evaluation of a certain project helps to dig deeper into the analysis. Probably *selection bias* can never be completely avoided as long as there are uncertainties in our data and our evaluations.

Conclusions

Systematic reviews of well results are essential in capturing the learnings which help derisking future targets. A lookback at the quality of reservoir depth predictions in the Southern North Sea area (253 wells) shows that the uncertainty amounts to 38 m (1 sigma) which equals 1.2% of the (average) depth. Intriguingly, a bias of 10 m (*deep to prognosis*) is observed in the dataset. A possible explanation is given by the mechanism of *selection bias*. Crestal areas, genuine or spurious, are more likely to be selected for drilling in the portfolio ranking process. Is is difficult to rule out that selection bias is playing a role in any project planning, in particular during the concept select phase. Being aware of the mechanism of *selection bias* is helpful in trying to reduce its impact on the project.

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