Handling Seismic Anomalies on Multiple Targets

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Summary

It is well understood that anomaly information such as a flat spot, conformance, AVO, boosts the chance of success (COS) of an exploration target. Similarly, lack of anomaly information, when expected, attenuates the COS of the target. However, what happens when a prospect is composed of multiple targets (zones, compartments) with differential anomaly information?

This paper presents a methodology that captures the intuitive notion that the aggregate effect of anomaly indicators at the target level depends on the degree of risk dependency between the discrete targets in the prospect. If the targets are relatively risk independent, then the prospect level COS will be a direct consequence of risk modification at the target level. On the other hand, if there is significant risk dependency, then the aggregate effect can be a relatively stronger boost or a significant attenuation depending on whether the signatures are consistent or mixed. The approach is illustrated with a North Falkland Basin multiple target prospect.

Introduction

Many companies have developed a risking scheme for systematic use of seismic anomaly information. The approaches vary. Some involve direct adjustments of individual geologic chance of adequacy estimates. Other schemes involve the upgrade of an initial geologic risk score with an empirically calibrated factor that captures the combined effect of a large number of observed amplitude attributes as well as an assessment of seismic and well data quality. This paper presents a Bayesian risk modification scheme that has been operationally implemented and that is in practical use.

As argued elsewhere (Stabell et al, 2003), the Bayesian approach has a number of advantages: It promotes a balanced interpretation of the seismic anomaly indicator as it requires explicit consideration of possible failure case scenarios that might produce the observed seismic signature. The approach thereby counteracts success case bias. The approach is consistent with the principles of statistical estimation. It can therefore also easily be expanded to cover new or additional data sources such CSEM data. It can equally well handle situations where no seismic anomaly is observed, but where it is expected. In this case the Bayesian scheme can produce an attenuation of the initial COS estimates.

In this paper we consider how the Bayesian risk modification scheme can and has been extended to handle multiple target prospects. We first review briefly both the basics of Bayesian risk modification and the main elements of how the multiple target application. We develop an illustrative numerical example using the Ernest prospect, a North Falkland Basin prospect. The review does not build on the formal mathematical notation, but emphasizes rather development of the key ideas.

Bayesian Risk Modification

There are two main ideas behind the Bayesian risk modification approach. First, instead of focusing solely on what the seismic indicator information might tell about the probability of finding hydrocarbons, the approach requires that we develop a range of alternative hypotheses concerning prospect conditions that might be related to the seismic observations. The conditions can involve different pore-fluid and rock-matrix combinations. In other words, we do not solely consider the case of success fluids (oil and/or gas), but also consider failure fluids such as water and low saturation gas. We also consider not only the success matrix type, but also failure alternatives such as non-reservoirs (for example shales or volcanics) and reservoirs that are too tight or low quality relative to the definition of success case reservoir description. All the cases have in common that they might produce the observed seismic indicator signature.

The second key idea is to treat the observed seismic indicator as an additional, distinct piece of information where a Bayesian framework is used to update initial COS estimates. This approach involves both estimating the background (prior) probability of the set of alternative conditions and estimating the likelihood of the observed seismic indicator given the different success and failure conditions. The background COS condition is estimated using the traditional chance of adequacy (or risk) factor approach (White, 1993). The initial (background) estimates use all information available other than the observed seismic indicator information that is directly related to the exploration target.

The method is called DFI (Direct Fluid (and matrix) Indicator) risk modification. The DFI label signals that the method does not pre-judge the message of the seismic indicator; risk modification signals that the approach also makes effective use of the traditional bases for geological risking of prospects.

The objective is to get a modified estimate of the chance of success given the observed seismic indicator. The approach used is to estimate the opposite: the likelihood of the observed seismic indicator, given the set of possible fluid and matrix conditions that might be present.

Consider a target Alpha East in the Alpha prospect where we have estimated that the geologic chance of success is COS. Alpha East is an oil target and we estimate that there is only one possible failure condition, brine, due to failure of seal.

Bayes' formula for the modified COS in light of the observed seismic anomaly indicator (AI), P(Oil | AI), is the joint probability of oil and the AI, P(AI & Oil) = P(AI|Oil)*P(Oil), divided by P(AI):

$$COS_{modified} = P(Oil \mid AI) = \frac{P(AI \mid Oil) * COS}{\{(P(AI \mid Oil) * COS) + (P(AI \mid Brine) * (1-COS))\}} = \frac{P(AI \mid Oil) * P(Oil)}{P(AI)}$$

Figure1: An Illustrative Bayesian Risk Modification Formula

The Alpha prospect is composed of Alpha East and Alpha West, where Alpha West is another target with seismic anomaly information. The COS of the Alpha prospect is defined as the chance that at least one of the targets (or what we call segments) is a success – given that we drill out both targets.

The Alpha COS can be estimated using Monte Carlo simulation where we model drilling both targets in Alpha. For targets that have risks that have been modified in light of seismic anomaly indicators, we simulate the prospect outcomes using the initial risk assessment. The trials obtained are thereafter weighted according to the DFI likelihoods that were estimated at the target level. With this approach we can both honor risk dependencies and still capture the effect of the DFI risk modification.

The Ernest Prospect

To illustrate the handling of seismic anomaly information in a prospect with multiple targets we consider the Ernest prospect in the North Falkland Basin (see MacGregor, Lucy et al 2007).

Ernest has a 4-way closure and a 3-way fault-dependent closure. The two closures are separated by a saddle at 1060 m. Spill point for the combined structure is 1080m. There is a weak seismic anomaly on the 4-way closure while there is no anomaly apparent on the 3-way closure.

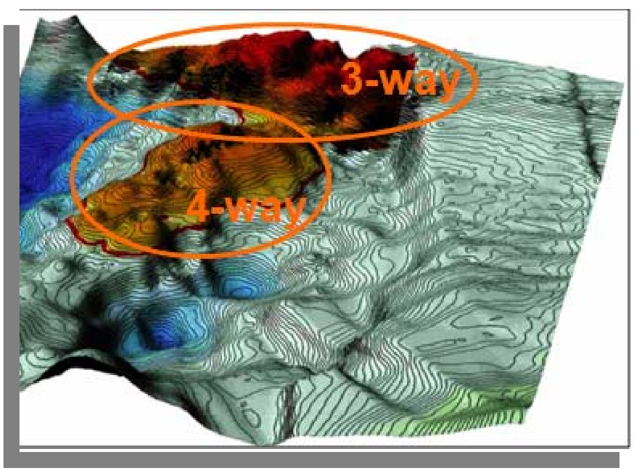

Figure 2: The Ernest Prospect with a 4-way closure and a 3-way closure (Rockhopper, 2006)

We have assessed that the 4-way closure has a high chance for a successful trap and seal (80%). There is a slight chance that the seal could be breached by a thief zone or sub-seismic faulting. The 3-way closure is riskier: only a 30% chance for an adequate fault seal. There is no trap risk dependency between the two closures. The targets are in the same sand, which has an 35% chance of being present. The two targets share both their reservoir presence and their chance of source and migration.

The initial risk assessment concludes that the 4-way closure has an initial COS of 17.8% while the initial COS of the 3-way is 11.2%

Bayesian risk modification on the 4-way closure with weak anomaly indicator leads to a boost of the COS to 25.7. The lack of any anomaly indicator on the 3-way closure, on the other hand, leads to an assessed attenuation of the COS to 8.1%.

Case	P(DFI | case)	P(case, success)	P(case, failure)	P(case & DFI)	P(case | DFI)	DFI strength
Oil & Eval. Res. [%]	60	17.9		10.8	25.7	1.582
Water & Eval. Res. [%]	30		17.1	5.1	12.2	0.677
Water & Non Res. 1 [%]	40		65	26	62.1	0.882
Success Total		17.9		10.8	25.7	1.582
Failure Total			82.1	31.1	74.3	
DFI				41.9		

Table 1: Bayesian Risk Modification for the Ernest 4-way Closure

Case	P(DFI | case)	P(case, success)	P(case, failure)	P(case & DFI)	P(case | DFI)	DFI strength
Oil & Eval. Res. [%]	30	11.2		3.4	8.1	0.703
Water & Eval. Res. [%]	50		23.8	11.9	28.8	1.298
Water & Non Res. 1 [%]	40		65	26	63	0.917
Success Total		11.2		3.4	8.1	0.703
Failure Total			88.8	37.9	91.9	
DFI				41.3		

Table 2: Bayesian Risk Modification for the Ernest 3-way Closure

For the analysis of the Ernest prospect, we initially simulate the different outcomes obtained using the initial COS estimates for the 4-way closure and the 3-way closure. The resulting estimates of the frequency of the different success outcomes (4-way alone, 3-way alone and 4-way and 3-way together) are subsequently weighted by their likelihood as estimated in the risk modification. The weighted trials (last column in red in Table 3) provide an estimate of the prospect COS that honors both the integration of seismic anomaly information and the target risk dependencies.

4-way closure	*3-way closure*	P(outcome)	*P(Joint DFI | outcome)*	*P(DFI & outcome)*	*P(outcome)*
X		8.8 %	25.61%	2.251 %	**13.21%**
X	X	9.1 %	18.00%	1.634 %	**9.58%**
	X	2.5 %	11.36%	0.282 %	**1.66%**
		79.6 %	16.17%	12.877 %	**75.55%**
				17.045 %	

Table 3: Weighted trials for the Ernest prospect with seismic anomaly modified target risks

In the case of the Ernest prospect, where one closure has a (weak) seismic anomaly while the other has no seismic anomaly,, the result is a prospect COS of 24.5%. This is less than the risk modified COS of the 4-way closure alone (25.7%). In other words, when the two targets are combined in the Ernest prospect, the mixed DFI effects “propagate” between the targets to produce a prospect-level effect that is relatively weak.

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