Z-99 Application of Integrated Risking on a South African Prospect

M. GLINSKY, G. DUNCAN, M. JAMIESON, and A. MORRISON
BHP Billiton Petroleum, 1360 Post Oak Blvd., Houston Texas 77056, USA

Abstract

An integration of all interpretations, including geology, petroleum system, seismic amplitude, seismic imaging velocity, and spectral decomposition of the seismic data gives the risk of a prospect in offshore South Africa. This risking is done using the presently available 2D seismic data and well data. This quantification is used as a justification for the acquisition and processing of the 3D seismic data. The integration of the information is based on a Bayesian formulism[1]. Prior probabilities are determined by standard means using an analysis of the geology and the petroleum system. These probabilities are then updated in a sequential way with the seismic amplitude, seismic imaging velocity and spectral decomposition. Knowledge of the conditional probabilities of the responses[2,3] is used along with the inclusion of "soft" knowledge through fuzzy logic[4]. The advantage of this approach is repeatability. The same answers to the same fixed questions, with the same hard data will always lead to the same risk. This enables post drill lookbacks to be used to update the risking process – leading to better future decisions.

Introduction

For quantitative interpretation to have business impact, it must be distilled into a form that can be digested by the decision makers. Many different pieces of information may have value on their own, but their combination adds together non-linearly. That is to say that the whole is more valuable that the sum of its parts. These are qualitative, intuitive statements. A mathematical expression of this non-linear, but communicative, "addition", is sequential Bayesian updating[1]. There are two important properties of this update procedure. The first is the fact that two plus two can equal eight, under suitable conditions. The second is the saturation property – a prospect that already has a very high probability of success, like 90%, will not have the same increase in probability as a prospect with a low probability given the addition of the same technical information.

This methodology also guides the technical developments that we support. They must be targeted to quantify uncertainty, such as giving the probability distribution of a spectral decomposition response given that the seismic reflector is a reservoir. If the technology is not put in a form that can be integrated, it is of much less value to our decision makers.

The mathematical formulism is used as a guide to the combination. There is still a significant amount of qualitative information that must be included. Along with this qualitative information is the associated intuition, that is, empirical knowledge of the experienced geoscientists that must be respected, then validated by lookback studies. An example is the statement that a particular prospect should have a probability of success of 75% after the inclusion of seismic amplitude information, even though the probability of success without that information would be only 35%. The important property of the risking method is that it should be repeatable and auditable. To this end we have employed some fuzzy logic[4] and the recording of the important inputs as well as final conclusions.

This paper will not focus on the details of the individual pieces of technical information, but rather will explore the holistic assimilation of the parts. It also will not hypothetically propose a methodology, but will rather present the application of the method to an offshore, South African deepwater prospect called Cabernet. The results, of which, were used by the decision makers to determine what further information would be acquired before the prospect would be drilled.

The discussion will start with a presentation of the prospect, giving its geologic background and risks from a petroleum system and geologic perspective. It will then add the interpretation of the seismic imaging velocities. This will be a good example of not over applying the Bayesian framework. It will be used to eliminate certain non-commercial possibilities and determine the range of reservoir porosities. The seismic amplitude response will then be added using both a Bayesian update and fuzzy logic. The result of spectral decomposition contributes a quantitative Bayesian boost to the reservoir probability. Unfortunately, because of the current state of understanding of the spectral decomposition response to fluids, only a small qualitative decrease to the fluid risk was made. This is a good example of a technical gap, and how that gap should be filled. The integrated risking results will be formed along with a variant that examines the possible value of 3D seismic data acquisition and analysis.

Geologic background and prospect description

BHP Billiton Petroleum ("BHPB") holds a 90% equity interest in Blocks 3B/4B, located in the Orange Basin off the west coast of South Africa along with Global Energy who hold the remaining 10% equity. The blocks cover an area of ~21,500 km² in water depths ranging from 300 m to 2,500 m. The Block lies to the south of two significant gas discoveries, the Kudu Field in Namibia and the Ibhubezi Field in South Africa, both of which are under appraisal.

BHPB is pursuing an oil play on Block 3B/4B, the elements of which have been proven to exist regionally by wells in the basin. Thick oil prone marine shales (Mid-Aptian age) have been penetrated in the DSDP 361 well and can be correlated to 0-A1 immediately to the northwest, south of blocks 3B/4B and as far north as Kudu in Namibia. Directly overlying the Aptian source rocks are sandstones of Early Albian to Cenomanian age proven in many shelf wells to the east. These clastic reservoirs were deposited in a deltaic setting on the shelf during relative high stands, but during the low stands, clastics have been deposited in base of slope distributary channels and sheet sands into the deeper parts of the basin. These sands drape across a substantial pre-existing basement ridge. This ridge forms large, structurally low relief closures (average size 90 km²) but more importantly acts as a migration focal point for hydrocarbons, both from the east and the west. This relationship of source to reservoir/carrier system would allow for a very efficient petroleum system to occur across this basement ridge, which provides as a natural drain point in the basin and block.

A substantial number of AVO anomalies have been observed at the Cenomanian reservoir levels, which typically are associated with the structural highs along the basement ridge. The Upper Cabernet Lead, the subject of this paper, is one such feature. The lead is a combination structural/stratigraphic trap targeting Upper Cenomanian base of slope channel systems and terminal lobes directly overlying a well-developed package of mid-Aptian aged source rocks. The Turonian sequence boundary (16AT1) marks the top structure, where approximately 70 m of closure is mapped over 40 km^2. A coarsely spaced 2D grid (6 by 8 km) acquired by Global and BHPB as part of a more extensive 2D program in 2002 covers this lead. These data were acquired with a 6km cable enabling good imaging at target levels. There is an AVO anomaly associated with the Upper Cabernet feature, which exhibits a broad conformance of amplitude to structure. This AVO signature was verified via the reprocessing of 180 line km of 2D over the Cabernet lead, which was undertaken to ensure the data was true amplitude preserving. In addition to the AVO effects, a velocity inversion was observed at the target level along with a frequency anomaly within the amplitude package and attenuation of frequencies directly below. It is the integration of these various pieces of data that has enabled the geological team to reduce the risk for reservoir presence and for hydrocarbons being present.

After a extended review of this information, but before explicit consideration of the AVO information, a group of geologic peers agreed that the probabilities were: 44% reservoir, 69% trap, 51% seal, 88% source migration and timing, and 24% gas only charge. This results in a 14% risk of finding hydrocarbons and 10% risk of finding oil at the prospect.

Seismic imaging velocity

The interval velocities were derived from the seismic migration velocities. The results are shown in Fig. 1. A significant velocity inversion is seen above the objective level. The results of the petrophysical analysis indicated that the objective level was very unlikely to be a limestone or low porosity clastic reservoir based on velocity alone. The phase of the reflector and geologic control updip of this prospect also confirmed this information. The strength of this information was considered so strong that a detailed probabilistic analysis was not done. The unlikely scenarios where just eliminated.

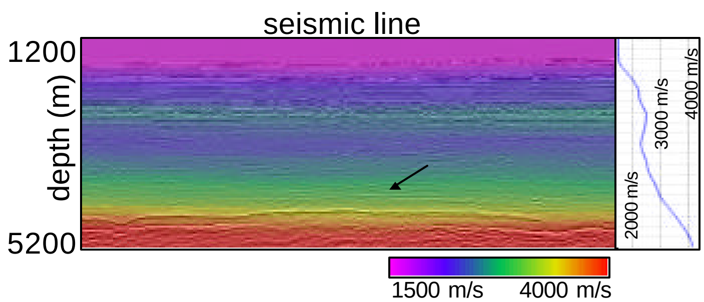


Figure 1. Seismic interval velocity displayed as color behind seismic data displayed as black and white. Plotted as a function of seismic line location and depth. A line average velocity is plotted vs. depth. The location of the prospect is indicated by the black arrow, near the base of the velocity inversion.

Seismic amplitude response

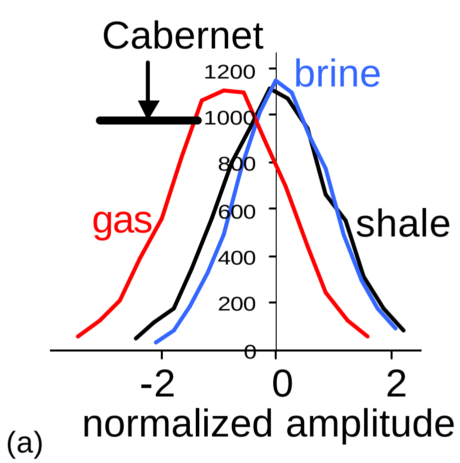
A detailed petrophysical analysis was done. The seismic imaging velocities were used to extrapolate the data from well control. Not only were the most likely petrophysical correlations derived, such as end-member sand porosity vs. compressional velocity, but the uncertainties in those relationships. A stochastic amplitude analysis was done and compared to the observed amplitude response. There was a prediction of a soft seismic reflection that would increase with offset. The results can be seen in Fig. 2a and 3. More details can be found in Ref. 2.

These results were used to do a Bayesian update of the results of the geologic and petroleum systems analysis. It was necessary to transform the risks that came out of this analysis into situations that the amplitude information could discriminate (see Fig. 4). This was done using some straightforward algebraic expressions. The amount of this update was reduced because of lack of confidence in the seismic data. The amount of this reduction was based on the answers to a series of 5 questions (e.g., Was the processing amplitude preserving?). The answers to these questions were combined by fuzzy logic to give a seismic confidence level of 31%. This is interpreted to mean that 69% of the time there is a serious problem with the seismic data and the results of the Bayesian update based on seismic amplitudes should not be used. Another Bayesian update to the probability of hydrocarbon is done based on structural evidence alone (i.e., fit to structure and flat spots). The amount of the update is estimated by answering the question: to what probability should a 50% probability of success prospect should be increased because of the structural information? This is aided by comparison to a catalog of structural evidence with associated boosted probabilities. For the current 2D data, the number used is 57%.

Spectral decomposition

Various spectral decompositions were done of the seismic data. All gave similar results. The mean scale of the reflector and the range of scales of the reflector were compared to a quantitative estimate of the conditional probabilities of the same properties of the spectral decompositions given the geologic lithofacies[3]. This was used to give a Bayesian update to the reservoir probability. It was assumed that only two lithofacies were possible (thin sand and sand) because of the observed seismic imaging velocities. These results can be seen in Figs. 2b and 3. Similar to the seismic amplitudes, a data confidence factor was used to reduce the effect of this update. Because of evidence that the prope rties of the spectral decomposition are more robust to problems with seismic imaging[3], a larger confidence factor of 40% was used. The magnitude of this update is quite large. If the seismic confidence would be 100%, the 44% reservoir probability would be increased to 97%. Because of the limited confidence, it was increased to only 65%.

There is a reasonable amount of antidotal evidence of effects of fluids on the spectral decomposition, both in terms of the spectral response of the reflector (increase in the mean scale) and in a shadowing of a reference reflector below the target reflector (reduction of reflection of the reference reflector beneath the target reflector at the scale of the target reflector)[5]. There is not yet quantitative theoretical explanations of these effects. For this reason a detailed quantitative Bayesian update was not made. A qualitative increase to the structural boost of 3% was made to take this into account.



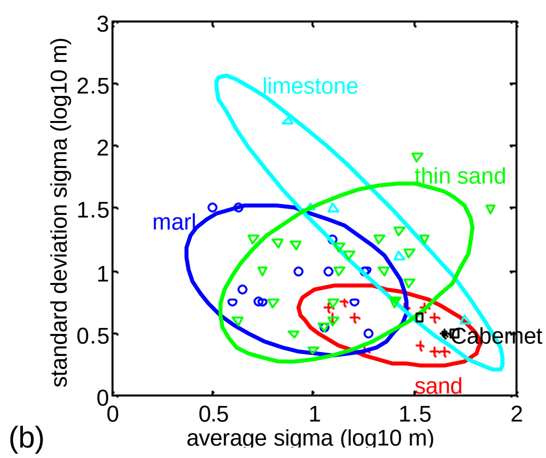


Figure 2. (a) Conditional probability of seismic (far stack) amplitude response, given the fluid. Normalized to the RMS amplitude of the brine filled sand reflector. The RMS of the target reflector, normalized to the RMS of the downdip reflector, is shown by the black arrow labeled Cabernet. The bl ack bar indicates the standard deviation. Black is the for a shale-shale reflection, blue is a shale-brine sand reflection, and red is a shale-gas sand reflector. (b) Conditional probability of spectral decomposition response, given the geologic lithofac ies.

Horizontal axis is the mean scale, logarithmic. Vertical axis is the standard deviation of the logarithm of the scale. Points are for seismic scale refection packages taken from several different wells. The ovals are fit, two standard deviation, ellipsoidal distribution functions. The color key for the ovals and points is: light blue triangles = limestone, blue circles = marl, green inverted triangles = thinly bedded sands, red pluses = massive sands, black squares = volcanics. The observed value for the prospect is shown as an asterix and labeled as Cabernet.

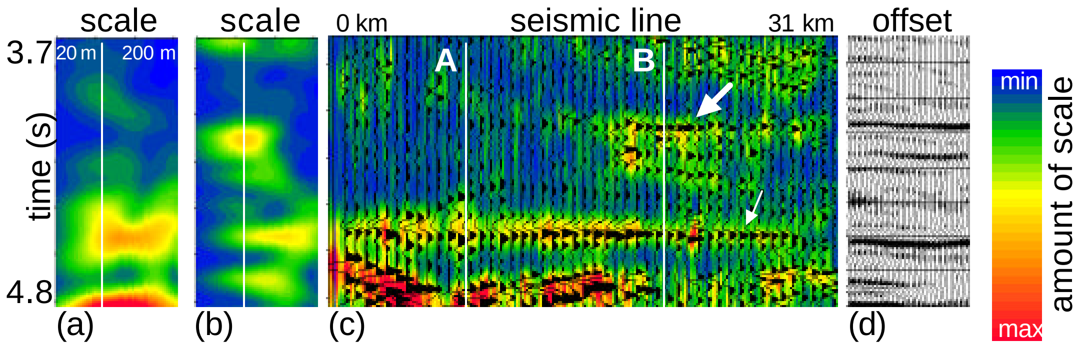


Figure 3. (a) Spectral decomposition at location A in Fig. 3c, off structure. Vertical axis is time. Horizontal axis is scale, logarithmic. The vertical white line indicates the scale that is plotted behind the seismic data in Fig. 3c. The color legend is shown on the right. It is the absolute value of the continuous wavelet transform using a Gabor wavelet. It is smoothed using a 20 ms boxcar filter. (b) spectral decomposition at location B, on structure. (c) Seismic data plotted as wiggles, reflection coefficient phase, right kick is soft. It is stratigraphically flattened. Spectral decomposition at a scale of 53 m plotted as color backdrop. Top of objective package is indicated by large white arrow. Reference reflector showing frequency attenuation is indicated by the small white arrow. (d) prestack time migrated gather, reflection coefficient phase, right kick is soft. Shows soft reflector with increasing amplitude with offset. Maximum offset is 4250 m.

Integrated risking framework and the value of 3D seismic

The integration of the work is shown in Fig. 4. The starting point is the geologic and petroleum system risks. These are updated by the seismic amplitude evidence, then the spectral decomposition evidence. The resulting probability of oil, 21%, was subjected to a reasonableness test. The internal experts were asked: given the totality of the evidence, is there a one in 5 chance that this will be an economic oil discovery? The optimistic outcome, if 3D seismic was acquired and analyzed, was agreed to be that the evidence would all be consistent with an oil reservoir, the amplitude confidence would increase to 90%, the spectral decomposition confidence would increase to 50%, and the structural update would increase to 80% from 60%. The resulting integrated oil probability would increase to 41%. This was also subjected to a reasonableness test by the experts. At 21% the prospect is considered undrillable. At 41% it is drillable. The decision was therefore to proceed with the data acquisition before drilling.

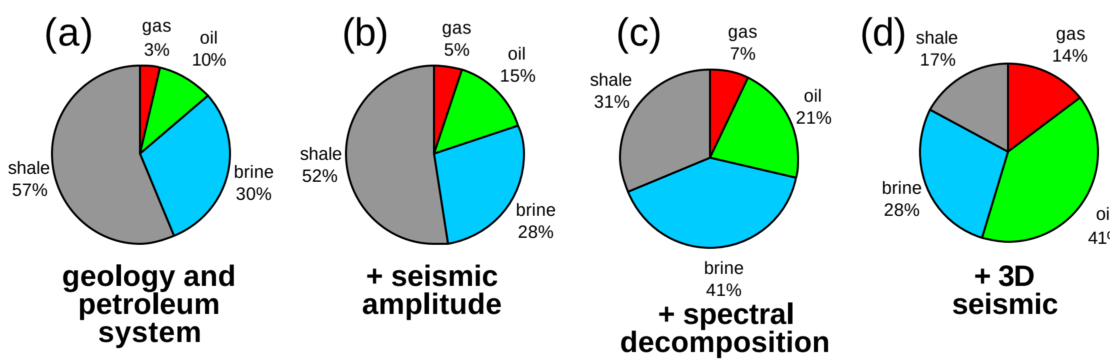


Figure 4. Updates to probability cases (shale=grey, brine sand = blue, oil sand = green, gas sand = red): (a) using results of geologic and petroleum system analysis, (b) adding the seismic amplitude observations, (c) taking into account the spectral decomposition, (d) optimistic case after acquisition and analysis of 3D seismic.

Conclusions

A Bayesian framework allows for the quantitative integration of all of the available information with desirable mathematical properties. This integration had business impact. Spectral decomposition added significant value for reservoir prediction, and has the promise of fluid prediction but further work needs to be done. Repeatability, auditability and fuzzy logic allows for feedback – learning and improvement.

Although the risks have been quoted to the closest percentage point, the emphasis in the decision process is on the leading order. The prospect, without any amplitude or spectral decomposition, is perceived to have a 1 in 10 chance of success. With the currently available data, it has a 1 in 5 chance of success. The goal, with the acquisition of 3D data, is to decrease the risk to at least 1 in 4 with a reasonable chance of decreasing it to 1 in 3. The absolute maximum decrease would be to 2 in 5. The threshold for this project is accepted to be between 1 in 5 and 1 in 4. Therefore the data acquisition has a very high value since it has the potential to push the prospect over the threshold. This is what has led to the method influencing a business decision and possibly leading to business value.

References

[1]R.T. Clemen, R.T., *Making Hard Decisions: an Introduction to Decision Analysis* (Duxbury Press, Pacific Grove, 1996), pp. 388-390.

[2]G. Duncan et al., "LFP Methodology in Lightly Explored Basins," to be presented at 2004 ASEG conference (2004).

[3]SM. Strauss, et al., "Geologic Lithofacies Identification using the Multiscale Character of Seismic Reflections," J. Appl. Phys. **94**, 5350 (2003).

[4]G.J. Klir and B. Yuan, *Fuzzy Sets and Fuzzy Logic: Theory and Applications* (Prentice-Hall, New Jersey, 1995).,

[5] J.P. Castagna, S. Sun and R.W. Siegfried "Instantaneous spectral analysis: Detection of low-frequency shadows associated with hydrocarbons", Leading Edge **22**, 120 (2003).