Fractured basement reservoirs are amongst the most difficult types of reservoir to evaluate. Yet, of all reservoirs, they are the most important to evaluate early in the field life cycle to minimise the costs of drilling unnecessary wells. It is essential to acquire important fracture characterization data early in order to optimise future well locations and paths, to predict field rates and recovery, and to economically deplete the field.

There are a number of crucial fracture parameters that need to be quantified (or at least semi-quantified) before developing an effective static/dynamic fracture model; and deciding if the discovery is an economic field. These parameters include:

1. Fracture identification: e.g. how to differentiate between natural, stress-enhanced natural and drilling induced fractures.
2. Fracture geometry: orientation, height, length, density and clustering
3. Is the fracture open or closed.
4. Fracture aperture – can we really measure aperture from image logs?
5. The importance of understanding the in-situ stress regime to determine which of the many fractures really matter.

This talk presents a critical assessment of common datasets and methodologies. Each parameter is discussed and the traps and pitfalls are highlighted using examples from Vietnam, Indonesia, Australia, Yemen and the USA.
Introduction

A majority of oil companies today build geological models mostly from well data making these models detailed and reliable near the wells, but away from the wells little or no information is available. Many oil companies have invested in seismic data and interpretation of that data; data that contains information that could increase understanding of inter well properties, improve geological models and thereby reduce reservoir uncertainty. But despite existing “Seismic to Simulation” software few oil companies integrate 3D seismic properties with geological models. Even if they do, critical aspects of the reservoir may be lost or distorted when they transfer data from the seismic grid to the geological grid. This in turn can result in erroneous prediction of reservoir and net pay.

One reason the transfer of properties results in loss of information is the fundamental differences in geometry and scale between the two grid types containing seismic data and geological model. A seismic grid is a regular orthogonal grid that doesn’t hold any stratigraphic or structural information, only X, Y and Z references, while a geological grid or Corner Point Grid (CPG) is based on an irregular hexahedral grid with I, J and K references that includes fault and stratigraphic information. Typically a seismic grid contains 100-200 million cells while a geological grid is 1-20 million cells.

Resampling of Seismic Grids

It is clear that we need to do a regridding of the geometry and a resampling of the property values when transferring data from the “fine scaled” seismic grid to the “coarser” CPG. Standard averaging or sampling methods will usually not handle this transfer without smearing property values across geological layers and zones. The result can be values assigned to incorrect layers and disconnected flow zones. This is most apparent when reservoir beds are thin and dipping and when the CPG is coarser in I and J direction than in X and Y direction in the seismic grid or when the CPG is rotated with respect to the seismic grid.

Here we present a methodology to correctly sample the seismic derived property (Figure 1) into a geological grid without the abovementioned averaging problems and at the same time ensuring that it is structurally and stratigraphically correct.

Stratigraphic Resampling

Standard techniques for transferring data from seismic to geological grids do not usually consider the differences in grid structure in a sophisticated way. For example, in averaging methods like “Z Sampling”, the determination of which seismic grid cells should contribute to the property estimate of a cell on the corner point grid is based purely on the overlap between the seismic grid cells and the target grid cell, regardless of which stratigraphic layer the seismic grid cells are in. If the layers are flat lying, the seismic and geological grids have the same cell size and are oriented in the same direction, the impact of this simple approach will be negligible. However, this is very rarely the case: cell size and grid orientation are usually (very) different and geology is often far from flat lying. Therefore standard techniques will distort properties derived on a seismic grid during transfer to a corner point grid, in particular when thin layers are present, but also in general. This distortion can significantly affect the static and dynamic properties of the reservoir such as porosity, permeability and flow.

To overcome these problems we create a Stratigraphic Model Grid (SMG) that preserves the seismic grid resolution but at the same time has the correct stratigraphic information from the geological grid. The
Stratigraphic Model Grid is used as a “transitional” step between the two grids. When using stratigraphic resampling, the layer that the SMG cell belongs to is considered when making a determination as to whether the cell should be included in the resampling calculation. With stratigraphic resampling, grid cells that belong to a different layer than the target grid cell are not included in the resampling, even if they overlap the target grid cell. In this way the lateral connectivity of properties is preserved and the vertical and lateral resolution maintained even for thin dipping layers. Figure 2 shows the result after using “Z Sampling” and Figure 3 after using stratigraphic resampling of the same seismic property shown in Figure 1. It is clear that more details are preserved with stratigraphic resampling compared to “Z sampling” where layers with high sand probability have not been preserved and values have been incorrectly sampled. This in turn can significantly affect flow predictions and flow behaviour when layers become disconnected or even disappear.

Net Pay

Once the property has been correctly resampled it can be used, for example, as a 3D trend for modelling other reservoir properties such as lithology through indicator simulation with external drift, or porosity through co-simulation. As the initial property has been correctly resampled these other derived properties will be more accurate and thus create a more predictive geological model. If we calculate and create net pay maps for the three properties and compare the maps we can clearly see that stratigraphic resampling has better preserved the values in the original seismic property (Figure 4). The “Z sampling” net pay map show lower net pay due to averaging effects.

Summary

Standard methods resample seismic property values into a geological grid by using various averaging methods. Because of the different grid geometries some cells belonging to non-reservoir layers or zones will be included in the averaging of the reservoir properties causing smearing of values across geological defined layers. We have presented a new method termed stratigraphic resampling for correctly incorporating 3D properties from a seismic grid into a geological grid. This method solves the problem with resampling and regridding. This way, important geological features will be preserved producing more predictive geological models and giving oil companies a way of fully using the inter well information contained in the seismic data.

Figure 1: Seismic Property Reservoir Lithology Probability) derived from Geostatistical Inversion, honouring seismic amplitude. The seismic grid has no stratigraphic information only grid cell values and X, Y and Z
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**Figure 2:** Seismic Property (see Figure 1) resampled to a Corner Point Grid using “ZSampling”. Cell values have been sampled and averaged incorrectly causing thin layers to disappear.

**Figure 3:** Seismic Property (see Figure 1) resampled to a Corner Point Grid using stratigraphic resampling. Notice that the fine details and thin features present in the Seismic Property in Figure 1 have been preserved.

**Figure 4:** Net pay maps derived from the seismic property (left), the “Z sampling” property (middle) and the stratigraphic resampling property (right). The stratigraphic resampling Net pay map corresponds much better with the seismic property Net pay map.
THE MONTE CARLO MYTH, OR WHY A RESERVOIR ISN’T A ROULETTE WHEEL

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Investigations into reservoir uncertainty are becoming more commonplace, not just into reserves or static uncertainty but also into the behavioural uncertainty associated with the flow characteristics of the reservoir. Unfortunately many of these investigations rely on two assumptions; 1) that the input property distributions can be defined by normal distributions and 2) that Monte Carlo methods are applicable for the analysis of multivariate relationships (particularly those of spatial properties). These two assumptions have long been abandoned in other areas of uncertainty modeling and risk assessment, most noticeably in financial engineering.

This paper will discuss the relevance of these practices to the evaluation of reservoir behaviour. If they show any validity in the petroleum industry it is important to understand under which conditions these assumptions can continue to be used.

The paper goes on to identify those areas where conventional understanding of random behaviour is flawed and indicates courses of action to improve the effectiveness of uncertainty modeling and risk analysis of complex depositional systems.

Good models, great models?

Somewhere during the 1990s the process of reservoir characterisation was hijacked and veered towards the pursuit of more and more detailed geological models. It is important to consider; 1) whether the construction of detailed geological models is possible, and 2) whether it is desirable. Let us first try to agree on what a good model is.

If we consider the construction of geological models in the same way as any other construction project it is likely that we will find some excellent models, several good models, a large number of fairly average models and some poorer models. What is it about the model that we can describe as good or bad? This is a very difficult question to answer, especially in fields where there are few wells or where data is poor quality. Many modelers would reply that accuracy is an important characteristic of a good model. Yet, unless you actually leave out data in the construction of the model and then use this to calibrate your model, the model is likely to be accurate to the data that was used to create it. How often is any new data, from wells or new seismic used to validate the modeling approach of a previously built model? Almost never. Instead the new data is usually just added to the existing model which is then updated with the new information.

This process lacks the feedback that is necessary to ensure that models are improving. It is easier and quicker to build a new model than understand why the previous model was wrong.

Other modelers believe that if the model looks realistic then it is more likely to be right. By combining the constraint of realism with the accuracy constraint you will get something that is accurate and looks realistic. Is this a good model? Or is it a realistic picture built from a very small amount of dubious data?

The only measure by which we can determine how good a model is must surely be in its capability to predict. Whether the model looks realistic or not and whether the model fits the small amount of hard data that we have collected are irrelevant compared to the model’s ability to provide good predictions of the reservoir. So, to measure the quality of a model we need to study it’s capability for prediction.

Random processes

Most text books on probability begin with an analysis of the toss of a coin or the roll of a dice and move on to more complex systems like roulette wheels. Yet the difficult part of understanding the uncertainty
in reservoirs is in the determination of the odds and the distributions associated with reservoir behaviours. Our attempts to use probability to analyse risk in reservoirs fails at the input stage.

Consider these questions; What does a probability of 1 in 10 mean? What does a probability of 1 in 20 mean? Could you tell the difference between a 1 in 10 chance and a 1 in 20 chance of success with your next well? And what does 1 in 1,000,000 mean? That it will never happen? Our inability to accurately assess probabilities or odds means that it is very difficult for us to estimate P10, P50 and P90 values. This is because we can’t really tell the difference between P90 and P95 for a complex system like a reservoir. Yet it would make a very significant difference to the shape of a distribution and therefore to the expected value. Corbett & Jensen, 1992 studied the problem of estimating the number of sample measurements needed to determine the mean or expected value from a population, but this number of samples may not be sufficient to tell you much about the shape of the distribution itself.

If you accept that it is hard to determine P10 and P90 values and you acknowledge that the expected value of a distribution is highly dependent on the fourth moment of the distribution, the kurtosis, then it is possible that you would be aware of the limitations of the Gaussian distribution. Painter, 1995 realized that the Gaussian distribution was poorly suited to the investigation of natural processes primarily because of poor fitting of the tails of the distribution. It is ironic that most of the dynamic behaviour of a reservoir is characterized by the extreme values – the parts of the distribution least likely to fit.

Liu & Pinho, 2004 discuss the frequency of freak waves and conclude that they’re not really freaks at all. We just didn’t fit the correct distribution to wave heights. Does this sound familiar? How much difference does it make to the expected oil-in-place if you get the mean or the variance of your input distributions wrong in your Monte Carlo simulation?

Taleb & Pilpel, 2004, (in an unpublished article available on Taleb’s website which is a translation of a published Italian text; Taleb & Pilpel, 2004), discuss the difficulties of inference from unknown probability distributions and specifically from those distributions in which the influence of the tails of the distributions are large. They were working with financial data. It is abundant and relatively cheap to collect. How should we approach a situation where a small amount of data can cost hundreds of thousands of dollars to collect?

Games

The roulette wheel represents a game of chance in which all the uncertainties can be computed. The probability of the a given number is 1 in 37 in Europe or 1 in 38 in the United States. In theory, everything about the problem is known and the odds of winning are easily computed. Like roulette, the mathematical models that have been constructed for most casino games are good, in that they will accurately predict the behaviour of a large number of bets on the spin of the wheel or roll of the dice or deal of the cards. They are awful at predicting the outcome of a single spin.

A reservoir is very different. The odds are unknown. The parameters are unknown. The distribution of any parameter is unknown. The relationships between dependent variables are unknown. And, if it is not possible to predict the result of a single spin of a roulette wheel, is it possible to predict the outcome of any single test of a reservoir?

Instead of spinning the wheel, it would make more sense to try to improve our understanding of the wheel itself. By reducing the complexity of the questions that we are asking, our success in answering those questions will increase. The study of games is useful for the purpose of understanding probability and in learning about optimizing strategies but its use in the context of uncertainty prediction for small numbers of events is limited.

Reservoir uncertainty – ranking realisations

In attempting to predict from past events such as financial forecasting or flow simulation it is possible to construct some sort of history match to calibrate the parameters and then to model forward based on the best choice of parameters. Of course, this process is not likely to be able to predict significant shocks such as the recent economic crisis, or other events that lie in the tails of distributions, but it may be valuable for predicting in well-behaved systems – whatever they are.
Tavassoli et al, 2005 examined the process of flow prediction in simple models and showed that the system was highly chaotic, even when there were only 2 wells, one fault and two permeability values – high and low. Taking the parameters that gave the best history match would rarely give the best forward prediction, though using the group of parameters that gave good fits to the history would give the best, though far from perfect, prediction. The conclusion from this is that choosing parameters from a group of similar parameter sets which have good matches is better than a single match even if this single match appears better. For example, when analyzing the results from any Monte Carlo software, it is not sufficient to pick the single realization that corresponds to the P90 value. You have to look at all those realizations close to the P90 and pick the realizations that are in the most similar group.

**The Perils of Prediction**

To make money in a game of chance you need to have a good understanding of probabilities. To make money when betting, you need to have a better understanding of probabilities and more importantly you need to be able to identify situations where the odds are not what they seem. Better understanding of odds creates opportunities. In 1991 two English gamblers (the Hole-in-One Gang) realized that bookmakers were giving odds of around 100-1 against any golfer scoring a hole-in-one at a tournament. The real odds, based on previous tournaments in England should have been about even. They made £500,000. In 1982 a new design of roulette wheel was developed which reduced the bias. Previously, observing the results of multiple spins of roulette wheels often gave sufficient information to suggest an improved long-term betting strategy. Notice that in each of these two examples the emphasis is on the determination of a small and highly specific piece of information that illuminates the real chance of success rather than an exhaustive analysis of the entire problem.

The peril of prediction that is typically encountered in reservoir modeling is the danger associated with trying to predict too much from too little information. This can take the form of trying to predict too far into the future in flow simulation, or trying to prediction in too much detail spatially from limited information.

Let's go back to the casino again. Between 1979 and the early part of this century students from MIT developed sophisticated strategies to improve their success at blackjack. Blackjack was chosen because it has the lowest house advantage (ie the percentage which the house expects to win) of all the casino games. Even playing a basic strategy in blackjack can reduce the house advantage to about 2%. More importantly the game of blackjack has 'history'. For roulette, each spin of the wheel has no dependency on the last spin. In blackjack cards are dealt and not replaced in the shoe so there can be situations where a larger proportion of advantageous cards may be in the shoe waiting to be dealt - this is a good time to sit down and play. The success of the MIT blackjack team was due to their ability to identify these advantageous situations. The success of reservoir characterisation will also be due to the ability of the modeling groups to identify similarly advantageous situations.

**Preconditions for Monte Carlo modeling**

For Monte Carlo modeling to be successful you must know the odds. You must have lots of information. You must be able to determine the probability distribution function, including the tails. It is interesting to note that geostatistics uses a variogram, rather than a correlogram because of the difficulties in accurately determining the mean (Deutsch, 1992) but to run meaningful Monte Carlo models it is necessary to have the whole distribution, not just the mean and variance.

Is it sufficient to use our input distribution and use a normal scores transform to make a Gaussian distribution? Well, that depends on whether you believe that the input distribution is representative of the population of data. If it is then use it. If you think that it is not representative then change the distribution, but document the alterations that you make so that when (if) you model is audited you know what has happened.

Be especially careful in situations where extreme values are likely to have a big impact on the system. If you suspect this then it is very important to get more information on the shape of the probability distribution function at the tails.

**Alternative strategies where Monte Carlo assumptions may not apply**

1. Change the problem into one in which Monte Carlo modeling may be used.
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You may not have sufficient information to correlate sands in a low net-to-gross fluvial environment but you could have enough information to determine the connectivity of the sands as a function of net-to-gross or unit thickness.

2. Simplify the problem.
   Answer the smallest number of questions that you need to determine the effectiveness of your development plans.

3. Consider the extreme events and use the statistics to prepare for them or to design experiments to improve your assessment of their probability.

4. Try to isolate those parameters in the modeling process that may have leptokurtotic distributions or situations where 'freak' values may not be freaks but part of the distribution. Investigate these parameters with vigour to get a better picture of their possible probability distribution.

Conclusions

The validity of reservoir prediction is still unclear. The ability of the most respected modelers to create good models of reservoirs is unknown and the concept of a "good model" is poorly understood. Attempts to construct a detailed model of a reservoir with less than 50-100 wells is likely to be very time-consuming, unlikely to improve understanding of the reservoir and deficient in its predictive capability.

It is only in those reservoirs that have an abundance of data that detailed geological modeling of the entire reservoir can be performed with confidence, but it is still doubtful whether this would improve our understanding of the behaviour of the reservoir (and it is our ability to understand the dynamic behaviour of the reservoir that allows us to propose profitable development plans). There may be good reasons to embark on a more detailed geological model of some parts of the reservoir such as those regions within which our current understanding is poor but which are vital to improving our dynamic model. Our ability to do this depends on the quality of the data that is available.

Better geological modeling strategies should be focused on decision support. That is, for a reservoir and a number of potential development strategies it is possible to design experiments, either field-based, model-based or completely philosophical, that are limited in scope and which will show the relative advantage of the different possible development decisions. This modeling strategy will give better results more quickly and with less effort.

Play more blackjack and less roulette and your expected returns will improve.

References

UNCONVENTIONAL GAS RESOURCES – DO PARADIGMS NEED TO CHANGE?

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The relatively mature state of global hydrocarbon exploration combined with increasing global energy demand and challenged accessibility to areas of significant conventional potential has caused industry to focus in additional resource arenas such as unconventional gas. While the recent flurry of announcements in North America unconventional plays involving tight gas, shale gas and coal bed methane may seem monumental to some, it is really only a reflection of the continuing evolution of the hydrocarbon extraction industry. Emerging information from many of these plays appears to challenge some established industry paradigms. Modifications to the technical approach used to identify, characterize and successfully manage some of these resource types may need to be considered.

Unconventional gas plays are varied in nature and are found in diverse locations around the globe. Technology advancements in horizontal drilling, well stimulation and even liquefied natural gas processing and transport continues to expand the commercial landscape for these plays. Recent industry activities and advancements suggest that an even more technically diverse portfolio of gas opportunities may be on the horizon.

The rapid commercial extraction of gas from the unconventional resource play is one of the main objectives for industry. Accurate subsurface characterizations, matched to appropriate drilling and completion practices, are required to achieve this goal. Many of the opportunities involve formations with low porosity (less than 5%), low permeability (micro $[10^{-6}]$ to nano $[10^{-9}]$ darcy) and contain a variety of natural fracture styles. The origins of the gas found within these reservoirs can be thermogenic or biogenic and the gas may be completely adsorbed onto organic carbon, free within porosity and fractures or exist in some combination of these two states. Artificial stimulation of the pay intervals utilizing multi-frac techniques with innovative fluids in horizontal wells are commonly required to economically extract this gas. These opportunities can be found in regionally continuous accumulations and material production volumes may require drilling thousands of wells. Reducing the surface footprint of this activity as well as minimizing the draw upon local water resources are significant additional challenges currently being addressed.

While industry has begun the journey, it is clear that the work of many scientists will be required to identify and solve the novel issues associated with this growing portfolio of unconventional gas ventures in the coming decades. This will require creativity and innovation from many disciplines. Members of these integrated teams must be prepared to work in a highly technical and dynamic environment which have been, and continue to be, both challenging and rewarding.
COALBED METHANE (CBM) PROSPECT IN JAMALGANJ COAL FIELD, BANGLADESH

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Methane and coal are formed together during coalification, a process in which plant biomass is converted by biological and geological forces into coal. The Methane that is stored in coal seams and the surrounding strata are released during coal mining.

Although coalbed methane (CBM) technology is yet to start in Bangladesh there is a good prospect of CBM development in certain coal fields especially in Jamalganj coal field. The high-volatile to medium-volatile bituminous coal of Jamalganj coal field is very suitable for CBM exploration in terms of their depth of occurrence, thickness of coal seam, coal reserve and areal extent. The thickest seam III (over 40m) can be a primary target for CBM development especially where it combines with seam IV in the eastern part of the coalfield. However, there are a number of unknown factors like actual gas content of coal, the coal permeability, and in-seam pressure that should be evaluated before the commercial CBM development.

In fact, interest in CBM development in Jamalganj coal field was shown by a multinational company. In early 1990s, the company submitted a proposal for undertaking exploration and development of CBM in Jamalganj coal field. They projected a conceptual target of producing 26 billion cubic feet gas per year. Accordingly, the total gas that could be produced would be about 340 bcf (0.34 Tcf). However there was no report of a positive negotiation between the company and the Government of Bangladesh subsequent to the submission of the report.

Bangladesh is now badly in need of energy resources for her growing economy, that's why CBM exploration in Jamalganj coal field can be a very good option. It can provide natural gas that is equivalent to a small size gas field compared to eastern Bangladesh gas province.
RELATIONSHIP BETWEEN GAS (CO₂) TRAPS AND STRUCTURAL STYLES IN THE AL JAMOUSE AREA, MELUT BASIN, SUDAN

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One of the recent exploration challenges in the continental rift basins of Sudan is the flushing effects of hydrocarbon (oil) from the structural traps by carbon dioxide (CO₂). This presentation will show some examples from the most prospective traps in the Melut basin (half graben basin) (Fig.1) of Sudan that proved this phenomenon. These prospects were originally categorized as the high rank drilling candidates in term of the size and petroleum system elements (source rock, reservoir rock, trap, migration, timing...etc).

During drilling, good and continuous hydrocarbon shows were encountered along the targeted reservoir intervals of the Adar and Yabus/Samma sands (Tertiary Reservoirs) in the kitchen area (Fig.2a). However, the formation evaluation (e-log) confirmed that the zones were gas bearing (from the density-neutron cross-over and pressure gradient plot) (Fig2b). Production tests were performed on the potential gas hydrocarbon zones. The tests results concluded that the reservoirs were filled with carbon dioxide (CO₂) rather than hydrocarbon gas bearing (up to 90% CO₂). As the result, the prospectivity of this area was downgraded and the exploration strategy was subsequently changed.

After drilling a couple of exploration wells surrounding the area, better understanding of the geological trend and model was recognized. It has been observed that all the traps flushed by CO₂ were directly associated with the downthrown side of the major listric faults. These listric faults were deeply cut and penetrated into the basement/mantle.

The existence of CO₂ is known in Adar and Yabus/Samma Tertiary reservoirs in Melut basin especially in the kitchen area. Lab analysis indicates that the carbon dioxide (CO₂) recovered from the reservoirs is of magmatic origin (Fig3). This support the geological modeling stating that the (CO₂) has migrated through the deeply cut listric faults to the younger reservoirs (Fig.1). Hence, it flushes the oil from nearest traps of the major faults to the traps further away from these deep seated listric faults system.

This can be clearly seen in the Al Jamouse area in Melut basin where the reservoir is dominated with CO₂. As we move away from the listric major fault towards the basement high, the reservoir becomes oil bearing e.g. Teng area in Melut Basin (Fig 4).

This flushing phenomenon could also be the reason behind the strong migration of oil from the kitchen to the basement high of the Palouge Giant Field – the biggest faulted anticline oil field in Sudan.
**Figure 1:** Melut Basin is a half graben, and CO₂ migrated up through listric fault.

**Figure 2a:** Showing the continuous hydrocarbon shows in the kitchen area.
Figure 2b: confirmed that the zones were gas bearing.

Figure 3: Ranges in carbon isotope signatures from different sources.
Figure 4: CO₂ distribution.