VALUE OF INFORMATION FROM A DIVERSE PORTFOLIO OF CORING AND CORE ANALYSIS PROJECTS

O.B. Wilson (1), P.J. Tarabbia (1), A. Jabri (1), M. Kraaijveld (2)
(1) Petroleum Development Oman (PDO)
(2) Shell Exploration & Production

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Halifax, Nova Scotia, Canada, 4-7 October, 2010

ABSTRACT

Information derived from core is one of the key sources of knowledge necessary for proper field development planning and management. Throughout the development life-cycle of a reservoir, the recovery mechanism may change from basic primary depletion to enhanced oil recovery. Hence, coring and core analysis is considered essential for initial hydrocarbon volumes quantification, formation evaluation and other longer-term potential recovery scenarios.

In this paper we will outline best practices that have worked in PDO with respect to planning, justification, designing and executing optimal coring and data acquisition programs that meet short and long term data gathering objectives. In the planning phase of a core and core analysis project, we found that very little review of known information versus desired information was done, and there was no “wider scope” corporate information considered in any acquisition plan. Also, in the justification stage, Value of information (VOI) was rarely done. It has become essential that a Value of information analysis (not really required if the prize is very large) should be performed as this is a powerful tool to express the impact on project decisions. At the designing and executing phase of the core and SCAL process, we have implemented a series of dynamic process work flows. On the SCAL side there have been carefully thought-out pre-defined milestones that act as decision gates during the execution phase. By limiting, eliminating or optimizing the SCAL program in real time, substantial benefits have been seen with a measurable increase in probability of success.

INTRODUCTION

An in-depth and robust understanding of sub-surface fluid flow and rock-fluid dynamics is ubiquitous and fundamental to effectively manage assets and achieving business targets. In this respect, PDO has acquired a vast amount of cores to support business needs and targets. Along with this, a large number of individual SCAL investigations have been carried out. This legacy data represents a unique information resource to utilize particularly if invalid data can be identified and filtered out.

At all stages of an asset's life-cycle, risk-based decisions on investment have been practised for many years using various methodologies (1). The concept behind such methods is to quantify the impact of uncertainty in a monetary sense and to quantify the risk associated with investment decisions. VOI in terms of asset management is the increase or decrease of an asset's value after acquiring information. More importantly, the VOI, or embedded decisions, is a function of the magnitude of the uncertainty of the key variables for which we are considering gathering data, and the reliability of the information itself (1).

VOI analysis is not about cost-cutting, or a reduction in data acquisition; it is about value assurance. The value assurance process identifies what information is required to address key uncertainties that will assist in key decisions to be made for a project. If the desired information has no impact on the asset value, referred to as net present value (NPV), or no influence on a project decision, in principle the VOI is zero (2).

Understanding oil-in-place and recovery mechanisms is largely derived from information obtained from core. Core also plays an important role in the integration and reconciliation process, together with other information in refining subsurface uncertainty. As the post-appraisal and development stages of the life-cycle of a project proceed over time, it becomes more and more important to understand reservoir performance since the cost associated with executing development plans may increase as a function complexity of the recovery process. The impact of information from core analysis on NPV will therefore decrease as a function of increased understanding of reservoir performance (Figure 1).

In this paper, aspects of VOI in the context of planning, justifying and executing core data acquisition programs are discussed in detail. Examples from implementing a simple fit-for-purpose process are used to illustrate the effect of it, and VOI is also discussed in this context.

EFFECT OF IMPLEMENTING A PROCESS WORK FLOW

Challenges associated with managing a very active coring and core data acquisition program would be demanding in any oil company. Front-end aspects such as planning and justification are as important as quality control and post implementation on the back-end. Core analysis in PDO feeds the diverse activities that are presently in our portfolios. However, there is one aspect that is critical in terms of the laboratories that do the work and that is the challenge of delivering "quality data on time". Below we will discuss the various aspects that make-up the current practices within PDO, and give consideration to how VOI can be incorporated in the justification process of core data acquisitions.

Probability Of Success, Coring And Core Analysis

Reliability of the information from core data determines the degree of uncertainty in the information. In context of a VOI analysis this means adding probability of success (POS) to the interpretation (3). This can, in principle, be established from historical key performance indicators (KPIs). Figures 2 and 3 are examples of hard KPIs for 108 individual coring jobs representing several kilometres of cores. Figure 2 shows that core recovery is independent of lithology. On the other hand, high core recovery is not necessarily related to high quality core material (Figure 3). This kind of data is made available to the perspective team that is intending to core a well. Given the nature of the cored material, this helps tremendously with preparing the team for expected core recovery and quality that may affect further analysis. This is usually where job preparation is highlighted with very real challenges.

One aspect that was developed for the planning process was a very clear rating of previously cored core quality. The quantification of core quality has been integrated into the sedimentological core description work flows, by following a classification scheme identifying the fraction of coring, handling, or transport induced damage. Quality indicators of 1, 2, 3 and 4 are made of the core material (Figure 3). These correspond to less than 5 % damage (1), less than 35 % damage (2), less than 50 % damage (3), and more than 50 % damage (4). By using an accept criteria of obtaining a minimum of 90 % core recovery, with quality indicator 2 or better, it is possible to calculate the combined probability of achieving high core recovery with high quality core based on lithology. Using the two frequency distribution curves presented in Figures 2 and 3, and the above defined accept criteria, gives POS for coring in carbonate and sand environment of 81% and 66% respectively. Low quality content of cored unconsolidated sand is the main reason for the low POS in sand. This methodology has assisted greatly when discussing coring projects with the teams and improved the overall awareness and commitment.

A similar approach to the one outlined above can be used to design probabilities for other areas having core data acquisition such as SCAL. This process together with the Bayesian theory (4) can then be used for imperfect VOI analysis (1). On the other hand, probability is based on statistics where aspects such as securing fit-for-purpose SCAL programs, with underlying procedures designed to minimize experimental failures, is not captured. In the following sections a simple process for dealing with this is outlined, and examples of the effect of implementation are illustrated.

Process for Justification and Execution of SCAL

SCAL data for building capillary pressure or relative permeability models are essential at an early stage of studying development options when VOI is high. Total timing for planning, justification, execution, and data implementation of such information can be time consuming. It is therefore essential to have a good routine at the front-end planning, where the outcome relies upon focusing on delivering quality data on time from contractors. One possible way of achieving this is to define a process for justification, execution and close out of SCAL projects. Below is a brief description of the process steps that have been implemented, followed by cases to illustrate the effects of implementation:

Peer Review & Front-End Planning

Mandatory Peer Reviews for all planned SCAL activities have been implemented in PDO to ensure that any proposed core data acquisition is being properly utilized. As any potential SCAL is identified early at the well planning stage, when it finally gets to the formal Peer Review, a lot of the objectives are roughly known. At the Peer Review session, we firm up these sets of objectives and targets with special attention to fit-for-purpose design and to secure any risk or opportunities on a corporate data gathering level. The Peer Reviews are conducted by special core analysis experts in conjunction with senior staff (with a number of junior staff invited to gain knowledge and expertise) as all aspects of the planned data acquisition are challenged. The Peer Review is initiated if the proposed SCAL program is larger than a defined maximum cost. Furthermore, the SCAL program will not proceed without the full endorsement of the Peer Review committee.

Milestone Driven Targets & SCAL Project Execution

During SCAL project execution, it is important to have a finger on the pulse to ensure quality deliverables on time. This was resolved by having pre-identified milestones in all steps of the program. These milestones consist of pre-identified “stops” in the laboratory flow of the analysis with clear definitions of deliverables to be reviewed. By doing this, quality and timelines are constantly in focus. It also gives reviewers an opportunity to fine tune plug selection for a planned experimental sub-program, take ownership of experimental design, and base decisions that affect the continuation of the program on measured results.

All laboratories are given a PDO standard SCAL monitoring program that generates data reporting templates for all experimental data types. The developed program scans data for reporting requirements and ensures that all raw data measurements essential for judging quality, drag and drop mistakes, variables defining the data set, and consistency in understanding properties are captured. The tool also serves as a first stage quality control step from a data management perspective, and flags any anomalies to the user, i.e. the labs which need to correct data before they can be archived to corporate database. By doing this, data completeness is dynamically updated in monthly milestone review with the vendors.

Close Out Reviews

An important aspect which is often overlooked is a comprehensive review of quality associated with final deliverables. There should be no surprises, as the milestone reviews have taken care of any data disqualification and analysis issues. This ensures all data have gone into the appropriate databases and prevents today’s data acquisition becomes tomorrow’s legacy data.

In the following sections, a few case studies are presented to demonstrate the value of implementing such a structured process.

Case 1: Value of Information in Context of Justifying a Core

Case Information

In this example, the asset team is working with a gas reservoir (M) consisting of two gas bearing formations, named UM (carbonate) and LM (sandstones). These reservoirs are located approximately 1500 meters below a major oil producing zone (S) in Oman (Figure 4).

On the surface there is major infrastructure consisting of roads, pipelines and field facilities in place for producing the S reservoir and more than 600 wells causing congestion in the subsurface. It is the first time that the rocks of the gas reservoirs (M) have been considered in a study. The objectives of the study were to provide information that could be utilised in the generation of a field development plan (FDP).

So far there are only five well penetrations into the M gas reservoir units. Fluid analysis of the gas indicates that gas condensate banking is an issue. The field is planned to be developed using natural depletion, with a financial decision gate in 4 years for further development optimisation.

The asset team was considering a coring program with the objectives of the data acquisition program enabling them to support a field study. It was noted that there is a wide uncertainty range in the petrophysical parameters for log interpretations, and the impact of anisotropy and heterogeneity were also unknown. As a part of the justification process for coring it was decided to perform a VOI analysis before bringing the planned SCAL data acquisition for a peer review.

VOI

High uncertainty in the petrophysical parameters in this case would have an impact on Gas Initially In Place (GIIP), hence NPV. Uncertainty associated with the effect of anisotropy and heterogeneity, will also affect inflow performance and hence NPV. Due to the low flexibility caused by the surface and sub-surface infrastructure, the asset team considered a combination of one horizontal and several vertical wells in UM or alternatively only vertical wells. Only vertical wells were considered as an option for LM. Spacing between wells is also an issue. The information needed would assist in a better understanding of GIIP and will also have an impact on important project decisions.

From a VOI analysis perspective, we can construct “The value driver chain” for the case (Figure 5). Figure 5 illustrates that uncertainty with respect to the degree of heterogeneity in nature will have a primary impact on inflow performance. This will have an impact on ultimate recovery (UR). By acquiring data to reduce uncertainty, this information affects the decision on investment, i.e. in this case well trajectory and spacing.

Figure 6 illustrates the principles behind establishing a decision-uncertainty matrix for one of the possible scenarios established by numerical sensitivity simulation runs in a concept model, i.e. for a specific uncertainty scenario and a set of well spacing design options in UM. How to do appropriate scenario simulations including sensitivity tests systematically are described by several authors in the literature (2, 3, 5). The principles are to understand multivariable influence on uncertainty, perform scenario simulations in a model including sensitivity runs (3). By assuming we don't have the information when the decision is made, expected NPV is:

$$\text{NPV}*0.7+(\text{NPV}-\$45\text{M})*0.3=\text{NPV}-\$13.5\text{M} \qquad (1)$$

The constants in $ reflects the changes in monetary value relative to a base case NPV for a given well design option, i.e. constants in equation 1 is case dependent. By assuming we do know the state of nature when the decision is made we can make the appropriate choice of well design, spacing etc. to maximize the expected NPV:

$$\text{NPV}*0.7+(\text{NPV}-\$35\text{M})*0.3=\text{NPV}-\$10.5\text{M} \qquad (2)$$

All constants in equation 1 and 2 are case dependent, and the way to set up the equation can be seen in Figure 6, where equation 1 is the maximum expected NPV calculated horizontally in the matrix, and equation 2 is derived by maximizing expected NPV calculated vertically in the matrix. VOI will be the difference in expected NPV with or without information available:

$$(\text{NPV}-\$10.5\text{M})-(\text{NPV}-\$13.5)=\$3.0\text{M} \qquad (3)$$

This means we can spend up to $3.0M to acquire perfect information in this case. The constants in the equation reflects changes to NPV for well design-spacing options studied, at a given probability scenario. It should be noted that the analysis does not take into consideration what other acquisition methods would give the same information, nor the fact that there is a probability of not achieving perfect information (3). It will be the sensitivity analysis of the probabilities that determine the robustness of the VOI analysis. As an example, if prior probability in this case was 90-10 or 10-90 instead of 70-30, the outcome from the VOI analysis would be different.

This case demonstrates the basic principle of doing a VOI analysis in the context of justifying a core, with the objectives of understanding heterogeneity. The case shows that there was ample justification for acquiring information.

SCAL Program Peer Review

The Peer review was conducted shortly after the core had been taken. At the review, the team indicated that in addition to the key uncertainties described for the carbonate reservoir (UM) above, the following challenges had been identified for the sandstone units (LM). Firstly, clay content and the effect of this clay on production were not known for all sandstone units. Secondly, there was a high permeable sandstone unit in the water leg, which may have caused water encroachment (Figure 7). And lastly, PLT logs indicated a poorer contribution of gas inflow was coming from the lower sandstone beds compared with upper sandstone beds. During the coring operation, the main producing sandstone unit was missed. However, from the core they had obtained, it was observed that there log porosity was a reasonable to good match with conventional core analysis porosity.

With all these points outlined, the reviewers agreed that there were very good reasons for proceeding with a SCAL program. On further questioning by the Peer Reviewers, it became apparent that there was a lack of a proper formation water sample which has an impact on several of the SCAL experiments. The recommendation to the team was to acquire this sample as the first step, i.e. before starting the main SCAL program. Given the uncertainty of the clays present in the sandstone, the reviewers also recommended performing a pre-investigation study to understand the impact of clays before starting on any advanced SCAL.

The PLT interpretation that was presented it turned out to be a bit of a red herring. From well logs it appeared that the properties of the sandstone units in the upper and lower sandstones were the same. As the PLT conflicts with this notion, it was realised that either the interpreted porosity or permeability were erroneous or alternatively that the PLT may have been taken in less than ideal circumstances and hence could be misleading. Correct understanding of this issue may affect GIIP. Therefore, it was advised to pay more attention to this issue (coring the sand interval) when considering the next opportunity to core.

This case is an example of how a well-structured and rigorous process can maximise the value for the acquisition of core and analyses. Without reliable data to reduce uncertainty, investment-decisions are associated with high risk. However, if the team had launched into a full blown SCAL program without getting a representative water composition, or understanding the impact of clays, the SCAL program could have ended in misleading data later.

Case 2: Quality Review of Existing Data Acquisition

Case Information

A complex carbonate oil reservoir for a Cretaceous Reef complex, consisting of three main production areas (A, B and C), was considered for SCAL to reduce uncertainty in understanding field performance. The reservoir units are all from one of the most characterised formations in Oman. Porosity variation for the field varies from 10 to 25 %, with permeability variation between 1 mD-1 D. All areas have been producing oil since the early 70’s. The reservoir oil is under-saturated with viscosity around 2 cP.

Opportunities in the two flank areas (A and B) are framing targets for appraisal in this case. The flank areas are in the transition zone, and there is a poor history match with the models in these two areas. There exists a large amount of SCAL data acquired from the late 1970’s to the early 2000’s. The team considered doing more SCAL and a SCAL program was presented for a Peer Review.

Peer Review Of SCAL

It became apparent at the Peer Review that SCAL would not be approved for this team. In this case it was decided to understand the quality associated with existing SCAL data, before justifying further data acquisition. In parallel, there was an effort to have a closer look at the sequence stratigraphy; fault, structural modelling, depositional environmental modelling, seismic evaluation and uncertainty modelling.

A quality review of a large amount of SCAL data revealed a mixture of misleading experiments and excellent quality SCAL acquired over several decades. After filtering out data with quality indicators, i.e. experiments established by restored state with representative crude oil under aging at reservoir temperature, with available raw data behind calculations, mass balance indicators etc, numerical interpretation of relative permeability and capillary pressure was used as an input to modelling.

An integrated study team delivered a study with a full history match without acquiring further information beyond what was already available. In this case, the execution of a new SCAL program would add no value to the study team. It would only result in increased statistics and a delay of the delivery of the study. As a result of that, the integrated study team delivered the study 18 months ahead of schedule. Opportunities and new targets are now outlined, speeding up further development plans significantly.

This case is a very good example of added value by utilisation of existing information before considering new data acquisition. It also shows that it takes commitment and courage to challenge the teams when in a Peer Review. It is only now that uncertainty, risk and opportunities can be explored further with respect to further optimisation. Figures 8-10 present the history match of the flank area B, utilising existing available information.

Case 3: Impact of Understanding Electrical Properties in Tight Gas

Case Information

Saturation distribution for a couple of tight sandstone units in a gas field was one of main uncertainty, and it was suggested to expand an ongoing SCAL program.

The reservoir is a dry gas reservoir and there are several cores from the reservoir unit. The reservoir consists of a couple of good quality sandstone units, and several units with very low porosity and permeability. Porosity and permeability are presented in Figure 11. Porosity for the low pay sandstone units varies between 2-6% (Log porosity with high uncertainty) with permeability less than 0.2 mD. There is reliable SCAL data for the good quality sandstone units. The planned data acquisition was targeting the poor quality sandstone units, with the dual objectives of understanding both capillary pressure and electrical properties.

Impact of Electrical Properties-Sensitivity Analysis

The objective in this case was to get a more reliable estimate of GIIP. A proper understanding of GIIP has an impact on NPV. Another aspect of this case is the limitation of applying standard reliable SCAL techniques for determining n-exponent (6).

In this case, it was decided not to expand the SCAL program for the tight sand units after performing sensitivity analysis of the impact of the electrical properties on water saturation. The outcome of the analysis is shown in Figures 12 and 13. The plots show that the impact of not using the correct m-factor on saturation increases as a function of decreasing porosity, while the impact of not using the correct n-exponent on saturation decreases as a function of decreasing porosity.

Formation Resistivity Factor (FRF) is a simple measurement and fairly accurate in tight sandstones, given that proper procedures are in place. On the other hand, the accuracy of determining the n-exponent in tight sandstones is highly questionable. Therefore, it was decided to limit the tight gas investigation to increase statistics of the m-factor, perform MICP measurements, and use the n-exponent from the good quality sand units. Tight gas accumulations in Oman are also associated with high salinity brines i.e. resistivity signals typically 10-15 ohm-m in tight formations, which is also favourable in context of accepting the uncertainty of not knowing the n-exponent from measurements.

This case is an example that a VOI analysis needs to be considered as a complementary tool in the justification process. In this case, reduction in uncertainty was obtained by doing simple fit for purpose measurements. Understanding GIIP in tight gas may represent an opportunity, but this is not an argument for extending the limitations of standard SCAL techniques.

CONCLUSION

1. VOI analysis is a powerful supplement in the justification process for any data acquisition considerations. It is recommended to use simple VOI analysis assuming perfect information from core, instead of imperfect VOI analysis using decision trees. Imperfect VOI analysis requires robust statistics of historical performance interpreted in context of probability of success.
2. The effect of implementing a simple but structured process, with emphasis on the front end planning and justification side of core data acquisition, have resulted in a more uniform justification process, with fit for purpose SCAL solutions.
3. Understanding quality, uncertainty, and how to utilize available information before justifying further data acquisition, are essential before costly studies are conducted.

ACKNOWLEDGEMENTS

We thank the Ministry of Oil & Gas of Oman for granting permission to publish this paper. We also thank our colleagues in Petroleum Development Oman (PDO) for allowing us to use their data and excellent work.

REFERENCES

1. A.J. Bouchard and M.J. Fox.: “Incorporating core analysis data uncertainty in asset value assessment” SCA-9905, presented at the SCA 1999 conference
2. M. Scott and M. Evans.:” Use of pressure monitoring to improve reservoir management in an offshore recycled gas reservoir” SPE-50077-MS, presented at the SPE annual conference in 1998.
3. E. M. Coopersmith, P.C. Cunningham.: “A practical approach to evaluating the value of information and real option decision in the upstream petroleum industry” SPE-77582-MS, presented at the SPE annual conference in 2002.
4. J.O. Berger.: “Statistical Decision theory and Bayesian Analysis”, New York Springer-Verlag, MBR0804611, ISBN 0-387-96098-8, 2nd edition.
5. C.C. Mezzomo.: “Field development projects optimization integrated to risk analysis” SPE 106525-STU, presented at the SPE annual conference in 2006.
6. M. Z. Kalam, K. Al Hammadi, O.B.Wilson, M. Dernaika: “Importance of porous plate measurements on carbonates at pseudo reservoir conditions” SCA2006-28 presented at the SCA 2006 conference.

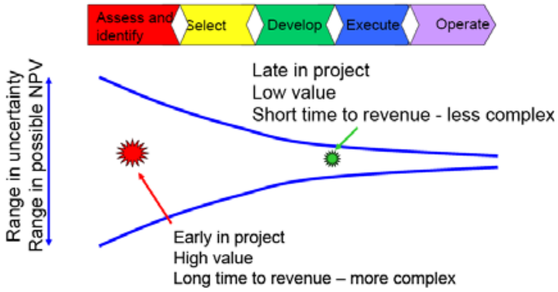


Figure 1. Impact of information vs. project life cycle.

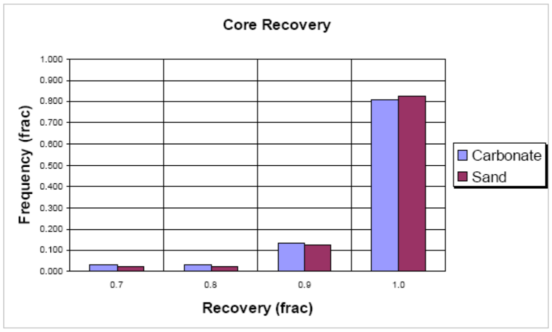


Figure 2. Frequency of core recovery for 108 individual coring jobs.

Figure 3. Frequency of quality of core material from 108 individual coring jobs (1 good -4 poor).

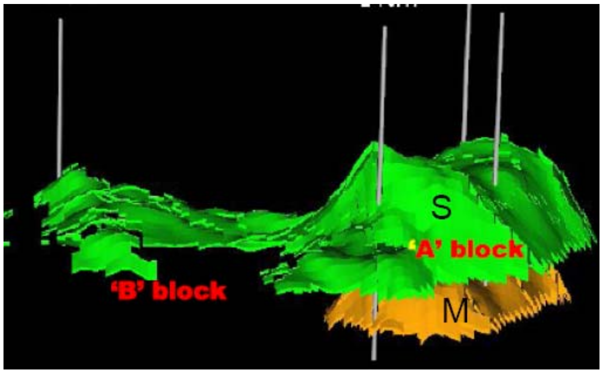


Figure 4. Overview of Case 1, M is a gas reservoir located 1500 m below a major oil reservoir S.

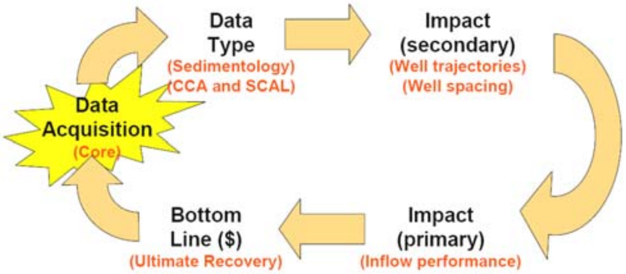
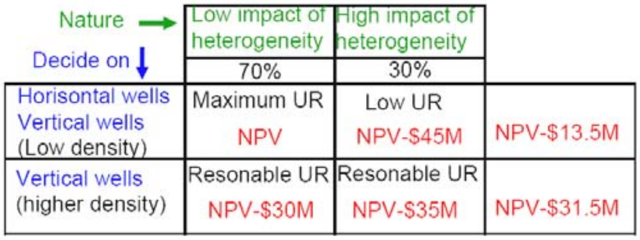
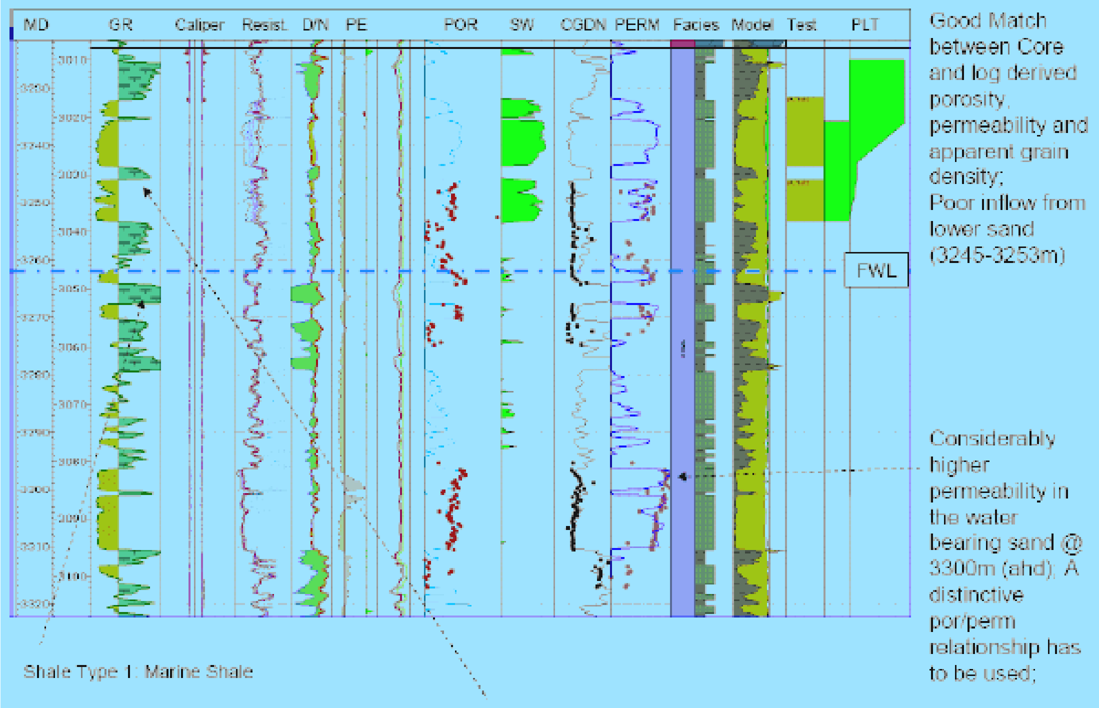


Figure 5. Value driver chain for Case 1. Heterogeneity will have an impact on inflow performance, hence NPV.



Nature →	Low impact of heterogeneity	High impact of heterogeneity	
Decide on ↓	70%	30%	
Horisontal wells Vertical wells (Low density)	Maximum UR NPV	Low UR NPV-$45M	NPV-$13.5M
Vertical wells (higher density)	Resonable UR NPV-$30M	Resonable UR NPV-$35M	NPV-$31.5M

Figure 6. Decision- uncertainty matrix for one of the scenarios in case 1.



Good Match between Core and log derived porosity, permeability and apparent grain density;
Poor inflow from lower sand (3245-3253m)

Considerably higher permeability in the water bearing sand @ 3300m (ahd). A distinctive por/perm relationship has to be used;

Shale Type 1: Marine Shale

Figure 7. Interpreted well log for LM sand units, Case 1.

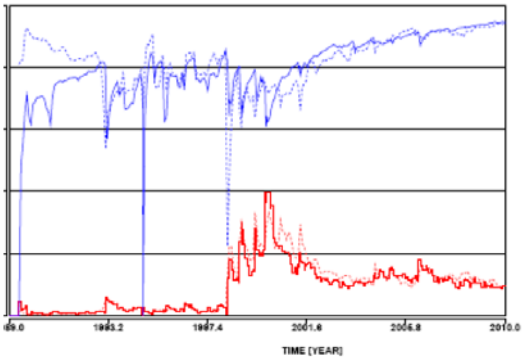


Figure 8. History Match of oil production rate and water cut for flank area B in Case 2.

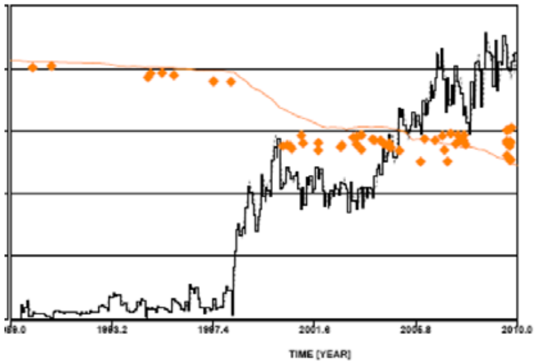


Figure 9. History match of liquid rate and average static bottom hole pressure (all wells) for the flank area B in Case 2.

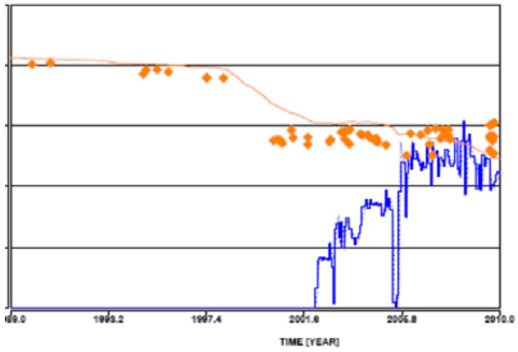


Figure 10. History match of water injection rate and average static bottom hole pressure (all wells) for the flank area B in Case 2.

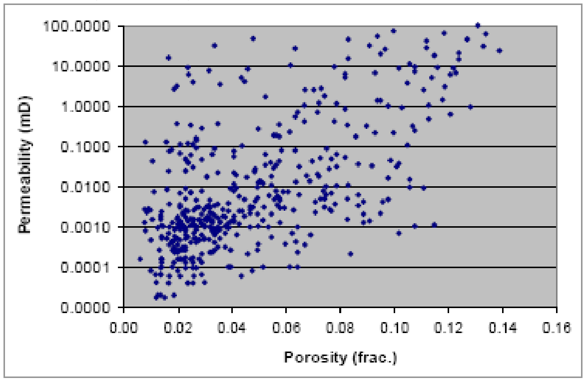


Figure 11. Porosity versus permeability for a gas field in Case 3. Porosity and permeability for the tight gas units, i.e. less that 6% and 0.2mD, is highlighted with pink background

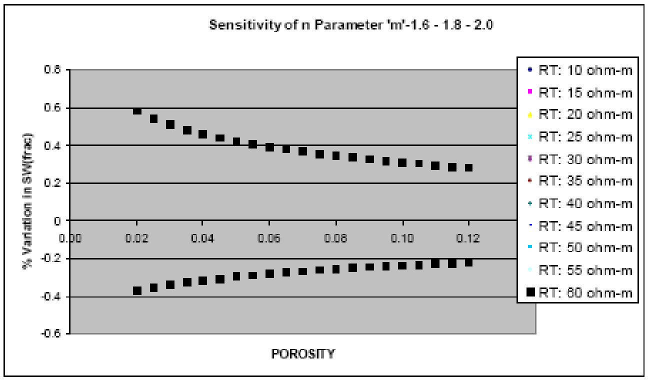


Figure 12. Sensitivity analysis of m-factor for tight sand in Case 3. The plot illustrates the impact of uncertainty in m-factor on saturation interpretation relative to a base case of m=1.8.

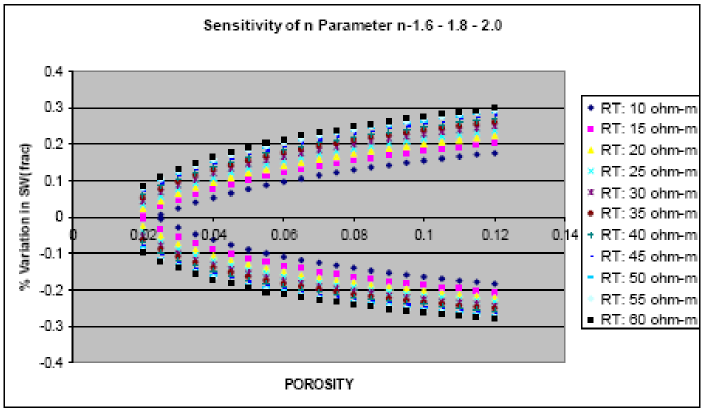


Figure 13. Sensitivity analysis of n-exponent for tight sand in Case 3. The plot illustrates the impact of uncertainty from n-exponent on saturation interpretation relative to a base case of n=1.8.