CONVENTIONAL OIL AND GAS EXPLORATION

Improving cost control and efficiencies to meet today's exploration challenges

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Introduction

In recent years, the oil and gas industry has suffered a significant downturn. Oil prices, which were more than $120 per barrel in 2012, fell to below $30 per barrel in 2016 as a result of an oversupply from shale producers and the cooling of global economic growth.

Exploration impact of downturn

With this momentous shift, the focus of the oil and gas sector turned towards delivering efficiency improvements. Building on cost reductions and the rationalisation of activity, in particular the deferral or scrapping of major projects[1], the industry has positioned itself to succeed in this 'lower for longer' price environment.

In the conventional sector, exploration has played its traditional role in upstream growth but, with the lower price environment, that has been particularly challenging. Though discovery rates have remained stable, fewer wells have been drilled globally[2]. In 2016, there were only 174 oil and gas discoveries globally, versus an average of 400-500 per year up until 2013[3].

Signs of recovery

Recently, as prices have become less volatile, there has been increased offshore exploration activity, with wells being drilled in a number of new and existing areas. This is potentially an early sign of a global recovery.

Some key indicators of improving industry confidence in oil price include:

- Activity levels in the Deepwater GOM are returning to pre-slump levels[4].
- Tullow, BP and Kosmos bid on and were awarded blocks offshore Cote d'Ivoire.
- ExxonMobil's continued activity and success offshore Guyana.
- Significant interest in Mexico's bid round in 2018.
- Siccar Point's Cambo appraisal and Lyon exploration wells, to be drilled in the West of Shetlands in 2018.

Over the coming months and years, we can expect to see oil and gas companies increasing their exploration capital expenditure (CAPEX) and resuming drilling in a bid to build and replenish their oil and gas portfolios.

Their focus is likely to be in these areas:

1. Exploration near existing assets in well understood/calibrated plays, where the cost of development is lower, reserves are brought on stream quicker through existing infrastructure and success rates are significantly higher than average at >50%.
2. Frontier and under-explored areas where there is potential for significant discoveries but where success rates are <15%.
3. Deepwater environments which are high-cost and high-risk ventures, with significantly variable success rates and, often, challenging economics for gas discoveries.

Exploration challenges ahead

With renewed confidence in exploration, oil and gas companies are now focused on pursuing their targets with firm cost control and efficiency. This impacts on their approach to subsurface interpretation.

For near-field exploration, companies need to focus on improved workflows for better decision making. In frontier and deepwater environments, the goal will often be to extract as much information as possible from poor quality and/or vintage 2D and 3D seismic datasets in areas with sparse well control.

Conventional exploration challenges presented today fall into four key themes:

- Mature basins
- Frontier and under-explored basins
- Deepwater basins
- High-pressure and high-temperature environments

This paper will explore what is needed to unlock the potential of each of these existing and yet-to-be-found hydrocarbon sources.

Revisiting Mature Basins to Unlock Potential

Exploring in a mature basin often requires a fine-scale approach to unlock additional hydrocarbon potential. Traps can be more subtle, and largely stratigraphic, facies and rock property variations may also be subtle or previously unseen, and often seismic and well data are old and of variable quality.

New technology advancements also play a pivotal role, opening up new approaches and revitalising the portfolio through the collaboration of data management, regional exploration, geological and geophysical groups.

Although working with existing infrastructure and data is the easiest model for exploration in terms of time-to-market and cost-effectiveness, mature basins are often still very challenging.

Software to Optimise Mature Basin Exploration

Ikon Science offers a range of subsurface modelling and analysis software that can extract greater information from existing data in mature basins and optimise basin exploration.

- Ikon Science's Rock Physics module allows geoscientists to establish a consistent, validated interpretation framework and Bayesian priors for probabilistic seismic reservoir characterisation. New concepts can be developed and tested against existing seismic data adding rigour to play element presence assessment. Reservoir, seal and even source rock may be defined by their unique rock physics.
- Advanced well tie and wavelet estimation tools guarantee robust wavelets and uncertainties for use in seismic characterisation. Of particular importance is the treatment of modern broadband seismic, where correct analysis and handling of the low-frequency content is critical to extracting the full value of the data.
- Ikon Science's RokDoc Attrimod, a multi-2D seismic forward modelling tool, offers advanced multi-2D modelling capabilities to test new geological concepts. It can also be used to provide training data for geoscientists to mine their data, or for machine learning algorithms.
- Ikon Science's RokProbe provides a robust statistical 1D rock physics and seismic amplitude modelling framework, to assess relationships between seismic amplitudes and impedances and to determine probabilistic estimates of net pay.
- Seismic data conditioning tools ensure seismic are fit for purpose for AVO inversion and boost signal: noise ratios of seismic data, which are required to detect thin, marginal hydrocarbon pools.
- Ikon Science's Joint Impedance and Facies Inversion (Ji-Fi) provides a pioneering, consistent means of estimating pre-drill and post-drill reservoir and pay distributions, along with their in-place volumes and associated uncertainties
- Ikon Science's Pressure Prediction module allows geoscientists to evaluate, in near and in-field settings:
  - The localised reservoir plumbing/connectivity (often informed by hi-resolution seismic reservoir characterisation).
  - The impact of field depletion on surrounding (sub-regional) pressures.
  - Whether regional overpressure variations might give rise to hydrodynamics, impacting fluid distribution and hydrocarbon reserves and influencing both exploration and field development strategies.

Frontier and Under-Explored Basins

Frontier areas are typically defined as basins with few drilled wells or where exploration activities have not yet been carried out, basins with relatively-new exploration activities, or basins where significant volumes have been categorised as undiscovered.

Frequently, such basins are located in harsh climates or challenging working environments (e.g. Offshore Myanmar, Labrador Sea, Mexican Gulf, Papua New Guinea, West Africa, Uruguay and Barents Sea) with water depths often more than 500 meters.

Activity in these basins has seen a recent resurgence due to the increased pressure on oil companies to find new hydrocarbons and replace diminishing reserves[5]. There is also a realisation by host governments that fiscal regimes and associated terms must compete globally to attract inward investment[6].

Frontier and under-explored basins have the potential for significant discoveries. Though substantial infrastructure investment is usually required to bring these volumes onstream, the large finds will generally support this. These basins are, however, inherently technically challenging.

Such basins are frequently characterised by scant datasets of variable age and quality; offset well data is typically rare or irrelevant, having targeted highs rather than mini-basins; and the primary dataset is limited to seismic amplitudes and interval velocities (vintage 2D lines). Seismic stratigraphic interpretation is often limited and uncertain, representing uncalibrated geological intervals and depositional systems.

Crucially, the types of questions that are considered when exploring in such basins are relatively simple, at least compared to well-explored basins. Questions might typically focus on the presence of an active petroleum system, seal/trap and reservoir presence, source, timing and charge. The answers are often heavily reliant on seismic data interpretation.

Reducing uncertainty and increasing chances of success

To help reduce the uncertainty within these basins, development of innovative workflows and processes that revolve around play identification/evaluation and prospect assessment are crucial[7]. Furthermore, geoscientists need to develop a broader understanding of subsurface
workflows, spanning multiple disciplines, in order to develop a predictive interpretation framework and strategy.

To do this successfully at the regional scale, the tectonic setting, geological processes and the impact of these processes on rock properties must first be understood[8]. With knowledge of compaction regime, burial history, etc., geological process-driven 'what-if' scenarios can then be generated to understand the impact on reservoir quality, fluid types and the seismic response.

With these data to hand, interpreters can perform quantitative analysis and geological validation of prospective amplitude anomalies observed in the seismic. Once prospects are validated, a consistent approach may then be adopted to rank them in terms of their chance of success.

Finally, the development of a drilling prognosis is possible, and the first exploration well can be planned.

Software to Enhance Frontier and Under-Explored Basin Exploration

Ikon Science's software enables the greatest possible insight from local and regional data available today, and incorporates it with global data to create realistic and accurate models in poorly-understood basins, environments and play-types.

- Seismic data conditioning tools reduce noise in legacy data and extracts as much detail for large-scale prospect screening workflows as the original data quality allows.
- Ikon Science's Rock Physics Module provides an integrated workflow for the combination of basin models, local data and analogues into depth, stratigraphic sequence, lithology, pressure and temperature-aware rock physics models, allowing asset teams to validate seismic interpretations.
- Ikon Science's Joint Impedance and Facies Inversion (Ji-Fi) integrates information from basin models, global analogues and local data with pressure/temperature driven rock physics model priors to provide a comprehensive seismic reservoir characterisation system. Ji-Fi makes optimal use of knowledge from the broad range of disciplines involved in regional exploration, providing insight at the play/play segment scale.
- Ikon Science's Pressure Prediction Module allows for accurate pressure models to be built, capturing tool measurement, geological and geophysical uncertainties. Pressure models can be incorporated into geophysical workflows to explore the elastic and seismic response under differing stress conditions. Well plans can be developed that properly reflect subsurface uncertainties for effective communication to drilling departments.

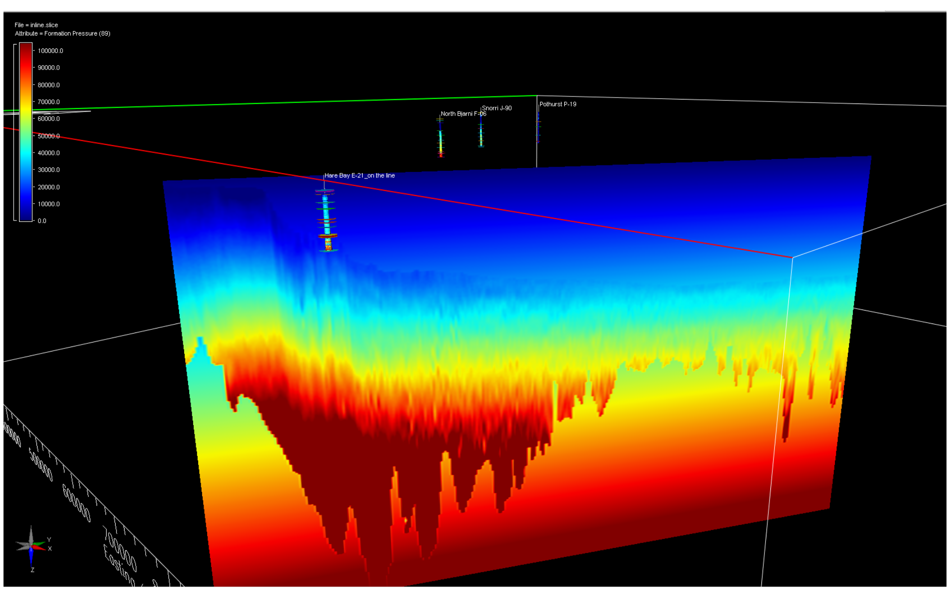

Figure 1 Formation pressure across the Labrador Shelf (Ikon Science/Nalcor Energy, 2014[9])

Meeting Deepwater Challenges

Deepwater exploration presents some of the industry's most complex challenges. Prospects must be defined, and wells constructed to optimise recovery while minimising capital expenditure. Successfully unlocking these resources in these high-cost drilling environments means that a multidisciplinary approach is a pre-requisite of any exploration strategy.

Geopressure models for well planning

One of the key solutions to de-risk well designs in the ultra- and deepwater blocks is to build a geologically consistent, plausible geopressure model for well planning purposes[10]. Such models rely on a detailed understanding of lithologies, facies and depositional settings.

An example study could be the presence of deepwater turbidites forming slope channel fan complexes, stratigraphic pinch-outs and rotated fault blocks. The pressure model constructed must explain the current occurrence of overpressure, taking into account the local geology and incorporating data from analogous areas. Structure, stress, temperature, basin history, sedimentation rates and depositional architecture must be considered. These multiple working hypotheses can then be utilised in the sense-checking of seismic velocity-based interpretations
of overpressure.

Once the pore pressures and the fracture gradients are defined, the drilling window can be assessed. Uncertainties around the pore and fracture gradient models should be appropriately captured by Low, Expected and High-case scenarios in order to optimise the well architecture. These scenarios are, consequently, highly informed through integrated multi-disciplinary interpretation and data analysis.

Early evaluation of pore pressures can provide valuable insight into seal integrity, column height prediction and quantify the risk of catastrophic hydraulic failure ahead of costly drilling decisions. Regional pressure analysis can establish whether reservoirs are dynamically connected and/or naturally draining, providing insight into oil and gas migration pathways.

Furthermore, field size, column lengths and in-place volumes can be estimated and sense checked pre-drill by combining them with seismically derived facies maps, connected body analysis and characterisation of elastic properties relative to the interpreted pressure regime.

Figure 2 shows an example of facies-based seismic inversion used for well planning. The facies-based lithology column was used in pre-drill planning in order to optimise the well design.

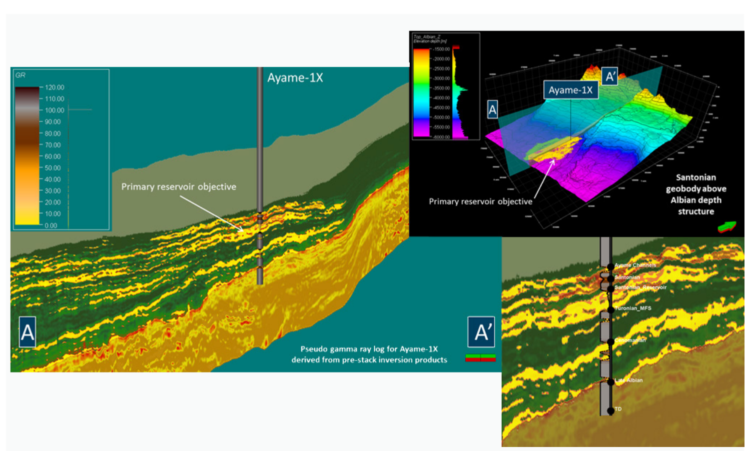

Figure 2 Facies-based seismic inversion highlighting the sand and shale facies (Edwards et al. 2017[11]).

Understanding and Minimising Risk in High Pressure and High Temperature Environments

High Pressure - High Temperature (HPHT) conditions (>10,000 psi and 150°C) are becoming common drilling targets in many basins worldwide as exploration and production companies target deeper and hotter objectives. Examples include the Jackdaw and Culzean Fields in the UK Central North Sea, Xana-1 and Svane-1/1A wells in the Danish North Sea and the Jaguar-1 well offshore Guyana.

Within mature basins, such as the North Sea, Gulf of Mexico and Niger Delta, HPHT reservoirs are being developed and re-developed, requiring the management of depleted zones, often interbedded with strata which retain original pressures[12].

Such large changes in pore pressure and associated stress can lead to complex and potentially costly geomechanical issues[13]. Casing deformation and long-term wellbore integrity, 'narrow' mudweight windows through the production and overburden intervals, deformation and seal integrity issues and fault re-activation are all possible challenges.

It is critical to note that the mudweight window will vary as a function of wellbore deviation[14]. Thus, a target that can be drilled successfully with a vertical wellbore may encounter significant well integrity issues when deviated development/appraisal wells are drilled.

HPHT environments provide some of the greatest and most significant technical and safety challenges, both in predicting the pore pressure and geomechcal properties pre-drill, and in the safe, affordable well design and execution of the well itself.

Improving prediction accuracy

Typically, pore pressure models assume mechanical compaction only[15] and utilise seismic interval velocities in addition to offset well data. The issue with these assumptions, particularly in such environments, is that complex diagenetic processes can occur, leading to under-estimates of pore pressures and elastic properties. These are then carried through to the geomechanical model.

As narrow-margin drilling conditions are common in HPHT environments, the accuracy of upper and lower-bound mudweight limits and their uncertainties becomes critical. The greater the accuracy of prediction, the greater the opportunity for well simplification, reducing contingency in design which represents significant cost reduction and fewer operational challenges.

To extract the greatest value from modelling, updating the pre-drill model with real-time data during drilling will consolidate confidence in the pre-drill model and ensure safer onward drilling.

Modelling to establish risk and uncertainty

A solution to the HPHT challenges is to build predictive, high-resolution geomechanical models that are based on rock properties and multiple data types, accounting for the interdependent links between the pore pressure, rock properties and geomechanics.

For example, a pragmatic approach to follow would be to:

- Gather information from existing well data.
- Establish what lithologies are present.
- Integrate reservoir facies and distributions.
- Integrate temperature and/or age-related diagenetic effects.
- Understand shale rock elastic properties (e.g. TOC, shale types).
- Provide a velocity/effective stress relationship, if possible.
- Interpret seismic data.
- Constrain understanding with analogue areas.

Ultimately, an internally consistent, robust, geologically-driven pore pressure and geomechanical model is created. This model can be used to reduce risk, cost, rig time and unnecessary materials during an HPHT drilling campaign.

Software to Improve Deepwater and HPHT Exploration

Ikon Science offers a selection of software tools and techniques to explore and understand the unique challenges of deepwater and HPHT environments, improving safety and reducing costs.

- Ikon Science’s Reservoir Characterisation Module provides a highly flexible tool for generation of surface to pre-reservoir shared-earth (petro-elastic) models that integrate data from geological, geophysical and engineering sources. Multiple static and dynamic models can be easily combined, along with pressure-consistent (normal compaction trend) elastic models for the population of a field-scale, integrated model for geomechanical analyses.
- Ikon Science’s Ji-Fi delivers some of the most robust elastic properties possible from seismic data. These facies outputs provide context to pore pressure data analysis, while the elastic properties provide a sound basis for construction of geomechanical models.
- Ikon Science’s Rock Physics Model allows geoscientists to perform fluid substitutions, forward-model missing logs and combine all data types to improve the accuracy and reliability of geomechanical models.
- Ikon Science’s Pressure Prediction module allows for pore pressure modelling, in both reservoir and non-reservoir units. Shale-focused pore pressure modelling allows for greater accuracy in casing and well designs.
- Ikon Science’s Geomechanics module builds robust well design and well bore stability models to quickly communicate mud/drilling programs, optimise well design and safely minimise drilling costs.
- Ikon Science’s Real-Time module helps reduce costly non-productive time. It allows seamless integration between pre-drill, real-time and post-drill analyses in a single application, using the latest data from across a field to help improve drilling efficiency and safety. Both depth- and time-based analysis are incorporated and interpreted to improve casing and mudweight designs.

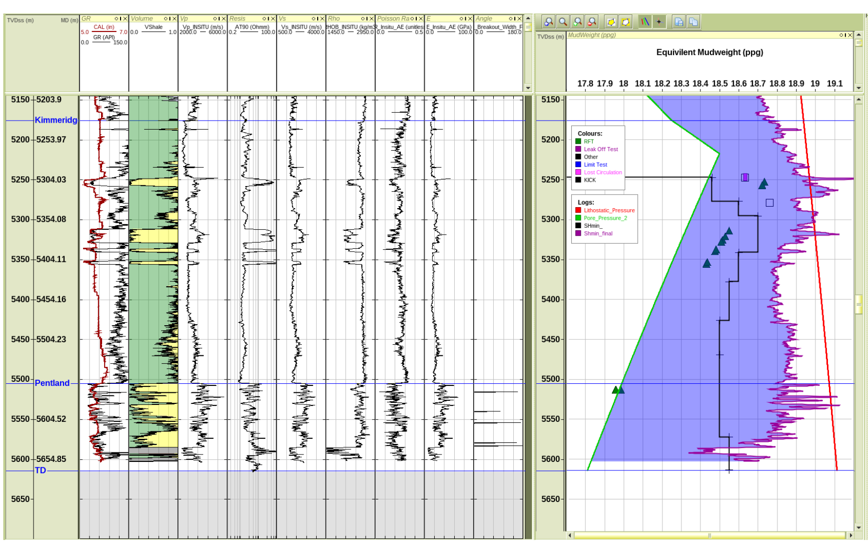

Figure 3 High pressure and high temperature well, with narrow drilling margin (shaded area) from the central North Sea.

Conclusion

At Ikon Science we've stepped up to today's exploration challenges by focusing on our clients' need to become more efficient and improve their decision making. We have streamlined workflows, reduced button clicks and increased software performance, reducing the time required to achieve quantitative and meaningful results.

We have also developed novel, integrated multi-discipline workflows and modelling capabilities. Our software is designed to be highly intuitive, making it easily accessible to generalist interpreters,

Our constant goal is to create the most valuable products for oil and gas operators in today's price environment.

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